CHAPTER 7

WAVES AND VIBRATIONS

STUDENT LEARNING OBJECTIVES

After studying this chapter, the students will be able to:

- Use the principle of superposition of waves to solve problems. [illegible]
- Differentiate between constructive and destructive interference.
- Apply the principle of superposition to explain the working of noise cancelling headphones.
- Illustrate experiments that demonstrate stationary waves [illegible] strings and air columns. [illegible]
- Explain the formation of a stationary wave using graphical representation.
- Explain the formation of harmonics in stationary waves.
- Describe an experiment that demonstrates diffraction [illegible] relative to the wavelength of the wave [illegible]
- Explain beats [illegible] two waves of slightly different frequencies interfering with each other.
- Illustrate examples of how beats are generated in musical instruments.
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- Explain the applications of the Doppler effect [illegible]

7.1 WAVES

Q. What is a Wave?

WAVES

A wave is a regular disturbance or variation that carries energy and spreads out from its source. A wave is the mechanism by which energy is transferred by disturbance in a medium from one place to another without transporting matter. For example, light waves transfer energy from the Sun to the Earth and they can even travel through a vacuum.

Examples:

- Water waves in the ocean
- Ripples on a still pond due to rain drop
- Sound waves in air

Fig 7.1: [illegible]

Q. How do waves transfer energy in a medium?

Waves Transfer Energy in a Medium

[illegible]

Q. What is Displacement in a Wave?

Displacement in a Wave

[illegible]

Parameters of Waves

[illegible]

Amplitude (A)

[illegible]

Wavelength (λ)

[illegible]

Speed (v)

[illegible]

$$v = f\lambda$$

Vibration

[illegible]

Fig 7.2: [illegible]

Time Period (T)

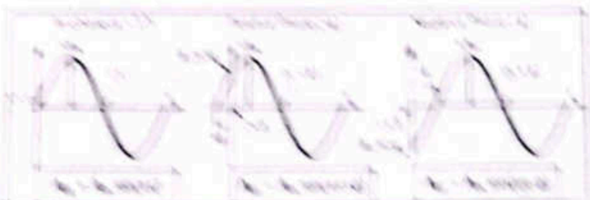
[illegible]

Frequency (f)

[illegible]

Phase (Φ)

[illegible]



Q What are the types of Waves?

TYPES OF WAVES

Waves exist in various forms, each with unique characteristics.

> **Do you know?**
> These wave types are essential to understand various phenomena in physics, engineering, and everyday life.

1. **Mechanical Waves:**
   Definition: These waves require a physical medium (like a solid, liquid, or gas) to travel.

Examples: Water waves (ocean waves, pond ripples), sound waves (audible vibrations in air, water, or solids), and seismic waves (earthquakes).

2. **Electromagnetic Waves:**
   Definition: These waves do not require a medium to propagate and can, therefore, travel through a vacuum.
   Examples: Radio waves (used in wireless communication), Microwaves (used for cooking and heating), Infrared waves (IR or heat radiation), Visible light (sunlight, lamp light), Ultraviolet waves (UV radiation), X-rays (medical imaging), and Gamma rays (high-energy radiation).

3 **Quantum Waves:**
   Definition: These waves are associated with particles such as electrons and photons.
   Examples: Matter waves/particle waves (like electron waves in atoms) or de-Broglie waves, and photon waves (light quanta).

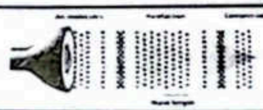
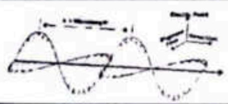
4. **Surface Waves:**
   Definition: These waves travel along the surfaces or interfaces between two different mediums.
   Examples: Ocean surface waves (waves driven by wind) and seismic surface waves.

5. **Quantum Waves:**
   Definition: Quantum waves are associated with particles like electrons and photons.
   Examples:
   - Matter waves/particle waves (electron waves in atoms)
   - De-Broglie waves
   - Photon waves (light quanta), etc.

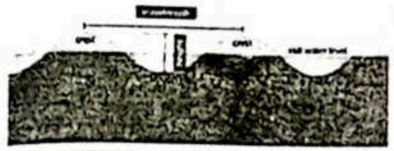
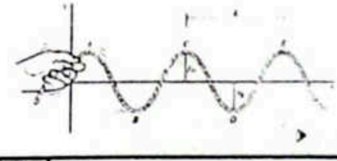
6. **Surface Waves**
   Definition: Surface waves propagate along surfaces or interfaces between two mediums.
   Examples:
   - Ocean surface waves (wind-driven waves)
   - Seismic surface waves, etc.

DIFFERENTIATE BETWEEN TYPES OF THE WAVES

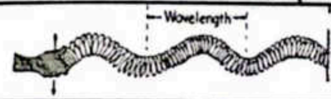
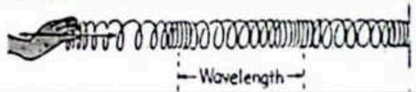
1. ON THE BASIS OF MEDIUM:

Mechanical Waves	Electromagnetic waves
DEFINITION	
• The waves which need a **material / medium** for their propagation are called **mechanical waves**. • These waves propagate due to the oscillation of material particles.	• The waves which require **no medium** for their propagation are called **electromagnetic waves**. • These waves are produced and propagate due to oscillating **electric** and **magnetic** fields.
EXAMPLES	
• Water waves • Sound waves • String waves etc.	• Radio wave • Light waves • Micro waves • X-Rays etc.
DIAGRAM	
	

2. ON THE BASIS OF ENERGY TRANSFER:

Progressive or Travelling Waves	Standing or Stationary Waves
DEFINITION	
• The waves which **transfer energy** by moving away from the source of disturbance are called progressive or traveling waves.	• The waves which **do not transfer energy** are called standing or stationary waves.
EXAMPLES	
• Water ripples waves • Sound waves etc.	• Wave in string • waves in air column
DIAGRAM	
	
CHARACTERISTICS	
• In progressive waves, no point in the medium is at permanent rest. • The relation $v = f\lambda$ is applicable in progressive waves • Progressive waves may be transvers or longitude	• In stationary waves, there are some points at permanent rest called nodes. • The relation $v = f\lambda$ is applicable in the case of stationary waves. • Stationary waves may be Transverse or Longitudinal.

3. ON THE BASIS OF VIBRATION OF THE MEDIUM PARTICLES:

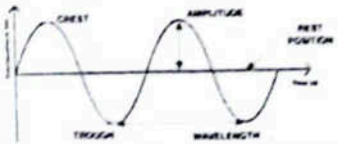
Transverse Waves	Longitudinal Waves
DEFINITION	
• The waves, in which particles of the medium are displaced **perpendicular** to the direction of propagation of the waves, are called **transverse waves**.	• The waves, in which particles of the medium are displaced **parallel** to the direction of propagation of the waves, are called **longitudinal waves**.
EXAMPLES	
• Waves slinky spring.	• Sound Wave • Wave in spring
DIAGRAM	
	
CHARACTERISTICS	
• In transverse waves, the **Crest** and **Trough** are produced. • The relation $v = f\lambda$ is applicable in the case of **periodic transverse waves**. • During the propagation of transverse waves, the pressure is same everywhere. • Transverse waves are produced only in **solids**. They die out quickly in fluids. **Crest:** The portion of the transverse wave **above** the mean level is called as **crest**.	• In longitudinal waves, **Compression** and **Rarefaction** are produced. • The relation $v = f\lambda$ is applicable in the case of **periodic longitudinal waves**. • During the propagation of longitudinal waves, the pressure is **maximum** at compression and **minimum** at rarefaction. • Longitudinal waves can be produced in **all states of matter**. **Compression:** It is a region in a longitudinal wave

Trough: The portion of the transverse wave **below** its mean level is called as **trough**.

Wavelength: The distance between two consecutive crests or two consecutive troughs is known as wave length.

It is denoted by λ.

Amplitude: The **maximum displacement** either sides of the mean position is called amplitude.

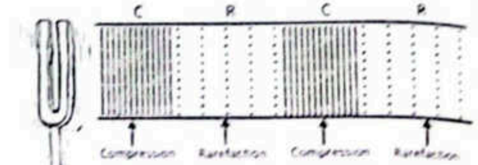


where the particles are **closer together (crowded)**.

Rarefaction: It is a region in a longitudinal wave where the particles are **farther apart**.

Wavelength: The distance between two consecutive **compressions** or two consecutive **rarefaction** is known as wave length.

It is denoted by λ.



4. ON THE BASIS OF DISTURBANCE

Periodic Waves	Pulse waves (non-periodic)
DEFINITION	
• The waves which are set up by **continuous** and **rhythmic disturbances** in a medium are called periodic waves.	• The waves which are set up by a **single** disturbance in a medium are called pulse waves or non-periodic.
EXAMPLES	
• Snapping one end of the rope periodically.	• Snapping of one end of a rope or a coil spring.
DIAGRAM	
	

MULTIPLE CHOICE QUESTIONS

- **A wave is essentially a disturbance that primarily carries:**

(a) Matter (b) Energy (c) Particles (d) Force

Answer: (b) Energy

Explanation: Waves are known for transferring energy from one point to another without necessarily transferring matter.

- **Which of the following wave parameters represents the maximum displacement of a particle from its equilibrium position?**

(a) Wavelength (λ) (b) Frequency (f) (c) Amplitude (A) (d) Period (T)

Answer: (c) Amplitude (A)

Explanation: Amplitude is the maximum displacement or distance moved by a point on a vibrating body or wave measured from its equilibrium position.

- **The relationship between wave speed (v), frequency (f), and wavelength (λ) is given by:**

(a) $v = \lambda/f$ (b) $v = f/\lambda$ (c) $v = f\lambda$ (d) $v = T/\lambda$

Answer: (c) $v = f\lambda$

Explanation: This is the fundamental wave equation, stating that wave speed is the product of its frequency and wavelength.

- **Which type of wave does NOT require a physical medium to propagate?**

(a) Sound waves (b) Water waves (c) Electromagnetic waves (d) Seismic waves

Answer: (c) Electromagnetic waves

Explanation: Electromagnetic waves (like light, radio waves, X-rays) can travel through a vacuum, meaning they do not need a medium for propagation.

- **If the period of a wave is 0.5 seconds, its frequency is:**

(a) 0.5 Hz (b) 1.0 Hz (c) 2.0 Hz (d) 5.0 Hz

Answer: (c) 2.0 Hz

Explanation: Frequency is the reciprocal of the period ($f = 1/T$). So, $f = 1/0.5 = 2.0$ Hz

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define a wave.**

Ans: A wave is a regular disturbance or variation that carries energy, which spreads out from its source through a medium or vacuum.

- **List three parameters used to describe a wave.**

Ans: Three parameters used to describe a wave are amplitude (A), wavelength (λ), frequency (f), and period (T).

- **What is the difference between a transverse wave and a longitudinal wave?**

Ans: In a transverse wave, the particles of the medium vibrate perpendicular to the direction of wave energy travel. In a longitudinal wave, the particles vibrate parallel to the direction of wave energy travel.

- **Give two examples of mechanical waves.**

Ans: Two examples of mechanical waves are water waves and sound waves.

- **What is "phase" in the context of a wave?**

Ans: Phase refers to the relative position of a point on the wave at a given time, indicating its state of oscillation (e.g., whether it's at a crest, trough, or zero-crossing, and moving up or down).

- **What happens when a pebble is dropped into a quite pond? (LHR, RWP 2023 GII)**

Ans: The pebble will produce ripples and spread out across the water. The ripples are examples of progressive waves because they carry energy across the water surface.

- **What do you mean by the term progressive waves? Also define periodic waves. (SGD 2016 GII)**

Ans: **Progressive wave:** A wave that continuously travels in a particular direction inside a medium and carry energy away from source is called a progressive or a traveling wave.

Periodic waves: the wave which repeat its motion again and again is called periodic waves.

- **What are mechanical and electromagnetic waves? (RWP, FSD, DGK 2019) (SGD 2022 GI)**

Ans: **Mechanical waves: -**

- The mechanical waves are governed by all the Newton's laws of motion.
- Medium is needed for propagation of the wave.
- For Example - Water Waves, Sound Waves

Electromagnetic waves:

- Electromagnetic waves are related to electric and magnetic fields.
- An electromagnetic wave, does not need a medium to propagate, it carries no mass, does carry energy.
- Examples: - Satellite system, mobile phones, radio, music player, x-rays and microwave.

- **What is difference between longitudinal and transverse wave? (MTN 2017 GII) (SWL 2018) (DGK 2018 GI) (DGK, SGD 2018 GII) (BWP 2019 GI) (SGD 2021)**

Ans: **Transverse Wave:**

- The transverse waves are those in which direction of disturbance or displacement in the medium is perpendicular to that of the propagation of wave.
- Examples: water wave, the wave in a rope etc.
- The upper portion from the mean position is called crest.
- The lower portion from the mean position is called trough.

Longitudinal Wave:

- In longitudinal waves direction of disturbance or displacement in the medium is along the propagation of the wave.

- For example - Sound waves.
- In a Longitudinal wave there are regions where particles are very close to each other are known as compressions. The regions where the particles are far apart known as rarefactions.

- **What features do longitudinal waves have in common with transverse waves? (RWP, SGD 2017) (LHR 2017 GII) (BWP, SGD 2018 GII) (AJK 2019) (MTN 2019 GI) (SGD 2019 GII) (DGK 2021) (MTN 2022 GI) (LHR, GRW 2022 GII) (GRW, SGD 2023 GI) (SGD, DGK 2023 GII)**

Ans:
(i) Both are longitudinal wave.
(i) They are having same mechanism of transferring of energy.
(ii) Their velocity of propagation depends upon elasticity and inertia.
(iii) Stationary wave can be produced both types of waves.
(iv) Both waves satisfied the relation $v = f\lambda$.
(v) Oscillatory motion is involved for their production.
(vi) Both are mechanical wave, as they required medium for their propagation.
(vii) Phenomenon of beats can be studied in both types of wave.

7.2 PRINCIPLE OF SUPERPOSITION

Q. What is the Principle of Superposition?

Ans

PRINCIPLE OF SUPERPOSITION

Statement:

"When a particle of the medium is **simultaneously** acted upon by n waves, then the resultant displacement of the particle is the **algebraic sum** of their individual displacements.

Let $y_1, y_2, y_3, \ldots\ldots, y_n$ be the displacement due to individual waves then the resultant displacement " y " is given by.

$$y = y_1 + y_2 + y_3 + \cdots \ldots y_n$$

This is called principle of superposition.

Superposition of two waves which are in phase:

If two waves are in phase, resultant displacement after superposition will be;

$$Y = Y_1 + Y_2$$

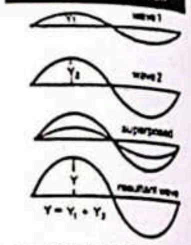
Superposition of two "out of phase" waves:

If two waves which cross each other have opposite phase and there resultant will be;

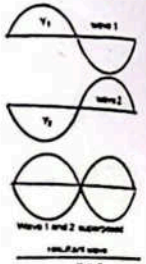
$$Y = Y_1 - Y_2$$

Particularly, if $Y_1 = Y_2$ then; $Y = 0$

For Your Information



Superposition of two waves of the same frequency which are exactly in phase.



Superposition of two waves of the same frequency which are exactly out of phase.

IMPORTANT CASES OF SUPERPOSITION:

(i) **Interference:**
Superposition of two waves having **same frequencies** and **travelling in the same direction** is called interference.

(ii) **Beats:**
Superposition of two waves having **slightly different frequencies** and travelling **in the same direction** is called beat.

(iii) **Stationary Waves:**
Superposition of two waves having **same frequencies** and travelling in the **opposite direction**, results in stationary waves.

Applications of the Principle of Superposition

The principle of superposition is utilized in noise-canceling headphones to effectively eliminate unwanted noise, creating a more peaceful listening experience.

How Noise-Canceling Headphones Work:

1. **Noise Capture:** The headphones have microphones that capture ambient noise, such as background chatter or engine rumble.
2. **Signal Transmission:** The captured sound signals are sent to an amplifier and a processing unit within the headphones.
3. **"Anti-Noise" Generation:** The processing unit generates an "anti-noise" signal that is the exact opposite of the ambient noise in terms of amplitude and phase.
4. **Signal Combination:** This anti-noise signal is then played through the headphones along with the desired audio (e.g., music).
5. **Cancellation:** When the anti-noise signal meets the ambient noise, the two waves interfere destructively, largely canceling each other out, resulting in a much quieter listening experience.

Ponder upon!

An interference pattern formed with white light.

While actual noise-canceling headphones use complex algorithms and multiple microphones for optimal performance, the basic principle of superposition is fundamental to their operation.

MULTIPLE CHOICE QUESTIONS

- **The Principle of Superposition states that when two or more waves overlap, the resultant displacement at any point is the:**
(a) Product of their individual displacements.
(b) Algebraic sum of their individual displacements.
(c) Difference between their individual displacements.
(d) Geometric mean of their individual displacements.

Answer: (b) Algebraic sum of their individual displacements.
Explanation: This is the core definition of the superposition principle for waves displacements add vectorially.

- **If two waves of the same frequency and amplitude are exactly in phase and superpose, their resultant amplitude will be:**
(a) Zero (b) The same as individual amplitude.
(c) Twice the individual amplitude. (d) Half the individual amplitude.

Answer: (c) Twice the individual amplitude.
Explanation: When in phase, their crests meet crests and troughs meet troughs, leading to an amplification where amplitudes add up ($y = y_1+y_2 = 2y_1$ if $y_1 = y_2$).

- **The Principle of Superposition applies primarily to:**
(a) Non-linear waves (b) Very large amplitude waves.
(c) Linear waves or small amplitude waves. (d) Only sound waves

Answer: (c) Linear waves or small amplitude waves.
Explanation: The principle holds true for waves whose amplitudes are small enough that the medium's properties don't change significantly, allowing for linear behavior.

- **Which phenomenon is NOT a direct consequence of the Principle of Superposition?**
(a) Interference (b) Beats (c) Stationary waves (d) Refraction

Answer: (d) Refraction
Explanation: Interference, beats, and stationary waves all arise from the superposition of waves. Refraction is the bending of waves as they pass from one medium to another.

- **If two waves of the same frequency and amplitude are exactly out of phase and superpose, their resultant displacement will be:**
(a) Maximum. (b) Zero.
(c) Twice the individual amplitude. (d) Half the individual amplitude.

Answer: (b) Zero.
Explanation: When out of phase, a crest meets a trough, causing cancellation. If amplitudes are equal, the resultant displacement is zero ($y = y_1 + (-y_2) = 0$ if $y_1 = y_2$).

- **S1 and S2 are two coherent sources of waves which are equidistant from P. Operating alone, S1 produces waves of intensity I at P while S2 produces waves of intensity 4I at P. When both are operating in phase, the resultant intensity of waves at P is.**

(a) 5I (b) $5\sqrt{21}$ (c) 9I (d) 3I

Solution:

$x_1 \propto \sqrt{I_1} \Rightarrow 2, x_2 \propto \sqrt{I_2} = 1$

$x_{max} = x_1 + x_2 = 3$

$I_{max} \propto (x_{max})^2 = 9$ so

$I_{max} = 9I$

SLO BASED SHORT QUESTIONS & ANSWERS

- **State the Principle of Superposition of Waves.**

Ans: The Principle of Superposition states that when a particle of a medium is simultaneously acted upon by two or more waves, the resultant displacement of the particle is the algebraic sum of their individual displacements.

- **What is the effect of superposition if two waves are "exactly in phase"?**

Ans: If two waves are exactly in phase, their amplitudes add up, resulting in a larger resultant displacement (constructive interference).

- **What is the effect of superposition if two waves are "exactly out of phase"?**

Ans: If two waves are exactly out of phase, their displacements tend to cancel each other out, resulting in a smaller or even zero resultant displacement (destructive interference).

- **List three phenomena that result from the Principle of Superposition.**

Ans: Three phenomena are interference, beats, and stationary (standing) waves.

- **How do noise-cancelling headphones apply the principle of superposition?**

Ans: Noise-cancelling headphones use microphones to detect ambient noise and then generate an "anti-noise" signal that is exactly out of phase with the unwanted noise. When these two waves superpose, they destructively interfere, effectively canceling out the noise.

- **Explain principle of superposition. (GRW.2015)**
- **Write three results of principle superposition**
- **Explain "Principle of Superposition". (MTN 2018 GI) (BWP 2018 GII) (GRW 2019 GI) (DGK 2019 GII) (GRW 2022 GI) (SGD 2022 GII) (GRW 2023 GII)**

Ans: Principle of super positions: When a particle of a medium is disturbed by two or more waves, then the resultant displacement of the particle will be the vector sum of their individual displacement.

7.3 INTERFERENCE AND THEIR TYPES:

Q. What is Interference? Explain its types with experiment.

Ans

INTERFERENCE:

In 1801, Thomas Young, Proposed and successfully tested the phenomenon of interference.

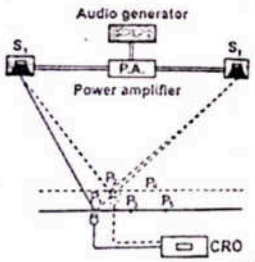
Definition:

When two identical waves meet each other in a medium then at some points they **reinforce** the effect of each other and at some points they **cancel** the effect of each other, this phenomenon is called interference.

Condition of interference:

Interference requires the superposition of two waves having:

- Same frequency
- Travelling in the same direction



TYPES OF INTERFERENCE:

They are two types of interference

(i) Constructive Interference

(ii) Destructive interference

(i) **Constructive interference:**

When two **identical waves** meet each other in a medium then at some points they **reinforce the effect** of each other, result in constructive interference.

(ii) **Destructive interference:**

When two **identical** waves meet each other in a medium then at some points they **cancel the effect of each other**, result in destructive interference.

Interesting fact!

Interference pattern produced by a thin soap film illuminated by white light

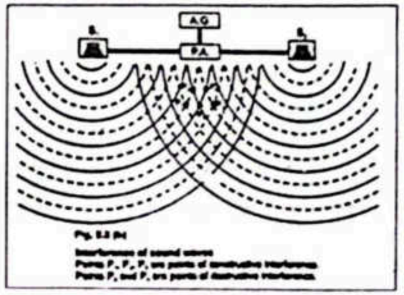
Interference of Sound Waves:

Super position of two sound waves having the same frequency and travelling in the same direction results in a phenomenon, called interference of sound waves.

Interference of sound waves can be studied by the following experiment.

Experimental Arrangement:

An experimental set up to observe the interference effect in sound wave is shown in fig.



Coherent Sources:

Two loud speakers S1 and S2 act as two sources of harmonic sound waves of a fixed frequency produced by an audio generator. Since the two speakers are driven from the same generator, they vibrate **in phase**. Such sources of waves are called **coherent** sources.

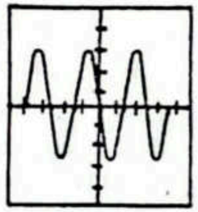


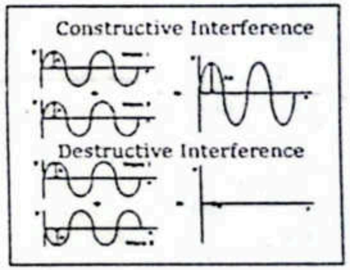
Fig. 8.8(c)
Constructive Interference
Large displacement is displayed on the CRO screen

Cathode Ray Oscilloscope:

The CRO is a device to **display** the input signal into **waveform** on its screen.

Microphone:

A microphone attached to a sensitive cathode ray oscilloscope (CRO) acts as a detector of sound waves. The microphone is placed at various points, turn by turn, in front of the loud speakers as shown in the fig. 8.8 (b).



CONSTRUCTIVE INTERFERENCE:

At point P_1, P_3 and P_5 a large signal is seen on the CRO fig. 8.8 (c), at points P_1, P_3 and P_5 we find that compression meets with a compression and rarefaction meets a rarefaction. So, the displacement of two waves are added up at these points and a large resultant displacement is produced which is seen on the CRO screen fig. 8.8(c).

Path Difference:

Now from fig. 8.8 (b), we find that the path difference ΔS between the waves at point P_1, P_3 and. P_5;

At point P_1	At point P_3	At point P_5
$\Delta S = S_2P_1 - S_1P_1$	$\Delta S = S_2P_3 - S_1P_3$	$\Delta S = S_2P_5 - S_1P_5$
$\Delta S = 4\frac{1}{2}\lambda - 3\frac{1}{2}\lambda$	$\Delta S = 4\lambda - 4\lambda$	$\Delta S = 3\frac{1}{2}\lambda - 4\frac{1}{2}\lambda$
$\Delta S = \lambda$	$\Delta S = 0$	$\Delta S = -\lambda$

Conditions for Constructive Interference:

- Wherever path difference is an **integral multiple** of wavelength displacements, the two waves are **added up**. This effect is called **constructive interference**.
- Therefore, the condition for constructive interference can be written as:

$$\Delta S = n\lambda$$

Where

$$n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots\ldots\ldots$$

DESTRUCTIVE INTERFERENCE:

Whereas at points P_2 and P_4 no signal is displayed on CRO screen fig. 8.8 (d). This effect is explained in fig. 8.8 (b) in which compressions and rareffactions are alternately emitted by both speakers. Continuous lines shown compression and dotted lines show rarefactions. So, that they cancel each other's effect. The resultant displacement **becomes zero**, as shown in fig. 8.8 (d).

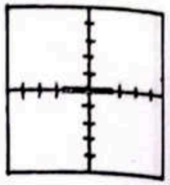


Fig. 8.8(d)
Destructive Interference
Zero displacement is displayed on the CRO screen

Path Difference:

Now let us calculate the path difference between the waves at points P_2 and P_4.

At point P_2	At point P_4
$\Delta S = S_2P_2 - S_1P_2$ $\Delta S = 4\lambda - 3\frac{1}{2}\lambda$ $\Delta S = \frac{1}{2}\lambda$	$\Delta S = S_2P_4 - S_1P_4$ $\Delta S = 3\frac{1}{2}\lambda - 4\lambda$ $\Delta S = -\frac{1}{2}\lambda$

Conditions for Destructive Interference:

- Whenever the path difference is **odd integral multiple of half of wavelength**, the displacements of two waves cancel the effect of each other. This effect is called **destructive interference**.
- Therefore the condition for **destructive interference** can be written as:

$$\Delta S = (2n + 1)\frac{\lambda}{2}$$

Where

$$n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots\ldots\ldots$$

MULTIPLE CHOICE QUESTIONS

- **Interference occurs when two waves, having the same frequency, travel:**
  (a) In opposite directions. (b) In the same direction and superpose.
  (c) At different speeds. (d) Through different media.

Answer: (b) In the same direction and superpose.

Explanation: Interference is specifically defined as the superposition of two waves of the same frequency (and typically constant phase difference) traveling in the same direction.

- **For constructive interference to occur, the path difference between two waves must be:**
  (a) An odd integral multiple of half the wavelength.
  (b) An integral multiple of the wavelength.
  (c) Any fractional multiple of the wavelength.

  (d) Half the wavelength

Answer: (b) An integral multiple of the wavelength

Explanation: Constructive interference occurs when crests meet crests and troughs meet troughs, which happens when the path difference (ΔS) is nλ, where n = 0, ±1, ±2.

- **Sources of waves that vibrate in phase and have a fixed frequency are called:**
  (a) Independent sources (b) Coherent sources (c) Incoherent sources (d) Random sources

Answer: (b) Coherent sources

Explanation: Coherent sources are essential for observing stable and clear interference patterns, as they maintain a constant phase relationship.

- **At a point of destructive interference, a compression meets a:**
  (a) Compression (b) Rarefaction (c) Crest (d) Node

Answer: (b) Rarefaction.

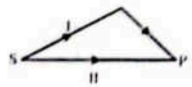
Explanation: Destructive interference occurs when a compression (high pressure/displacement) meets a rarefaction (low pressure/displacement), leading to cancellation.

- **If the path difference between two interfering waves is 3λ/2, the interference will be:**
  (a) Constructive (b) Destructive (c) No interference (d) Partial constructive

Answer: (b) Destructive

Explanation: A path difference of 3λ/2 is an odd integral multiple of half a wavelength ((2n+1)λ/2 for n=1), which is the condition for destructive interference.

- **Waves from a sources S arrive at P through two paths as shown below.**
  Given that resultant wave amplitude at P is minimum, the phase difference between the two wave trains from S is:



(a) $n\pi$ rad (b) $\left(n + \frac{1}{2}\right)\pi$ rad (c) $\left(2n + \frac{1}{2}\right)\pi$ rad (d) $(2n + 1)\pi$ rad

Solution:

$(2n + 1)\pi$ rad is the phase difference equation for a minimum.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define interference of waves.**

Ans: Interference is the phenomenon that results from the superposition of two waves having the same frequency (and usually a constant phase relationship) and traveling in the same direction, leading to a new wave pattern of varying amplitude.

- **What is the condition for constructive interference in terms of path difference?**

Ans: The condition for constructive interference is that the path difference (ΔS) between the two interfering waves must be an integral multiple of the wavelength (ΔS=nλ, where n=0,±1,±2,...).

- **What is the condition for destructive interference in terms of path difference?**

Ans: The condition for destructive interference is that the path difference (ΔS) between the two interfering waves must be an odd integral multiple of half the wavelength (ΔS=(2n+1)λ/2, where n=0,±1,±2,...).

- **What are "coherent sources" in the context of interference?**

Ans: Coherent sources are sources of waves that have the same frequency and a constant phase difference between them, producing a stable interference pattern.

- **In the experimental setup for sound wave interference, what does a large resultant displacement on the CRO screen indicate?**

Ans: A large resultant displacement on the CRO screen indicates constructive interference, where the waves reinforce each other, leading to a maximum loudness of the sound.

- **What is the condition for path difference in constructive and destructive interference? (LHR, DGK**

2019) (MTN 2019 GII) (DGK 2023 GI)

Ans. For constructive interference the path difference should be an integral multiple of wavelength λ

The condition for constructive interference can be written as

$\Delta S = n\lambda$ $\qquad n = \pm 1, \pm 2, \pm 3,$ ———

For destructive interference the path difference should be odd integral multiple of half of wavelength λ.

The condition for constructive interference can be written as

$\Delta S = (2n + 1)\frac{\lambda}{2}$

Or $\Delta S = (n + \frac{1}{2})\lambda$ $\qquad n = \pm 1, \pm 2, \pm 3,$ ———

7.4 STATIONARY WAVES AND THEIR FORMATION:

Q. What are Stationary Waves (Standing Waves)? How they are produced? Write its properties.

Ans

STATIONARY WAVES

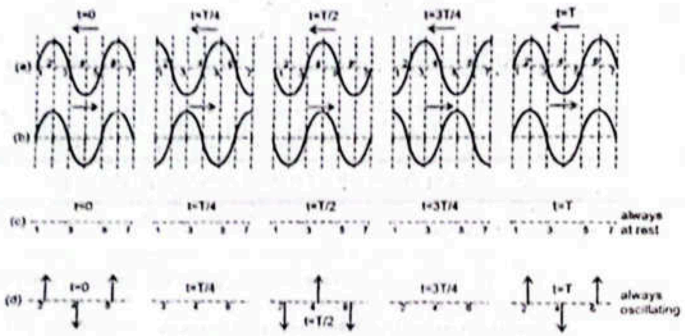
The resultant wave produced by the **superposition** of two identical waves traveling in **opposite direction** is called stationary wave.

-OR-

Superposition of two waves having **same frequencies** and travelling in the **opposite direction,** results in stationary waves.

Production of Stationary Waves:

Consider the superposition of two waves moving along a string in opposite directions. The picture of such two waves at instants $t = 0, \frac{T}{2}, \frac{T}{4}, \frac{3T}{4}$ and T, as shown in figure a and b.



When two waves superpose to each other, we want to find out the displacements of the points 1,2,3,4,5,6 and 7 shown calculated by applying the superposition principle.

- Fig (c) shows that the resultant displacement of the point 1,3,5,7 at the instants $t = 0, \frac{T}{4}, \frac{T}{2}, \frac{3T}{4}$ and T. It can be displacement is always zero at all the instants. -
- Fig (d) shows the resultant displacement of points 2,4 and 6 at instant $t = 0, \frac{T}{4}, \frac{T}{2}, \frac{3T}{4}$ and T. These points movewith maximum displacement from mean positions.

PROPERTIES OF STATIONARY WAVES:

i. In stationary waves particles of medium which permanently show **zero displacement** are called **nodes**

ii. In stationary waves particles of medium which shows **maximum is placement** are called **antinodes**.

iii. The distance between two consecutive nodes or anti nodes is **$\lambda/2$**.

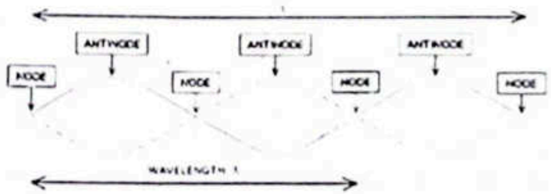
iv. The distance between one node and next antinode is **$\lambda/4$**.

v. The energy remains standing in the medium between nodes because the nodes remain at rest, so energy cannot flow through these points. That is why stationary waves are also called **standing waves**.

vi. Energy oscillates between P.E. and K.E. between nodes.

vii. When anti nodes are at their **extreme displacement** the energy stored is wholly **potential**.

viii. When anti nodes are **passing** through the mean position the energy is wholly **kinetic**.



Q What is the difference between progressive and stationary waves? (LHR 2022 GI)

Ans. Difference between progressive and stationary wave:

(i) A stationary wave is formed by the superposition of two equal progressive waves travelling in opposite directions whereas, a progressive wave is formed due to continuous vibration of the particles of the medium.

(ii) There is no flow of energy in stationary waves whereas, in progressive waves, there is a flow of energy

(iii) Particles at the node are at rest in stationary waves whereas, in progressive waves, no particles in the medium are at rest.

(iv) In stationary waves, amplitude of particles are different, whereas in progressive waves, amplitude of all the particles is the same.

(v) In stationary waves, all particles in a loop are in the same phase and they are in opposite phase with respect to particles in adjacent loops, whereas in progressive waves, phase change continuously from particle to particle.

7.5 STATIONARY WAVES ON STRETCHED STRING

Q. Explain formation of stationary waves on a stretched string.

Ans

Let us consider a string of length ℓ. It is stretched and is clamped at its two ends. The tension in the string is denoted by F. When the string is plucked and then released, two waves are generated which moves in opposite directions along the string. Both of these are reflected back from the clamped ends of string with opposite phase to generate stationary waves on the string.

As the two ends are **clamped with rigid supports,** so these do not vibrate and we get **nodes at these ends**.

Examples: Stationary waves produced in the string of **guitar and violin**.

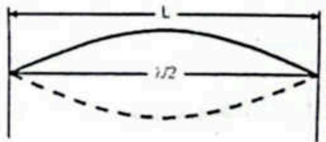
Note:

Stationary waves in stretched string are **transverse in nature**.

Speed of Waves in String

The speed of wave depends upon tension F in the string and mass per unit length m (i.e. thickness and nature of wire).

$v = \sqrt{\frac{F}{m}}$ i



STRING PLUCKED AT ITS MIDDLE POINT (FIRST HARMONIC)

When the string is plucked at the **middle** of its length then the string vibrates in a **single loop** as shown in figure. Such a mode is called fundamental mode of vibration.

Distance between two consecutive nodes = $\frac{\lambda}{2}$

If λ_1 be the wave length and f_1 be the frequency of vibration in this mode, then

$$\ell = \frac{\lambda_1}{2}$$

$$\lambda_1 = \frac{2\ell}{1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{ ii}$$

Thus, speed of wave v is

$$v = f_1\lambda_1$$

$$f_1 = \frac{1v}{\lambda_1}$$

Putting value of λ_1, we get

$$f_1 = \frac{1v}{2\ell} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{ iii}$$

Here, the frequency f_1 is called fundamental frequency.
Putting value of v from equation (1) in equation (3),
Weget

$$f_l = \frac{1}{2l}\sqrt{\frac{F}{m}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{ iv}$$

A standing-wave pattern is formed when the length of the string is an integral otherwise no standing wave is formed.

STRING PLUCKED AT QUARTER LENGTH (SECOND HARMONIC)

When the string is plucked from one quarter of its length then the string vibrates into two loops as shown in figure. If λ_2 be the wave length and f_2 be the frequency of vibration in this mode,

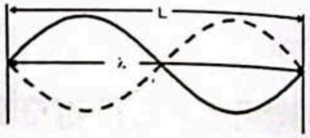
Then:

$$\ell = \frac{\lambda_2}{2} + \frac{\lambda_2}{2}$$

$$\ell = \frac{\lambda_1 + \lambda_2}{2}$$

$$\ell = \frac{2\lambda_2}{2}$$

$$\lambda_2 = \frac{2l}{2}$$



Thus, speed of wave v is

$$v = f_2\lambda_2$$

Putting value of λ_2, we get

$$f_2 = \frac{v}{\lambda_2}$$

$$f_2 = \frac{2v}{2\ell}$$

$$f_2 = \frac{v}{1}$$

$$f_2 = \frac{2v}{2\ell}$$

$$f_2 = 2\left(\frac{v}{2\ell}\right)$$

$$f_2 = 2f_1$$

$$[\text{since } \frac{v}{2l} = f_1]$$

Thus when the string vibrates in **two loops**, its frequency is **double** than when it vibrates in one loop. f_2 is called **second harmonic or first overtone**.

STRING PLUCKED AT 1/6th QUARTER LENGTH (SECOND OVERTONE):

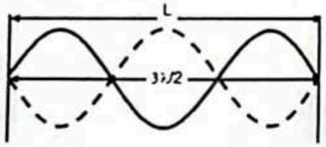
When the string is plucked from one sixth (1/6) of its length then the string vibrates into three loops as shown in figure. If λ_3 be the wave length and f_3 be the frequency of vibration in this mode,

$$\ell = \frac{\lambda_3}{2} + \frac{\lambda_3}{2} + \frac{\lambda_3}{2}$$

Then,

$$\ell = \frac{3\lambda_3}{2}$$

$$\lambda_3 = \frac{2\ell}{3}$$



So the speed becomes,

$$v = f_3\lambda_3$$

$$f_3 = \frac{v}{\lambda_3}$$

$$f_3 = \frac{3v}{2l}$$

$$f_3 = 3\left(\frac{v}{2l}\right)$$

$$f_3 = 3f_1$$

The frequency f_3 is called **third harmonic or 2nd overtone**.

STRING PLUCKED AT AN ARBITRARY POINT:

If string vibrates in n loops then,

$$f_n = \frac{nv}{2l}$$

From above relation it is clear that as string vibrates in more and more loops, its frequency goes on **increasing($f_n \propto n$)**.

And wavelength is

$\lambda_n = \frac{2l}{n}$ Where n = 1,2,3,4,5, . … . . . . .

From above formula it is clear that as string vibrate in more and more loops, its wave length gets shorter.

$$\left(\lambda_n \propto \frac{1}{n}\right)$$

$$f_n = nf_1$$

Harmonic Series:

So the stationary wave have a **discrete or quantized** set of frequencies $f_1, 2f_1, 3f_1, \ldots\ldots nf_1$, which is known as harmonic series.

- The frequency f_1 is known as fundamental frequency, and the other are called over tones.
- The stationary waves can be set up in the string only with the frequencies of harmonic series determined by the **tension, length and mass per unit length** of the string.
- Waves not in harmonic series are quickly damped out.

Key Learnings from the Discussion Above:

1. **Discrete Set of Frequencies:** Stationary waves have a discrete set of frequencies ($f_1, 2f_1, 3f_1, \ldots, nf_1$). The lowest characteristic frequency (f_1) is known as **the fundamental frequency (or first harmonic or fundamental frequency)**. Subsequent frequencies ($f_2=2f_1$, $f_3=3f_1$, etc.) are called **harmonics or overtones**. For instance, f_2 corresponds to the second harmonic or first overtone.
2. **Quantization of Frequencies (Resonance Frequencies):** In other words, quantum jumps in frequency exist between the resonance frequencies. This phenomenon is known as the Quantization of frequencies. It means $f_n=nf_1$, where n=1,2,3,... (integral multiples). Stationary waves can only be set up on the string with frequencies that are whole number multiples of the fundamental frequency determined by the tension, length, and mass per unit length of the string. Waves that are not in harmonic series are quickly damped out.
3. **Adjusting Frequency of Musical Instruments:** The frequency of a string on a musical instrument can be changed by varying the tension or by changing the length. For example, in a guitar or violin, musicians tune the strings by tightening the pegs (changing tension) and vary the frequency by moving their fingers along the neck (changing the vibrating length).

Brain Teaser:

- **A guitar string is plucked at its center. What harmonic is produced?**

Ans: When plucked at its center, the string vibrates in its fundamental mode (one loop), producing the first harmonic (f_1).

Brain teaser

A guitar string is plucked at its centre. What harmonic is produced?

MULTIPLE CHOICE QUESTIONS

- **Stationary waves (standing waves) are formed by the superposition of two waves with:**
  (a) Different frequencies and amplitudes
  (b) The same frequency and amplitude, traveling in the same direction
  (c) The same frequency and amplitude, traveling in opposite directions
  (d) Different wavelengths and speeds

Answer: (c) The same frequency and amplitude, traveling in opposite directions

Explanation: This specific condition of two identical waves moving in opposite directions is what creates a stationary wave pattern.

- **Points on a stationary wave that always remain at rest (zero amplitude) are called:**
  (a) Antinodes (b) Crests (c) Troughs (d) Nodes

Answer: (d) Nodes

Explanation: Nodes are points of permanent zero displacement in a standing wave.

- **The distance between two consecutive nodes in a stationary wave is always:**
  (a) λ (b) λ/2 (c) λ/4 (d) 2λ

Answer: (b) λ/2

Explanation: The pattern of nodes and antinodes repeats every half-wavelength.

- **In the first mode of vibration (fundamental frequency) of a stretched string fixed at both ends, how many nodes and antinodes are present?**
  (a) 1 node, 1 antinode (b) 2 nodes, 1 antinode (c) 1 node, 2 antinodes d) 2 nodes, 2 antinodes

Answer: (b) 2 nodes, 1 antinode

Explanation: With ends clamped, nodes must be at the ends. The simplest vibration has one antinode in the middle, creating one loop.

- **The speed of waves on a stretched string depends upon the:**
  (a) Amplitude and frequency. (b) Wavelength and period.
  (c) Tension in the string and its mass per unit length.
  (d) The point from where the string is plucked.

Answer: (c) Tension in the string and its mass per unit length.

Explanation: The speed of a transverse wave on a string is given by v=F/m, where F is tension and m is mass per unit length.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define a stationary wave.**

Ans. A stationary wave (or standing wave) is a wave pattern that oscillates in a fixed position, without moving or propagating, formed by the superposition of two identical waves traveling in opposite directions.

- **What are "nodes" and "antinodes" in a stationary wave?**

Ans. Nodes are points on a stationary wave where the displacement is always zero (points of no vibration). Antinodes are points where the displacement is maximum (points of maximum vibration).

- **What is the distance between a node and the next antinode in a stationary wave?**

Ans. The distance between a node and the next antinode is λ/4 (one-quarter of a wavelength).

- **When a stretched string fixed at both ends vibrates in its first mode (fundamental), how is the length of the string related to the wavelength of the wave?**

Ans. In the first mode, the length of the string (L) is equal to half the wavelength of the wave (λ1/2), so L=λ1/2.

- **What happens to the energy at the nodes of a stationary wave?**

Ans. At the nodes of a stationary wave, the particles always remain at rest, so no energy flows past these points. Energy is considered to be "standing" (or trapped) between the nodes, alternating between potential and kinetic forms at the antinodes.

How frequency of a string on a musical instrument (guitar / violin) is changed?

Ans. As we know that; $f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$

The frequency of a string on a musical instrument can be changed either by varying the tension or by changing the length

The tension in guitar and violin strings is varied by tightening the pegs on the neck of the instrument. Once the instrument is tuned, the musicians vary the frequency by moving their fingers along the neck, thereby changing the length of the vibrating portion of the string

- **Explain why energy remains "standing" in the medium between nodes? (SWL, SGD 2017)**

Ans. In a vibrating string, there is no movement at the node points. Midway between the nodes the string moves from maximum elastic stretch (maximum potential energy) to zero stretch and maximum kinetic energy,of motion. It then moves, again to maximum stretch, then back to maximum velocity. Between the nodes the energy thus oscillates between maximum kinetic energy and maximum potential energy

- **How the K.E and P.E alternates in stationary waves? (AJK 2021 GII)**

Ans. When anti-nodes are all their extreme displacements, the energy stored in wholly potential. When they are simultaneously passing through their equilibrium position, the energy is wholly kinetic

- **On what factors does the fundamental frequency in a stretched string depends? (SWL, DGK 2019) (AJK 2021 GI)**

Ans. As the fundamental frequency can be expressed as $f = \frac{1}{2l}\sqrt{\frac{F}{m}}$

Its shows it depends upon the tension F, length l of the string and the mass per unit length m of string

- **What are the quantities which affect the frequency of standing waves along a string? (SWL 2019)**

Ans. The natural frequency of vibration in a stretched string depends on length, density, radius, and tension in the string

- **What do you mean by harmonic series? (Quantization of frequency) (GRW 2019) (MTN 2021)**

Ans. The frequency of stationary waves setup on strings will be

$$f_n = nf_1 \qquad n = 1,2,3,...$$

The stationary waves in any medium have discrete set of frequencies f_1, $2f_1$, ... nf_1. This is known as harmonic series. The fundamental frequency f_1 corresponds to the first harmonic, then $f_2 = 2f_1$ corresponds to the second harmonic and so on

7.6 STATIONARY WAVES IN AIR COLUMN

Q. Explain formation of stationary waves in open organ pipe.

Ans

STATIONARY WAVES

Stationary waves can be set up in air column inside a pipe or tube. A common example of vibrating air column is an organ pipe. Stationary waves in air column are **longitudinal** in nature.

Organ Pipe:

An organ pipe is a **wind instrument** in which sound is produced, due to setting up of stationary waves in air column e.g. **flute**.

It consists of a hollow long tube with both ends open or with one end open and the other closed.

Types of Organ Pipe:

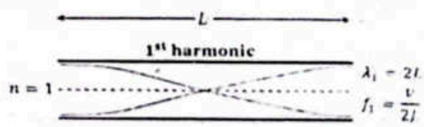
There are two types of organ pipes

(i) **Open Organ pipe:** It is that organ pipe whose both ends are open.

(ii) **Closed organ pipe:** It is that organ pipe whose one end is closed.

STATIONARY WAVE IN A PIPE WHOSE BOTH ENDS ARE OPEN:

If the reflecting end is open, the air molecules have **complete freedom** of motion and this behave as **antinodes**. If the end is closed, then it behaves as a node because the movement of the molecules is **restricted**.



1st mode of vibration (1st harmonic) Fundamental Mode of Vibration:

The mode of vibration of an air column in a pipe open at both ends are shown in fig (a). In fig (a) the longitudinal waves produce in the pipe have been represented by **transverse** curved lines showing the varying amplitude of vibration of the air particles at points along the axis of the pipe.

Let

"l" be the length of organ pipe.

"λ_1" is the wavelength.

"f_1" is the frequency of then the fundamental mode of vibration.

Then the distance between one node and next anti-node is $\frac{\lambda_1}{4}$

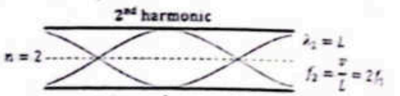
$$\ell = \frac{\lambda_1}{4} + \frac{\lambda_1}{4}$$
$$\ell = \frac{2\lambda_1}{4}$$
$$\ell = \frac{\lambda_1}{2}$$
$$\lambda_1 = \frac{2\ell}{1}$$
$$v = f_1\lambda_1$$
$$f_1 = \frac{v}{\lambda_1}$$
$$f_1' = \frac{1v}{2\ell}$$

Ponder upon!

Open pipes produce all harmonics, while closed pipes produced only odd harmonics.

This fundamental frequency "f_1" is first harmonic.

2^{nd} Mode of vibration:



Let

"λ_2" is the wavelength

"f_2" is the frequency of the stationary wave.

$$\ell = \frac{\lambda_2}{4} + \frac{\lambda_2}{4} + \frac{\lambda_2}{4} + \frac{\lambda_2}{4}$$
$$\ell = \frac{4\lambda_2}{4}$$
$$\ell = \lambda_2$$

Multiplying and dividing by 2

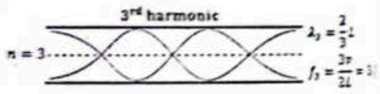
$$\lambda_2 = \frac{2l}{2}$$

As,

$$v = f_2\lambda_2$$
$$f_2 = \frac{v}{\lambda_2}$$
$$f_2 = \left(\frac{2v}{2l}\right)$$
$$f_2 = 2\ f_1$$

This is called **2^{nd} harmonic or 1^{st} overtone**.

3^{rd} mode of vibration:



Let

"λ_3" is the wavelength

"f_3" is the frequency of the stationary wave respectively.

$$\ell = \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4}$$
$$\ell = \frac{6\lambda_3}{4}$$
$$\ell = \frac{3\lambda_3}{2}$$
$$\lambda_3 = \frac{2l}{3}$$

As,

$$v = f_3\lambda_3$$
$$f_3 = \frac{v}{\lambda_3}$$

$$f_3 = \frac{v}{2\ell/3}$$
$$f_3 = 3\left(\frac{v}{2\ell}\right)$$
$$f_3 = 3f_1$$

This is called 3^{rd} harmonic.

n^{th} mode of vibration:

The wavelength of n^{th} mode of vibration is given by:

$$\lambda_n = \frac{2l}{n}$$

Where $n = 1,2,3,4,5, \ldots\ldots$

The frequency of n^{th} harmonic is given by:

$$f_n = n\left(\frac{v}{2\ell}\right)$$
$$f_n = nf_1$$

Harmonic Series

If "f_1" is the fundamental frequency then harmonics present in an open pipe are of frequencies $f_1, 2f_1, 3f_1, 4f_1, \ldots$

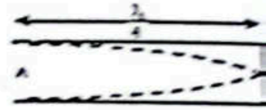
It means both even and odd harmonics are produced in an organ pipe open from both ends.

STATIONARY WAVES IN A PIPE WHOSE ONE END IS OPEN AND OTHER IS CLOSED

If the reflecting end is closed, then it behaves as a node because the movement of the molecules is restricted.

1^{st} mode of vibration / fundamental mode of vibration:

Let "f_1" and "λ_1" be the frequency and wavelength of **longitude** in al **transverse** waves respectively.

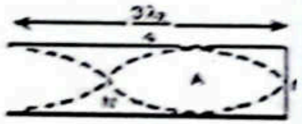


The distance between **one node and next anti-node** is $\frac{\lambda}{4}$

$$\ell = \frac{\lambda_1}{4}$$
$$\lambda_1 = \frac{4\ell}{1}$$
$$v = f_1\lambda_1$$
$$f_1 = v/\lambda_1$$
$$f_1 = \frac{v}{\lambda_1}$$
$$f_1 = \frac{v}{4\ell}$$

This is the **fundamental harmonic**.

2^{nd} Mode of vibration:



Let "λ_2" is the wavelength

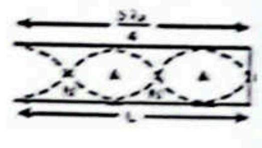
"f_2" is the frequency of the stationary wave respectively.

So,

$$\ell = \frac{\lambda_2}{4} + \frac{\lambda_2}{4} + \frac{\lambda_2}{4}$$
$$l = \frac{3\lambda_2}{4}$$
$$\lambda_2 = \frac{4\ell}{3}$$

As,

$$v = f_2\lambda_2$$
$$f_2 = \frac{v}{4\ell/3}$$
$$f_2 = \frac{3v}{4\ell}$$
$$f_2 = 3f_1$$



3rd Mode of Vibration:

Let

" λ_3 " is the wavelength

" f_3 " is the frequency of the stationary wave respectively

$$\ell = \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} + \frac{\lambda_3}{4} = \frac{5\lambda_3}{4}$$

$$\ell = \frac{5\lambda_3}{4}$$

$$\lambda_3 = \frac{4\ell}{5}$$

As,

$$v = f_3\lambda_3$$

$$f_3 = \frac{v}{\lambda_3}$$

$$f_3 = \frac{v}{4\ell/5}$$

$$f_3 = \frac{5v}{4l}$$

So

$$f_3 = 5f_1$$

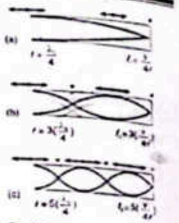


Fig. 7.9:
Stationary longitudinal waves in a pipe closed at one end. Only odd harmonics are present.

n^{th} Mode of vibration:

The wavelength of n^{th} mode of vibration is given by:

$$\lambda_n = \frac{4l}{n}$$

The frequency of n^{th} harmonic is given by:

$$f_n = \frac{nv}{4l}$$

$$f_n = nf_1 \qquad n = 1,3,5,7, \ldots \ldots \ldots$$

Scientific Fact

In an organ pipe, the primary driving mechanism is wavering sheet like jet of air from flue-slit, which interacts with the upper lip and the air column in the pipe to maintain a steady oscillation.

Harmonic Series

If "f_1" is the fundamental frequency then the harmonics present in closed pipe are of frequencies $f_1, 3f_1, 5f_1, 7f_1, \ldots$, it means that only odd harmonics are presents in a closed pipe.

This shows that the pipe with open at both ends is richer in harmonics.

BRAIN TEASER:

- **A flute player notices that the flute is producing a pitch which is slightly sharp. What could be the cause of this problem?**

Ans: If the pitch is slightly sharp, it means the frequency is too high. For a flute (an open pipe), frequency is inversely proportional to length ($f \propto 1/l$). So, the flute's effective length might be slightly too short, or the player's embouchure (lip and facial muscle position) is causing the air column to vibrate at a higher frequency. To correct it, the player might need to adjust their embouchure or pull the head joint out slightly to increase the effective length.

Brain teaser

A flute player notices that the flute is producing a pitch which is slightly sharp. What could be the cause of this problem?

MULTIPLE CHOICE QUESTIONS

- **In an organ pipe open at both ends, the fundamental mode of vibration has:**
  (a) A node at both ends. (b) An antinode at both ends.
  (c) A node at one end and an antinode at the other.
  (d) Two nodes in the middle.

Answer: (b) An antinode at both ends.

Explanation: For an open end, air molecules have complete freedom of motion, thus forming an antinode. In the fundamental mode of an open pipe, there are antinodes at both ends and one node in the middle.

- **A closed organ pipe (closed at one end) produces only:**
  (a) All harmonics. (b) Even harmonics. (c) Odd harmonics. (d) No harmonics.

Answer: (c) Odd harmonics.

Explanation: Due to the boundary conditions (node at closed end, antinode at open end), closed pipes can only support odd multiples of the fundamental frequency (odd harmonics).

- **An organ pipe closed at one end has fundamental frequency of 1500 Hz. The maximum number of over tones generated by this pipe which a normal person can hear is:**
  (A) 14 (b) 13 (c) 6 (d) 9

Solution: For n=13 it means 6^{th} overtone $f_{13} = 13 \times 1500 = 19500$ Hz. Above this it means > 20,000 Hz humans cannot hear.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Describe the fundamental mode of vibration in an organ pipe open at both ends.**

Ans: In an organ pipe open at both ends, the fundamental mode of vibration consists of an antinode at each open end and a single node exactly in the middle of the pipe.

- **Why does an organ pipe closed at one end only produce odd harmonics?**

Ans: An organ pipe closed at one end produces only odd harmonics because its boundary conditions require a node at the closed end and an antinode at the open end, which limits the possible standing wave patterns to only those with odd multiples of quarter wavelengths fitting in the pipe.

- **In the experiment using microwaves to demonstrate stationary waves, how are nodes and antinodes identified?**

Ans: Nodes are identified as points where the probe detector shows zero signal intensity, while antinodes are identified as points where the detector shows maximum signal intensity.

- **How does the length of a closed organ pipe relate to the wavelength for its fundamental mode?**

Ans: For a closed organ pipe, its length (L) for the fundamental mode is equal to one-quarter of the wavelength of the sound wave (λ1/4), so L=λ1/4.

- **Which is richer in harmonics, and why: (a) An open organ pipe (b) A closed organ pipe. (LHR 2017 GI) (MTN 2019 GII) (FSD, SGD 2021) (GRW 2023 GI)**

Ans. In case of open organ pipe the frequencies is given by

$f_n = nf_1 \qquad n = 1,2,3, \ldots n$

In case of closed organ pipe the frequencies is given by

$f_n = nf_1 \qquad n = 1, 3, 5, \ldots n$

In case of closed organ pipe even frequencies are missing and only odd frequencies are present. So, therefore open organ pipe richer in harmonics.

7.7 EXPERIMENT DEMONSTRATING STATIONARY WAVES USING MICROWAVES

Q. What are Microwaves? How are Stationary Microwaves produced?

Ans

MICROWAVES

Microwaves are a form of electromagnetic radiation. They are called "micro" waves because their wavelengths are typically in the order of millimeters or centimeters, much shorter than radio waves.

STATIONARY MICROWAVES PRODUCED

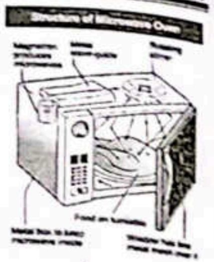
Stationary waves, also known as standing waves, can be produced by microwaves when they are confined to a specific region or cavity, such as a wave guide or resonant chamber (like a microwave oven). In these structures, microwaves can bounce back and forth, creating a standing wave pattern with nodes and antinodes. This happens when the microwave frequency matches the resonant frequency of the cavity.

SIMPLE METHOD TO CREATE STATIONARY MICROWAVE WAVES:

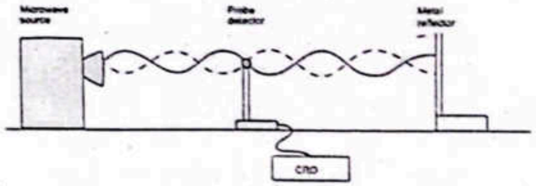
The experiment setup consists of:

- A microwave source (transmitter)
- A probe detector
- A metal reflector (a metallic plate for the reflection of microwaves).

Experimental Procedure:



1. The microwave source emits microwaves towards the metal plate.
2. The microwaves reflect off the metal plate, traveling back towards the source.
3. The incident and reflected waves superpose to create a stationary wave pattern.
4. The probe detector is used to measure the intensity of the signal at different points between the transmitter and the metal plate.
5. By moving the probe or plate, we can observe antinodes (points of maximum intensity) and nodes (points of zero intensity).
6. The distance from one antinode to the next node is $\lambda/4$, which allows us to determine the wavelength of the microwave.



MULTIPLE CHOICE QUESTIONS

- **In the experiment demonstrating stationary waves using microwaves, the detector measures the:**
  (a) Temperature of the microwaves. (b) Intensity of the signal.
  (c) Frequency of the microwaves. (d) Phase of the microwaves.

Answer: (b) Intensity of the signal

Explanation: The probe detector measures the intensity of the microwave signal at various points, which is related to the amplitude of the standing wave, allowing identification of nodes (zero intensity) and antinodes (maximum intensity).

- **In an open organ pipe, the length (L) for the fundamental frequency is related to the wavelength (λ) as:**
  (a) $L=\lambda/4$ (b) $L=\lambda/2$ (c) $L=\lambda$ (d) $L=2\lambda$

Answer: (b) $L=\lambda/2$

Explanation: The fundamental mode of an open pipe has antinodes at both ends and one node in the middle, forming half a wavelength within the pipe length.

- **When a microwave probe detector is placed at a node in a stationary microwave pattern, it will show:**
  (a) Maximum signal intensity. (b) Half signal intensity.
  (c) Zero signal intensity. (d) Fluctuating signal intensity.

Answer: (c) Zero signal intensity.

Explanation: Nodes are points of zero amplitude, so the intensity (proportional to amplitude squared) will be zero at these points.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What type of waves are microwaves, and how are they used to demonstrate stationary waves experimentally?**

Ans: Microwaves are a form of electromagnetic radiation. They are used to demonstrate stationary waves by creating standing wave patterns in a cavity or region by reflecting incident waves from a metal plate, causing superposition with reflected waves.

7.8 DIFFRACTION OF WAVES

Q. What is Diffraction of Waves? Where can Diffraction be observed?

Ans

DIFFRACTION OF WAVES

Diffraction of waves is the bending of waves around sharp edges or corners of obstacles, or the spreading of waves beyond an opening (a slit) that is comparable in size to the wavelength of the wave. The longer the wavelength, the greater the spreading, and vice versa.

For your information

Diffraction of white light is shown by a fine diffraction grating

Where can Diffraction be observed?

Diffraction can be observed in various types of waves, including water waves, sound waves, light waves, and electromagnetic waves.

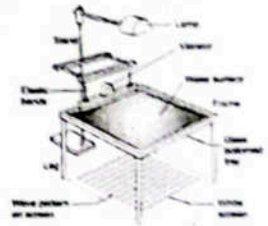
Examples of Diffraction:

- Hearing sound waves around corners or through a door, even when the source is not directly visible.
- Diffraction of X-rays by crystals, where the spacing between the regular arrays of atoms is of the order of the X-ray wavelength.

Significance of Diffraction:

Diffraction is a fundamental aspect of wave behavior and has many practical applications in various fields.

THE RIPPLE TANK

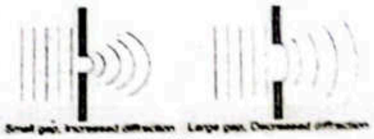


A ripple tank is a useful apparatus primarily used to generate water waves and demonstrate wave properties such as reflection, diffraction, and refraction.

How does it work for Diffraction?

- A vibrator generates a series of concentric circles (or parallel waves) on the water surface.
- An obstacle (e.g., a small gap, a needle, or a semicircular barrier) is placed in the water.
- When the waves encounter the obstacle, they bend or spread out beyond it.
- **Qualitative Effect of Gap Width relative to Wavelength:**
  - **Small gap (comparable to wavelength):** If the gap width is small compared to the wavelength, the waves bend significantly, creating pronounced circular wavefronts after passing through the gap (large diffraction).
  - **Large gap (much larger than wavelength):** If the gap width is large compared to the wavelength, the waves bend very little, and the waves mostly pass through in a straight line with only slight bending at the edges (decreased diffraction).

  This experiment visually demonstrates the relationship between gap width and wavelength, illustrating wave behavior.



Small gap, Increased diffraction Large gap, Decreased diffraction

Fig. 7.12

MULTIPLE CHOICE QUESTIONS

- **Diffraction of waves is the phenomenon of:**
  (a) Reflection from a surface.
  (b) Bending of waves around sharp edges or through an opening.
  (c) Interference between two waves. (d) Change in speed as waves enter a new medium.

Answer: (b) Bending of waves around sharp edges or through an opening.

Explanation: Diffraction is the characteristic spreading of waves as they encounter an obstacle or pass through a slit.

- **The extent of diffraction is most significant when the gap width relative to the wavelength of the wave is:**
  (a) Much larger. (b) Much smaller. (c) Comparable. (d) Irrelevant.

Answer: (c) Comparable.
Explanation: Diffraction effects are most pronounced when the wavelength of the wave is approximately equal to or larger than the size of the obstacle or opening.

- **Which of the following phenomena demonstrates diffraction of waves?**
  (a) Seeing your reflection in a mirror. (b) Sound waves bending around a corner.
  (c) The colors observed in a soap bubble. (d) A straight beam of light in a vacuum.

Answer: (b) Sound waves bending around a corner.
Explanation: Sound waves have wavelengths comparable to everyday objects, allowing them to diffract readily around obstacles.

- **In a ripple tank experiment, if the gap width is small compared to the wavelength, the diffraction will be:**
  (a) Negligible. (b) Increased. (c) Decreased. (d) Absent.

Answer: (b) Increased.
Explanation: Diffraction is more pronounced when the wavelength is larger relative to the gap size, leading to greater spreading.

- **Diffraction can be observed in which types of waves?**
  (a) Only light waves. (b) Only sound waves.
  (c) Only water waves. (d) Water waves, sound waves, light waves, and electromagnetic waves.

Answer: (d) Water waves, sound waves, light waves, and electromagnetic waves.
Explanation: Diffraction is a general wave phenomenon, applicable to all types of waves.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define diffraction of waves.**

Ans: Diffraction of waves is the bending or spreading of waves around the sharp edges or corners of obstacles, or the spreading of waves beyond a barrier or through an opening.

- **What is the qualitative effect of gap width relative to wavelength on diffraction?**

Ans: Diffraction is more pronounced (increased) when the gap width is small compared to the wavelength of the wave, and it becomes less significant (decreased) when the gap width is much larger than the wavelength.

- **Give a practical example of diffraction of sound waves.**

Ans: A practical example of diffraction of sound waves is being able to hear sound from around a corner or through an open doorway, even when you cannot directly see the source.

- **What is a ripple tank used for in the study of waves?**

Ans: A ripple tank is a useful apparatus primarily used to generate and observe water waves and demonstrate wave properties such as reflection, refraction, interference, and diffraction.

- **How is diffraction of X-rays by crystals used?**

Ans: Diffraction of X-rays by crystals is used to study the arrangement of atoms in crystal structures, as the spacing between the regular atomic arrays in a crystal is comparable to the wavelength of X-rays.

7.9 BEATS

Q. What are beats? Explain formation of beats and it's applications.

Ans

BEATS

"The **periodic variations** of sound between **maximum and minimum** loudness are called beats".

-OR-

Superposition of two waves having **slightly different frequencies** and travelling in the **same direction** is called beat.

Conditions for Beats:

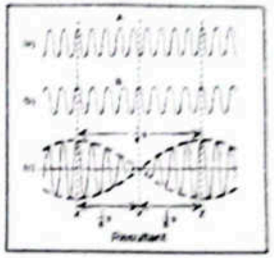
There are two conditions to be fulfilled;

- Two waves should have **slightly different frequencies**.

- These waves should **travel in same direction**.

Experiment:

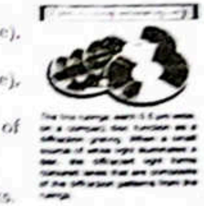
Consider two tuning forks A and B of same frequency say **32Hz** are sounded separately then they will produce pure notes. But when they are sounded simultaneously then it is difficult to differentiate the notes. The sound waves of two will be superposed on each other and will be heard by the human ear as single pure notes. If the frequency of tuning fork B is lowered slightly by loading it with some wax, say it becomes **30Hz**.



Now if A and B sounded together, a sound of alternately increasing and decreasing intensity will be heard. Such a note is called beat, which is due to interference between the sound waves from A and B as shown in figure below.

- **At some instantX** is the displacement of the two waves is in the same direction. The resultant displacement is large and a loud sound is heard.
- **After time $\frac{1}{4}$ sec,** the displacement of wave due to one tuning fork is opposite to the displacement of waves due to the other tuning fork. As a result, a minimum displacement is produced at Y. So a low or no sound is heard.
- **After next $\frac{1}{4}$ sec,** the displacements are again in the same direction and a loud sound is heard again at Z. It represents a loud sound is heard **two times** in one second because the frequency difference is **2Hz**.

Illustration of Beat Formation:



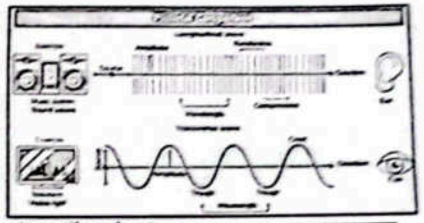
- When the waves are in phase, their amplitudes add up (constructive interference), resulting in maximum loudness.
- When the waves are out of phase, their amplitudes subtract (destructive interference), resulting in minimum (or zero) loudness.
- Because the frequencies are slightly different, the waves periodically drift in and out of phase, leading to the observed pulsations.

Number of Beats:

Number of beats per second is equal to the **difference** between frequencies of tuning forks.

Mathematically:

$$\text{number of beats per second} = f_A - f_B$$



Maximum Recognizable Beats:

When the difference between the frequencies of the two sounds is more than about **10Hz**, then it becomes difficult to recognize the beats.

USES OF BEATS:

Beats are used to;

- Tune a string instrument such as **piano or violin**, by beating a note against a note of known **frequency**. The string can then be adjusted to the desired frequency by **tightening or loosening** it until no beats are heard.
- Find unknown frequency of vibrating body.
- Produce variety in music.

The difference between the frequencies of the two waves is termed as beat frequency f_{beats}.

One can use beats to tune a string instrument, such as piano or violin, by beating a note against a note of known frequency. The string can then be adjusted to the desired frequency by tightening or loosening it until no beats are heard.

TUNING MUSICAL INSTRUMENTS

Here are some examples of how beats are generated in musical instruments:

1. **Guitar:** When playing two strings with slightly different tunings, beats are created. For example, playing a standard tuned string and a string tuned a few

cents higher or lower.

2. **Piano:** Playing two keys white and black, adjacent to each other, create beats.
3. **Violin:** When playing two strings with slightly different bow pressures or speeds, beats are generated.
4. **Drums:** When two drums with slightly different tunings are played simultaneously, beats are created.
5. **Flute:** When playing two notes with slightly different embouchure (lip and facial muscles) positions, beats are generated.
6. **Organ:** When playing two pipes with slightly different tunings, beats are created.
7. **Synthesizer:** Generating two oscillators with slightly different frequencies creates beats.

In these examples, the slight difference in frequency between the two sound sources creates a periodic increase and decrease in amplitude, resulting in a "beat" or pulsation effect. Musicians often intentionally use beats for interesting rhythmic effects or to create a sense of tension and release. In some cases, beats can be unwanted and may require adjustments to tuning, pitch, or playing technique to minimize their impact.

Do you know?

In 1711, F. J. Shore, who was a royal trumpeter and lutenist invented tuning forks

MULTIPLE CHOICE QUESTIONS

- **Beats are produced when two waves of slightly different frequencies:**
  (a) Travel in opposite directions. (b) Interfere with each other.
  (c) Have the same wavelength. (d) Are in phase.

Answer: (b) Interfere with each other. **Explanation:** Beats are specifically the result of the superposition of two waves with slightly different frequencies, causing a periodic variation in loudness.

- **Beats are perceived as a pulsation in:**
  (a) Frequency (b) Wavelength (c) Amplitude (loudness). (d) Pitch

Answer: (c) Amplitude (loudness). **Explanation:** Beats cause a periodic rise and fall in the intensity (loudness) of the resultant sound.

- **The number of beats per second is equal to the:**
  (a) Sum of the two frequencies. (b) Difference between the two frequencies.
  (c) Product of the two frequencies. (d) Ratio of the two frequencies.

Answer: (b) Difference between the two frequencies. **Explanation:** The beat frequency (f_b) is given by $|f_1-f_2|$.

- **Beats are primarily used in musical instruments for:**
  (a) Changing the timbre. (b) Amplifying the sound. (c) Tuning. (d) Creating echo effects.

Answer: (c) Tuning. **Explanation:** Musicians listen for beats to determine if two instruments or strings are precisely in tune; when the beat frequency approaches zero, they are in tune.

- **If two tuning forks produce 4 beats per second, and one has a frequency of 256 Hz, the other tuning fork's frequency could be:**
  (a) 252 Hz only. (b) 260 Hz only. (c) Either 252 Hz or 260 Hz. (d) 256 Hz.

Answer: (c) Either 252 Hz or 260 Hz. **Explanation:** Beat frequency = $|f_1-f_2|$. So, $4=|256-f_2|$, meaning f_2 could be $256-4=252$ Hz or $256+4=260$ Hz.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What are "beats" in waves?**

Ans: Beats are the periodic variations in the amplitude (loudness) of the sound produced when two sound waves of slightly different frequencies interfere with each other.

- **How is the "beat frequency" calculated?**

Ans: The beat frequency (number of beats per second) is calculated as the absolute difference between the frequencies of the two interfering waves ($f_b=|f_1-f_2|$).

- **What happens to the loudness of the sound when beats are produced?**

Ans: The loudness of the sound periodically increases and decreases, resulting in a distinct pulsation or throbbing sensation.

- **Give an example of how beats are generated in a musical instrument for tuning.**

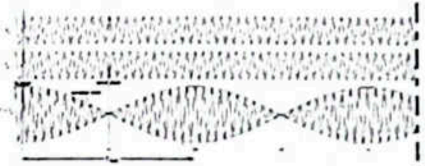
Ans: When tuning a guitar, if the string is slightly out of tune with a reference note, beats will be heard. The musician adjusts the string tension until the beat frequency approaches zero, indicating perfect tuning.

- **Why must the two interfering waves have "slightly different frequencies" to produce audible beats?**
  - **Answer:** The frequencies must be slightly different so that the phase relationship between the waves slowly changes, causing the points of constructive and destructive interference to shift, resulting in audible pulsations in loudness. If frequencies were too different, the pulsations would be too fast to perceive as distinct beats.

- **Explain beats. What are beats draw the diagram to show beats. (Fsd 2018) (Ajk 2021) (Fsd 2023 GII)**

Ans. The periodic variation of sound between maximum and minimum loudness is called beats.

Condition: when two sound waves interfere having slightly different frequencies produce beat. It is noted that number of beats per second is the number of maxima and minima produced in one second.



Number of beats per second = $n = f_2 - f_1$

- **What is the difference between interference and beats? (FSD 2017) (SGD 2019 GI) (MTN, FBD, RWP 2021)**

Ans. **Interference:** When two wave having same frequency, while travelling in the same direction will produce the phenomena of interference.

Beats: When two wave having slightly different frequency, while travelling in the same direction will produce beats.

7.10 INTENSITY (I) OF WAVE:

Q. **What is intensity? What is the relation between intensity and amplitude?**

Ans.

INTENSITY

"The amount of energy transmitted per unit area per unit time in the direction of propagation of progressive wave is called intensity of wave."

- It is a measure of the power of a wave.
- It is usually denoted by the symbol of "I".
- It's SI unit is watts per square metre ($W\ m^{-2}$).

Explanation:

A progressive wave or travelling wave is one that travels through a medium in a consistent direction and transferring energy from one point to another.

it is a wave that propagates or moves forward, as opposed to a stationary or standing wave.

Examples of progressive waves include water waves, sound waves, light waves, etc.

Mathematically:

By definition, the intensity of a wave is:

$$I = \frac{E}{A \times t}$$

$$I = \frac{E/t}{A}$$

$$I = \frac{P}{A}$$

Here,
I = intensity of wave in ($W\ m^{-2}$)
E = Energy in joules (J)
t = time in seconds (sec)
P = Power in watts (W)

Relation between intensity and amplitude

We know that in mechanical waves, such as sound waves, water waves, or waves on a vibrating string, energy is stored as kinetic energy and potential energy of the medium's particles. How much energy is stored depends upon the displacement (amplitude) of the particles from the mean position. Therefore, the intensity I of waves is proportional to the square of the amplitude A, i.e.,

$$I \propto A^2$$

$$I = kA^2$$

Here k is the constant of proportionality and depends upon the physical properties of the wave and the medium.

TIDBIT

Sound cannot travel through a vacuum because there are no particles to transmit the sound wave.

The tidbit explains that **frequency and amplitude of a travelling wave are independent.**

In simpler terms:

- **Amplitude** relates to the **volume or intensity** of a wave (how "big" it is). When you turn up the volume of a song, you're increasing its amplitude.
- **Frequency** relates to the **pitch** of a wave (how high or low the sound is).

Because they are independent, you can change one without affecting the other. This is why you can make a song louder (increase amplitude) without changing the melody or tune (which depends on frequency/pitch).

Tidbit

Sound cannot travel through vacuum, as there are no particles to transmit the sound wave.

Tidbit

Frequency and amplitude of a traveling wave are independent of each other. That is why you can turn up the volume of a song (increase amplitude) without changing its pitch (which depends on frequency).

Brain Teaser:

Can you find the decibel level of a traveling wave whose intensity is 10 W m⁻²?

Ans: To find the decibel level (L_{dB}) of a sound, we use the formula: $L_{dB}=10\log_{10}(I/I_o)$

Where:

- I is the intensity of the sound wave (given as 10 W m^{-2}).
- I_0 is the reference intensity, which is the threshold of human hearing, approximately 10^{-12} W m^{-2}.

Now, let's plug in the values: $L_{dB}=10\log_{10}(10\ W\ m^{-2}/10^{-12}\ W/m2) = 10\log_{10}(10^1\times10^{12}) = 10\log10(10^{13})$

Using the logarithm property $\log_{10}(10^x)=x$: $L_{dB}=10\times13=130$ dB

Therefore, the decibel level of a travelling wave with an intensity of 10 W m^{-2} is 130 dB.

Brain teaser

Can you find the decibel level of a travelling wave whose intensity is 10 W m^{-2}?

MULTIPLE CHOICE QUESTIONS

- **Intensity of a wave is defined as the energy transmitted per unit area per unit:**
  (a) Length. (b) Time. (c) Volume. (d) Mass.

Answer: (b) Time.

Explanation: Intensity is power (energy per unit time) transmitted per unit area.

- **The SI unit of intensity of a wave is:**
  (a) Joule per square meter (J/m2) (b) Watt per square meter (W/m2)
  (c) Newton per square meter (N/m2) (d) Pascal (Pa)

Answer: (b) Watt per square meter (W/m2)

Explanation: Since Intensity = Power / Area, and Power is in Watts (J/s), the unit is W/m2.

- **The intensity of a progressive wave is directly proportional to the:**
  (a) Amplitude (b) Square of the amplitude (c) Wavelength (d) Frequency.

Answer: (b) Square of the amplitude.

Explanation: The energy carried by a wave is proportional to the square of its amplitude, and since intensity is energy per unit area per unit time, intensity is also proportional to the square of the amplitude (I∝A2).

- **If the amplitude of a progressive wave is doubled, its intensity will become:**
  (a) Doubled. (b) Half. (c) Four times. (d) One-fourth.

Answer: (c) Four times.

Explanation: Since I∝A2, if A is doubled (2A), then the new intensity is ∝(2A)2=4A2, so it becomes four times the original.

- **The energy of the Sun is transferred to the Earth in the form of light waves. This transfer primarily involves:**
  (a) Conduction (b) Convection (c) Radiation (d) Mechanical work

Answer: (c) Radiation

Explanation: Energy transfer via electromagnetic waves (like light) is known as radiation. This is how the Sun's energy reaches Earth through the vacuum of space.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define intensity of a wave.**

Ans: Intensity of a wave is defined as the amount of energy transmitted per unit area per unit time in the direction of wave propagation.

- **What is the SI unit of intensity?**

Ans: The SI unit of intensity is Watt per square meter (W/m2).

- **How is the intensity of a progressive wave related to its amplitude?**

Ans: The intensity of a progressive wave is directly proportional to the square of its amplitude (I∝A2).

- **If a sound source emits power 'P' uniformly in all directions, what is the intensity of the sound at a distance 'r' from the source?**

Ans: Assuming uniform emission, the intensity (I) at distance 'r' from the source would be I=P/(4πr2), following the inverse square law for power distributed over a spherical surface.

- **What physical quantity does "power/area" represent in the context of waves?**

Ans: "Power/area" represents the intensity of the wave.

7.11 DOPPLER'S EFFECT

Q. What is the Doppler Effect?

Ans

DOPPLER EFFECT

The Doppler Effect is the apparent change in the frequency (or pitch) of waves due to the relative motion between the source of the waves and the observer (listener).

How it was first observed?

This effect was first observed by John Doppler while he was observing the frequency of light emitted from a star. In some cases, the frequency of emitted light was found to be slightly different from that emitted from a similar source on Earth. This confirmed that the change in frequency of light depends upon the motion of a star relative to Earth.

How can it be observed with sound waves?

The Doppler Effect can be observed with sound waves. For example, when an observer is standing on a railway platform, the pitch of the whistle of an engine coming towards the platform appears to become higher. As the engine moves away, the pitch appears to become lower.

General Principle:

Consider a source of sound S at rest, which emits sound waves having wavelength λ. Let speed of the sound for a stationary observer (i.e., listener) be v. Then the number of waves received by the observer in one second is the frequency: $f=v/\lambda$.

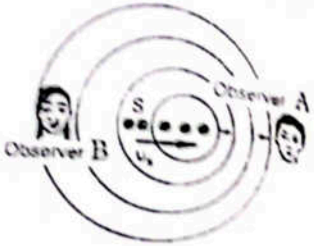
Example:

When an observer is standing on a railway platform, the pitch of the whistle of an approaching locomotive is heard to be higher. But when the same locomotive moves away, the pitch of the whistle becomes lower.

Case I

When source moves towards the stationary observer (A):

Suppose the source of sound moves towards the stationary observer with velocity "u_s" as shown in fig. the waves are compressed by an amount known as Doppler's shift denoted by " $\Delta\lambda$ ":



$$u_s = f\,\Delta\lambda$$

$$\Delta\lambda = \frac{u_s}{f}$$

The wavelength for observer " A " is then

$$\lambda_A = \lambda - \Delta\lambda$$

$$\lambda_A = \frac{v}{f} - \frac{u_s}{f}$$

$$\lambda_A = \left(\frac{v-u_s}{f}\right)$$

The modified frequency for observer "C" is given by

$$f_A = \frac{v}{\lambda_A}$$

$$f_A = \frac{v}{\frac{v-u_s}{f}}$$

P

$$f_A = \left(\frac{v}{v-u_s}\right)f$$

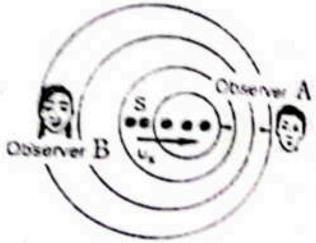
$$\frac{v}{v-u_s} > 1$$

$$f_A > f$$

So, when source is moving towards the stationary observer, the frequency or pitch of the sound increases.

Case II:

When source moves away from the stationary observer (B):



$$u_s = f\,\Delta\lambda$$

$$\Delta\lambda = \frac{u_s}{f}$$

The wavelength for observer " B " is then

$$\lambda_B = \lambda + \Delta\lambda$$

$$\lambda_B = \frac{v}{f} + \frac{u_s}{f}$$

$$\lambda_B = \left(\frac{v+u_s}{f}\right)$$

The modified frequency for observer "B" is given by

$$f_B = \frac{v}{\lambda_B}$$

$$f_B = \frac{v}{\frac{v+u_s}{f}}$$

$$f_B = \left(\frac{v}{v+u_s}\right)f$$

$$\frac{v}{v+u_s} < f$$

$$f_B < f$$

Info Corner	
Hearing Ranges	
Organisms	Frequencies in Hz
Dolphin	150 - 150,000
Bat	1000 - 120,000
Cat	60 - 70,000
Dog	15 - 50,000
Human	20 - 20,000

So, when source is moving **away** from the stationary observer, the **frequency or pitch** of the sound decreases.

NEXT TWO CASES ARE NOT GIVEN IN TEXT BOOK BUT INCLUDED FOR FURTHER STUDY AND INFORMATION

Case III:

When observer (A) moves towards the stationary source:

Suppose that:

"v" is the velocity of the sound in the medium

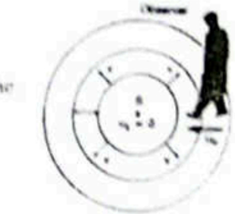
" f " is the frequency of the sound which emits by source

" λ " is the wavelength of the sound wave

If both source and observer are stationary, then

$$v = f\lambda$$

$$f = \frac{v}{\lambda}$$



If the observer "A" moves towards the source with velocity " u_o " as shown in fig.

The relative velocity of the waves and the observer is increased to $(v + u_o)$ then the number of waves received in one second or modified frequency " f_A " is given by

$$f_A = \frac{v+u_o}{\lambda}$$

Put the value of " λ " from above equation

$$f_A = \frac{v+u_o}{v/f}$$

$$f_A = \left(\frac{v+u_o}{v}\right)f$$

$$\frac{v+u_o}{v} > 1$$

$$f_A > f$$

So, when an observer is moving towards a stationary source then frequency or pitch of the sound increases.

Case IV:

When observer (B) moves away from the stationary source:

Suppose the observer moves away from the stationary source with the velocity " u_o ", the relative velocity of the waves and the observer is decreased to $(v - u_o)$ then the number of waves received in one second or modified frequency " f_B " is given by

$$f_B = \frac{v-u_o}{\lambda}$$

Put the value of " λ " from eq (1)

$$f_B = \frac{v-u_o}{v/f}$$

$$f_B = \left(\frac{v-u_o}{v}\right)f$$

As

$$\frac{v-u_o}{v} < 1$$

$$f_B < f$$

So, when an observer is moving away from a stationary source then frequency or pitch of the sound decreases.

For Your Information

- **Supersonic Speed:** When an object travels faster than the speed of sound, it creates a **shockwave** (sonic boom), a cone-shaped wave front.
- **Wavelength vs. Shockwave:** The normal wavefronts propagate outwards. When the source moves faster than the waves it creates, a shockwave forms.

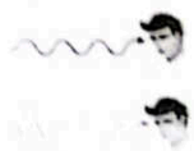
7.12 APPLICATIONS OF DOPPLER'S EFFECT

Q. What are the applications of Doppler's effect

Ans

APPLICATIONS OF DOPPLER EFFECT

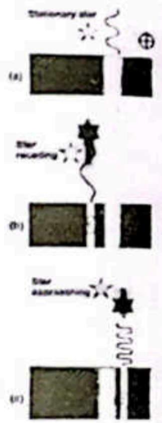
The Doppler effect has numerous important applications in various fields:



1. **Radar (Radio Detection And Ranging):**
   - **How it works:** Radar uses radio waves (part of the electromagnetic spectrum) to determine the velocity and elevation of airplanes. A radar device transmits radio waves and measures the frequency shift of the waves reflected from a moving object.

- **Example:** If an airplane is approaching, the reflected wavelength will be shorter (higher frequency). If it's moving away, the reflected wavelength will be larger (lower frequency). This allows calculation of the airplane's speed.
- **Satellite Application:** Similarly, the Doppler shift of signals from moving satellites around Earth can be used to determine their speed and position, enabling accurate location tracking.

2. **Sonar (Sound Navigation and Ranging):**
   - **How it works:** Sonar is a technique that uses sound waves to detect objects underwater, such as submarines or fish schools, and to measure distances. It relies on the change in relative speed between the source and observer.
   - **Principle:** A sound pulse is emitted, and the Doppler effect on the reflected echo is used to determine the target's speed.
   - **Applications:** Military applications (submarine control), fishing (depth measurement), and marine mapping.
3. **Astronomy:**
   - **How it works:** Astronomers use the Doppler effect to calculate the speeds of distant stars and galaxies.
   - **Red shift/ Blue shift:** By comparing the line spectrum of light from a star with light from a laboratory source, the Doppler shift of the star's light can be measured.
     - **Redshift:** If a star is moving away from Earth, its emitted waves have a longer wavelength (shifted towards the red end of the spectrum). This indicates the star is receding. All distant galaxies show redshift, indicating the expansion of the universe.
     - **Blueshift:** If a star is moving towards Earth, its emitted waves have a shorter wavelength (shifted towards the blue end of the spectrum). This indicates the star is approaching.
   - **Measuring Speeds:** The speed of the star can then be calculated from this shift.



4. **Radar Speed Traps:**
   - **How it works:** Police radar guns use electromagnetic waves (microwaves) emitted from a transmitter in short bursts.
   - **Principle:** Each burst is reflected off a car. If the car is moving, the reflected microwaves experience a Doppler shift. By measuring this Doppler shift, the speed at which the car moves is calculated by computer.
5. **Doppler Echocardiography:**
   - **How it works:** This medical application uses Doppler ultrasound to measure blood flow and calculate cardiac output.
   - **Principle:** Ultrasound waves are directed at blood cells. The Doppler shift in the reflected ultrasound waves indicates the speed and direction of blood flow.
   - **Applications:** It helps detect cardiac abnormalities, such as valve stenosis (narrowing) or regurgitation (leaking), and vascular stenosis or occlusion.

Bats navigate and find food by echo location

Doppler Effect Limitations:

- Doppler Effect is applicable only when the velocities of the source of the sound and the observer are much less than the velocity of sound.
- The motion of both source and the observer should be along the same straight line.

MULTIPLE CHOICE QUESTIONS

- **The Doppler effect describes the apparent change in the:**
  (a) Amplitude of a wave due to motion
  (b) Frequency (or pitch) of a wave due to relative motion between source and observer.

  (c) Wavelength of a wave due to medium change (d) Speed of a wave due to temperature

Answer: (b) Frequency (or pitch) of a wave due to relative motion between source and observer.
Explanation: The Doppler effect is specifically about the shift in observed frequency when there's relative motion.

- **When a source of sound waves moves towards a stationary observer, the observed frequency will be:**
  (a) Lower than the source frequency (b) Higher than the source frequency
  (c) Equal to the source frequency (d) Zero

Answer: (b) Higher than the source frequency. **Explanation:** As the source approaches, wave crests arrive more frequently, leading to a higher observed frequency (higher pitch).

- **Which of the following is an application of the Doppler effect?**
  (a) Microphones for sound recording (b) Radar speed traps
  (c) Optical microscopes (d) Thermometers

Answer: (b) Radar speed traps. **Explanation:** Radar speed traps use the Doppler effect of reflected radio waves to measure the speed of moving vehicles.

- **If a star is moving away from the Earth, the light observed from it will show a:**
  (a) Blueshift (shorter wavelength) (b) Redshift (longer wavelength)
  (c) No change in wavelength (d) Increase in amplitude

Answer: (b) Redshift (longer wavelength).
Explanation: When a light source moves away, the observed wavelength increases (shifts towards the red end of the spectrum) due to the Doppler effect for light.

- **SONAR uses the Doppler effect to determine:**
  (a) The temperature of water (b) The depth of water
  (c) The speed and direction of underwater objects (d) The salinity of water

Answer: (c) The speed and direction of underwater objects. **Explanation:** SONAR uses sound waves, and by analyzing the Doppler shift of the reflected sound, it can determine the relative velocity of objects underwater.

- **A passenger is sitting in a fast-moving train. The engine of the train blows a whistle of frequency n. If the apparent frequency of sound heard by the passenger is n' then:**
  (a) $n' < n$ (b) $n' > n$ (c) $n' = n$ (d) $n' = \frac{1}{n}$

Solution: Because passenger is inside train so no change in frequency will be observed.

- **The distance between source and listener is quadrupled, the intensity will become**
  (a) One sixteenth (b) One fourth (c) Halved (d) Sixteen times

Solution: $I \propto \frac{1}{x^2}$ if $x' = 4x$ so $I = \frac{1}{16}$

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define the Doppler Effect.**

Ans: The Doppler effect is the apparent change in the frequency (or pitch) of a wave as a result of the relative motion between the source of the wave and the observer.

- **What happens to the observed frequency of sound when a source moves away from a stationary observer?**

Answer: When a sound source moves away from a stationary observer, the observed frequency will be lower than the source frequency (lower pitch).

- **List two important applications of the Doppler Effect mentioned in the text.**

Answer: Two important applications of the Doppler effect are radar systems (e.g., speed traps) and SONAR systems.

- **How is the Doppler Effect used in astronomy to study stars and galaxies?**

Answer: In astronomy, the Doppler effect is used to determine the radial velocity of stars and galaxies. If light from a celestial object is redshifted, it means the object is moving away from Earth; if it's blueshifted, it's moving closer.

- **What is Doppler echocardiography, and how does it utilize the Doppler Effect?**

Answer: Doppler echocardiography is a medical application that uses Doppler ultrasound to measure blood flow velocity and detect cardiac abnormalities, such as valve stenosis or regurgitation, by analyzing the frequency shift of ultrasound waves reflected from moving blood cells.

- **What is "Doppler Effect"? Does it hold for both sound and light waves? (SGD 2022 GII)**

Ans. Doppler Effects: The apparent change in frequency of sound caused due to relative motion of source or observe is called Doppler's effect.
It is equally applicable on both Sound as well as light waves.

- **How should a sound source move with respect to an observer, so that the frequency of its sound does not change? (BWP 2018 GI) (MTN 2018 GII) (SGD 2019 GI) (DGK, BWP 2019 GII) (SWL 2023 GII)**

Ans. Sound source should have zero relative velocity with respect to observer.

- **What is effect on frequency of sound waves, when source and observer are moving towards each other? (LHR 2019 GI) (LHR 2019 GII)**

Ans. When source and observer are moving towards each other, according to the sign conventions, v_s is positive and v_o is also positive. Hence the apparent frequency increases.

- **Give two applications of Doppler's effect. (DGK 2018 GI) (RWP 2023 GI) (SGD 2023 GII)**

Ans. Applications of Doppler effect: Radar is an application of Doppler effect. It transmits and receives radio waves to know the position and speed of aeroplane.
Speed Trap is also an application of Doppler effect. A short burst of microwaves is emitted from a transmitter. Each burst is reflected off by any moving object and computer program calculate the speed by knowing the Doppler shift.

- **Define Doppler shift. Write down its formula. (LHF 2022 GII)**

Ans. Doppler Shift: if the source of wave is moving away or towards observer with certain velocity u_s, then a change in wavelength observed. This change in wavelength is known as Doppler shift.
Formula: $\Delta\lambda = \frac{u_s}{f}$

- **What do you mean by "Sonar"? (AJK 2018)**

Ans. Sonar represents "Sound navigation and Ranging". It is the name of a technique for detecting the presence of objects under water by acoustical echo. It employs the Doppler Effect., in which an apparent change in frequency occurs when the source and the object are in relative motion to one another.

- **How the Doppler Shift can be used in Radar Speed Trap? (DGK, SGD 2018 GI) GRW 2019)**

Ans. Radar Speed Trap is also an application of Doppler effect. A short burst of microwaves is emitted from a transmitter. Each burst is reflected off by any moving object in the path of microwave. Transmitter is open to detect reflected microwaves. By measuring the Doppler shift speed of object can be calculated by computer program.

- **Explain the term red shift and blue shift in Doppler's Effect. (LHR 2019 GI) (SGD 2019 GII) (MTN, RWP 2022 GI) (SWL 2023 GI)**

Ans. Star moving towards the earth show a blue shift. This is because the wavelength of light emitted by the star are shorter than if the star had been at rest. So, the spectrum is shifted towards shorter wavelength i.e. to the blue end of the spectrum.
Star moving away from the earth show a red shift. This is because wavelength of the light emitted by the star are longer than if the star had been at rest. So, the spectrum is shifted towards longer wavelength i.e. to the red end of the spectrum.

- **Why ultrasonic waves are preferred on radio waves for the use of undersea communication?**

Ans. 1. Due to the high attenuation of electromagnetic waves in sea water, radio communication between submerged submarines in a sea is not possible.
2. Since the attenuation of sound waves in water is low, ultrasonic waves are used for underwater communication.

- **How can the speed of a car be found by Doppler's effect? (FSD 2022 GI)**

Ans. Radar Speed Trap is used to find the speed of car by using Doppler effect. A short burst of microwaves is emitted from a transmitter. Each burst is reflected off by any moving car in the path of microwave. Transmitter is open to detect reflected microwaves. By measuring the Doppler shift speed of car can be calculated by computer program.

- **How can Doppler Effect be used to monitor blood flow through major arteries? (FSD 2018) (LHR 2019 GI)**

Ans. The Doppler effect can be used to monitor blood flow through major arteries. Ultrasound wave of frequencies 5 MHz to 10 MHz are directed towards the artery and a receiver defects the back scattered signal. The apparent frequency depends on the velocity of flow of the blood.

TEXT BOOK EXERCISE WITH SOLUTION

MULTIPLE CHOICE QUESTIONS

Tick the correct answer.

7.1 **The simple wave speed equation is represented by:**
(a) $v = f\lambda$ (b) $v = s/t$
(c) $v = r\omega$ (d) $\Delta d/\Delta t$

Answer: (a) $v = f\lambda$

7.2 **The principle of superposition in waves is stated as:**
(a) the displacement of a wave is the sum of the displacements of its individual components
(b) the velocity of a wave is the product of its individual components
(c) the frequency of a wave is the difference of its individual components
(d) the amplitude of a wave is the ratio of its individual components

Answer: (a) the displacement of a wave is the sum of the displacements of its individual components

7.3 **Anode in a stationary wave is:**
(a) a point of maximum displacement
(b) a point of intermediate displacement
(c) a point of zero displacement
(d) a point of infinite displacement

Answer: (c) a point of minimum i.e zero displacement

7.4 **An antinode in a stationary wave is:**
(a) a point of maximum displacement
(b) a point of minimum displacement
(c) a point of zero displacement
(d) a point of infinite displacement

Answer: (a) a point of maximum displacement

7.5 **Stationary waves are defined as:**
(a) waves that move with a constant velocity
(b) waves that move with a changing velocity
(c) waves that oscillate in a fixed position
(d) waves that propagate through a medium

Answer: (c) waves that oscillate in a fixed position

7.6 **Harmonics are:**
(a) integer multiples of a fundamental frequency
(b) integer sub-multiples of a fundamental frequency
(c) random frequencies
(d) non-integer multiples of a fundamental frequency

Answer: (a) integer multiples of a fundamental frequency

7.7 **The result of constructive interference between two waves is represented as:**
(a) a decrease in amplitude
(b) an increase in amplitude
(c) no change in amplitud
(d) a shift in phase

Answer: (b) an increase in amplitude

7.8 **If the amplitude of the wave is tripled, then the amount of energy is increased by:**
(a) 3 times (b) 6 times
(c) 9 times (d) 12 times

Answer: (c) 9 times (Energy and thus intensity, is proportional to the square of the amplitude. If amplitude is tripled (factor of 3), intensity increases by $3^2=9$ times.)

7.9 **What type of waves do headphones use to produce sound?**
(a) Electromagnetic waves
(b) Mechanical waves
(c) Pressure waves
(d) Longitudinal waves

Answer: (d) Longitudinal waves (Sound waves are longitudinal, and headphones produce sound.)

7.10 **The typical frequency range of microwaves is:**
(a) $10^3 - 10^5$ Hz (b) $10^5 - 10^7$ Hz
(c) $10^7 - 10^9$ Hz **(d) $10^9 - 10^{11}$ Hz**

Answer: (d) $10^9 - 10^{11}$ Hz (Microwaves typically range from 300 MHz to 300 GHz, which corresponds to 3×10^8 to 3×10^{11} Hz. $10^9 - 10^{10}$ Hz is a reasonable range within this.)

7.11 **The bending of waves around an obstacle is called as:**
(a) refraction (b) reflection
(c) diffraction (d) interference

Answer: (c) diffraction

7.12 **The Doppler Effect used in astronomy is for:**
(a) measuring the diameters of stars
(b) determining velocity of galaxies
(c) analyzing properties of black holes
(d) studying behaviour of electromagnetic waves

Answer: (b) determining velocity of galaxies

SHORT ANSWER QUESTIONS

7.1 **What are the conditions for interference to occur?**

Ans: Superposition of two waves having the same frequency and travelling in the same direction results in phenomenon called interference.
For interference to occur, the waves must meet these conditions:

- Coherent Sources: The waves must come from coherent sources, meaning they have a constant phase difference and the same frequency.

- **Same Direction:** The waves must be traveling in approximately the same direction (or at least overlap in space).
- **Same Wavelength/Frequency:** They must have the same wavelength (and thus frequency) to produce a stable interference pattern.

7.2 Differentiate between constructive and destructive interference of waves.

Constructive interference

Ans: If the path difference between two waves having same frequency is integral multiple of wavelength while travelling in same direction, the interference will be constructive.

$$\Delta S = n\lambda$$

where $n = 0, \pm1, \pm2, \ldots$

Destructive interference

If the path difference between two waves having same frequency is odd integral multiple of half wavelength while travelling in same direction, the interference will be destructive.

$\Delta S = n\frac{\lambda}{2}$ where $n = \pm1, \pm3, \pm4 \ldots$

or $(2n+1)\frac{\lambda}{2}$ where $n = 0, \pm1, \pm2, \ldots$

7.3 What are coherent waves and coherent sources? Give examples.

Coherent waves

Ans: The waves that maintain a constant phase difference and have the same frequency are called coherent waves.

Example: If two speakers are driven by the same signal, the sound waves emitted from them will be coherent.

Coherent Sources

Two sources are said to be coherent if they produce waves of constant phase difference and of same frequency.

Example: Two speakers driven by the same audio generator.

7.4 Distinguish between longitudinal and transverse waves.

Transverse waves

Ans: The waves in which particles of medium are displaced in a direction perpendicular to the direction of propagation of wave are called transverse waves.

Longitudinal waves

The waves in which particles of medium are displaced along the direction of propagation of waves are called longitudinal waves.

7.5 Is it possible for two identical waves travelling in the same direction along a string to give rise to a stationary wave? How is it so?

Ans: No, it is not possible for two identical waves traveling in the same direction along a string to give rise to a stationary wave. Stationary waves are formed specifically when two identical waves (same frequency, amplitude, and wavelength) travel in opposite directions and superpose. If they travel in the same direction, they will interfere, but they will form a traveling wave with varying amplitude, not a stationary pattern of fixed nodes and antinodes.

7.6 How would you apply Doppler Effect in studying cardiac problems in humans?

Ans: The Doppler Effect is applied in medicine through Doppler echocardiography (a type of ultrasound). This technique uses high-frequency sound waves (ultrasound) to visualize and measure blood flow within the heart and blood vessels.

- **Application:** When ultrasound waves are emitted by a transducer and reflect off moving red blood cells, their frequency changes due to the Doppler Effect.
  Analysis: By analyzing the magnitude and direction of this frequency shift, the velocity and direction of blood flow can be calculated.
- **Cardiac Problems:** This allows doctors to:
  - Assess valve function (e.g., detect narrowed valves (stenosis) or leaky valves (regurgitation) by observing abnormal blood flow patterns).
  - Measure cardiac output (the amount of blood pumped by the heart).
  - Detect congenital heart defects.
  - Evaluate blood flow in arteries and veins to identify blockages or other vascular problems.

7.7 What is meant by diffraction of waves? For what purpose, the ripple tank is used?

Ans: **Diffraction of Waves:** Diffraction is the phenomenon where waves bend or spread out as they pass through an opening or around an obstacle. The extent of bending is most noticeable when the size of the opening or obstacle is comparable to the wavelength of the wave.

Purpose of Ripple Tank: A ripple tank is a shallow tank of water used to demonstrate fundamental properties of waves. Its primary purposes are to:

- **Demonstrate Wave Phenomena:** Visually show concepts like wave propagation, reflection, refraction, interference, and especially diffraction of water waves.
- **Illustrate Relationships:** Help students understand the qualitative relationship between wavelength and the extent of diffraction (e.g., how the bending changes with different gap sizes).

CONSTRUCTED RESPONSE QUESTIONS

7.1 Which measurement of a wave is the most important when determining the wave's intensity?

Ans: The most important measurement of a wave when determining its intensity is its amplitude. This is because the intensity of a wave is directly proportional to the square of its amplitude ($I \propto A^2$). This means that even a small increase in amplitude can lead to a significant increase in the wave's intensity.

$$I \propto A^2$$

Examples:

Sound: The louder a sound is, the higher the amplitude of the sound wave.

Light: Brighter light waves have higher amplitudes.

7.2 Can you apply Doppler Effect to light waves? Describe briefly.

Ans: Yes, the Doppler Effect can apply to light waves.

To observer the motion of stars and galaxies we use Doppler Effect. If there is a relative motion between stars and earth, then a change in frequency or wavelength observed.

If the source of light moves away from observe a red shift and if it moves toward observer a blue shift observed.

Applications: This effect is used in astronomy to measure the speed of stars and galaxies, detect binary stars, and study the rotation of stars and galaxies,

7.3 Can you compare the compressions and rarefactions of the longitudinal wave with the peaks and troughs of the transverse wave? Discuss.

Ans: **Comparison and Discussion:** Yes, we can compare the compressions and rarefactions of longitudinal waves with the peaks and troughs of the transverse waves. While compressions/rarefactions and peaks/troughs describe the displacement of particles in different types of waves, they are analogous.

- **Compression is analogous to a Crest:** Both represent a point of maximum positive displacement from the equilibrium position. In a compression, particles are displaced forward, and in a crest, particles are displaced upward.
- **Rarefaction is analogous to a Trough:** Both represent a point of maximum negative displacement from the equilibrium position. In a rarefaction, particles are displaced backward, and in a trough, particles are displaced downward.

The main difference lies in the *direction* of particle displacement relative to the wave's propagation: parallel for longitudinal waves (compressions/rarefactions) and perpendicular for transverse waves (crests/troughs). Both concepts fundamentally describe the periodic changes in the medium as energy is transferred by the wave.

7.4 How should a source of sound move with respect to an observer so that the frequency of its sound does not change? Write two examples.

Ans: The frequency of a sound source will not change with respect to an observer if there is no relative motion between the source and the observer along the line connecting them. This means:

- Both the source and the observer are stationary.
- Both the source and the observer are moving in the same direction at the exact same speed.
- The source is moving perpendicular to the line connecting it to the observer (though this is more complex, as there's no radial velocity component).
- Source must circulate observer placed at center.

7.5 Why is it difficult to recognize beats when the frequency difference is greater than 10 Hz? Exemplify.

Ans: Human hearing has a "persistence" or "after-image" effect. The impression of a sound remains in our auditory system for about 0.1 seconds (or 1/10th of a second).

When the beat frequency exceeds 10 Hz, the time interval between successive beats (1/frequency) becomes shorter than 0.1 seconds. This means the human ear doesn't have enough time to perceive the individual loud and soft sounds as distinct beats.

Instead of a distinct pattern of beats, the ear perceives the combined sound as a more or less continuous, blended tone.

COMPREHENSIVE QUESTIONS

7.1 State and explain the principle of superposition of waves. Apply this principle to elaborate the working of noise canceling headphones.

7.2 What are standing waves? Illustrate a detailed experiment that demonstrates the standing waves using stretched strings.

7.3 Find the frequencies of the harmonics produced in organ pipe when it is open at one end and when it is open at both ends.

7.4 Define and exemplify diffraction of waves. Describe this phenomenon by ripple tank experiment.

7.5 What is meant by the term beats? Prove that number of beats per second is equal to the difference between the frequencies of vibrating tuning forks.

7.6 What do you understand by progressive waves? Discuss the intensity of progressive waves.

7.7 Keeping in mind "Doppler effect", analyze the following cases

(a) when source of sound moves away from the stationary observer.

(b) when source of sound moves towards the stationary observer.

SOLVED EXERCISE

7.1 Two speaker are arranged as shown in the figure. The distance between them is 3.0 m and they emit a constant tone of 344 Hz. A microphone P is moved along a line parallel to and 4.0 m from the line connecting the two speakers. It is found that tone of maximum loudness is heard and displayed on the CRO when microphone is on the centre of the speaker line and opposite to each speaker. Calculate the speed of sound.

Solution: (Diagram)

Distance between speaker S_1S_2 = 3.0 m

Tone frequency f = 344 Hz

Distance between speakers and line of motion P S_2P = 4.0 m

Speed of sound v = ?

For tone of maximum loudness or the condition for constructive interference, the path difference must be $0 \pm 1\lambda, \pm 2\lambda, \pm 3\lambda, \ldots$

At middle point 'O' the path difference between two soundwaves is zero ($S_1O = S_2O$), thus at that point 'O' constructive inference takes place.

For the next point P of constructive inference, the path difference between waves should be λ. So λ = Path difference $S_2P_1 - S_1P_1$

Now, we calculate values of S_2P_1 from right angle triangle $S_1S_2P_1$

$S_2P_1 = \sqrt{(S_1S_2)^2 + (S_1P_1)^2}$

(By Pythagoras Theorem)

$S_2P_1 = \sqrt{(3m)^2 + (4m)^2}$

$= \sqrt{(9+16)}\,m = \sqrt{25}\,m = 5m$

Therefore $\lambda = S_2P_1 - S_1P_1$ or

λ = 5 m − 4 m = 1 m

As $v = f\lambda$

Putting the values, we have

$v = 344\ m\,s^{-1} \times 1\ m = 344\ m\,s^{-1}$

7.2 The wavelength of a signal from a radio transmitter is 1500 m and the frequency is 200 kHz. What is the wavelength for a transmitter operating at 1000 kHz and with what speed the radio waves travel?

Solution: (Diagram)

$\lambda_1 = 1500\ m = 1.5 \times 10^3\ m$,

$f_1 = 200\ kHz = 2.0 \times 10^2\ Hz$

$f_2 = 1000\ kHz = 1 \times 10^6\ kHz$,

λ_2 = ? v = ?, As $v = f\lambda$

Since, the speed of both the signals is same, so

$v = f_1\lambda_1$

$v = 2.0 \times 10^2\ Hz \times 1500\ m$

$v = 3.0 \times 10^8\ m\,s^{-1}$

$v = f_2\lambda_2$

$$\lambda_2 = \frac{v}{f_2}$$

$$\lambda_2 = \frac{3\times10^8\ m\,s^{-1}}{1\times10^6\ Hz}$$

$\lambda_2 = 3 \times 10^2\ m$

7.3 A stationary wave is established in a string which is 120 cm long and fixed at both ends. The string vibrates in four segment; at a frequency of 120 Hz. Determine its wavelength and fundamental frequency?

Solution:

$$\ell = 120\,cm = \frac{120}{100}\,m = 1.2\,m$$

n = 4

f_4 = 120 Hz

f_1 = ?

λ = ?

(i) As the string vibrates in four segments and the distance between two consecutive nods is $\lambda/2$ so, the wavelength of the string is

$$\ell = n\frac{\lambda_n}{2}$$

$$\lambda_n = \frac{2\ell}{n}$$

$$\lambda_4 = \frac{2\times1.2\,m}{4}$$

$\lambda_4 = 0.6\,m$

(ii) If string vibrates in n loops, then frequency of stationary waves will be

$f_n = nf_1$

$f_4 = 4f_1$

$120\,Hz = 4f_1$

$$f_1 = \frac{120\,Hz}{4}$$

$f = 30\,Hz$

7.4 An organ pipe has a length of 50 cm. Find the frequency of its fundamental note and the next harmonic, when it is:

(a) Open at both ends

(b) Closed at one end

(Speed of sound = 350000 m s⁻¹)

Solution:

$$\ell = 50\,cm = \frac{50}{100}\,m = 0.5\,m$$

$v = 350\ m\,s^{-1}$

(a) When pipe is open at both sides:

Fundamental frequency f_1 = ?

Next harmonic frequency f_2 = ?

The frequency for nth harmonic in an open organ pipe is

$f_n = n\dfrac{v}{2\ell}$ when n = 1,2,3, ...

So the fundamental frequency is

$f_1 = \dfrac{1\times350\,m\,s^{-1}}{2\times0.5\,m}$ put n = 1

$f_1 = 350\,Hz$

Next harmonic frequency i.e., n = 2

$$f_2 = \frac{2v}{2\ell}$$

$f_2 = \dfrac{v}{\ell} = \dfrac{350\,m\,s^{-1}}{0.5\,m} = 700\,s^{-1}$

$f_2 = 700\,Hz$

(b) When pipe is closed at one end:

Fundamental frequency f_1 = ?

Next harmonic frequency f_3 = ?

When the pipe is closed at one end, then frequency for nth harmonic is

$f_n = n\dfrac{v}{4\ell}$ when n = 1,3,5,

So fundamental frequency is

$f_1 = \dfrac{1\times350\,m\,s^{-1}}{4\times0.5\,m}$ putting n = 1

$f_1 = 175\,Hz$

Next harmonic frequency i.e., n = 3

$$f_3 = \frac{3v}{4\ell}$$

$$f_3 = \frac{3\times350\,m\,s^{-1}}{4\times0.5\,m}$$

$f_3 = 525\,Hz$

7.5 A church organ consists of pipes, each open at one end, of different lengths. The minimum length is 30 mm and the length is 4 m. Calculate the frequency range of the fundamental notes. (Speed of sound = 340 m s⁻¹)

Solution:

$\ell_{min} = 30\,mm = \dfrac{30}{1000}\,m = 30\times10^{-3}\,m$

$\ell_{max} = 4\,m$

$v = 340\,m\,s^{-1}$

Frequency range = ?

For an organ pipe open at one end only

$$f_n = \frac{nv}{4\ell}$$

(i) Minimum length

For fundamental frequency, n = 1

$$f_{1\,max} = \frac{nv}{4\ell_{min}}$$

$$f_{1\,max} = \frac{1\times340\,m\,s^{-1}}{4\times30\times10^{-3}\,m}$$

$f_{1\,max} = 2833.33\,Hz$

(ii) Maximum length:

For fundamental frequency, put n = 1

$$f_{1\,min} = \frac{nv}{4\ell_{max}}$$

$$f_{1\,min} = \frac{1\times340\,m\,s^{-1}}{4\times4\,m}$$

$f_{1\,min} = 21.25\,Hz$

So, the fundamental frequency range is approximately from 21 Hz to 2833 Hz

7.6 **In a ripple tank, a wave generator 500 pulses in 10 s. Find the frequency at time period of the pulses produced?**

Solution:

N = 500 pulses, t = 10 s, f = ?

$$\text{As Frequency} = \frac{\text{Number of pulses}}{\text{Time}}$$

$$f = \frac{500}{10\,s} = 50\,Hz$$

We know that: $T = \frac{1}{f} = \frac{1}{50\,Hz}$

$$T = 0.02\,s$$

7.7 **Two tuning forks exhibit beats a beat frequency of 3 Hz. The frequency of one fork is 256 Hz. Its frequency is then lowered slightly adding a bit of wax to one of its prongs. The two forks then exhibit a beat frequency of 1 Hz. Determine the frequency of the second tuning fork.**

Solution:

Frequency of first tuning fork = f_1 = 256 Hz

Beat frequency before loading = 3 Hz

Beat frequency after loading = 1 Hz

Frequency of second tuning fork = f_2 = ?

As $f_1 - f_2 = \pm n$

$f_2 = f_1 \pm n$

Putting the values, we have

$f_2 = 256\,Hz \pm 3\,Hz$

Either $f_2 = 256\,Hz + 3\,Hz$

$f_2 = 256\,Hz - 3\,Hz$

$f_2 = 259\,Hz$ or $253\,Hz$

let us consider 259Hz as correct answer (i.e., frequency of second tuning fork). When first fork is loaded with wax, the frequency of first fork must fall below 256 Hz i.e., 255 Hz, 254 Hz and thus the number of beats produced per second will increase and will be greater than 3 beats. Since the number of beats per second decreases on loading first fork is one, therefore 259 Hz is not correct frequency of second tuning fork.

Thus, Correct frequency = f_2 = 253 Hz

7.8 **(a) A wave has intensity of 0.5 W m^{-2} at a distance of 3.0 m from the source. What is the power of the wave?**

(b) Two progressive waves have intensities of 0.5 W m^{-2} and 0.25 W m^{-2}. Find total intensities of two waves.

Solution:

(a)

$I = 0.5\,W\,m^{-2}$

$r = 3.0\,m$

$P = ?$

$$\because I = \frac{P}{A}$$

$$\because I = \frac{P}{4\pi r^2}$$

Putting the values,

$$0.5\,W\,m^{-2} = \frac{P}{4\times 3.14(3.0)}$$

$P = 0.51 \times 13.04$

$P = 56.52\,W$

(b) $I_1 = 0.5\,W\,s^{-2}$

$I_2 = 0.25\,W\,m^{-2}$

$I = ?$

$I = I_1 + I_2$

$I = 0.5\,W\,s^{-2} + 0.25\,W\,m^{-2}$

$I = 0.75\,W\,m^{-2}$

7.9 **A speaker is emitting sound waves with a power of 50 watts. If the sound waves are spreading out evenly in all directions and intensity of the sound waved is measured at a distance of 5 m from the speaker, what is the intensity of the sound waves if the area of the sphere (the surface of a sphere) at that distance is approximately 314 m s^{-1}**

Solution:

Power P = 50 W

Area A = 314 m^2

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

$$I = \frac{P}{A}$$

$$I = \frac{50\,W}{314\,m^2}$$

$$I = 0.159\,Wm^{-2}$$

7.10 **Two trucks P and Q travelling along a motorway in the same direction. The loading trucks P travels at a steady speed of 12 m s^{-1}, the other truck Q, travelling at a steady speed of 20 m s^{-1}, sound its horn to emit a steady note which p's driver estimate, has a frequency of 830 Hz. What frequency does Q's own driver hear?**

(Speed of sound = 340 m s^{-1})

Solution:

$u_P = 12\,m\,s^{-1}$

$u_Q = 20\,m\,s^{-1}$

$v = 340\,m\,s^{-1}$

$f_P = 830\,Hz$

$f_Q = ?$

Speed of Q relative to

$P = u_s = u_Q - u_P = 20\,m\,s^{-1} - 12\,m\,s^{-1} = 8\,m\,s^{-1}$

$$f = \left(\frac{v}{v-u}\right) f'$$

$$f_P = \left(\frac{v}{v-u}\right) f_Q$$

putting the value, we have

$$830\,Hz = \left(\frac{340\,m\,s^{-1}}{340\,m\,s^{-1} - 8\,m\,s^{-1}}\right) f_Q$$

$$830\,Hz = \left(\frac{340\,ms^{-1}}{332\,m\,s^{-1}}\right) f_Q$$

or $$f_Q = \left(\frac{830\,Hz \times 332\,m\,s^{-1}}{340\,m\,s^{-1}}\right)$$

$$f_Q = 810.47\,Hz$$

7.11 **A train sounds its horn before it sets off from the station and an observer waiting on the platform estimates its frequency at 1200 Hz. The train then moves off and accelerates steadily. Fifty seconds after departure, the driver sounds the horn again and the platform observer estimates the frequency at 1140 Hz. Calculate the train speed 50 s after departure. How far from the station is the train after 50 s.**

(Speed of sound = 340 m s^{-1})

Solution:

Original frequency of horn = f = 1200 Hz

Apparent frequency = f = 1140Hz

Speed of sound = v = 340 m s^{-1}

Time = t = 50s

Speed of source (i.e., train) = u_s = ?

Distance covered by the train = S = ?

(i) $$f' = \left(\frac{v}{v+u}\right) f$$

Putting the values, we have

$$1140\,Hz = \left(\frac{340\,ms^{-1}}{340\,ms^{-1} + u}\right) \times 1200\,Hz$$

$$340\,ms^{-1} + u = \frac{340\,ms^{-1} \times 1200\,Hz}{1140\,Hz}$$

$u = 357.89 - 340$

$u = 17.89\,m\,s^{-1}$

$S = v_{av}\,t$

$$S = \left(\frac{v_i + v_f}{2}\right) t$$

$$S = \left(\frac{0 + 17.89\,ms^{-1}}{2}\right) 50s$$

S = 448 m

NUMERICAL PROBLEMS

7.1 **The speed of a wave on a typical string is 24 m s^{-1}. What driving frequency will it resonate if its length is 6.0 m? (Ans: 2 Hz)**

Given

Speed of wave = v = 24 m s^{-1}

Length of of string = l = 6 m

Frequency = f = ?

Solution

$$f = \frac{v}{2l}$$

$$f = \frac{24}{2(6)} = \frac{24}{12}$$

f = 2 Hz

7.2 **The lowest resonance frequency for a guitar string of length 0.75 m is 400 Hz. Calculate the speed of a transverse wave on the string. (Ans: 600 m s^{-1})**

Given

Length of string = 0.75 m

Frequency = f = 400 Hz

Speed of wave = v = ?

Solution

As $$f = \frac{v}{2l}$$

Or $v = 2fl$

$v = 2 \times 400 \times 0.75 = 600\,m\,s^{-1}$

7.3 **A tuning fork A produces 4 beats per second with another tuning fork B. It is found that by loading B with some wax, the beat frequency increases to 6 beats per second. If the frequency of A is 320 Hz, determine the frequency of B when loaded.**

Data:

Frequency of tuning fork A = f_A = 320 Hz

Beat frequency = n = 4

Beat frequency when B loaded with wax = n = 6

Frequency of tuning fork B = f_B = ?

Solution: Before Loading

As we know that,

$\pm n = f_A - f_B$

$f_B = f_A \pm n$

$f_B = 320 \pm 4 = 324\,Hz$ or $316\,Hz$

So frequency f_B is either 324 Hz or 316 Hz

After Loading

$\pm n = f_A - f_B$

$f_B = f_A \pm n$

$f_B = 320 \pm 6 = 326\,Hz$ or $314\,Hz$

Conclusion

The conditions for $f_A - f_B = 4$ and $f_A - f_B = 6$ satisfied only when f_B = 316 before loading and 314 after loading. Since frequency of tuning fork B decreases

after loading and difference of frequencies increases
Hence f_1 = 316 Hz

7.4 **A steel wire hangs vertically from a fixed point, supporting a weight of 80 N at its lower end. The diameter of the wire is 0.50 mm and its length from the fixed point to the weight is 1.5 m. Calculate the fundamental frequency emitted by the wire when it is plucked. Density of steel wire is 7.8×10^3 kg m^{-3}. (Ans: 76.2 Hz)**

Data:

Weight = W = 80 N = 80 kg ms^{-2}

Diameter of wire = D = 0.50 mm = 0.5×10^{-3} m

Radius of wire = r = $\frac{D}{2} = 0.25 \times 10^{-3}$ m

Length of the wire = l = 1.5 m

Density of steel wire = 7.8×10^3 kg m^{-3}

Required:

Fundamental frequency = f_1=?

Solution:

$$\text{Since } f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$$

To find mass per unit length we know that

Mass = volume × Density

= (Length × Area of cross section) × Density

$$m = \frac{\text{Mass}}{\text{length}} = \text{Area of cross section} \times \text{Density}$$

Mass per unit length = m = A × ρ= $\pi r^2 \times \rho$

So putting the values in equation, we get

m = 3.14×$(0.25\times 10^{-3})^2 \times (7.8\times 10^3)$

m = 1.53×10^{-3} kgm^{-1}

Now putting m and F in equation

$$f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}} = \frac{1}{2\times 1.5}\sqrt{\frac{80}{1.53\times 10^{-3}}}$$

f_1 = 76.2 S^{-1} or Hz

7.5 **Average intensity of sunlight on the surface of the Earth is nearly 500 W m^{-2}. Determine the amount of energy that falls on a solar panel having an area of 0.50 m^2 in four hours. (Ans: 3.6×10^6 J)**

Given

Intensity of sunlight = I = 500 W m^{-2}

Area of solar panel = A = 0.50 m^2

Time = t = 4 h = 4 × 3600 = 14400 s

Energy = E = ?

Solution

$$I = \frac{E}{A\times t}$$

E = A × I × t

E = 0.50 × 500 × 14400 = 3600000 = 3.6×10^6 J

7.6 **(a) If the intensity of a wave is 16 W m^{-2} and the amplitude is 2 m, what is the value of constant k? (Ans: 4 W m^{-4})**

(b) If the intensity of a wave is 25 W m^{-2} and the constant k is 5 W m^{-4}, what is the amplitude? (Ans: 2.24 m)

(a) **Given**

intensity of wave = I = 16 W m^{-2}

Amplitude of wave = A = 2 m

Value of constant = k = ?

Solution

I = k A^2

16 = k (2)^2

k = 4 W m^{-4}

(b) **Given**

intensity of wave = I = 25 W m^{-2}

Value of constant = k = 5 W m^{-4}

Amplitude of wave = A = ?

Solution

I = k A^2

25 = 5 A^2

A^2 = 5 m^2

A = 2.24 m

7.7 **(a) A sound system produces 200 watts of power. If the sound is directed at a crowd with an area of 150 m^2, what is the intensity of the sound? (Ans: 1.33 W m^{-2})**

(b) A light bulb emits 100 watts of power. If the light is spread out evenly over a sphere with a surface area of 400 m^2, what is the intensity of the light? (Ans: 0.25 Wm^{-2})

(a) **Given**

Power of sound system = 200 W

Area of crowd = A = 150 m^2

ntensity of sound = I = ?

Solution

P = I × A

200 = I × 150

I = 1.33 W m^{-2}

(b) **Given**

power of bulb =100 W

Surface are of sphere = A 400 m^2

Intensity of light = I = ?

Solution

$$I = \frac{P}{A}$$

$$I = \frac{100}{400} = 0.25 \text{ W m}^{-2}$$

7.8 **A radio antenna broadcasts 500 watts of power. If the signal is received at a distance of 10 km, what is the intensity of the signal? (Ans: 4×10^{-7} W m^{-2})**

Given

Broadcast power by antenna = 500 W

Distance = r = 10 km = 10000 m

Intensity of signal = I = ?

Solution

$$I = \frac{P}{A}$$

Or $$I = \frac{P}{4\pi r^2}$$

$$I = \frac{500}{4(3.14)10000^2} = 3.98\times 10^{-7} \text{ W m}^{-2}$$

= 4×10^{-7} W m^{-2}

7.9 **An organ pipe has a length of 1 m. Determine the frequencies of the fundamental and the first two harmonics:**
(a) if the pipe is open at both ends and
(b) if the pipe is closed at one end
(Speed of sound in air is 340 ms^{-1})
(Ans: 170 Hz, 340 Hz, 510 Hz; 85 Hz, 255 Hz, 425 Hz, respectively)

Data:

Speed of sound in air = v = 340ms^{-1}

Length of pipe = l = 1m

(a) For open pipe

f_1= ?

f_2 = ?

f_3= ?

(b) For closed pipe

f_1= ?

f_3= ?

f_5= ?

Solution:

(a) When pipe is open at length ends.

As $$f_n = \frac{nv}{2l}$$

For n = 1 Fundamental frequency)

$$f_1 = \frac{(1)(340)}{2\times(1)}$$

$$f_1 = \frac{340}{2} = 170 \text{ Hz}$$

f_1 = 170 Hz

For 2nd harmonic

f_2 = 2f_1

f_2 = 2× 170

f_2 = 340 Hz

For 3rd harmonic.

f_3 = 3f_1

f_3 = 3× 140

f_3 = 510 Hz

(b) When the pipe is closed at one end.

In this case only odd harmonics are present so

$$f_1 = \frac{v}{4\ell}$$

$$f_1 = \frac{340}{4\times 1} = 85 \text{ Hz}$$

F_1 = 85 Hz

For 2nd harmonic

f_3 = 3F_1

f_3 = 3× 85

f_3 = 255 Hz

For 3rd harmonic

f_5 = 5F_1

f_5 = 5× 85=425 Hz

7.10 **A train is approaching a station at 90 km h^{-1}, sounding a whistle of frequency 1000 Hz. What will be the apparent frequency of the whistle as heard by a listener sitting on the platform? What will be the apparent frequency heard by the same listener ifthe train moves away from the station with the same speed? (Speed of sound is 340 m s^{-1})**
(Ans: 1079.4 Hz, 931.5 Hz, respectively)

Data:

Frequency of source = f = 1000 HZ

Speed of sound = 340 ms^{-1}

Speed of train = U_s = 90 kmh^{-1}

$$= \frac{90\times 1000}{3600}$$

= 25 ms^{-1}

f′ = ?

f″ = ?

When train is approaching towards the listener, then using relation

$$f' = \frac{V}{V-U_s}f$$

Putting the values, we get

$$f' = \left(\frac{340}{340-25}\right)\times 1000$$

f′ = 1079.4 Hz

When the train is moving away from the listener, then using the relation

$$f'' = \left(\frac{V}{V+U_s}\right)f$$

$$f'' = \left(\frac{340}{340+25}\times 1000\right)$$

f″ = 931.5 Hz