

# CHAPTER 14: WAVES

## Class 11 CBSE Physics

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## 14.1 INTRODUCTION

In the previous chapter, we studied oscillations of objects in isolation. What happens in a system which is a collection of such objects? A material medium provides such an example.

### What is a Wave?

**Wave:** A pattern of disturbance that moves without the actual physical transfer or flow of matter as a whole.

#### **Classic Example:**

When you drop a pebble in still water:

- ✓ Circles rapidly move outward from disturbance point
- ✓ Cork pieces on surface move up and down but **not outward**
- ✓ Water mass does not flow outward with circles
- ✓ Only the **disturbance** travels, not the medium

## 💡 Key Properties of Waves

- **Transport Energy:** Waves carry energy from one point to another
- **Carry Information:** Pattern of disturbance contains information
- **No Mass Transfer:** Medium particles oscillate locally
- **Communication:** All our communications depend on wave transmission

## 🎯 Types of Waves

Type	Medium Requirement	Examples	Speed
<b>Mechanical Waves</b>	Require medium	Sound, water waves, seismic waves, string waves	Depends on medium properties
<b>Electromagnetic Waves</b>	Can travel through vacuum	Light, radio waves, X-rays	$c = 299,792,458$ m/s (in vacuum)
<b>Matter Waves</b>	Associated with particles	Electron waves, proton waves	Quantum mechanical

## Historical Note

### Famous Scientists in Wave Physics:

- **Christiaan Huygens (1629-1695):** Wave theory of light
- **Robert Hooke:** Contributions to wave propagation
- **Isaac Newton:** Early analysis of wave motion

The first scientific analysis of wave motion dates back to the **seventeenth century**.

## 14.2 TRANSVERSE AND LONGITUDINAL WAVES

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### Classification by Particle Motion:

**Transverse Wave:** Particle oscillation  $\perp$  to wave direction

**Longitudinal Wave:** Particle oscillation  $\parallel$  to wave direction

## Transverse Waves

### Transverse Wave Characteristics

- **Definition:** Constituents oscillate perpendicular to propagation direction
- **Medium:** Require shear modulus of elasticity
- **Propagation:** Only in solids and on liquid surfaces
- **Cannot propagate in:** Fluids (liquids and gases) in bulk

#### Examples:

- ✓ Waves on stretched string
- ✓ Ripples on water surface
- ✓ Electromagnetic waves
- ✓ Light waves

## Longitudinal Waves

### Longitudinal Wave Characteristics

- **Definition:** Constituents oscillate parallel to propagation direction
- **Medium:** Require bulk modulus of elasticity
- **Propagation:** In all elastic media (solids, liquids, gases)
- **Consists of:** Compressions and rarefactions

#### Examples:

- ✓ Sound waves in air
- ✓ Sound waves in water
- ✓ Ultrasonic waves
- ✓ Seismic P-waves

## Understanding Sound Propagation

### In Air:

- Sound creates compressions (high density) and rarefactions (low density)
- Change in density  $\delta\rho$  induces change in pressure  $\delta p$
- Pressure creates restoring force (like spring)
- Disturbance moves from region to region

### Example 14.1: Identifying Wave Types

**Question:** State whether the following represent transverse, longitudinal or combination:

- (a) Motion of kink in longitudinal spring displaced sideways
- (b) Waves in cylinder with piston moving back and forth
- (c) Waves from motorboat in water
- (d) Ultrasonic waves in air from vibrating quartz

**Answer:**

- (a) Transverse and longitudinal** - sideways displacement creates both types
- (b) Longitudinal** - piston creates compressions and rarefactions
- (c) Transverse and longitudinal** - water waves involve both up-down and back-forth motion
- (d) Longitudinal** - sound waves in air are always longitudinal

## Key Comparison

Property	Transverse	Longitudinal
Particle motion	Perpendicular to wave	Parallel to wave
Medium	Solids only (bulk)	All media
Elastic property	Shear modulus	Bulk modulus
Example	String wave	Sound wave



## 14.3 DISPLACEMENT RELATION IN A PROGRESSIVE WAVE

### Mathematical Description of Sinusoidal Travelling Wave:

$$y(x, t) = a \sin(kx - \omega t + \phi)$$

### Key Parameters

Symbol	Name	Meaning
$y(x,t)$	Displacement	Function of position $x$ and time $t$
$a$	Amplitude	Maximum displacement from equilibrium
$k$	Angular wave number	$k = 2\pi/\lambda$ (rad/m)
$\omega$	Angular frequency	$\omega = 2\pi/T = 2\pi v$ (rad/s)
$kx - \omega t + \phi$	Phase	Time-dependent quantity
$\phi$	Phase constant	Initial phase at $x=0, t=0$

## Wavelength and Angular Wave Number

**Wavelength ( $\lambda$ ):** Minimum distance between two points having the same phase

**Derivation:**

For displacement at  $t = 0$ :  $y(x, 0) = a \sin kx$

Since sine repeats after  $2\pi$ :

$$\sin kx = \sin k(x + \lambda) = \sin(kx + 2\pi)$$

Therefore:  $k\lambda = 2\pi$

$$\lambda = 2\pi/k \text{ or } k = 2\pi/\lambda$$

**k is angular wave number:** SI unit = rad/m

## Period, Frequency and Angular Frequency

**Period (T):** Time for one complete oscillation

**Frequency (v):** Number of oscillations per unit time

For element at  $x = 0$ :

$$y(0, t) = a \sin(-\omega t) = -a \sin \omega t$$

Since sine repeats after  $2\pi$ :  $\omega T = 2\pi$

$$T = 2\pi/\omega$$

$$v = 1/T = \omega/2\pi$$

$$\omega = 2\pi v = 2\pi/T$$

**Units:**

- T: second (s)
- v: hertz (Hz) =  $s^{-1}$
- $\omega$ : rad/s

## Understanding Wave Direction

- $y(x,t) = a \sin(kx - \omega t + \phi)$  → Wave travels in **+x direction**
- $y(x,t) = a \sin(kx + \omega t + \phi)$  → Wave travels in **-x direction**
- As t increases, x must increase to keep phase constant → positive direction

### **Example 14.2: Wave Parameters**

**Question:** A wave is described by  $y(x, t) = 0.005 \sin(80.0x - 3.0t)$  (SI units)

Calculate: (a) amplitude (b) wavelength (c) period and frequency

Also find displacement at  $x = 30.0$  cm,  $t = 20$  s

**Solution:**

Comparing with  $y = a \sin(kx - \omega t)$ :

**(a) Amplitude:**  $a = 0.005 \text{ m} = 5 \text{ mm}$

**(b) Wavelength:**

$$k = 80.0 \text{ m}^{-1}$$

$$\lambda = 2\pi/k = 2\pi/80.0 = \mathbf{7.85 \text{ cm}}$$

**(c) Period and Frequency:**

$$\omega = 3.0 \text{ rad/s}$$

$$T = 2\pi/\omega = 2\pi/3.0 = \mathbf{2.09 \text{ s}}$$

$$\nu = 1/T = \mathbf{0.48 \text{ Hz}}$$

**Displacement at  $x = 30$  cm,  $t = 20$  s:**

$$y = 0.005 \sin(80.0 \times 0.3 - 3.0 \times 20)$$

$$= 0.005 \sin(24 - 60)$$

$$= 0.005 \sin(-36 + 12\pi)$$

$$= \mathbf{\approx 5 \text{ mm}}$$



## 14.4 THE SPEED OF A TRAVELLING WAVE

### Wave Speed Derivation

**Method:** Track motion of a fixed phase point (e.g., crest)

**Step 1:** Fixed phase condition

$$kx - \omega t = \text{constant}$$

**Step 2:** As time changes by  $\Delta t$ , position changes by  $\Delta x$

$$k(x + \Delta x) - \omega(t + \Delta t) = kx - \omega t$$

$$k\Delta x - \omega\Delta t = 0$$

**Step 3:** Taking limit as  $\Delta t \rightarrow 0$

$$v = dx/dt = \omega/k$$

**Step 4:** Relating to  $\lambda$  and  $v$

$$v = \omega/k = (2\pi\nu)/(2\pi/\lambda) = \lambda\nu$$

## ☀ Wave Speed - Key Points

- ✓ In time  $T$  (one period), wave travels distance  $\lambda$  (one wavelength)
- ✓ Speed determined by **medium properties** only
- ✓ Independent of frequency for given medium
- ✓ Different wave types have different speeds in same medium

## 🎸 Speed of Transverse Wave on String

**Using Dimensional Analysis:**

**Relevant quantities:**

- Tension  $T$  in string:  $[MLT^{-2}]$
- Linear mass density  $\mu = m/L$ :  $[ML^{-1}]$

**Speed  $v$  has dimension:**  $[LT^{-1}]$

**Combining  $T$  and  $\mu$ :**

$$[MLT^{-2}]/[ML^{-1}] = [L^2T^{-2}]$$

$$\sqrt{(T/\mu)} = [LT^{-1}] \checkmark$$

$$\mathbf{v = \sqrt{(T/\mu)}}$$

**Note:** Exact derivation gives same result with constant  $C = 1$

### Example 14.3: String Wave Speed

**Question:** Steel wire 0.72 m long, mass  $5.0 \times 10^{-3}$  kg, under 60 N tension. Find wave speed.

**Solution:**

**Step 1:** Linear mass density

$$\mu = m/L = (5.0 \times 10^{-3}) / (0.72) = \mathbf{6.9 \times 10^{-3} \text{ kg/m}}$$

**Step 2:** Wave speed

$$v = \sqrt{T/\mu}$$

$$= \sqrt{60 / (6.9 \times 10^{-3})}$$

$$= \mathbf{93 \text{ m/s}}$$

## Speed of Longitudinal Wave (Sound)

**For Longitudinal Waves:**

**Elastic property:** Bulk modulus B

$$B = -\Delta P / (\Delta V / V)$$

Dimension:  $[ML^{-1}T^{-2}]$  (same as pressure)

**Inertial property:** Density  $\rho$

Dimension:  $[ML^{-3}]$

**Speed dimension:**

$$\sqrt{(B/\rho)} = \sqrt{([ML^{-1}T^{-2}]/[ML^{-3}])} = [LT^{-1}] \checkmark$$

$$\mathbf{v = \sqrt{(B/\rho)}}$$

**General formula for longitudinal waves**

## Speed in Solid Bar

**For solid bar (negligible lateral expansion):**

$$\mathbf{v = \sqrt{(Y/\rho)}}$$

**where Y is Young's modulus**

## Speed of Sound in Gas

### Newton's Formula (Isothermal)

For ideal gas:  $PV = Nk_B T$

Isothermal change:  $B = P$

$$v = \sqrt{P/\rho}$$

(Newton's formula)

**Problem:** This gives  $v \approx 280$  m/s at STP, but experimental value is 331 m/s!

## Laplace Correction

**Error in Newton's Formula:** Assumed isothermal process

**Reality:** Sound waves propagate so fast that process is **adiabatic**

**For adiabatic process:**  $PV^\gamma = \text{constant}$

where  $\gamma = C_p/C_v$

**Adiabatic bulk modulus:**  $B_{\text{ad}} = \gamma P$

$$v = \sqrt{(\gamma P/\rho)}$$

(Laplace correction)

**For air:**  $\gamma = 7/5 = 1.4$

**Result:**  $v = 331.3 \text{ m/s}$  at STP ✓

### **Example 14.4: Speed of Sound in Air**

**Question:** Estimate speed of sound in air at STP. (1 mole air =  $29.0 \times 10^{-3}$  kg)

**Solution:**

**Step 1:** Density at STP

1 mole occupies 22.4 L at STP

$$\rho = (29.0 \times 10^{-3}) / (22.4 \times 10^{-3}) = \mathbf{1.29 \text{ kg/m}^3}$$

**Step 2:** Using Newton's formula

$$v = \sqrt{P/\rho} = \sqrt{(1.01 \times 10^5) / 1.29}$$

$$= \mathbf{280 \text{ m/s}}$$

**Step 3:** Using Laplace correction

$$v = \sqrt{(\gamma P/\rho)} = \sqrt{(1.4 \times 1.01 \times 10^5) / 1.29}$$

$$= \mathbf{331 \text{ m/s} \checkmark}$$

*Laplace correction gives the correct experimental value!*

## 🔊 Speed of Sound in Different Media

Medium	Speed (m/s)
<b>Gases</b>	
Air (0°C)	331
Air (20°C)	343
Helium	965
Hydrogen	1284
<b>Liquids</b>	
Water (0°C)	1402
Water (20°C)	1482
Seawater	1522
<b>Solids</b>	
Aluminium	6420
Copper	3560
Steel	5941
Granite	6000

**Observation:** Sound travels faster in solids > liquids > gases

## 14.5 THE PRINCIPLE OF SUPERPOSITION OF WAVES

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### **Principle of Superposition:**

When two or more waves traverse the same medium simultaneously, the resultant displacement is the algebraic sum of individual displacements

$$y(\mathbf{x},t) = y_1(\mathbf{x},t) + y_2(\mathbf{x},t) + \dots + y_n(\mathbf{x},t)$$

### **Key Points About Superposition**

- ✓ Each wave continues independently
- ✓ Waves retain identity after overlapping
- ✓ Net displacement = algebraic sum
- ✓ Can be positive or negative
- ✓ Waves do not affect each other

## Interference of Waves

Two harmonic waves with same  $\omega$ ,  $k$ , amplitude  $a$ :

$$y_1(x,t) = a \sin(kx - \omega t)$$

$$y_2(x,t) = a \sin(kx - \omega t + \varphi)$$

**Resultant:**

$$y = y_1 + y_2 = a[\sin(kx - \omega t) + \sin(kx - \omega t + \varphi)]$$

Using:  $\sin A + \sin B = 2 \sin[(A+B)/2] \cos[(A-B)/2]$

$$y(x,t) = [2a \cos(\varphi/2)] \sin(kx - \omega t + \varphi/2)$$

Amplitude depends on phase difference:

$$A(\varphi) = 2a \cos(\varphi/2)$$

## Constructive and Destructive Interference

Type	Phase Difference	Amplitude	Result
<b>Constructive</b>	$\varphi = 0, 2\pi, 4\pi, \dots$	$A = 2a$ (maximum)	Amplitudes add
<b>Destructive</b>	$\varphi = \pi, 3\pi, 5\pi, \dots$	$A = 0$ (minimum)	Amplitudes cancel
<b>Partial</b>	$0 < \varphi < \pi$	$0 < A < 2a$	Intermediate



## 14.6 REFLECTION OF WAVES

### Reflection at Boundaries

Two Types of Boundaries:

Boundary Type	Phase Change	Example
Rigid (Fixed End)	$\pi$ (180°)	String fixed to wall
Free (Open End)	0	Open end of organ pipe

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## Mathematical Description

**Incident wave:**

$$y_i(x,t) = a \sin(kx - \omega t)$$

**At rigid boundary:**

$$y_r(x,t) = -a \sin(kx + \omega t)$$

(phase change =  $\pi$ )

**At open boundary:**

$$y_r(x,t) = a \sin(kx + \omega t)$$

(no phase change)

**At rigid boundary:**  $y = y_i + y_r = 0$  at all times ✓

## 🎵 Standing Waves and Normal Modes

**When incident and reflected waves superpose:**

$$y_1 = a \sin(kx - \omega t)$$

$$y_2 = a \sin(kx + \omega t)$$

**Resultant:**

$$y = y_1 + y_2 = a[\sin(kx - \omega t) + \sin(kx + \omega t)]$$

**Using:  $\sin A + \sin B = 2 \sin A \cos B$**

$$\mathbf{y(x,t) = [2a \sin kx] \cos \omega t}$$

**This is a standing wave!**

## ☀️ Standing Wave Characteristics

- **Amplitude varies with position:**  $2a \sin kx$
- **All particles oscillate in phase**
- **No wave propagation** (stationary)
- **Nodes:** Points of zero amplitude
- **Antinodes:** Points of maximum amplitude

## Nodes and Antinodes

**Nodes (amplitude = 0):**

$$\sin kx = 0$$

$$kx = n\pi, n = 0, 1, 2, 3, \dots$$

$$x = n\lambda/2, n = 0, 1, 2, 3, \dots$$

**Distance between consecutive nodes =  $\lambda/2$**

**Antinodes (amplitude = maximum):**

$$\sin kx = \pm 1$$

$$kx = (n + 1/2)\pi, n = 0, 1, 2, 3, \dots$$

$$x = (n + 1/2)\lambda/2, n = 0, 1, 2, 3, \dots$$

**Distance between consecutive antinodes =  $\lambda/2$**

## Normal Modes of Stretched String

**String fixed at both ends ( $x = 0$  and  $x = L$ ):**

**Boundary conditions:** Both ends are nodes

At  $x = L$ :  $L = n\lambda/2$ ,  $n = 1, 2, 3, \dots$

$$\lambda = 2L/n, n = 1, 2, 3, \dots$$

$$v = nv/2L, n = 1, 2, 3, \dots$$

**Harmonics:**

- $n = 1$ : Fundamental frequency (first harmonic) =  $v/2L$
- $n = 2$ : Second harmonic =  $2v/2L$
- $n = 3$ : Third harmonic =  $3v/2L$
- All harmonics present!

## Normal Modes of Air Column

### Pipe closed at one end ( $x = 0$ ), open at other ( $x = L$ )

#### Boundary conditions:

- $x = 0$ : Node (closed end)
- $x = L$ : Antinode (open end)

$$L = (n + 1/2)\lambda/2, n = 0, 1, 2, \dots$$

$$\lambda = 4L/(2n+1)$$

$$v = (n + 1/2)v/2L = (2n+1)v/4L$$

#### Harmonics:

- $n = 0$ : Fundamental =  $v/4L$
- $n = 1$ : Third harmonic =  $3v/4L$
- $n = 2$ : Fifth harmonic =  $5v/4L$
- Only odd harmonics present!

### **Example 14.5: Pipe Resonance**

**Question:** Pipe 30.0 cm long, open at both ends. Which harmonic resonates with 1.1 kHz source?

Will resonance occur if one end closed? ( $v = 330$  m/s)

**Solution:**

**Open pipe (both ends):**

$$v_n = nv/2L = n(330)/(2 \times 0.3) = 550n \text{ Hz}$$

For  $v = 1100$  Hz:

$$1100 = 550n$$

$$n = 2$$

**Answer: Second harmonic**

**Pipe closed at one end:**

$$v_n = (2n+1)v/4L = (2n+1)(330)/(4 \times 0.3) = 275(2n+1) \text{ Hz}$$

For  $v = 1100$  Hz:

$$1100 = 275(2n+1)$$

$$4 = 2n+1$$

$$n = 1.5 \text{ (not integer!)}$$

**Answer: No resonance** (1100 Hz is not a natural frequency)



## 14.7 BEATS

**Beats:** Periodic variation in amplitude when two waves of slightly different frequencies interfere

Two waves with nearly equal frequencies:

$$s_1 = a \cos \omega_1 t$$

$$s_2 = a \cos \omega_2 t$$

**Resultant (at  $x = 0$ ):**

$$s = s_1 + s_2 = a(\cos \omega_1 t + \cos \omega_2 t)$$

Using:  $\cos A + \cos B = 2 \cos[(A+B)/2] \cos[(A-B)/2]$

$$s = [2a \cos \omega_b t] \cos \omega_a t$$

where:

- $\omega_b = (\omega_1 - \omega_2)/2$
- $\omega_a = (\omega_1 + \omega_2)/2$

**Interpretation:**

- Oscillation at average frequency  $\omega_a$
- Amplitude varies as  $2a \cos \omega_b t$
- Intensity waxes and wanes

$$\text{Beat Frequency: } \nu_{\text{beat}} = \nu_1 - \nu_2$$

## 🎵 Applications of Beats

- ✓ **Tuning musical instruments:** Musicians adjust until beats disappear
- ✓ **Measuring small frequency differences**
- ✓ **Detecting slight detuning**
- ✓ Human ear can detect up to ~7 beats per second

### **Example 14.6: Sitar Tuning**

**Question:** Two sitar strings A and B produce beats of 5 Hz. When tension in B increased, beat frequency decreases to 3 Hz. If  $v_A = 427$  Hz, find  $v_B$ .

**Solution:**

**Key insight:** Increasing tension increases frequency

**Case 1:** Original beat frequency = 5 Hz

$$|v_A - v_B| = 5$$

**Two possibilities:**

- $v_B = 427 + 5 = 432$  Hz, or
- $v_B = 427 - 5 = 422$  Hz

**Case 2:** After increasing tension, beat frequency = 3 Hz

**If  $v_B = 432$  Hz:**

Increasing it further would increase beat frequency  $\times$

**If  $v_B = 422$  Hz:**

Increasing it makes it closer to 427, decreasing beat frequency  $\checkmark$

**Answer:  $v_B = 422$  Hz**

## SUMMARY

### Key Concepts

Concept	Formula/Description
<b>Wave</b>	Disturbance propagating through medium without mass transfer
<b>Transverse Wave</b>	Particle motion $\perp$ to propagation direction
<b>Longitudinal Wave</b>	Particle motion $\parallel$ to propagation direction
<b>Progressive Wave</b>	$y(x,t) = a \sin(kx - \omega t + \phi)$
<b>Wave Speed</b>	$v = \lambda \nu = \omega/k$
<b>String Wave Speed</b>	$v = \sqrt{T/\mu}$
<b>Sound Speed</b>	$v = \sqrt{\gamma P/\rho}$ for gases
<b>Superposition</b>	$y = y_1 + y_2 + \dots + y_n$
<b>Standing Wave</b>	$y(x,t) = [2a \sin kx] \cos \omega t$
<b>String Normal Modes</b>	$v = n\lambda/2L, n = 1, 2, 3, \dots$
<b>Pipe (one end closed)</b>	$v = (2n+1)\lambda/4L, n = 0, 1, 2, \dots$
<b>Beat Frequency</b>	$\nu_{\text{beat}} =  \nu_1 - \nu_2 $

## IMPORTANT EXAM QUESTIONS

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### Section A: Multiple Choice Questions (1 mark)

**Q1.** Transverse waves cannot propagate in:

- (a) Solids
- (b) Liquids (bulk) ✓
- (c) Gases (bulk) ✓
- (d) Both (b) and (c) ✓

**Answer: (d)** - Transverse waves need shear modulus

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**Q2.** The speed of wave on string depends on:

- (a) Frequency
- (b) Amplitude
- (c) Tension and linear mass density ✓
- (d) Wavelength

**Answer: (c)** -  $v = \sqrt{T/\mu}$

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**Q3.** In standing wave, distance between node and adjacent antinode is:

- (a)  $\lambda$
- (b)  $\lambda/2$
- (c)  $\lambda/4$  ✓
- (d)  $2\lambda$

**Answer: (c)** - Nodes at  $n\lambda/2$ , antinodes at  $(n+1/2)\lambda/2$

## Section B: Short Answer Questions (2-3 marks)

**Q4.** Why did Newton's formula for speed of sound give wrong result? How did Laplace correct it?

**Answer:**

- **Newton's assumption:** Sound propagation is isothermal ( $B = P$ )
  - **Reality:** Sound waves propagate so fast that process is adiabatic
  - **Laplace correction:** Used  $B = \gamma P$  for adiabatic process
  - **Result:**  $v = \sqrt{(\gamma P/\rho)}$  gives correct experimental value
- 

**Q5.** What is the principle of superposition? Give applications.

**Answer:**

When two or more waves traverse same medium simultaneously, resultant displacement is algebraic sum of individual displacements.

**Applications:**

- Interference of waves
- Formation of standing waves
- Beats phenomenon
- Sound quality in music

### Section C: Long Answer Questions (5 marks)

**Q6.** Derive expression for standing wave on string. Show that nodes and antinodes are formed at specific positions.

**Answer:** [Complete derivation as shown in section 14.6]

**Key Steps:**

1. Start with incident and reflected waves
2. Apply principle of superposition
3. Use trigonometric identity
4. Show  $y(x,t) = [2a \sin kx] \cos \omega t$
5. Find nodes:  $\sin kx = 0 \rightarrow x = n\lambda/2$
6. Find antinodes:  $\sin kx = \pm 1 \rightarrow x = (n+1/2)\lambda/2$
7. Distance between consecutive nodes/antinodes =  $\lambda/2$

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## FINAL SUCCESS TIPS

### Master These Concepts:

- ✨ Difference between transverse and longitudinal waves
- ✨ Wave equation  $y(x,t) = a \sin(kx - \omega t + \phi)$  and all parameters
- ✨  $v = \lambda\nu$  is fundamental relationship
- ✨ Speed formulas:  $v = \sqrt{T/\mu}$  for string,  $v = \sqrt{\gamma P/\rho}$  for gas
- ✨ Laplace correction is important for sound in gases
- ✨ Principle of superposition leads to interference
- ✨ Standing waves have fixed nodes and antinodes
- ✨ String: all harmonics; Closed pipe: only odd harmonics
- ✨ Beat frequency = difference in frequencies

### KEY TO SUCCESS:

**"Waves are Everywhere - Master Them to Understand  
Sound, Light, and Beyond!"**

### Must Practice:

- All derivations (wave speed, standing waves, beats)
- 15 numerical problems on wave speed
- 10 problems on standing waves and normal modes
- Superposition and interference problems
- Beat frequency calculations
- All NCERT examples and exercises



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## Study Material Information

This comprehensive study material on **Waves** has been prepared following the latest CBSE curriculum and examination pattern for Class 11 Physics. The content includes detailed explanations of mechanical waves, transverse and longitudinal waves, wave equation derivations, speed of waves in different media, Newton's and Laplace's formulas for sound, principle of superposition, interference, reflection, standing waves, normal modes, beats, complete derivations from NCERT, and practice questions aligned with current board exam format.

### Key Features of This Material:

- Complete chapter coverage with crystal-clear concepts
- Transverse vs longitudinal waves explained thoroughly
- Progressive wave equation with all parameters
- Step-by-step derivations with clear explanations
- String wave speed and sound speed formulas
- Newton's formula and Laplace correction detailed
- Principle of superposition and interference
- Standing waves and normal modes complete analysis
- Beats phenomenon with musical applications
- All NCERT solved examples
- Multiple choice and descriptive practice questions
- Formula summary and important concepts
- Exam-focused tips and strategies

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*Disclaimer: This material is prepared as a comprehensive study aid for Class 11 students. While every effort has been made to ensure accuracy and alignment with CBSE curriculum, students are advised*

to refer to their NCERT textbooks and official CBSE guidelines for examination preparation. This material covers Chapter 14: Waves from Class 11 Physics NCERT textbook (Reprint 2025-26).

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