FREE NOTES · NCERT + JEE/NEET LEVEL

Waves

Transverse aur longitudinal waves, wave ka equation, taar aur hawa me speed, superposition, reflection, standing waves, taar aur pipe ke harmonics, beats aur Doppler effect.

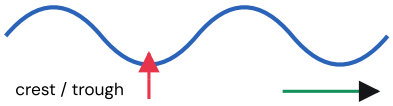
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02 Transverse vs longitudinal
03 Wave ka equation
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01 Wave kya hai

Wave ek **disturbance** hai jo energy aur momentum ko ek jagah se doosri jagah le jaati hai, par medium ke particles khud aage nahi jaate, apni jagah pe hi hilte hain. Taalaab me patthar phenko: lehar kinare tak jaati hai, par patta wahin upar-neeche hota hai.

Type	Medium chahiye?	Example
Mechanical	Haan	Sound, taar ki wave, paani ki lehar
Electromagnetic	Nahi (vacuum me bhi)	Light, radio, X-ray
Matter waves	—	Electron, proton se judi waves

02 Transverse vs longitudinal



Transverse: particle ⊥ wave direction



Longitudinal: particle ∥ wave direction

	Transverse	Longitudinal
Particle ka hilna	Wave ki direction ke ⊥	Wave ki direction ke along
Bante hain	Crest aur trough	Compression aur rarefaction
Kahan	Solids, taar, liquid ki surface (fluids ke andar nahi)	Solid, liquid, gas sab me
Example	Taar ki wave, light	Sound, spring me dhakka

03 Wave ka equation

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

+x direction me chalti wave. (kx + ωt) ho toh -x direction.

Quantity	Formula	Matlab
Amplitude a	—	Max displacement
Wavelength λ	$k = 2\pi/\lambda$	Do lagaataar crest ke beech doori
Angular wave number k	$2\pi/\lambda$ (rad/m)	—
Frequency ν	$\omega = 2\pi\nu$	1 s me kitne oscillations
Wave speed v	$v = \nu\lambda = \omega/k$	Wave kitni tez aage badhti

PHASE DIFFERENCE

Do points jo Δx door hain: $\Delta\varphi = (2\pi/\lambda)\,\Delta x$. λ door wale points same phase me, λ/2 door wale ulti phase me.

DHYAN DO

Wave speed (v = ω/k) aur particle ki speed (∂y/∂t = -aω cos(…)) **alag** cheezein hain. Particle ki max speed = aω.

04 Taar pe wave ki speed

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

T = tension, μ = mass per unit length (kg/m). Taar jitni tight, wave utni tez. Frequency pe depend nahi karti (frequency source decide karta hai).

Medium badlne pe **frequency same** rehti hai, speed aur wavelength badalte hain.

05 Sound ki speed

GENERAL

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

Solid rod: $v = \sqrt{(Y/\rho)}$

Speed order: solid > liquid > gas (steel ≈ 5000, paani ≈ 1500, hawa ≈ 340 m/s).

GAS ME: NEWTON AUR LAPLACE

Newton (isothermal): $v = \sqrt{(P/\rho)} \approx 280$ m/s (galat)

Laplace (adiabatic): $v = \sqrt{(\gamma P/\rho)} = \sqrt{(\gamma RT/M)} \approx 331$ m/s

Sound me compression bahut tezi se hota hai, heat ko behne ka time nahi ⇒ adiabatic.

Factor	Asar
Pressure (T same)	Koi asar nahi (P/ρ constant)
Temperature	$v \propto \sqrt{T}$; har 1 °C pe ≈ 0.61 m/s badhti
Humidity (nami)	Speed badhti (nami wali hawa halki)
Wind	Wind ki direction me tez

06 Superposition principle

STATEMENT

Jab do ya zyada waves ek jagah milti hain, toh net displacement = har wave ke displacement ka **algebraic sum**: $y = y_1 + y_2 + \ldots$. Milne ke baad har wave apni raah chali jaati hai, badli nahi.

SAME FREQUENCY, PHASE DIFFERENCE Φ

$$A = \sqrt{(a_1^2 + a_2^2 + 2a_1a_2 \cos \varphi)}$$

φ = 0, 2π…: **constructive** ($A = a_1 + a_2$). φ = π, 3π…: **destructive** ($A = |a_1 - a_2|$). Intensity ∝ A^2.

07 Reflection of waves

Boundary	Kya hota hai
Rigid / fixed end (deewar se bandhi taar)	Wave **ulti** lautti: phase change π (crest trough ban jaata)
Open / free end	Bina phase change ke lautti
Patle se mote medium me	Reflected wave me phase change π

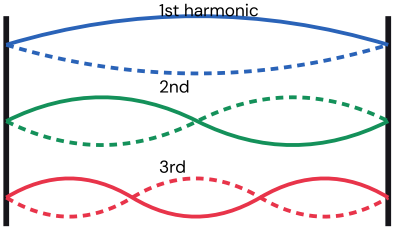
Sound ka reflection: **echo** (kam se kam 17 m door deewar chahiye, kyunki kaan 0.1 s ka fark pehchaanta hai).

08 Standing waves & vibrating string

Do barabar waves ulti direction me milein toh **standing (stationary) wave**: kuch points kabhi nahi hilte (**nodes**), kuch sabse zyada hilte (**antinodes**). Energy aage nahi jaati.

$$y = 2a \sin(kx) \cos(\omega t)$$

Node se node ya antinode se antinode = λ/2. Node se antinode = λ/4.



Dono sire fixed taar

TAAR (LENGTH L, DONO SIRE FIX)

$$\nu_n = n\, v / (2L),\ n = 1, 2, 3\ldots$$

Fundamental $v_1 = (1/2L)\sqrt{(T/\mu)}$. Saare harmonics (1 : 2 : 3 …) aate hain. Sonometer isi pe kaam karta hai.

09 Organ pipes

	Closed pipe (ek sira band)	Open pipe (dono khule)
Ends	Band sire pe node, khule pe antinode	Dono sire antinode
Frequencies	$\nu = n\, v/(4L),\ n = 1, 3, 5\ldots$	$\nu = n\, v/(2L),\ n = 1, 2, 3\ldots$
Harmonics	Sirf **odd** (1 : 3 : 5)	Saare (1 : 2 : 3)
Fundamental	$v/4L$	$v/2L$ (closed ka 2 guna)

END CORRECTION (JEE)

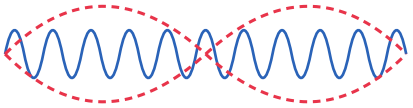
Antinode khule sire se thoda bahar banta hai: e ≈ 0.6r. Closed: L + e, open: L + 2e. Resonance tube me: $\lambda/2 = L_2 - L_1$ (end correction cancel).

10 Beats

Do sounds jinki frequency thodi alag hai, saath bajein toh awaaz **badhti-ghatti** (wah-wah) sunai deti hai.

$$\text{Beat frequency} = |\nu_1 - \nu_2|$$

Kaan sirf ≤ 10 beats/s alag se pehchaan sakta hai.



Amplitude ka upar-neeche hona = beats

TUNING FORK TRICK

Fork pe **mom (wax)** lagao ⇒ frequency ghatti. Fork ko **ghis (file)** do ⇒ frequency badhti. Beats badhe ya ghate dekh ke unknown frequency nikaalo.

11 Doppler effect (JEE/NEET)

Source ya sunne wala chal raha ho toh sunaai deni wali frequency badal jaati hai. Ambulance paas aate hue tez (pitch upar), door jaate hue mota.

$$\nu' = \nu\,(v \pm v_o) / (v \mp v_s)$$

v = sound ki speed, v_o = observer, v_s = source. **Paas aa rahe ho** toh frequency badhe aisa sign lo: upar $+v_o$, neeche $-v_s$. Door jaa rahe ho toh ulta.

DHYAN DO

Source aur observer dono same velocity se chalein (ya sirf medium chale aur dono ruke) toh frequency nahi badalti. Source aur observer ka effect same speed pe bhi barabar nahi hota.

12 JEE Extra + Tricks

JEE LEVEL

- Wave speed: dori $\sqrt{(T/\mu)}$; gas me awaaz $\sqrt{(\gamma P/\rho)}$ (Laplace correction); $v \propto \sqrt{T}$ (kelvin).
- Open pipe: saare harmonics $f_n = nv/2L$; closed pipe: sirf odd harmonics $f = (2n - 1)v/4L$. End correction $e = 0.6r$.
- Beats: $f_{beat} = |f_1 - f_2|$. Tuning fork ghisne pe f badhti; wax lagane pe ghatti.
- Doppler: $f' = f(v \pm v_o)/(v \mp v_s)$ (paas aane pe upar wale signs).
- Dono sire bandhi dori: $f_n = nv/2L$, saare harmonics; siron pe nodes.

13 Solved numericals (v_{sound} = 340 m/s)

Q1. $y = 0.02 \sin(2\pi x - 100\pi t)$ (SI). Amplitude, λ, ν, speed?
a = 0.02 m. $k = 2\pi \Rightarrow \lambda = 1$ m. $\omega = 100\pi \Rightarrow \nu = 50$ Hz. $v = \nu\lambda = 50$ m/s. **Ans: 2 cm, 1 m, 50 Hz, 50 m/s**

Q2. Taar me tension 100 N, μ = 0.01 kg/m. Wave speed?
$v = \sqrt{(100/0.01)} = 100$ m/s. **Ans: 100 m/s**

Q3. 50 cm ki taar (dono sire fix), wave speed 100 m/s. Fundamental aur 3rd harmonic?
$\nu_1 = 100/(2 \times 0.5) = 100$ Hz. $\nu_3 = 300$ Hz. **Ans: 100 Hz, 300 Hz**

Q4. 85 cm lambi closed pipe ka fundamental aur agla overtone?
$\nu_1 = 340/(4 \times 0.85) = 100$ Hz. Agla: $3\nu_1 = 300$ Hz. **Ans: 100 Hz, 300 Hz**

Q5. Tuning fork A (256 Hz) aur B saath me 4 beats/s. B pe mom lagaya, beats 6 ho gaye. B ki frequency?
B = 252 ya 260. Mom se frequency ghatti, beats badhe ⇒ 252 → 250 (6 beats) ✓. 260 → 258 hota toh beats 2 hote. **Ans: 252 Hz**

Q6. 500 Hz ka horn wali car 20 m/s se ruke hue aadmi ki taraf aa rahi. Aadmi ko frequency?
$v' = 500 \times 340/(340 - 20) = 500 \times 340/320 \approx 531$ Hz. **Ans: ≈ 531 Hz**

14 Common mistakes

- Medium badalne pe frequency badal dena. Frequency same, v aur λ badalte.
- Sound ki speed pressure pe depend maan lena.
- Closed pipe me even harmonics bhi le lena.
- Wave speed aur particle velocity ko same samajhna.
- Doppler me sign galat lagana: paas aane pe frequency badhni chahiye, check karo.
- Beats wale sawaal me mom/ghisne ka asar ulta lena.

15 Formula sheet

Wave equation	$y = a\sin(kx - \omega t)$
Relations	$k = 2\pi/\lambda,\ \omega = 2\pi\nu,\ v = \nu\lambda = \omega/k$
String speed	$v = \sqrt{(T/\mu)}$
Sound in gas	$v = \sqrt{(\gamma P/\rho)} = \sqrt{(\gamma RT/M)}$
Superposition	$A^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\varphi$
String (both fixed)	$\nu = nv/2L,\ n = 1, 2, 3\ldots$
Closed pipe	$\nu = nv/4L,\ n = 1, 3, 5\ldots$
Open pipe	$\nu = nv/2L,\ n = 1, 2, 3\ldots$
Beats	$\lvert\nu_1 - \nu_2\rvert$
Doppler	$\nu' = \nu(v \pm v_o)/(v \mp v_s)$

16 Practice questions

1. Taar ki tension 4 guna. Fundamental frequency?
2. Open pipe aur closed pipe same length. Fundamentals ka ratio?
3. Temperature 27 °C se 127 °C. Sound ki speed kitni guna?
4. Do waves ki amplitudes 3 aur 4, phase difference 90°. Resultant amplitude?
5. Do points ke beech phase difference π/2, λ = 2 m. Unke beech doori?

ANSWERS

1) 2 guna · 2) open : closed = 2 : 1 · 3) √(400/300) ≈ 1.15 guna · 4) 5 · 5) Δx = λΔφ/2π = 0.5 m

17 Quick revision: exam se pehle 5 minute

BASICS

- Wave energy le jaati, matter nahi.
- Transverse ⊥, longitudinal ∥.
- $v = \nu\lambda$; medium badle ⇒ ν same.

SPEED

- String $\sqrt{(T/\mu)}$.
- Gas $\sqrt{(\gamma P/\rho)}$ (Laplace), $\propto \sqrt{T}$.
- Solid > liquid > gas.

STANDING WAVES

- Node–node = $\lambda/2$.
- String/open pipe: $n\nu/2L$ (saare).
- Closed pipe: $n\nu/4L$ (odd).
- Fixed end: phase change π.

BEATS & DOPPLER

- Beats = $|\nu_1 - \nu_2|$.
- Wax ⇒ $\nu \downarrow$, file ⇒ $\nu \uparrow$.
- Paas aaye ⇒ $\nu' \uparrow$.

Doubt hai? padhaiadda.netlify.app pe AI Doubt Solver se poocho, ya is chapter ka mock test do.