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Oscillations and Waves — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take g = 10 m/s² unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Simple harmonic motion · Phase · Oscillations of a spring · Energy in simple harmonic motion · Simple pendulum · Progressive waves · Speed of a wave · Principle of superposition · Reflection of waves · Standing waves in strings · Organ pipes · Beats

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. A particle executes simple harmonic motion with a period of 2 s. The least time it takes to go from its mean position to a point halfway to an extreme position is

(1) 1/2 s

(2) 1/4 s

(3) 1/6 s

(4) 1/3 s

2. A particle performs simple harmonic motion with an amplitude of 5 cm and a period of 1 s. When it is 3 cm from its mean position, its speed and the magnitude of its acceleration are

(1) 8π cm/s and $12\pi^2$ cm/s²

(2) 6π cm/s and $12\pi^2$ cm/s²

(3) 8π cm/s and $20\pi^2$ cm/s²

(4) 10π cm/s and $12\pi^2$ cm/s²

3. A particle executes simple harmonic motion of amplitude A. At what distance from the mean position are its kinetic and potential energies equal?

(1) A/2

(2) A/√2

(3) A/4

(4) √3A/2

4. Two identical springs of force constant k are joined once in series and once in parallel, and the same block is attached to each combination. The ratio of the period of oscillation with the series combination to that with the parallel combination is

(1) 1 : 2

(2) 4 : 1

(3) √2 : 1

(4) 2 : 1

5. A block attached to a light spring oscillates with period T. The spring is cut into three equal parts, and the same block is attached to one part. The new period is

(1) T/√3

(2) √3 T

(3) T/3

(4) 3T

6. A block of mass 1 kg on a smooth horizontal surface is attached between two springs whose other ends are fixed to walls on either side; the force constants are 100 N/m and 300 N/m. Both springs are at their natural lengths when the block is at rest. The period of small oscillations of the block along the line of the springs is

(1) $\pi/5$ s

(2) $\pi/10$ s

(3) $\pi\sqrt{3}/30$ s

(4) $2\pi/\sqrt{75}$ s

7. When a block is hung from a light vertical spring, the spring stretches by 4 cm. If the block is pulled down a little and released, the period of its oscillation is about ($g = 10$ m/s^2)

(1) 1.26 s

(2) 0.13 s

(3) 0.40 s

(4) 0.20 s

8. A simple pendulum has a period T when the lift it hangs in is at rest. When the lift moves upward with a constant acceleration of g/3, its period becomes

(1) $(2/\sqrt{3})T$

(2) $(\sqrt{3}/2)T$

(3) $(3/4)T$

(4) $\sqrt{(4/3)}\ T \times 2$

9. Two simple pendulums of lengths 1.00 m and 1.21 m are set swinging in phase. After how many oscillations of the shorter pendulum will they first be in phase again?

(1) 10

(2) 21

(3) 12

(4) 11

10. Which of the following displacements (ω a positive constant) represent simple harmonic motion?

(A) $x = \sin \omega t + \cos \omega t$

(B) $x = \sin^2 \omega t$

(C) $x = \sin \omega t + \sin 2\omega t$

(D) x = e^(−ωt)

(E) $x = 3 \sin(\omega t + \pi/4)$

Choose the correct answer from the options given below:

(1) (A) and (E) only

(2) (A), (C) and (E) only

(3) (A), (B) and (E) only

(4) (B), (C) and (D) only

11. A particle is subjected simultaneously to two simple harmonic motions along the same line, $x_1 = A \sin(\omega t + \pi/6)$ and $x_2 = A \cos \omega t$. The phase difference between them, and the amplitude of the resultant motion, are

(1) $\pi/3$ and $A\sqrt{3}$

(2) $\pi/3$ and A

(3) $2\pi/3$ and $A\sqrt{3}$

(4) $\pi/6$ and $A\sqrt{2}$

12. A transverse wave on a string is $y = 0.05 \sin(20\pi t - 0.5\pi x)$, with x and y in metres and t in seconds. The speed of the wave and the greatest speed of a particle of the string are

(1) 10 m/s and π m/s

(2) 40 m/s and 2π m/s

(3) 40 m/s and π m/s

(4) 20 m/s and π m/s

13. A wire 50 cm long, of linear mass density 0.01 kg/m, is fixed at both ends and kept under a tension of 100 N. Its fundamental frequency, and the wavelength of its third harmonic, are

(1) 200 Hz and 1/3 m

(2) 100 Hz and 1/3 m

(3) 100 Hz and 1/2 m

(4) 50 Hz and 1/3 m

14. The first overtone of a pipe closed at one end has the same frequency as the fundamental of a pipe open at both ends. The ratio of the length of the closed pipe to that of the open pipe is

(1) 3 : 4

(2) 2 : 3

(3) 4 : 3

(4) 3 : 2

15. A sonometer wire produces 5 beats per second with a tuning fork of frequency 300 Hz. When the tension in the wire is increased slightly, the number of beats per second falls to 3. The original frequency of the wire was

(1) 305 Hz

(2) 295 Hz

(3) 297 Hz

(4) 303 Hz

16. A standing wave on a string is $y = 4 \sin(5\pi x) \cos(100\pi t)$, with y in cm, x in m and t in s. The distance between adjacent nodes, and the speed of each of the travelling waves that make it up, are

(1) 0.4 m and 20 m/s

(2) 0.2 m and 20 m/s

(3) 0.2 m and 500 m/s

(4) 0.1 m and 20 m/s

17. The ratio of the speed of sound in helium (a monoatomic gas, molar mass 4 g/mol) to that in oxygen (diatomic, molar mass 32 g/mol) at the same temperature is about

(1) 2.8

(2) 4.0

(3) 3.1

(4) 1.4

18. Statement I: A wave on a string reflected from a rigidly fixed end undergoes a phase change of π.
Statement II: At the closed end of an organ pipe there is a displacement antinode.
In the light of the above statements, choose the correct answer from the options given below:

(1) Both Statement I and Statement II are true

(2) Both Statement I and Statement II are false

(3) Statement I is false but Statement II is true

(4) Statement I is true but Statement II is false

19. A particle of mass 0.2 kg executes simple harmonic motion of amplitude 0.1 m and frequency 5 Hz. Its total energy is

(1) $\pi^2/5$ J

(2) $\pi^2/20$ J

(3) π^2 J

(4) $\pi^2/10$ J

20. Two waves $y_1 = A\sin(kx - \omega t)$ and $y_2 = A\sin(kx - \omega t + \varphi)$ travel together along a string. The resultant wave has amplitude A when φ is

(1) π/3

(2) π/2

(3) 2π/3

(4) π

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. A particle executes simple harmonic motion with amplitude 10 cm and period 2 s. Its speed (in cm/s) when it is 6 cm from the mean position is _____ (to the nearest integer).

Answer: _____

22. A string 1.5 m long is fixed at both ends. Two consecutive resonant frequencies of the string are 420 Hz and 490 Hz. The speed (in m/s) of transverse waves on the string is _____.

Answer: _____

23. A block of mass 2 kg attached to a spring of force constant 200 N/m rests on a smooth horizontal surface. It is given a speed of 1 m/s at its equilibrium position. The amplitude (in cm) of its oscillation is _____.

Answer: _____

24. Two sound waves in air have wavelengths of 1.00 m and 1.01 m. The speed of sound is 330 m/s. The number of beats heard per second is _____ (to the nearest integer).

Answer: _____

25. A particle executes simple harmonic motion with an amplitude of 2 cm and a frequency of 5 Hz. The magnitude of its greatest acceleration (in m/s^2) is _____ (take $\pi^2 = 10$).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(3)	(1)	(2)	(4)	(1)	(2)	(3)	(2)	(4)	(3)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(1)	(3)	(2)	(4)	(2)	(2)	(3)	(4)	(4)	(3)

Q21	Q22	Q23	Q24	Q25
25	210	10	3	20

WORKED SOLUTIONS

Q1. Answer (3). $x = A \sin \omega t$ reaches $A/2$ when $\omega t = \pi/6$, i.e. $t = T/12 = 2/12 = 1/6$ s. (Half the distance takes only a third of the $T/4$ needed to reach the extreme, because the particle is fastest near the mean position.)

Q2. Answer (1). $\omega = 2\pi$ rad/s. $v = \omega\sqrt{(A^2 - x^2)} = 2\pi \times 4 = 8\pi$ cm/s; $a = \omega^2 x = 4\pi^2 \times 3 = 12\pi^2$ cm/s². ($20\pi^2$ cm/s² is the acceleration at the extreme.)

Q3. Answer (2). $U = \tfrac{1}{2}kx^2$ and $K = \tfrac{1}{2}k(A^2 - x^2)$. They are equal when $x^2 = A^2/2$, $x = A/\sqrt{2} \approx 0.71A$. At $A/2$ the potential energy is only a quarter of the total.

Q4. Answer (4). Series: $k/2$; parallel: $2k$. $T \propto 1/\sqrt{k}$, so $T_{series}/T_{parallel} = \sqrt{(2k/(k/2))} = \sqrt{4} = 2$.

Q5. Answer (1). A spring's force constant is inversely proportional to its length (each third stretches a third as much under the same force), so each piece has constant $3k$. $T \propto 1/\sqrt{k}$ gives $T/\sqrt{3}$.

Q6. Answer (2). A displacement x stretches one spring and compresses the other, so both push the block back: $F = -(100 + 300)x$. $k = 400$ N/m, $\omega = 20$ rad/s and $T = 2\pi/20 = \pi/10$ s ≈ 0.31 s (the springs act in parallel, though they are on opposite sides).

Q7. Answer (3). In equilibrium $kx_0 = mg$, so $m/k = x_0/g = 0.004$ s². $T = 2\pi\sqrt{(m/k)} = 2\pi\sqrt{(x_0/g)} = 2\pi \times 0.0632 \approx 0.40$ s. Gravity only shifts the centre of the oscillation.

Q8. Answer (2). In the lift's frame the effective gravity is $g + g/3 = 4g/3$. $T \propto 1/\sqrt{g_{eff}}$, so $T' = T\sqrt{(3/4)} = (\sqrt{3}/2)T$: the pendulum swings faster.

Q9. Answer (4). $T \propto \sqrt{L}$, so $T_2/T_1 = \sqrt{1.21} = 1.1$. They are in phase again when the shorter one has made exactly one more oscillation: $nT_1 = (n - 1)T_2 = (n - 1)(1.1)T_1$, so $0.1n = 1.1$ and $n = 11$.

Q10. Answer (3). Motion is simple harmonic if the acceleration is $-\Omega^2(x - x_0)$ for a fixed centre x_0. (A) $= \sqrt{2}\sin(\omega t + \pi/4)$: SHM. (B) $= \tfrac{1}{2} - \tfrac{1}{2}\cos 2\omega t$: SHM about $x = \tfrac{1}{2}$ with angular frequency 2ω. (C) is periodic but a mix of two frequencies: not SHM. (D) is not even periodic. (E) is SHM.

Q11. Answer (1). $x_2 = A\sin(\omega t + \pi/2)$, so the phase difference is $\pi/2 - \pi/6 = \pi/3$. Resultant amplitude $= \sqrt{(A^2 + A^2 + 2A^2\cos 60°)} = A\sqrt{3}$.

Q12. Answer (3). $\omega = 20\pi$ rad/s and $k = 0.5\pi$ rad/m, so the wave speed is $\omega/k = 40$ m/s ($\lambda = 4$ m, $f = 10$ Hz). A particle moves in SHM with amplitude 0.05 m, so its greatest speed is $A\omega = 0.05 \times 20\pi = \pi$ m/s.

Q13. Answer (2). $v = \sqrt{(T/\mu)} = \sqrt{(100/0.01)} = 100$ m/s. Fundamental: $\lambda = 2L = 1$ m, $f_1 = 100$ Hz. Third harmonic: $\lambda_3 = 2L/3 = 1/3$ m ($f_3 = 300$ Hz).

Q14. Answer (4). Closed pipe: only odd harmonics, $f = (2n - 1)v/(4L_c)$; its first overtone is $3v/(4L_c)$. Open pipe fundamental: $v/(2L_o)$. Equal: $3/(4L_c) = 1/(2L_o)$, so $L_c/L_o = 3/2$.

Q15. Answer (2). The wire is at 300 ± 5 Hz. Raising the tension raises its frequency ($f \propto \sqrt{T}$). The beats fall only if the wire's frequency moves towards 300 Hz from below, so it was 295 Hz (now about 297 Hz). Had it been 305 Hz, the beats would have increased.

Q16. Answer (2). Nodes are where $\sin(5\pi x) = 0$: x = 0, 0.2, 0.4, … m, so adjacent nodes are 0.2 m (λ/2) apart, with λ = 0.4 m. The component waves travel at $\omega/k = 100\pi/(5\pi) = 20$ m/s, each with amplitude 2 cm.

Q17. Answer (3). $v = \sqrt{(\gamma RT/M)}$. Ratio = $\sqrt{((5/3)/4 \div (7/5)/32)} = \sqrt{((5/12) \times (160/7))} = \sqrt{(800/84)} \approx 3.09$. Ignoring γ gives $\sqrt{8} \approx 2.83$.

Q18. Answer (4). Statement I: the fixed end cannot move, so the reflected wave must cancel the incident one there: it is inverted (phase change π). True. Statement II: air at a closed end cannot move, so it is a displacement node (and a pressure antinode). False.

Q19. Answer (4). $\omega = 2\pi f = 10\pi$ rad/s. $E = \tfrac{1}{2}m\omega^2A^2 = \tfrac{1}{2} \times 0.2 \times 100\pi^2 \times 0.01 = \pi^2/10$ J ≈ 0.99 J.

Q20. Answer (3). The resultant amplitude is $2A\cos(\varphi/2)$. Setting $2A\cos(\varphi/2) = A$ gives $\cos(\varphi/2) = \tfrac{1}{2}$, $\varphi = 2\pi/3$. ($\varphi = \pi/2$ gives $A\sqrt{2}$; $\varphi = \pi$ gives zero.)

Q21. Answer 25. $\omega = \pi$ rad/s and $v = \omega\sqrt{(A^2 - x^2)} = \pi\sqrt{(100 - 36)} = 8\pi \approx 25.1$ cm/s, i.e. 25.

Q22. Answer 210. Consecutive harmonics differ by the fundamental: $f_1 = 490 - 420 = 70$ Hz (420 Hz is the 6th harmonic). $v = 2Lf_1 = 2 \times 1.5 \times 70 = 210$ m/s.

Q23. Answer 10. $\omega = \sqrt{(k/m)} = 10$ rad/s. At the mean position $v_{max} = A\omega$, so A = 1/10 m = 10 cm (equivalently $\tfrac{1}{2}mv^2 = \tfrac{1}{2}kA^2$).

Q24. Answer 3. $f_1 = 330/1.00 = 330$ Hz and $f_2 = 330/1.01 \approx 326.7$ Hz. Beats = $f_1 - f_2 \approx 3.3$ per second, i.e. 3.

Q25. Answer 20. $a_{max} = \omega^2A = (2\pi \times 5)^2 \times 0.02 = 100\pi^2 \times 0.02 = 2\pi^2 = 20$ m/s².

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: oscillators by integrating their equations of motion and timing them, and waves by sampling the wave functions (crest positions, particle speeds, nodes and resultant amplitudes).