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Kinematics — 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: Motion in a straight line · Average and instantaneous velocity · Uniformly accelerated motion · Non-uniform motion · Graphs of motion · Relative velocity · Motion in a plane · Projectile motion · Uniform circular motion

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

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

1. The position of a particle moving along the x-axis is $x = 2t^3 - 15t^2 + 24t$, where x is in metres and t in seconds. The distance travelled by the particle and the magnitude of its displacement in the first 5 s are, respectively,

(1) 49 m and 5 m

(2) 27 m and 5 m

(3) 49 m and 16 m

(4) 38 m and 5 m

2. A particle moving along a straight line has speed v_0 at $x = 0$, and its speed decreases with distance as $v = v_0 - kx$, where k is a positive constant. The time taken for its speed to fall to $v_0/2$, and the distance covered in that time, are

(1) $1/k$ and $v_0/(2k)$

(2) $(\ln 2)/k$ and $v_0/(2k)$

(3) $(\ln 2)/k$ and v_0/k

(4) $2/k$ and $v_0/(2k)$

3. A particle starts from rest at the origin and moves along the x-axis with acceleration $a = (6 - 2t)$ m/s² (t in s). Its greatest velocity in the first 6 s, and its position at $t = 6$ s, are

(1) 9 m/s and 36 m

(2) 9 m/s and 18 m

(3) 6 m/s and 36 m

(4) 18 m/s and 54 m

4. A driver takes 0.5 s to react before applying the brakes, and the car then decelerates uniformly. Travelling at 72 km/h, the car stops 30 m from the point where the driver saw the danger. With the same reaction time and deceleration, the stopping distance from 108 km/h is

(1) 45 m

(2) 52.5 m

(3) 67.5 m

(4) 60 m

5. A ball thrown vertically upward from the ground is 25 m above the ground at $t = 1$ s and again at $t = 5$ s. The speed of projection and the greatest height reached are ($g = 10$ m/s²)

(1) 25 m/s and 31.25 m

(2) 30 m/s and 50 m

(3) 30 m/s and 45 m

(4) 60 m/s and 180 m

6. A stone is dropped from the top of an 80 m tower. One second later another stone is thrown vertically upward from the foot of the tower with a speed of 40 m/s. The stones meet at a height above the ground of ($g = 10$ m/s²)

(1) 60 m

(2) 48.75 m

(3) 31.25 m

(4) 35 m

7. A particle at the origin has velocity $6\hat{i}$ m/s at t = 0, and moves with a constant acceleration $(-2\hat{i} + 2\hat{j})$ m/s². Its least speed in the motion that follows, and the time at which it has that speed, are

(1) 3 m/s at t = 3 s

(2) $3\sqrt{2}$ m/s at t = 3 s

(3) zero at t = 3 s

(4) $3\sqrt{2}$ m/s at t = 1.5 s

8. The velocity–time graph of a particle moving along a straight line is a straight line that falls from 10 m/s at t = 0 to −10 m/s at t = 5 s. For these 5 s, the average speed and the magnitude of the average velocity of the particle are

(1) 10 m/s and zero

(2) 5 m/s and zero

(3) 5 m/s and 5 m/s

(4) zero and zero

9. The position of a particle moving along the x-axis is $x = 5 + 3t - t^3$ (x in m, t in s). Its average velocity between t = 0 and t = 2 s, and the instant in this interval at which its instantaneous velocity equals that average velocity, are

(1) −1 m/s and $t = 2/\sqrt{3}$ s

(2) −1 m/s and t = 1 s

(3) 1 m/s and $t = 2/\sqrt{3}$ s

(4) −1 m/s and $t = \sqrt{2}$ s

10. A river 400 m wide flows at 5 m/s. A boat can move at 3 m/s relative to the water. If the boatman wants to be carried downstream as little as possible while crossing, the least distance by which he is carried downstream is

(1) 300 m

(2) 533 m

(3) 400 m

(4) 667 m

11. Ship B is 20 km due east of ship A. A sails due north at 15 km/h and B sails due west at 20 km/h. The least distance between the ships, and the time after which it occurs, are

(1) 12 km and 48 min

(2) 16 km and 38.4 min

(3) 12 km and 38.4 min

(4) 15 km and 36 min

12. A projectile launched from the ground passes through two points, each 10 m above the ground, at horizontal distances of 10 m and 30 m from the point of launch. The angle of projection and the horizontal range are (g = 10 m/s²)

(1) $\tan^{-1}(4/3)$ and 30 m

(2) $\tan^{-1}(3/4)$ and 40 m

(3) 45° and 40 m

(4) $\tan^{-1}(4/3)$ and 40 m

13. A ball is projected from the foot of a fixed smooth incline of inclination 30°, with a speed of 20 m/s at 60° to the horizontal (up the incline). The distance along the incline from the point of projection to the point where the ball lands on it is ($g = 10\ m/s^2$)

(1) 80/3 m

(2) $40/\sqrt{3}$ m

(3) 40 m

(4) 20 m

14. A particle starts from rest and moves along a circle with a constant tangential acceleration. Through what angle has it turned when its acceleration makes an angle of 45° with its velocity?

(1) 1 rad

(2) $\pi/4$ rad

(3) 1/2 rad

(4) 2 rad

15. A particle moves with constant speed v on a circle of radius R. Over half a revolution, the magnitudes of its average velocity and of its average acceleration are

(1) $2v/\pi$ and $2v^2/(\pi R)$

(2) zero and zero

(3) v and v^2/R

(4) $2v/\pi$ and zero

16. The coordinates of a particle moving in the xy-plane are $x = 3t$ and $y = 4t - t^2$ (x, y in m; t in s). The radius of curvature of its path at $t = 0$ is

(1) 25/2 m

(2) 125/8 m

(3) 125/6 m

(4) 25/6 m

17. Statement I: If a particle moves in a plane with constant speed, its acceleration is perpendicular to its velocity at every instant.
Statement II: If the acceleration of a particle is perpendicular to its velocity at some instant, its speed is constant.
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) Statement I is false but Statement II is true

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

(4) Both Statement I and Statement II are false

18. The velocity of a particle moving along the x-axis varies with its position as $v^2 = 16 - 4x$ (SI units). The particle is at $x = 0$ at $t = 0$, moving in the +x direction. Its acceleration, and the time after which it is back at $x = 0$, are

(1) $-4\ m/s^2$ and 2 s

(2) $-2\ m/s^2$ and 2 s

(3) $-4\ m/s^2$ and 4 s

(4) $-2\ m/s^2$ and 4 s

19. Two particles are projected at the same instant from the same point with the same speed of 20 m/s, one at 30° and the other at 60° to the horizontal. As seen from the first particle (while both are in flight), the second particle moves

(1) along a parabola, with speed changing

(2) along a straight line, with a constant speed of 40 sin 15° m/s

(3) along a straight line, with a constant speed of $20\sqrt{2}$ m/s

(4) along a parabola, with a constant speed of 40 sin 15° m/s

20. A balloon is rising vertically with a constant speed of 10 m/s. When it is 75 m above the ground, a stone is released from it. The time the stone takes to reach the ground, and its speed on reaching the ground, are ($g = 10\ m/s^2$)

(1) 3.87 s and 38.7 m/s

(2) 5 s and 50 m/s

(3) 3 s and 20 m/s

(4) 5 s and 40 m/s

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 ball is thrown from the top of a building 40 m high with a speed of 20 m/s at 30° above the horizontal. The horizontal distance (in m) from the foot of the building at which it lands on the level ground is _____ (to the nearest integer; $g = 10\ m/s^2$).

Answer: _____

22. A car starts from rest with a uniform acceleration of 2 m/s^2 at the instant a truck moving at 20 m/s passes it in the same direction. At that same instant the truck begins to brake with a uniform retardation of 1 m/s^2. The distance (in m) covered by the car before it overtakes the truck is _____ (to the nearest integer).

Answer: _____

23. A particle moves on a circle of radius 50 cm, and its angular position is $\theta = 2t^2$ (θ in rad, t in s). If a is the magnitude of its acceleration at t = 1 s, the value of a^2 (in $m^2\ s^{-4}$) is _____.

Answer: _____

24. A ball is projected from level ground with a speed of 50 m/s at an angle θ above the horizontal, where $\tan\theta = 3/4$. It hits a vertical wall 120 m away from the point of projection. The height (in m) above the ground at which it hits the wall is _____ ($g = 10\ m/s^2$).

Answer: _____

25. A ball is projected from level ground with a speed of 40 m/s at an angle θ above the horizontal, where $\sin\theta = 0.8$. The time (in s) after projection at which its velocity is perpendicular to its initial velocity is _____ ($g = 10\ m/s^2$).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

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

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

Q21	Q22	Q23	Q24	Q25
69	178	68	45	5

WORKED SOLUTIONS

Q1. Answer (1). $v = 6t^2 - 30t + 24 = 6(t - 1)(t - 4)$, so the particle turns at $t = 1$ s and $t = 4$ s. $x(0) = 0$, $x(1) = 11$ m, $x(4) = 128 - 240 + 96 = -16$ m, $x(5) = 250 - 375 + 120 = -5$ m. Distance $= 11 + 27 + 11 = 49$ m; displacement $= -5$ m, of magnitude 5 m.

Q2. Answer (2). $v = v_0/2$ when $kx = v_0/2$, i.e. $x = v_0/(2k)$. The acceleration is $a = v\,dv/dx = -kv$, so $dv/dt = -kv$ and $v = v_0e^{\wedge}(-kt)$: $v = v_0/2$ at $t = (\ln 2)/k$. (The particle never quite stops: it approaches $x = v_0/k$.)

Q3. Answer (1). $v = 6t - t^2$, which is greatest when $a = 0$, at $t = 3$ s: $v = 18 - 9 = 9$ m/s. $x = 3t^2 - t^3/3$, so $x(6) = 108 - 72 = 36$ m. (The velocity stays positive until $t = 6$ s, so 36 m is also the distance.)

Q4. Answer (4). At 20 m/s: 0.5 s of reaction covers 10 m, so braking covers 20 m and the deceleration is $20^2/(2 \times 20) = 10$ m/s². At 30 m/s: reaction 15 m and braking $30^2/20 = 45$ m, a total of 60 m. Scaling the whole 30 m with v^2 (67.5 m) wrongly scales the reaction distance too.

Q5. Answer (3). The ball takes as long to rise from 25 m to the top as to fall back, so the top is reached at $t = (1 + 5)/2 = 3$ s and $u = g \times 3 = 30$ m/s. Greatest height $= u^2/2g = 900/20 = 45$ m. (Check: at $t = 1$ s, $30 - 5 = 25$ m.)

Q6. Answer (2). Measuring t from the first stone's release: $y_1 = 80 - 5t^2$, $y_2 = 40(t - 1) - 5(t - 1)^2$. Setting them equal, $80 - 5t^2 = 50t - 45 - 5t^2$, so $t = 2.5$ s, and $y = 80 - 5 \times 6.25 = 48.75$ m. (The second stone is then moving up at $40 - 15 = 25$ m/s.) 60 m is the answer if both start together.

Q7. Answer (4). $v = (6 - 2t)\,\hat{\imath} + 2t\,\hat{\jmath}$, so $v^2 = (6 - 2t)^2 + 4t^2 = 8t^2 - 24t + 36$, least when $t = 24/16 = 1.5$ s: $v = 3\hat{\imath} + 3\hat{\jmath}$, speed $3\sqrt{2}$ m/s. (At that instant $v \cdot a = -2 \times 3 + 2 \times 3 = 0$: the acceleration is perpendicular to the velocity.) The x-component alone vanishes at $t = 3$ s, but the speed is then 6 m/s.

Q8. Answer (2). The acceleration is $-20/5 = -4$ m/s², and $v = 0$ at $t = 2.5$ s. The area under the graph is $+\frac{1}{2} \times 2.5 \times 10 = 12.5$ m before that and -12.5 m after it. Displacement $= 0$, so the average velocity is zero; distance $= 25$ m, so the average speed is $25/5 = 5$ m/s.

Q9. Answer (1). $x(0) = 5$ m and $x(2) = 5 + 6 - 8 = 3$ m, so the average velocity is $(3 - 5)/2 = -1$ m/s. $v = 3 - 3t^2 = -1$ gives $t^2 = 4/3$, $t = 2/\sqrt{3}$ s ≈ 1.15 s, inside the interval (as it must be, by the mean value theorem).

Q10. Answer (2). The boat is slower than the river, so it cannot go straight across. If it heads at angle φ upstream from the line straight across, the time is $400/(3 \cos \varphi)$ and the drift is $(5 - 3 \sin \varphi) \times 400/(3 \cos \varphi)$. This is least when $\sin \varphi = 3/5$, giving drift $= (5 - 9/5) \times 400/(3 \times 4/5) = (16/5) \times (500/3) = 533$ m $(= 400 \times 4/3)$. 667 m is the drift when heading straight across.

Q11. Answer (3). Relative to A, B starts at (20, 0) km and moves with velocity (−20, −15) km/h, of magnitude 25 km/h. The least distance is the perpendicular distance from A to this line: $|20 \times (-15) - 0 \times (-20)|/25 = 12$ km. It is reached after $(20 \times 20)/25^2 = 0.64$ h = 38.4 min.

Q12. Answer (4). The path $y = x \tan\theta\,(1 - x/R)$ is symmetric about $x = R/2$, so $R = 10 + 30 = 40$ m. At $x = 10$ m: $10 = 10 \tan\theta\,(1 - 10/40)$, so $\tan\theta = 4/3$ ($\theta \approx 53°$). (Then $u^2 = gR/\sin 2\theta = 400 \times 25/24$, $u \approx 20.4$ m/s.)

Q13. Answer (1). Take axes along and perpendicular to the incline. The ball leaves at $\alpha = 30°$ to the incline: $u_perp = 20 \sin 30° = 10$ m/s, $g_perp = g \cos 30° = 5\sqrt{3}$ m/s², so the time of flight is $2 \times 10/(5\sqrt{3}) = 4/\sqrt{3}$ s. Along the incline, $u = 20 \cos 30° = 10\sqrt{3}$ m/s and the deceleration is $g \sin 30° = 5$ m/s²: $s = 10\sqrt{3}(4/\sqrt{3}) - \tfrac{1}{2} \times 5 \times 16/3 = 40 - 40/3 = 80/3$ m ≈ 26.7 m.

Q14. Answer (3). With tangential acceleration a_t, $v^2 = 2a_t\, s = 2a_t\, R\theta$ after turning through θ. The centripetal acceleration is $v^2/R = 2a_t\theta$. The acceleration makes 45° with the velocity when the two components are equal: $2a_t\theta = a_t$, $\theta = \tfrac{1}{2}$ rad, whatever the radius or a_t.

Q15. Answer (1). Half a revolution takes $\pi R/v$. The displacement is the diameter $2R$, so the average velocity is $2R/(\pi R/v) = 2v/\pi$. The velocity reverses, a change of $2v$, so the average acceleration is $2v/(\pi R/v) = 2v^2/(\pi R)$, less than the constant magnitude v^2/R of the instantaneous acceleration.

Q16. Answer (3). $v = (3, 4 - 2t)$ and $a = (0, -2)$. At $t = 0$, $v = (3, 4)$, speed 5 m/s. The component of a perpendicular to v is $|v \times a|/|v| = |3 \times (-2) - 4 \times 0|/5 = 6/5$ m/s². Radius of curvature $= v^2/a_\perp = 25/(6/5) = 125/6$ m ≈ 20.8 m. Using the whole 2 m/s² gives 25/2 m.

Q17. Answer (3). Statement I: $v^2 = v \cdot v$ is constant, so $d(v \cdot v)/dt = 2v \cdot a = 0$ at every instant. True. Statement II: $a \perp v$ at one instant only makes the rate of change of speed zero at that instant. A projectile at the top of its path has $a \perp v$, yet its speed changes. False.

Q18. Answer (4). Differentiating, $2v\, dv/dx = -4$, so $a = v\, dv/dx = -2$ m/s², constant. At $x = 0$, $v = 4$ m/s. Returning to $x = 0$: $4t - t^2 = 0$, so $t = 4$ s (the particle stops at $x = 4$ m at $t = 2$ s and comes back).

Q19. Answer (2). Both have the same acceleration g, so the relative acceleration is zero and the relative velocity stays equal to its initial value $u_2 - u_1$: a straight line at constant speed. Its magnitude is $2u \sin(30°/2) = 40 \sin 15°$ m/s ≈ 10.4 m/s.

Q20. Answer (4). The stone starts with the balloon's velocity, 10 m/s upward. With up positive: $-75 = 10t - 5t^2$, so $t^2 - 2t - 15 = 0$ and $t = 5$ s. Velocity $= 10 - 10 \times 5 = -40$ m/s: 40 m/s downward. 3.87 s is the time if the stone is taken to start from rest.

Q21. Answer 69. Vertical: $-40 = (20 \sin 30°)t - 5t^2 = 10t - 5t^2$, so $t^2 - 2t - 8 = 0$ and $t = 4$ s. Horizontal: $x = 20 \cos 30° \times 4 = 40\sqrt{3} \approx 69.3$ m, i.e. 69.

Q22. Answer 178. Car: $x = t^2$. Truck: $x = 20t - 0.5t^2$ (it would stop at $t = 20$ s). They meet when $t^2 = 20t - 0.5t^2$, i.e. $t = 40/3$ s ≈ 13.3 s, before the truck stops. The car has covered $(40/3)^2 = 1600/9 \approx 177.8$ m, i.e. 178.

Q23. Answer 68. $\omega = d\theta/dt = 4t = 4$ rad/s and $\alpha = 4$ rad/s² at $t = 1$ s. Tangential acceleration $R\alpha = 0.5 \times 4 = 2$ m/s²; centripetal acceleration $R\omega^2 = 0.5 \times 16 = 8$ m/s². $a^2 = 2^2 + 8^2 = 68$.

Q24. Answer 45. $u \cos\theta = 40$ m/s and $u \sin\theta = 30$ m/s. The ball reaches the wall after $120/40 = 3$ s, when its height is $30 \times 3 - 5 \times 9 = 45$ m. The top of the path is reached at $u \sin\theta/g = 3$ s, so the ball meets the wall at its highest point.

Q25. Answer 5. $v = u - g\,t\,\hat{j}$, so $v \cdot u = u^2 - g\,t\,u \sin\theta = 0$ gives $t = u/(g \sin\theta) = 40/8 = 5$ s. The time of flight is $2u \sin\theta/g = 6.4$ s, so the ball is still in the air.

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