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Laws of Motion — 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: Newton's laws of motion · Linear momentum · Impulse · Conservation of linear momentum · Equilibrium of concurrent forces · Static and kinetic friction · Laws of friction · Centripetal force · Vehicle on a level circular road · Vehicle on a banked road

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

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

1. A body of mass 2 kg, initially at rest on a smooth horizontal surface, is acted on by a horizontal force $F = 6t(2 - t)$ N for $0 \le t \le 2$ s (t in s), after which the force is removed. The velocity of the body at $t = 2$ s and the greatest force acting on it are

(1) 8 m/s and 6 N

(2) 4 m/s and 6 N

(3) 4 m/s and 12 N

(4) 2 m/s and 6 N

2. A shell fired from level ground would have a horizontal range R. At the highest point of its path it explodes into two fragments of masses m and 2m. The fragment of mass m retraces its path back to the gun. The other fragment lands at a distance from the gun of

(1) 2R

(2) 5R/2

(3) 3R/2

(4) 3R

3. A block A of mass 4 kg lies on a rough horizontal table (coefficient of kinetic friction 0.25). A light string tied to A passes over a smooth pulley at the edge of the table and carries a block B of mass 1 kg hanging vertically. A horizontal force F, directed away from the pulley, is applied to A. The value of F for which B rises with an acceleration of 2 m/s² is ($g = 10$ m/s²)

(1) 20 N

(2) 22 N

(3) 40 N

(4) 30 N

4. Three blocks of masses 1 kg, 2 kg and 3 kg are placed in contact in a row on a horizontal floor, and a horizontal force of 12 N pushes the 1 kg block towards the others. The contact force between the 2 kg and 3 kg blocks when the floor is smooth, and when the coefficient of kinetic friction between each block and the floor is 0.1, are respectively ($g = 10$ m/s²)

(1) 6 N and 6 N

(2) 6 N and 3 N

(3) 6 N and 4.5 N

(4) 10 N and 6 N

5. A block hangs from a spring balance fixed to the ceiling of a lift. When the lift accelerates upward with acceleration a, the balance reads 72 N; when it accelerates downward with the same acceleration a, it reads 48 N. The mass of the block and a are ($g = 10$ m/s²)

(1) 6 kg and 4 m/s²

(2) 6 kg and 2 m/s²

(3) 5 kg and 2 m/s²

(4) 12 kg and 2 m/s²

6. A body of mass 10 kg hangs at rest from two light strings attached to a horizontal ceiling. One string makes 30° and the other 60° with the ceiling. The tensions in the two strings are respectively ($g = 10\ m/s^2$)

(1) $50\sqrt{3}$ N and 50 N

(2) 100 N and $100\sqrt{3}$ N

(3) 50 N and $50\sqrt{3}$ N

(4) 50 N and 100 N

7. A uniform rope of mass 1 kg and length 2 m hangs vertically with a block of mass 2 kg tied to its lower end. The top of the rope is pulled upward so that the whole system rises with an acceleration of $2\ m/s^2$. The tension at the midpoint of the rope is ($g = 10\ m/s^2$)

(1) 30 N

(2) 25 N

(3) 36 N

(4) 24 N

8. A block of mass 5 kg rests on a rough horizontal floor (coefficient of static friction 0.5). A force F is applied to it at an angle above the horizontal. The least value of F that can just start the block moving, and the angle at which it must be applied, are ($g = 10\ m/s^2$)

(1) 25 N, horizontally

(2) $10\sqrt{5}$ N, at $\tan^{-1} 2$ above the horizontal

(3) $10\sqrt{5}$ N, at $\tan^{-1}(1/2)$ above the horizontal

(4) 20 N, at 30° above the horizontal

9. A block is projected up a fixed incline of inclination 37° ($\sin 37° = 3/5$) with a speed of 10 m/s. The coefficient of static and of kinetic friction between the block and the incline is 0.5. The speed with which the block returns to the point of projection, and the total time from projection to return, are ($g = 10\ m/s^2$)

(1) $2\sqrt{5}$ m/s and $(1 + \sqrt{5})$ s

(2) 10 m/s and 2 s

(3) $2\sqrt{5}$ m/s and 2 s

(4) $\sqrt{10}$ m/s and $(1 + \sqrt{5})$ s

10. A block of mass 2 kg rests on top of a block of mass 3 kg, which lies on a smooth horizontal floor. The coefficient of static and of kinetic friction between the blocks is 0.4. A horizontal force F is applied to the lower block. The greatest F for which the blocks move together, and the acceleration of the lower block when F = 30 N, are ($g = 10\ m/s^2$)

(1) 8 N and $22/3\ m/s^2$

(2) 20 N and $6\ m/s^2$

(3) 20 N and $22/3\ m/s^2$

(4) 12 N and $10\ m/s^2$

11. Consider the following statements.
(A) The limiting force of static friction is nearly independent of the area of contact.
(B) The coefficient of kinetic friction between two surfaces is generally less than the coefficient of static friction.
(C) Rolling friction is usually much smaller than sliding friction.
(D) The force of static friction on a body at rest is always equal to $\mu_s N$.
(E) For ordinary speeds, kinetic friction depends strongly on the relative speed of the surfaces.
Choose the correct answer from the options given below:

(1) (A), (B), (C) and (E) only
(2) (A), (B) and (D) only
(3) (A), (B), (C), (D) and (E)
(4) (A), (B) and (C) only

12. A circular road of radius 100 m is banked so that the ideal speed (no friction needed) is 15 m/s. The coefficient of static friction between the tyres and the road is 0.5. The greatest speed at which a car can go round without skidding is about ($g = 10\ m/s^2$)

(1) 22.4 m/s
(2) 25.0 m/s
(3) 28.6 m/s
(4) 32.1 m/s

13. A car starts from rest on a level circular track of radius 50 m and speeds up with a constant tangential acceleration of 3 m/s^2. The coefficient of static friction between the tyres and the road is 0.4. The speed at which the car begins to skid is about ($g = 10\ m/s^2$)

(1) 11.5 m/s
(2) 14.1 m/s
(3) 10.0 m/s
(4) 12.6 m/s

14. A small stone tied to a light string of length 1 m moves in a horizontal circle (a conical pendulum), with the string making 60° with the vertical. The tension in the string, in terms of the weight mg of the stone, and the angular speed of the stone are ($g = 10\ m/s^2$)

(1) 2mg and $\sqrt{10}$ rad/s
(2) mg/2 and $2\sqrt{5}$ rad/s
(3) $\sqrt{3}mg/2$ and $2\sqrt{5}$ rad/s
(4) 2mg and $2\sqrt{5}$ rad/s

15. A horizontal jet of water of cross-sectional area 2 cm^2 strikes a vertical wall at 10 m/s. The force on the wall if the water comes to rest on striking it, and if it instead rebounds with the same speed, are (density of water 1000 kg/m^3)

(1) 20 N and 40 N
(2) 20 N and 20 N
(3) 10 N and 20 N
(4) 40 N and 80 N

16. Block A of mass m lies on a smooth horizontal table. A light string tied to A passes over a fixed smooth pulley at the edge of the table, goes down and round a light movable pulley from which block B of mass m hangs, and goes up again to a fixed hook (the string segments near B are vertical). The accelerations of A and B are

(1) g/2 and g/4

(2) 2g/5 and g/5

(3) g/3 and g/6

(4) 2g/3 and g/3

17. A person of mass 60 kg stands on a trolley of mass 120 kg at rest on a smooth horizontal floor. The person jumps off horizontally with a speed of 3 m/s relative to the trolley. The speed of the trolley just after the jump is

(1) 1.5 m/s

(2) 1 m/s

(3) 2 m/s

(4) 0.5 m/s

18. A ball of mass 0.2 kg falls from rest through 5 m onto a horizontal floor and rebounds to a height of 1.8 m. It is in contact with the floor for 0.02 s. The magnitude of the change in the momentum of the ball during the contact, and the average force exerted on it by the floor, are ($g = 10\ m/s^2$)

(1) 3.2 N s and 160 N

(2) 0.8 N s and 40 N

(3) 3.2 N s and 162 N

(4) 3.2 N s and 158 N

19. A small bob hangs from a light string attached to the roof of a car. The car moves on a straight horizontal road with a constant acceleration of $g/\sqrt{3}$. Relative to the car, the bob hangs at rest with the string making an angle with the vertical, and the tension in the string, of

(1) 60° and 2mg

(2) 30° and $\sqrt{3}mg/2$

(3) 30° and $2mg/\sqrt{3}$

(4) 45° and $\sqrt{2}mg$

20. A block of mass 10 kg rests on a fixed incline of inclination 37° ($\sin 37° = 3/5$). The coefficient of static friction is 0.25. A force F acting up the incline, parallel to it, keeps the block at rest. The least and greatest values of F are ($g = 10\ m/s^2$)

(1) 40 N and 80 N

(2) 20 N and 60 N

(3) 40 N and 60 N

(4) 60 N and 80 N

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.

21. A circular road of radius 200 m is banked at an angle θ with $\tan\theta = 0.2$. The coefficient of static friction between the tyres and the road is 0.1. The least speed (in m/s) at which a car can go round without slipping down the slope is _____ (to the nearest integer; $g = 10\ m/s^2$).

Answer: _____

22. A block of mass 2 kg is at rest on a rough horizontal floor, with coefficients of static and of kinetic friction both 0.3. From t = 0 a horizontal force F = 2t N (t in s) acts on it. The speed of the block (in m/s) at t = 7 s is _____ (g = 10 m/s²).

Answer: _____

23. A block of mass 2 kg on a smooth horizontal table is tied to a light string that passes over a light smooth pulley at the edge of the table and carries a hanging block of mass 3 kg. The magnitude of the force (in N) exerted by the string on the pulley is _____ (to the nearest integer; g = 10 m/s²).

Answer: _____

24. A particle of mass 0.5 kg tied to a light string of length 1 m moves in a horizontal circle on a smooth horizontal table, the other end of the string being fixed at the centre. It makes 2 revolutions per second. The tension in the string (in N) is _____ (to the nearest integer; take $\pi^2 = 9.87$).

Answer: _____

25. A bomb of mass 6 kg at rest explodes into three pieces. A piece of mass 1 kg moves due east at 30 m/s and a piece of mass 2 kg moves due north at 20 m/s. The total kinetic energy (in J) released in the explosion is _____ (to the nearest integer).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

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

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

Q21	Q22	Q23	Q24	Q25
14	8	17	79	1267

WORKED SOLUTIONS

Q1. Answer (2). Impulse = $\int_0^2 (12t - 6t^2)\,dt = 24 - 16 = 8$ N s = change of momentum, so $v = 8/2 = 4$ m/s. $F = 12t - 6t^2$ is greatest where $dF/dt = 12 - 12t = 0$, at $t = 1$ s: $F = 6$ N. 8 m/s forgets to divide the impulse by the mass.

Q2. Answer (3). At the top the shell (3m) moves horizontally at u. The fragment m retraces its path, so it moves at −u. Momentum: $3mu = -mu + 2mv$, so $v = 2u$. Both fragments fall from the same height in the time the shell would take to cover the remaining R/2, so the heavy fragment covers $2 \times R/2 = R$ more: it lands $R/2 + R = 3R/2$ from the gun.

Q3. Answer (4). B: $T - 10 = 1 \times 2$, so $T = 12$ N. A moves away from the pulley, so kinetic friction $0.25 \times 40 = 10$ N acts on it towards the pulley: $F - T - 10 = 4 \times 2$, so $F = 30$ N. Forgetting the friction gives 20 N.

Q4. Answer (1). Smooth: $a = 12/6 = 2$ m/s², and the contact force pushes the 3 kg block alone: $N = 3 \times 2 = 6$ N. Rough: total friction $0.1 \times 60 = 6$ N, $a = (12 - 6)/6 = 1$ m/s², and on the 3 kg block $N - 3 = 3 \times 1$, so $N = 6$ N again. Friction proportional to each mass does not change how the push is shared.

Q5. Answer (2). $m(g + a) = 72$ and $m(g - a) = 48$. Adding, $2mg = 120$, so $m = 6$ kg; subtracting, $2ma = 24$, so $a = 2$ m/s².

Q6. Answer (3). Horizontal: $T_1 \cos 30° = T_2 \cos 60°$, so $T_2 = \sqrt{3}\,T_1$. Vertical: $T_1 \sin 30° + T_2 \sin 60° = 100$, i.e. $T_1/2 + 3T_1/2 = 100$, so $T_1 = 50$ N (the string at 30°) and $T_2 = 50\sqrt{3}$ N (the string at 60°, the steeper one, carries more).

Q7. Answer (1). Below the midpoint hang the block (2 kg) and half the rope (0.5 kg), 2.5 kg in all, rising at 2 m/s²: $T - 25 = 2.5 \times 2$, so $T = 30$ N. 25 N is the tension when the system is at rest; 36 N is the tension at the top.

Q8. Answer (3). At angle θ the normal force is $mg - F \sin\theta$, so the block just moves when $F \cos\theta = \mu(mg - F \sin\theta)$: $F = \mu mg/(\cos\theta + \mu \sin\theta)$. The denominator is greatest, $\sqrt{1 + \mu^2}$, when $\tan\theta = \mu = ½$. $F_{min} = \mu mg/\sqrt{1 + \mu^2} = 25/\sqrt{1.25} = 10\sqrt{5}$ N ≈ 22.4 N, less than the 25 N needed when pulling horizontally.

Q9. Answer (1). Going up, both gravity and friction oppose the motion: $a = g(\sin 37° + \mu \cos 37°) = 10(0.6 + 0.4) = 10$ m/s², so it stops after 1 s and 5 m. Since $\tan 37° = 0.75 > 0.5$, it does not stay there; it slides back with $a = g(0.6 - 0.4) = 2$ m/s². Over 5 m: $v = \sqrt{(2 \times 2 \times 5)} = 2\sqrt{5}$ m/s, taking $\sqrt{(2 \times 5/2)} = \sqrt{5}$ s. Total time $(1 + \sqrt{5})$ s.

Q10. Answer (3). The upper block can be accelerated by friction at most at $\mu g = 4$ m/s². Moving together at 4 m/s² needs $F = 5 \times 4 = 20$ N, the greatest value. At $F = 30$ N the blocks slip: friction on the lower block is $0.4 \times 20 = 8$ N backward, so its acceleration is $(30 - 8)/3 = 22/3$ m/s² (the upper block's is 4 m/s²).

Q11. Answer (4). (A), (B) and (C) are laws of friction found by experiment. (D) is wrong: static friction adjusts to the applied force, up to the limiting value $\mu_s N$, which is its greatest value, not its value in general. (E) is wrong: for ordinary speeds kinetic friction is nearly independent of the relative speed.

Q12. Answer (3). $\tan\theta = v_0^2/(rg) = 225/1000 = 0.225$. At the greatest speed friction acts down the slope at its limiting value: $v^2 = rg(\tan\theta + \mu)/(1 - \mu \tan\theta) = 1000 \times 0.725/0.8875 \approx 816.9$, so $v \approx 28.6$ m/s (about 103 km/h). 22.4 m/s is the limit on a level road with the same friction.

Q13. Answer (1). Friction alone provides both the tangential acceleration a_t and the centripetal acceleration v^2/r, so it must supply $m\sqrt{(a_t^2 + v^4/r^2)} \le \mu mg$. Skidding starts when $9 + v^4/2500 = 16$, so $v^4 = 17500$ and $v \approx 11.5$ m/s. 14.1 m/s = $\sqrt{(\mu gr)}$ ignores the tangential acceleration.

Q14. Answer (4). Vertical: $T \cos 60° = mg$, so $T = 2mg$. Horizontal: $T \sin 60° = m\omega^2(L \sin 60°)$, so $\omega^2 = T/(mL) = 2g/L = 20$ and $\omega = 2\sqrt{5}$ rad/s ≈ 4.47 rad/s.

Q15. Answer (1). Mass striking per second = $\rho Av = 1000 \times 2 \times 10^{-4} \times 10 = 2$ kg/s. Brought to rest, the momentum destroyed per second is $2 \times 10 = 20$ N. Rebounding at the same speed, the change is $2 \times 20 = 40$ N.

Q16. Answer (2). If B goes down by y, both vertical segments lengthen by y, so A moves 2y: $a_A = 2a_B$. The tension T is the same throughout: on A, $T = m\,a_A = 2m\,a_B$; on B, $mg - 2T = m\,a_B$. So $mg = 5m\,a_B$: $a_B = g/5$ and $a_A = 2g/5$.

Q17. Answer (2). Let the person move at v and the trolley at −V (ground frame): $v + V = 3$ and $60v = 120V$. So $v = 2V$, $3V = 3$, $V = 1$ m/s (and the person moves at 2 m/s). 1.5 m/s wrongly takes 3 m/s as the person's speed relative to the ground.

Q18. Answer (3). It strikes at $\sqrt{(2 \times 10 \times 5)} = 10$ m/s and leaves at $\sqrt{(2 \times 10 \times 1.8)} = 6$ m/s upward, a change of momentum $0.2 \times 16 = 3.2$ N s. During the contact the net impulse is $(N - mg)\Delta t = 3.2$, so $N = 3.2/0.02 + 2 = 162$ N. Leaving out the weight gives 160 N.

Q19. Answer (3). The string must give the bob both the acceleration $g/\sqrt{3}$ and support its weight: $T \sin\theta = mg/\sqrt{3}$ and $T \cos\theta = mg$. So $\tan\theta = 1/\sqrt{3}$, $\theta = 30°$, and $T = m\sqrt{(g^2 + g^2/3)} = 2mg/\sqrt{3}$. The bob leans backward, opposite to the acceleration.

Q20. Answer (1). $mg \sin 37° = 60$ N and the limiting friction is $0.25 \times 80 = 20$ N. Least F (block about to slide down, friction up the slope): $F = 60 - 20 = 40$ N. Greatest F (about to move up, friction down the slope): $F = 60 + 20 = 80$ N.

Q21. Answer 14. At the least speed friction acts up the slope at its limiting value: $v^2 = rg(\tan\theta - \mu)/(1 + \mu \tan\theta) = 2000 \times 0.1/1.02 \approx 196.1$, so $v \approx 14.0$ m/s. (The ideal speed is $\sqrt{(rg \tan\theta)} = 20$ m/s.)

Q22. Answer 8. Limiting friction is $0.3 \times 20 = 6$ N, so the block stays at rest until $F = 2t = 6$ N, at $t = 3$ s. After that, friction is 6 N and $a = (2t - 6)/2 = t - 3$. $v(7) = \int_3^7 (t - 3)\,dt = 8$ m/s. (Taking the impulse of F from t = 0, 49 N s, without friction gives 24.5 m/s.)

Q23. Answer 17. $a = 3g/5 = 6$ m/s² and $T = 2 \times 6 = 12$ N. The pulley is pulled by T horizontally and by T vertically downward, a resultant of $T\sqrt{2} = 12\sqrt{2} \approx 17.0$ N at 45°.

Q24. Answer 79. $\omega = 2\pi \times 2 = 4\pi$ rad/s. $T = m\omega^2 r = 0.5 \times 16\pi^2 \times 1 = 8\pi^2 \approx 79.0$ N.

Q25. Answer 1267. The third piece (3 kg) has momentum $-(30\,\hat{\imath} + 40\,\hat{\jmath})$ kg m/s, of magnitude 50 kg m/s, so its speed is 50/3 m/s. Kinetic energy = ½ × 1 × 900 + ½ × 2 × 400 + ½ × 3 × (50/3)² = 450 + 400 + 416.7 ≈ 1266.7 J, i.e. 1267.

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