



Work, Energy and Power — JEE (Main) Pattern Sample 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 $g = 10 \text{ m/s}^2$ 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: Work by a variable force · Work–energy theorem · Work by friction · Potential energy of a spring · Conservative and non-conservative forces · Potential energy and equilibrium · Conservation of mechanical energy · Motion in a vertical circle · Power · Collisions

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

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

1. A force $F = (xy \hat{i} + y^2 \hat{j})$ N acts on a particle (x and y in m). It moves the particle from the origin to the point (1 m, 1 m) once along the straight line $y = x$ and once along the parabola $y = x^2$. By how much does the work done by F along the straight line exceed the work done along the parabola?

- (1) Zero, since the end points are the same
- (2) $1/12$ J
- (3) $1/6$ J
- (4) $7/12$ J

2. A particle of mass m starts from the origin and moves along the x -axis so that its speed at position x is $v = \alpha\sqrt{x}$, where α is a positive constant. The work done by the net force on the particle in the first t seconds of its motion is

- (1) $m\alpha^4 t^2/4$
- (2) $m\alpha^2 t^2/8$
- (3) $m\alpha^4 t^2/8$
- (4) $m\alpha^4 t^2/2$

3. A 2 kg block rests at $x = 0$ on a rough horizontal floor (coefficients of static and kinetic friction both 0.2). A horizontal force $F = (12 - 2x)$ N, with x in m, is applied along the $+x$ axis. The maximum speed of the block and the position where it comes to rest are, respectively ($g = 10 \text{ m/s}^2$)

- (1) 4 m/s and $x = 8$ m
- (2) 6 m/s and $x = 12$ m
- (3) 4 m/s and $x = 6$ m
- (4) $2\sqrt{2}$ m/s and $x = 8$ m

4. A 5 kg block lies on a smooth horizontal floor. A light string tied to it passes over a small smooth pulley fixed 3 m above the floor, and its other end is pulled with a constant force of 25 N. The block starts from rest at a horizontal distance of 4 m from the point on the floor directly below the pulley. Its speed when it reaches that point is

- (1) $2\sqrt{10}$ m/s
- (2) $4\sqrt{2}$ m/s
- (3) $\sqrt{10}$ m/s
- (4) $2\sqrt{5}$ m/s

5. A small block of mass m is pulled very slowly up a rough hill, from its foot to its top, by a force that is always tangential to the surface. The top is at a height h above the foot and at a horizontal distance L from it, and the coefficient of friction is μ everywhere. The surface curves smoothly but its slope never changes sign. The work done by the pulling force is

- (1) mgh
- (2) $mg(h + \mu L)$
- (3) $mg(h + \mu\sqrt{h^2 + L^2})$
- (4) $mg(h + \mu h)$

6. Two light springs of force constants 200 N/m and 300 N/m are joined end to end. One free end is fixed and the other is pulled until the combination stretches by 5 cm in total. The total elastic energy stored and the ratio (energy in the 200 N/m spring) : (energy in the 300 N/m spring) are

- (1) 0.15 J and 3 : 2
- (2) 0.15 J and 2 : 3
- (3) 0.625 J and 3 : 2
- (4) 0.625 J and 2 : 3

7. A block A of mass 1 kg is attached to the upper end of a vertical light spring of force constant 300 N/m, whose lower end is fixed to a block B of mass 2 kg resting on the floor. A is in equilibrium. It is pushed vertically down and released. The minimum distance by which A must be pushed down from its equilibrium position so that B just leaves the floor is ($g = 10 \text{ m/s}^2$)

- (1) 3.3 cm
- (2) 6.7 cm
- (3) 10 cm
- (4) 13.3 cm

8. Block A (2 kg) on a rough horizontal table (coefficient of kinetic friction 0.5) is tied by a light string, passing over a smooth pulley at the edge, to block B (2 kg) hanging vertically. The system is released from rest. When B has descended 1 m, the string breaks. The speed of A when the string breaks, and the further distance A slides on the table, are ($g = 10 \text{ m/s}^2$)

- (1) $\sqrt{10} \text{ m/s}$ and 1 m
- (2) $\sqrt{5} \text{ m/s}$ and 0.5 m
- (3) $\sqrt{5} \text{ m/s}$ and 1 m
- (4) $\sqrt{10} \text{ m/s}$ and 0.5 m

9. A particle of mass m moves on a circle of radius R . It starts from rest and its speed increases with a constant tangential acceleration a_t . The power delivered by the net force on the particle at the instant its total acceleration makes 45° with its velocity is

- (1) $\sqrt{2} m a_t \sqrt{a_t R}$
- (2) $m a_t \sqrt{2 a_t R}$
- (3) $m a_t \sqrt{a_t R}$
- (4) $2m a_t \sqrt{a_t R}$

10. A car of mass m moves on a level road with its engine delivering a constant power P . The air resistance on it is bv^2 , where v is its speed and b is a constant; other resistances are negligible. The distance it covers while its speed rises from (nearly) zero to half its terminal speed is

- (1) $(m/3b) \ln (8/7)$
- (2) $(m/b) \ln (8/7)$
- (3) $(m/3b) \ln 2$
- (4) $(m/2b) \ln (4/3)$

11. A particle of mass m moves along the x -axis ($x > 0$) in the potential energy $U(x) = a/x^2 - b/x$, where a and b are positive constants. The period of its small oscillations about the equilibrium position is

- (1) $2\pi \sqrt{ma^3} / b^2$
- (2) $4\pi \sqrt{2ma^3} / b^2$
- (3) $4\pi \sqrt{ma^3} / b^2$
- (4) $2\pi \sqrt{2ma^3} / b^2$

12. A particle of mass 1 kg moves along the x -axis in the potential energy $U(x) = 3x^2 - x^3$ (U in J, x in m). Match List-I with List-II.

List-I: (A) Position (in m) of stable equilibrium; (B) Position (in m) of unstable equilibrium; (C) Least kinetic energy (in J) the particle must have at the stable equilibrium position to escape to $x \rightarrow +\infty$; (D) Angular frequency (in rad/s) of small oscillations about the stable equilibrium position.

List-II: (I) $\sqrt{6}$; (II) 0; (III) 4; (IV) 2.

Choose the correct answer from the options given below:

- (1) (A)–(II), (B)–(IV), (C)–(III), (D)–(I)
- (2) (A)–(IV), (B)–(II), (C)–(III), (D)–(I)
- (3) (A)–(II), (B)–(IV), (C)–(I), (D)–(III)
- (4) (A)–(II), (B)–(III), (C)–(IV), (D)–(I)

13. A small bob hangs at rest from a light inextensible string of length L . It is given a horizontal speed $\sqrt{4gL}$. The string becomes slack at some point, after which the bob moves freely. The greatest height reached by the bob, measured above its initial (lowest) position, is

- (1) $5L/3$
- (2) $2L$
- (3) $50L/27$
- (4) $3L/2$

14. A uniform chain of mass M and length L lies straight on a rough horizontal table, perpendicular to its edge (coefficient of static and of kinetic friction $1/3$). The greatest possible length of it hangs over the edge with the chain at rest. It is then given a negligibly small push. Neglecting the edge's curvature and friction at the edge, the speed of the chain as its last link leaves the table is

- (1) $\sqrt{15gL/16}$
- (2) $\sqrt{3gL/8}$
- (3) $\sqrt{gL/2}$
- (4) $\sqrt{3gL/4}$

15. A particle moves along a circle of radius R . Its kinetic energy depends on the distance s covered along the circle as $K = cs^2$, where c is a constant. The magnitude of the net force on the particle, as a function of s , is

- (1) $2cs$
- (2) $2cs \sqrt{1 + s^2/R^2}$
- (3) $2cs^2/R$
- (4) $2cs (1 + s/R)$

16. A bullet of mass 50 g moving horizontally at 200 m/s gets embedded in a block of mass 950 g at rest on a smooth horizontal floor. The block is attached to a light horizontal spring of force constant 400 N/m whose other end is fixed to a wall. The maximum compression of the spring and the percentage of the bullet's initial kinetic energy converted into heat and other forms are

- (1) 0.5 m and 5%
- (2) $\sqrt{5}$ m and 0%
- (3) 0.5 m and 95%
- (4) 0.25 m and 95%

17. A ball of mass m moving at speed u collides head-on and elastically with a ball of mass $3m$ at rest, which then collides head-on and elastically with a ball of mass $9m$ at rest. The fraction of the first ball's initial kinetic energy that is finally carried by the ball of mass $9m$ is

- (1) $\frac{3}{4}$
- (2) $\frac{9}{25}$
- (3) $\frac{9}{16}$
- (4) 1

18. A ball strikes a smooth horizontal floor with its velocity making 30° with the vertical. The coefficient of restitution between the ball and the floor is $\frac{1}{3}$. The angle its velocity makes with the vertical just after the bounce, and the fraction of its kinetic energy lost in the impact, are

- (1) 30° and $\frac{8}{9}$
- (2) 60° and $\frac{8}{9}$
- (3) 60° and $\frac{2}{3}$
- (4) 45° and $\frac{2}{3}$

19. Given below are two statements.

Statement I: When two bodies collide elastically, the total kinetic energy of the two bodies is the same at every instant during the collision.

Statement II: When a body of mass m_1 collides head-on and sticks to a body of mass m_2 at rest, the fraction of the initial kinetic energy lost is $\frac{m_2}{(m_1 + m_2)}$.

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

20. Consider the following statements.

- (A) The work done by a conservative force on a particle moving round any closed path is zero.
- (B) When two bodies slide over each other, the total work done by the pair of kinetic friction forces between them is always negative.
- (C) The work done by a static friction force on a body is always zero.
- (D) If the net work done on a particle between two instants is zero, its speed must have stayed constant between them.
- (E) The elastic potential energy of a spring is least at its natural length.

Choose the correct answer from the options given below:

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

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. Blocks A (2 kg) and B (3 kg) rest on a smooth horizontal floor, joined by a light spring of force constant 100 N/m at its natural length. A constant horizontal force of 10 N is applied to B, directed away from A. The maximum extension of the spring (in cm) in the motion that follows is _____.

Answer: _____

22. A car of mass 1500 kg has an engine of constant power 80 kW. The total resistance to its motion is proportional to its speed, and its maximum speed on a level road is 40 m/s. With the same power, its maximum speed (in m/s) up an incline that rises 1 m for every 5 m along the road is _____. ($g = 10 \text{ m/s}^2$)

Answer: _____

23. A block of mass 2 kg is on a rough incline of inclination 37° ($\sin 37^\circ = 3/5$), with coefficients of static and kinetic friction both 0.5. It is attached to a light spring of force constant 20 N/m parallel to the incline, whose upper end is fixed. The block is released from rest with the spring at its natural length. The maximum extension of the spring (in cm) is _____. ($g = 10 \text{ m/s}^2$)

Answer: _____

24. A uniform rope of mass 4 kg and length 2 m lies in a heap on the floor. One end is lifted vertically upward at a constant speed of 1 m/s. The work done (in J) by the lifting force from the start until the rope just leaves the floor is _____. ($g = 10 \text{ m/s}^2$; the size of the heap is negligible.)

Answer: _____

25. A simple pendulum of length 1.5 m is held with its string taut and horizontal and released from rest. A thin nail is fixed vertically below the point of suspension at a distance d from it. When the string meets the nail, the bob begins to move in a circle about the nail. The minimum value of d (in cm) for which the bob completes the circle about the nail is _____.

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

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

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

Q21	Q22	Q23	Q24	Q25
8	20	40	44	90

WORKED SOLUTIONS

Q1. Answer (2). $W = \int (xy \, dx + y^2 \, dy)$. Along $y = x$: $\int_0^1 (x^2 + x^2) \, dx = 2/3 \, \text{J}$. Along $y = x^2$ ($dy = 2x \, dx$): $\int_0^1 (x^3 + 2x^5) \, dx = 1/4 + 1/3 = 7/12 \, \text{J}$. The difference is $2/3 - 7/12 = 1/12 \, \text{J}$. The force is not conservative ($\partial F_x / \partial y = x$ but $\partial F_y / \partial x = 0$), so the work depends on the path; 'zero' assumes it is conservative.

Q2. Answer (3). $dx/dt = \alpha\sqrt{x}$ gives $2\sqrt{x} = \alpha t$, so $x = \alpha^2 t^2 / 4$ and $v = \alpha^2 t / 2$ (the acceleration is the constant $\alpha^2 / 2$). By the work–energy theorem, $W = \frac{1}{2}mv^2 - 0 = \frac{1}{2}m(\alpha^2 t^2 / 2)^2 = m\alpha^4 t^2 / 8$. $m\alpha^4 t^2 / 4$ forgets the $\frac{1}{2}$ in the kinetic energy.

Q3. Answer (1). Kinetic friction is $0.2 \times 20 = 4 \, \text{N}$, so the net force is $(8 - 2x) \, \text{N}$. The speed is greatest where the net force is zero, at $x = 4 \, \text{m}$: $W = \int_0^4 (8 - 2x) \, dx = 16 \, \text{J} = \frac{1}{2} \times 2 \times v^2$, so $v = 4 \, \text{m/s}$. It stops where $\int_0^x (8 - 2x) \, dx = 8x - x^2 = 0$, i.e. $x = 8 \, \text{m}$. There $F = -4 \, \text{N}$, which static friction (up to $4 \, \text{N}$) can just balance, so it stays at rest. Ignoring friction gives $6 \, \text{m/s}$ and $x = 12 \, \text{m}$.

Q4. Answer (4). The tension is constant and the pulled end moves by the change in the length of string between pulley and block, from $\sqrt{4^2 + 3^2} = 5 \, \text{m}$ to $3 \, \text{m}$. So the work done on the block $= 25 \times (5 - 3) = 50 \, \text{J} = \frac{1}{2} \times 5 \times v^2$, and $v = 2\sqrt{5} \, \text{m/s}$. (The vertical pull never exceeds $25 \, \text{N} < mg$, so the block stays on the floor.) $25 \times 4 = 100 \, \text{J}$ treats the string as horizontal throughout; $25 \times 0.8 \times 4 = 80 \, \text{J}$ freezes the initial angle.

Q5. Answer (2). Moving slowly, the block has no acceleration, so the pull is $mg \sin \phi + \mu mg \cos \phi$, where ϕ is the local slope (the normal force is $mg \cos \phi$). Over a length ds of the path, $\sin \phi \, ds = dy$ and $\cos \phi \, ds = dx$. So $W = mg \int dy + \mu mg \int dx = mg(h + \mu L)$, whatever the shape of the hill. $\mu\sqrt{(h^2 + L^2)}$ wrongly uses the path length for the friction.

Q6. Answer (1). In series, $k = 200 \times 300 / 500 = 120 \, \text{N/m}$, so $U = \frac{1}{2} \times 120 \times 0.05^2 = 0.15 \, \text{J}$. Both springs carry the same force F , and each stores $F^2 / 2k$, so the energies are in the inverse ratio of the force constants: $300 : 200 = 3 : 2$ (the softer spring stores more). $0.625 \, \text{J}$ is for the springs in parallel.

Q7. Answer (3). At equilibrium the spring is compressed by $m_A g / k = 1/30 \, \text{m}$. B just leaves the floor when the spring is stretched by $m_B g / k = 2/30 \, \text{m}$, i.e. when A is $3/30 \, \text{m} = 10 \, \text{cm}$ above equilibrium. A moves symmetrically about its equilibrium position (spring and gravity together act like one spring about that point), so it must be pushed down by $(m_A + m_B)g / k = 10 \, \text{cm}$. $6.7 \, \text{cm}$ is only $m_B g / k$; $13.3 \, \text{cm}$ is the compression measured from the natural length.

Q8. Answer (2). Motion starts because $m_B g = 20 \, \text{N}$ exceeds the maximum friction on A, $10 \, \text{N}$. For the system over $1 \, \text{m}$: work by gravity on B $= 20 \, \text{J}$, work by friction on A $= -10 \, \text{J}$ (the tension's work cancels). So $10 \, \text{J} = \frac{1}{2}(2 + 2)v^2$, $v = \sqrt{5} \, \text{m/s}$. After the break, A decelerates at $\mu g = 5 \, \text{m/s}^2$ and slides $v^2 / (2\mu g) = 5/10 = 0.5 \, \text{m}$. Leaving out friction gives $\sqrt{10} \, \text{m/s}$.

Q9. Answer (3). The angle is 45° when the centripetal acceleration v^2 / R equals a_t , i.e. $v = \sqrt{a_t R}$. Only the tangential component of the force does work: $P = (m a_t) v = m a_t \sqrt{a_t R}$. The centripetal part is perpendicular to the velocity; multiplying the full force $\sqrt{2} m a_t$ by v gives the first option.

Q10. Answer (1). The terminal speed satisfies $P/v_T = b v_T^2$, so $P = b v_T^3$. With $a = v dv/dx$: $m v dv/dx = P/v - bv^2$, so $dx = m v^2 dv/(P - bv^3)$. Integrating, $x = (m/3b) \ln[P/(P - bv^3)]$. At $v = v_T/2$, $bv^3 = P/8$, so $x = (m/3b) \ln(8/7)$. The answer does not depend on P .

Q11. Answer (2). $U'(x) = -2a/x^3 + b/x^2 = 0$ at $x_0 = 2a/b$. $U''(x) = 6a/x^4 - 2b/x^3$; at x_0 this is $6ab^4/16a^4 - 2b^4/8a^3 = b^4/8a^3 > 0$, so x_0 is stable with effective force constant $k = U''(x_0)$. $T = 2\pi\sqrt{(m/k)} = 2\pi\sqrt{(8ma^3)/b^2} = 4\pi\sqrt{(2ma^3)/b^2}$.

Q12. Answer (1). $U' = 6x - 3x^2 = 0$ at $x = 0$ and $x = 2$. $U'' = 6 - 6x$: $+6$ at $x = 0$ (stable), -6 at $x = 2$ (unstable). To escape to $+\infty$ the particle must pass over the barrier $U(2) - U(0) = 12 - 8 = 4$ J (beyond $x = 2$, U falls without limit). $\omega = \sqrt{U''(0)/m} = \sqrt{6}$ rad/s. So (A)–(II), (B)–(IV), (C)–(III), (D)–(I).

Q13. Answer (3). Let the string make angle θ above the horizontal. Energy: $v^2 = 4gL - 2gL(1 + \sin \theta)$. Radially, $T + mg \sin \theta = mv^2/L$, so $T = 0$ when $v^2 = gL \sin \theta$: $2gL - 2gL \sin \theta = gL \sin \theta$ gives $\sin \theta = 2/3$, at height $L(1 + 2/3) = 5L/3$, with $v^2 = 2gL/3$. The velocity is perpendicular to the string, so its vertical component is $v \cos \theta$, with $\cos^2 \theta = 5/9$. The bob rises a further $v^2 \cos^2 \theta / 2g = (2gL/3)(5/9)/(2g) = 5L/27$. Greatest height = $5L/3 + 5L/27 = 50L/27$. $5L/3$ stops at the slack point; $2L$ assumes it completes the circle.

Q14. Answer (4). Limiting equilibrium: $(y/L)Mg = \mu(L - y)Mg/L$ gives $y_0 = \mu L/(1 + \mu) = L/4$. As the hanging length goes from $L/4$ to L : work by gravity = $(M/L)g(L^2 - y_0^2)/2 = 15MgL/32$; work by friction = $-\mu(M/L)g\int(L - y)dy = -\mu Mg(L - y_0)^2/2L = -(1/3)Mg(9L/16)/2 = -3MgL/32$. So $\frac{1}{2}Mv^2 = 12MgL/32$ and $v = \sqrt{(3gL/4)}$. $\sqrt{(15gL/16)}$ leaves out friction.

Q15. Answer (2). Tangential force = $dK/ds = 2cs$ (work–energy theorem along the path). Centripetal force = $mv^2/R = 2K/R = 2cs^2/R$. These are perpendicular, so $F = \sqrt{[(2cs)^2 + (2cs^2/R)^2]} = 2cs\sqrt{(1 + s^2/R^2)}$. $2cs$ is only the tangential part.

Q16. Answer (3). Momentum (the collision is too quick for the spring to act): $0.05 \times 200 = 1.0 \times v$, $v = 10$ m/s. Kinetic energy before = $\frac{1}{2} \times 0.05 \times 200^2 = 1000$ J; after = $\frac{1}{2} \times 1 \times 10^2 = 50$ J, so 950 J (95%) is lost — the fraction $M/(m + M)$ for a perfectly inelastic collision with a body at rest. The 50 J goes into the spring: $\frac{1}{2} \times 400 \times x^2 = 50$, $x = 0.5$ m. $\sqrt{5}$ m conserves kinetic energy in the collision.

Q17. Answer (3). In a head-on elastic collision with a body at rest, the fraction of kinetic energy transferred is $4m_1m_2/(m_1 + m_2)^2$. $m \rightarrow 3m$: $4 \times 3/16 = 3/4$. $3m \rightarrow 9m$: $4 \times 27/144 = 3/4$. So $9m$ carries $(3/4)^2 = 9/16$. (This is more than the $9/25$ that m would give $9m$ directly — an intermediate mass equal to the geometric mean improves the transfer.) There are no further collisions: after the first, m moves back at $u/2$ and $3m$ moves on at $u/2$; after the second, $3m$ moves back at $u/4$ (slower than m) while $9m$ moves on at $u/4$.

Q18. Answer (3). The smooth floor does not change the horizontal component, $u \sin 30^\circ = u/2$; the vertical component becomes $e \times u \cos 30^\circ = (1/3)(\sqrt{3}u/2) = u/(2\sqrt{3})$. $\tan \theta' = (u/2)/(u/(2\sqrt{3})) = \sqrt{3}$, so $\theta' = 60^\circ$. Kinetic energy lost = $\frac{1}{2}m(u \cos 30^\circ)^2(1 - e^2) = \frac{1}{2}mu^2 \times (3/4)(8/9) = \frac{1}{2}mu^2 \times 2/3$. $8/9$ applies $(1 - e^2)$ to the whole kinetic energy.

Q19. Answer (4). Statement I is false: during the contact the bodies deform, and part of the kinetic energy is stored as elastic potential energy; it is all returned only by the end of an elastic collision (at the moment of greatest compression both move with the centre-of-mass velocity and the kinetic energy is least). Statement II is true: the final speed is $m_1u/(m_1 + m_2)$, so $K_{\text{final}}/K_{\text{initial}} = m_1/(m_1 + m_2)$ and the fraction lost is $m_2/(m_1 + m_2)$.

Q20. Answer (3). (A) true — that is the definition of a conservative force. (B) true: the pair does total work $-f \times$ (relative displacement), which is negative whenever they slide. (C) false: static friction does positive work on a box carried by an accelerating truck (it does no total work as a pair, since there is no relative slipping). (D) false: zero net work only means equal speeds at the two instants (e.g. a ball thrown up and caught at the same height). (E) true: $U = \frac{1}{2}kx^2 \geq 0$, zero at $x = 0$.

Q21. Answer 8. Relative to the centre of mass (acceleration $F/5 = 2$ m/s²), A feels a pseudo-force and the extension x obeys $\mu \ddot{x} = -kx + F m_A/(m_A + m_B)$, with $\mu = m_A m_B/(m_A + m_B)$. So the extension oscillates about $x_0 = F m_A/[k(m_A + m_B)] = 10 \times 2/(100 \times 5) = 0.04$ m, starting from $x = 0$ at zero relative speed. The maximum extension is $2x_0 = 0.08$ m = 8 cm. (Taking the whole force as stretching the spring, $2F/k$, gives 20 cm.)

Q22. Answer 20. On the level, $P = cv^2$ with $v = 40$ m/s, so $c = 80000/1600 = 50$ N s/m. Up the incline the component of gravity along it is $mg/5 = 3000$ N. At maximum speed the driving force P/v balances $50v + 3000$: $80000 = 50v^2 + 3000v$, i.e.

$v^2 + 60v - 1600 = 0$, $v = 20$ m/s (the other root is negative). Taking the resistance as a constant 2000 N gives 16 m/s, which is not the condition given.

Q23. Answer 40. Along the incline: gravity component $mg \sin 37^\circ = 12$ N, kinetic friction $\mu mg \cos 37^\circ = 0.5 \times 16 = 8$ N up the slope while the block slides down. Work–energy from release to the lowest point (zero speed): $12x - 8x - \frac{1}{2}(20)x^2 = 0$, so $x = 2 \times 4/20 = 0.4$ m = 40 cm. There the spring pulls up with 8 N and gravity pulls down with 12 N; static friction of 4 N (less than its maximum 8 N) holds the block, so it stays at 40 cm. Without friction it would be 120 cm.

Q24. Answer 44. With $\lambda = 2$ kg/m and y metres in the air, the force must support the lifted weight λgy and supply the momentum of the rope being set in motion each second, $(\lambda v)v$: $F = \lambda gy + \lambda v^2$. $W = \int_0^2 F \, dy = \lambda g \times 2^2/2 + \lambda v^2 \times 2 = 40 + 4 = 44$ J. Of this, 40 J is potential energy, $\frac{1}{2} \times 4 \times 1^2 = 2$ J is the rope's kinetic energy, and 2 J is lost in the jerks as each piece is suddenly set moving. ($Mg \times L/2$ alone gives 40.)

Q25. Answer 90. At the lowest point $v^2 = 2gL$. About the nail the radius is $r = L - d$, and completing that circle needs $v^2 \geq 5gr$ at its lowest point: $2gL \geq 5g(L - d)$, so $d \geq 3L/5 = 0.9$ m = 90 cm. (The string meets the nail with the bob at its lowest point, so the speed there is unchanged.)

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