A Level Mechanics
Practice Test 4: Work, Energy, and Power

Instructions:
Answer all questions. Show your working clearly.
Calculators may be used unless stated otherwise.
Draw diagrams where appropriate to illustrate your solutions.
Time allowed: 3 hours

Section A: Work and Energy Fundamentals [28 marks]

Question 1 [**9 marks**]

(a) Define work done by a force and explain the significance of the angle between force and displacement. [**3 marks**]

(b) State and explain the conditions for: (i) maximum work done, (ii) minimum work done, (iii) zero work done. [**3 marks**]

(c) Distinguish between the concepts of work and energy, explaining their relationship. [**3 marks**]

Question 2 [**11 marks**] Four forces act simultaneously on an object: $\vec{F_1} = (15\hat{i} - 8\hat{j})$ N, $\vec{F_2} = (-6\hat{i} + 18\hat{j})$ N, $\vec{F_3} = (12\hat{i} + 5\hat{j})$ N, and $\vec{F_4} = (-9\hat{i} - 12\hat{j})$ N. The object moves from $(1, 3)$ m to $(8, -2)$ m.

(a) Calculate the net force acting on the object. [**2 marks**]

(b) Determine the displacement vector. [**1 mark**]

(c) Calculate the work done by each force individually. [**4 marks**]

(d) Find the total work done using individual forces. [**2 marks**]

(e) Verify your result using the net force method. [**2 marks**]

Question 3 [**8 marks**] A 9 kg object initially moving at 4 m/s has a force of 54 N applied to it at 45° to its direction of motion for 3.5 seconds.

(a) Calculate the component of force in the direction of motion and find the acceleration. [**3 marks**]

(b) Determine the distance traveled and work done by the force. [**3 marks**]

(c) Find the final kinetic energy and verify the work-energy theorem. [**2 marks**]

Section B: Work Done by Constant Forces [25 marks]

Question 4 [**13 marks**] A wooden crate of mass 35 kg is pulled 30 m up a rough ramp inclined at 18° to the horizontal. The pulling force is 220 N acting parallel to the ramp surface. The coefficient of kinetic friction is 0.20.

(a) Draw a detailed force diagram for the crate. [**2 marks**]

(b) Calculate the normal force and friction force. [**3 marks**]

(c) Find the work done by: (i) the pulling force, (ii) gravity, (iii) friction. [**4 marks**]

(d) Determine the net work done on the crate. [**2 marks**]

(e) Calculate the final speed if the crate starts from rest. [**2 marks**]

Question 5 [**12 marks**] An aircraft of mass 75,000 kg accelerates down a runway from rest to 85 m/s over a distance of 1200 m. The aircraft experiences air resistance and rolling friction totaling 18,000 N.

(a) Calculate the change in kinetic energy of the aircraft. [**3 marks**]

(b) Find the work done against resistance forces. [**2 marks**]

(c) Determine the work done by the engine thrust. [**2 marks**]

(d) Calculate the average engine thrust force. [**2 marks**]

(e) If the aircraft then decelerates to 60 m/s over 800 m using only air brakes (resistance = 35,000 N), verify this is possible. [**3 marks**]

Section C: Variable Force and Work-Energy Theorem [31 marks]

Question 6 [**17 marks**] A particle of mass 2.8 kg moves along the x-axis under a variable force $F = 20x - 3x^3$ N, where x is in metres.

(a) Calculate the work done as the particle moves from $x = 0$ to $x = 3$ m. [**4 marks**]

(b) Find the work done as the particle moves from $x = 1.5$ m to $x = 2.5$ m. [**4 marks**]

(c) If the particle has speed 3 m/s at $x = 0.5$ m, calculate its speed at $x = 2$ m. [**3 marks**]

(d) Find all positions where the force equals zero. [**3 marks**]

(e) Determine where the force reaches its maximum value in the interval $[0, 3]$. [**3 marks**]

Question 7 [**14 marks**]

(a) State and derive the work-energy theorem for a system with multiple forces. [**4 marks**]

(b) A stone of mass 1.5 kg is projected at 38° above horizontal with initial speed 28 m/s. Find the speed when it reaches 18 m above the launch point. [**4 marks**]

(c) A 25 kg block slides down a rough inclined plane (angle 40°) for 12 m. With friction coefficient 0.28, calculate the final speed from rest. [**4 marks**]

(d) A 12 kg object experiences force $F(t) = 45\cos(2t)$ N for π seconds starting from rest. Find the final kinetic energy. [**2 marks**]

Section D: Gravitational Potential Energy [26 marks]

Question 8 [**8 marks**]

(a) Define gravitational potential energy and explain why gravity is classified as a conservative force. [**3 marks**]

(b) Prove that gravitational work depends only on vertical displacement, not the path. [**3 marks**]

(c) Explain how the choice of reference level affects potential energy calculations. [**2 marks**]

Question 8 [**18 marks**] A projectile of mass 3.2 kg is launched from the top of a 25 m building with initial velocity 32 m/s at 48° above horizontal.

(a) Calculate the initial kinetic and potential energies (ground level reference). [**3 marks**]

(b) Find the total mechanical energy. [**1 mark**]

(c) Use energy conservation to determine the maximum height above ground. [**4 marks**]

(d) Calculate the speed when the projectile is 35 m above ground. [**3 marks**]

(e) Find the speed just before impact with the ground. [**3 marks**]

(f) At what height above ground does kinetic energy equal 1.5 times potential energy? [**2 marks**]

(g) Determine the velocity components at the highest point of trajectory. [**2 marks**]

Section E: Elastic Potential Energy [24 marks]

Question 10 [**14 marks**] A spring system has spring constant $k = 1500$ N/m and is compressed 0.30 m from equilibrium.

(a) Calculate the elastic potential energy stored. [**2 marks**]

(b) A 2.5 kg mass is attached and released. Find the maximum speed achieved. [**3 marks**]

(c) At what compression does the mass have speed 5 m/s? [**3 marks**]

(d) Calculate the acceleration when compression is 0.22 m. [**2 marks**]

(e) Find where kinetic energy is three times the potential energy. [**2 marks**]

(f) Determine the force exerted by the spring at maximum compression. [**2 marks**]

Question 11 [**10 marks**] A 5 kg block hangs from a vertical spring with spring constant 1000 N/m. The block is displaced 0.35 m below equilibrium and released.

(a) Calculate the equilibrium extension when the block hangs freely. [**2 marks**]

(b) Find the total mechanical energy of the system. [**2 marks**]

(c) Determine the maximum speed during oscillation. [**2 marks**]

(d) Calculate the speed when the block is 0.25 m below equilibrium. [**2 marks**]

(e) Find the maximum height reached above the release point. [**2 marks**]

Section F: Conservation of Mechanical Energy [29 marks]

Question 12 [**17 marks**] A pendulum bob of mass 1.8 kg is suspended by a 3 m string and released from rest at 48° from vertical.

(a) Calculate the initial height above the lowest point. [**3 marks**]

(b) Find the speed at the bottom using energy conservation. [**3 marks**]

(c) Calculate the tension in the string at the lowest point. [**3 marks**]

(d) Determine the speed when the string makes 25° with vertical. [**3 marks**]

(e) Find the minimum release angle for completing a full vertical circle. [**3 marks**]

(f) Calculate the tension at the top of the circle for this critical case. [**2 marks**]

Question 13 [**12 marks**] A 1200 kg roller coaster car begins from rest at 42 m height and travels along a track with energy losses due to friction.

(a) Calculate the speed at ground level assuming no friction. [**2 marks**]

(b) The car climbs to 28 m height. Find the speed there with no friction. [**3 marks**]

(c) If friction dissipates 45,000 J total energy, find the actual speed at 28 m. [**3 marks**]

(d) For a vertical loop of radius 7 m at ground level, determine the minimum starting height with this friction. [**4 marks**]

Section G: Power Calculations [26 marks]

Question 14 [**10 marks**]

(a) Define average and instantaneous power, explaining their applications. [**3 marks**]

(b) Derive the power equation $P = \vec{F} \cdot \vec{v}$ from first principles. [**4 marks**]

(c) Explain the importance of power considerations in mechanical design. [**3 marks**]

Question 15 [**16 marks**] A tower crane lifts construction materials under various operating conditions.

(a) Calculate the power needed to lift 2000 kg at constant speed 2.2 m/s. [**2 marks**]

(b) With motor efficiency 82%, find the electrical power input required. [**2 marks**]

(c) The crane accelerates 1800 kg upward at 1.1 m/s^2 from rest. Calculate the required motor force. [**3 marks**]

(d) Find the power output after 6 seconds of this acceleration. [**3 marks**]

(e) Calculate the total work done during the first 10 seconds of acceleration. [**3 marks**]

(f) If the crane operates at constant speed for 20 seconds after acceleration, find total energy consumed. [**3 marks**]

Section H: Power in Vehicle Motion [22 marks]

Question 16 [**14 marks**] A racing motorcycle engine produces constant power 150 kW. The bike has mass 320 kg and experiences air resistance $F_r = 350 + 2.2v^2$ N, where v is speed in m/s.

(a) Find the maximum speed by balancing engine force and resistance. [**3 marks**]

(b) Calculate the acceleration when traveling at 30 m/s. [**4 marks**]

(c) Determine the speed when acceleration is 1.8 m/s². [**3 marks**]

(d) Estimate the time to accelerate from 25 m/s to 40 m/s. [**4 marks**]

Question 17 [**8 marks**] A heavy truck (mass 18,000 kg) operates with constant power 180 kW.

(a) On level road with 1200 N resistance, find maximum speed. [**2 marks**]

(b) When climbing a 4° gradient at steady speed, calculate the new maximum speed. [**3 marks**]

(c) What power is needed to maintain 12 m/s up this gradient? [**3 marks**]

Section I: Energy in Collisions and Springs [24 marks]

Question 18 [**14 marks**] A 6 kg object moving at 14 m/s collides elastically with a 9 kg object initially at rest.

(a) Apply conservation laws to find both final velocities. [**5 marks**]

(b) Calculate kinetic energies before and after collision to verify conservation. [**3 marks**]

(c) Find the velocity change for each object. [**2 marks**]

(d) Calculate the impulse magnitude for each object during collision. [**2 marks**]

(e) Determine the kinetic energy transferred between objects. [**2 marks**]

Question 19 [**10 marks**] A 0.30 kg ball moving horizontally at 20 m/s strikes a wall and rebounds at 16 m/s.

(a) Calculate the momentum change and impulse magnitude. [**3 marks**]

(b) Find kinetic energies before and after collision. [**2 marks**]

(c) Determine energy lost and coefficient of restitution. [**3 marks**]

(d) With contact time 0.015 seconds, find the average impact force. [**2 marks**]

Section J: Comprehensive Applications [30 marks]

Question 20 [**18 marks**] An 8 kg block slides down a frictionless track from height 7 m, then encounters a spring (k = 3000 N/m) on a horizontal surface with friction coefficient 0.16.

(a) Calculate the speed just before contacting the spring. [**2 marks**]

(b) For a frictionless surface, find the maximum compression. [**3 marks**]

(c) With friction present, write the energy conservation equation for maximum compression. [**3 marks**]

(d) Calculate the actual maximum compression including friction. [**3 marks**]

(e) Find the speed when the block leaves the spring on return. [**3 marks**]

(f) Determine the height reached on the return journey up the track. **[2 marks]**

(g) Calculate the total mechanical energy lost to friction. **[2 marks]**

Question 21 [12 marks] A tidal power station harnesses energy from water flowing through turbines. At peak flow, 200 m^3/s of water passes through with a 15 m head difference.

(a) Calculate the gravitational potential energy converted per second. **[3 marks]**

(b) With turbine efficiency 89%, find the electrical power generated. **[2 marks]**

(c) If the station needs to supply 250 MW to the grid, what flow rate is required? **[3 marks]**

(d) During low tide, head reduces to 8 m. What flow rate maintains the same power output? **[2 marks]**

(e) Discuss the advantages of tidal power compared to other renewable sources. **[2 marks]**

Physics Data and Formulae

Work and Energy:

Work done: $W = \vec{F} \cdot \vec{s} = Fs\cos\theta$

Variable force: $W = \int_{s_1}^{s_2} F(s)\,ds$

Kinetic energy: $KE = \frac{1}{2}mv^2$

Gravitational potential energy: $PE_g = mgh$

Elastic potential energy: $PE_e = \frac{1}{2}kx^2$

Work-Energy Theorem:

$W_{net} = \Delta KE = KE_f - KE_i$

Conservation of Energy:

$E_{total} = KE + PE = \text{constant}$ (conservative forces)

$KE_i + PE_i = KE_f + PE_f + \text{energy dissipated}$

Power:

$P = \frac{W}{t}$ (average), $P = \frac{dW}{dt}$ (instantaneous)

$P = \vec{F} \cdot \vec{v} = Fv\cos\theta$

Efficiency: $\eta = \frac{P_{useful}}{P_{input}} \times 100\%$

Springs and Harmonic Motion:

Hooke's Law: $F = -kx$

Equilibrium position: $x_0 = \frac{mg}{k}$ (vertical spring)

Maximum speed: $v_{max} = A\sqrt{\frac{k}{m}}$ (amplitude A)

Circular Motion:

At bottom of loop: $T - mg = \frac{mv^2}{r}$

At top of loop: $mg + T = \frac{mv^2}{r}$

Minimum speed at top: $v_{min} = \sqrt{gr}$

Collisions:

Coefficient of restitution: $e = \frac{v_2 - v_1}{u_1 - u_2}$

Elastic: $e = 1$, Perfectly inelastic: $e = 0$

Impulse: $J = \Delta p = F_{avg}\Delta t$

Constants:

Acceleration due to gravity: $g = 9.8$ m/s^2
Density of water: $\rho = 1000$ kg/m^3

Trigonometric Values:

$\sin 4 = 0.070$, $\cos 4 = 0.998$, $\tan 4 = 0.070$
$\sin 18 = 0.309$, $\cos 18 = 0.951$, $\tan 18 = 0.325$
$\sin 25 = 0.423$, $\cos 25 = 0.906$, $\tan 25 = 0.466$
$\sin 38 = 0.616$, $\cos 38 = 0.788$, $\tan 38 = 0.781$
$\sin 40 = 0.643$, $\cos 40 = 0.766$, $\tan 40 = 0.839$
$\sin 45 = 0.707$, $\cos 45 = 0.707$, $\tan 45 = 1.000$
$\sin 48 = 0.743$, $\cos 48 = 0.669$, $\tan 48 = 1.111$

END OF TEST

Total marks: 285

Grade boundaries: A* 257, A 228, B 200, C 171, D 143, E 114

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