A Level Mechanics
Practice Test 3: 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 [27 marks]

Question 1 [**8 marks**]

(a) Define work done by a force and state when work is: (i) maximum, (ii) zero, (iii) negative. [**4 marks**]

(b) Explain why work is classified as a scalar quantity despite being calculated from two vector quantities. [**2 marks**]

(c) State the relationship between work and energy, giving the fundamental principle. [**2 marks**]

Question 2 [**12 marks**] Three forces act on an object: $\vec{F_1} = (8\hat{i} + 6\hat{j})$ N, $\vec{F_2} = (-4\hat{i} + 12\hat{j})$ N, and $\vec{F_3} = (10\hat{i} - 8\hat{j})$ N. The object moves from position $(2, 1)$ m to $(7, 5)$ m.

(a) Calculate the resultant force. [**2 marks**]

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

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

(d) Find the total work done by all forces. [**2 marks**]

(e) Verify your answer using the resultant force method. [**3 marks**]

Question 3 [**7 marks**] A 6 kg object initially at rest has a constant force of 36 N applied to it for 4 seconds at an angle of 30° to its direction of motion.

(a) Calculate the acceleration of the object. [**2 marks**]

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

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

Section B: Work Done by Constant Forces [26 marks]

Question 4 [**14 marks**] A package of mass 18 kg is dragged 25 m across a rough horizontal floor by a rope inclined at 28° to the horizontal. The tension in the rope is 85 N and the coefficient of kinetic friction between the package and floor is 0.15.

(a) Draw a complete force diagram for the package. [**2 marks**]

(b) Calculate the normal force between the package and floor. [**3 marks**]

(c) Find the friction force acting on the package. [**2 marks**]

(d) Calculate the work done by: (i) the tension force, (ii) friction, (iii) gravity. [**4 marks**]

(e) Determine the net work done and the final speed of the package. [**3 marks**]

Question 5 [**12 marks**] A train of mass 150,000 kg accelerates from 15 m/s to 45 m/s over a distance of 800 m while traveling up a 2° incline. The train experiences a total resistance force of 12,000 N.

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

(b) Find the work done against gravity. [**3 marks**]

(c) Calculate the work done against resistance forces. [**2 marks**]

(d) Determine the total work done by the engine. [**2 marks**]

(e) Find the average engine force during this acceleration. [**2 marks**]

Section C: Variable Force and Work-Energy Theorem [29 marks]

Question 6 [**15 marks**] A particle of mass 3 kg moves along the x-axis under a variable force $F = 15 - 4x + x^2$ N, where x is measured in metres.

(a) Calculate the work done as the particle moves from $x = 1$ m to $x = 4$ m. [**4 marks**]

(b) Find the work done as the particle moves from $x = 2$ m to $x = 5$ m. [**4 marks**]

(c) If the particle has speed 2 m/s at $x = 1$ m, find its speed at $x = 3$ m. [**3 marks**]

(d) Determine where the force is zero and classify these points. [**2 marks**]

(e) Find the position where the force is minimum in the interval $[0, 6]$. [**2 marks**]

Question 7 [**14 marks**]

(a) Prove the work-energy theorem starting from Newton's second law for variable force. [**4 marks**]

(b) A ball of mass 1.2 kg is thrown at 50° above horizontal with initial speed 22 m/s. Calculate the speed when it is 12 m above the launch point. [**4 marks**]

(c) A 20 kg crate slides down a rough ramp (angle 30°) for 10 m. With coefficient of friction 0.22, find the final speed from rest. [**4 marks**]

(d) An object of mass 8 kg experiences a time-varying force $F(t) = 30 - 5t$ N for 5 seconds. Starting from rest, calculate the final kinetic energy. [**2 marks**]

Section D: Gravitational Potential Energy [25 marks]

Question 8 [**7 marks**]

(a) Define a conservative force and explain why gravitational force is conservative. [**3 marks**]

(b) Show mathematically that the work done by gravity depends only on the change in height. [**2 marks**]

(c) Explain the significance of choosing different reference levels for potential energy. [**2 marks**]

Question 9 [**18 marks**] A golf ball of mass 0.05 kg is hit from ground level with initial velocity 35 m/s at 42° to the horizontal.

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

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

(c) Use energy conservation to determine the maximum height reached. [**3 marks**]

(d) Calculate the speed when the ball is at 2/3 of maximum height. [**4 marks**]

(e) Find the speed when the ball returns to ground level. [**2 marks**]

(f) At what height above ground is the potential energy twice the kinetic energy? [**3 marks**]

(g) Determine the horizontal and vertical components of velocity at maximum height. [**2 marks**]

Section E: Elastic Potential Energy [23 marks]

Question 10 [**13 marks**] A spring with spring constant $k = 1200$ N/m is compressed by 0.25 m from its equilibrium position.

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

(b) A mass of 2 kg is attached to the spring and released. Find the maximum speed. [**3 marks**]

(c) At what displacement from equilibrium is the speed 4 m/s? [**3 marks**]

(d) Calculate the acceleration when the compression is 0.18 m. [**2 marks**]

(e) Find the displacement where kinetic energy is maximum. [**1 mark**]

(f) Determine the ratio of kinetic to potential energy when displacement is 0.1 m. [**2 marks**]

Question 11 [**10 marks**] A 4 kg mass hangs from a vertical spring with spring constant 800 N/m. The mass is pulled down 0.4 m from its equilibrium position and released.

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

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

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

(d) Calculate the speed when the mass is 0.2 m below equilibrium. [**2 marks**]

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

Section F: Conservation of Mechanical Energy [27 marks]

Question 12 [**15 marks**] A pendulum consists of a 2 kg bob attached to a 2.5 m string. It is released from rest when the string makes 55° with the vertical.

(a) Calculate the initial height of the bob above its lowest position. [**2 marks**]

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

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

(d) Determine the speed when the string makes 30° with the vertical. [**3 marks**]

(e) Find the minimum release angle for the bob to just reach the top of a complete circle. [**2 marks**]

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

Question 13 [**12 marks**] A 1000 kg roller coaster car starts from rest at height 35 m and travels on a track with varying friction.

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

(b) The car then climbs to 20 m height. Calculate the speed at this point with no friction. [**3 marks**]

(c) If friction causes 30,000 J energy loss over the entire journey, find the actual speed at 20 m height. [**3 marks**]

(d) For a circular loop of radius 6 m at the bottom, find the minimum starting height needed to complete the loop with this friction. [**4 marks**]

Section G: Power Calculations [24 marks]

Question 14 [**9 marks**]

(a) Define power and derive the relationship between power, force, and velocity. [**4 marks**]

(b) Explain the difference between mechanical power and electrical power in motors. [**3 marks**]

(c) Why is efficiency important in power transmission systems? [**2 marks**]

Question 15 [**15 marks**] A construction crane lifts materials with varying loads and speeds.

(a) Calculate the power needed to lift 1500 kg at constant speed 1.8 m/s. [**2 marks**]

(b) If the motor has 78% efficiency, find the electrical power input. [**2 marks**]

(c) The crane accelerates a 1200 kg load upward at 0.8 m/s² from rest. Find the motor force. [**3 marks**]

(d) Calculate the power output after 5 seconds of this acceleration. [**3 marks**]

(e) Determine the total work done during the first 8 seconds of acceleration. [**3 marks**]

(f) If the crane then operates at constant speed for 15 seconds, calculate the total energy consumed. [**2 marks**]

Section H: Power in Vehicle Motion [21 marks]

Question 16 [**13 marks**] A sports car engine delivers constant power of 120 kW. The car has mass 1600 kg and faces air resistance $F_r = 400 + 1.5v^2$ N, where v is speed in m/s.

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

(b) Calculate the acceleration when the car travels at 25 m/s. [**4 marks**]

(c) Determine the speed when acceleration equals 0.5 m/s². [**3 marks**]

(d) Estimate the time required to accelerate from 20 m/s to 35 m/s. [**3 marks**]

Question 17 [**8 marks**] A delivery truck (mass 3500 kg including load) maintains constant power of 85 kW.

(a) On level road with 800 N resistance, find the maximum speed. [**2 marks**]

(b) When climbing a 6° gradient at steady speed, calculate the new maximum speed. [**3 marks**]

(c) What power would be required to maintain 15 m/s up this gradient? [**3 marks**]

Section I: Energy in Collisions and Springs [23 marks]

Question 18 [**13 marks**] A 5 kg object moving at 12 m/s collides elastically with a 7 kg object initially at rest.

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

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

(c) Find the change in kinetic energy of each object. [**2 marks**]

(d) Calculate the impulse experienced by each object. [**3 marks**]

Question 19 [**10 marks**] A 0.25 kg ball moving at 18 m/s hits a wall perpendicularly and rebounds at 14 m/s.

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

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

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

(d) If contact time is 0.012 seconds, calculate the average impact force. [**2 marks**]

Section J: Comprehensive Applications [30 marks]

Question 20 [**18 marks**] A 7 kg block slides down a frictionless track from height 6 m, then compresses a spring (k = 2200 N/m) on a horizontal surface with friction coefficient 0.18.

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

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

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

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

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

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

(g) Calculate the total energy dissipated by friction. **[2 marks]**

Question 21 [12 marks] A wind farm generates electricity using turbines in a steady 12 m/s wind. Each turbine has blade diameter 80 m and converts 35% of the wind's kinetic energy to electrical energy.

(a) Calculate the mass of air passing through one turbine per second (air density = 1.2 kg/m^3). **[3 marks]**

(b) Find the kinetic energy in this air mass per second. **[2 marks]**

(c) Calculate the electrical power output from one turbine. **[2 marks]**

(d) If the wind farm has 50 turbines, find the total power output. **[1 mark]**

(e) How many households can this supply if each uses 4 kW average power? **[2 marks]**

(f) Compare the environmental impact with equivalent fossil fuel generation. **[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:

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

$KE_i + PE_i = KE_f + PE_f +$ work done against friction

Power:

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

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

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

Springs and Oscillations:

Hooke's Law: $F = -kx$

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

Total energy: $E = \frac{1}{2}kA^2$ (amplitude A)

Collisions:

Coefficient of restitution: $e = \frac{\text{relative speed of separation}}{\text{relative speed of approach}}$

Elastic collision: $e = 1$, KE conserved

Perfectly inelastic: $e = 0$, objects stick together

Constants:

Acceleration due to gravity: $g = 9.8$ m/s^2

Air density (standard): $\rho_{air} = 1.2$ kg/m^3

Trigonometric Values:

$\sin 2 = 0.035$, $\cos 2 = 0.999$, $\tan 2 = 0.035$

$\sin 6 = 0.105$, $\cos 6 = 0.995$, $\tan 6 = 0.105$
$\sin 28 = 0.469$, $\cos 28 = 0.883$, $\tan 28 = 0.532$
$\sin 30 = 0.500$, $\cos 30 = 0.866$, $\tan 30 = 0.577$
$\sin 42 = 0.669$, $\cos 42 = 0.743$, $\tan 42 = 0.900$
$\sin 50 = 0.766$, $\cos 50 = 0.643$, $\tan 50 = 1.192$
$\sin 55 = 0.819$, $\cos 55 = 0.574$, $\tan 55 = 1.428$

END OF TEST

Total marks: 275

Grade boundaries: A* 248, A 220, B 193, C 165, D 138, E 110

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