A Level Mechanics
Practice Test 1: 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 [26 marks]

Question 1 [**8 marks**] Define the following terms and state their SI units:

(a) Work done by a force [**2 marks**]

(b) Kinetic energy [**2 marks**]

(c) Potential energy [**2 marks**]

(d) Power [**2 marks**]

Question 2 [**12 marks**] Explain the concept of work done by a force:

(a) State the formula for work done when a constant force acts through a displacement. [**2 marks**]

(b) Explain why work is a scalar quantity even though force and displacement are vectors. [**3 marks**]

(c) Under what conditions is no work done by a force? Give two examples. [**3 marks**]

(d) Explain the difference between positive and negative work with examples. [**2 marks**]

(e) How is work calculated when the force varies with displacement? [**2 marks**]

Question 3 [**6 marks**] A force of 75 N acts on an object at an angle of 35° to the horizontal. The object moves 12 m horizontally.

(a) Calculate the work done by the force. [**2 marks**]

(b) If the object has mass 8 kg and was initially at rest, find its final speed. [**2 marks**]

(c) What work is done against gravity if the object moves horizontally? Explain. [**2 marks**]

Section B: Work Done by Constant Forces [28 marks]

Question 4 [**16 marks**] A crate of mass 25 kg is pulled 18 m across a horizontal surface by a rope that makes an angle of 20° with the horizontal. The tension in the rope is 95 N, and there is a friction force of 55 N opposing the motion.

(a) Calculate the work done by the tension force. [**3 marks**]

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

(c) Determine the work done by the normal contact forces. **[3 marks]**

(d) Calculate the net work done on the crate. **[3 marks]**

(e) If the crate starts from rest, find its final speed using the work-energy theorem. **[3 marks]**

(f) Verify your answer by calculating the net force and using kinematics. **[2 marks]**

Question 5 [12 marks] A vehicle of mass 1400 kg accelerates from rest to 30 m/s over a distance of 250 m on a horizontal road. The vehicle experiences a constant resistance force of 750 N.

(a) Calculate the change in kinetic energy of the vehicle. **[2 marks]**

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

(c) Determine the work done by the driving force. **[2 marks]**

(d) Calculate the magnitude of the driving force. **[2 marks]**

(e) If the vehicle then brakes to a stop over 100 m, find the average braking force. **[4 marks]**

Section C: Variable Force and Work-Energy Theorem [32 marks]

Question 6 [14 marks] A particle moves along the x-axis under the action of a variable force $F = 8x - 3x^2$ N, where x is measured in metres.

(a) Calculate the work done by this force as the particle moves from $x = 0$ to $x = 2$ m. **[3 marks]**

(b) Find the work done as the particle moves from $x = 1$ m to $x = 3$ m. **[3 marks]**

(c) If the particle has mass 1.5 kg and starts from rest at $x = 0$, find its speed when $x = 1.5$ m. **[3 marks]**

(d) Determine the position where the force is zero. **[2 marks]**

(e) At what position is the force maximum? **[3 marks]**

Question 7 [18 marks] The work-energy theorem states that the net work done on an object equals its change in kinetic energy.

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

(b) A ball of mass 0.6 kg is thrown vertically upward with initial speed 18 m/s. Use the work-energy theorem to find the maximum height reached. **[3 marks]**

(c) The same ball is thrown at 40° to the horizontal with the same initial speed. Find the speed when it returns to the same level. **[3 marks]**

(d) A 12 kg block slides down a rough inclined plane (angle 35°) for a distance of 6 m. If the coefficient of kinetic friction is 0.25, find the final speed starting from rest. **[5 marks]**

(e) Verify your answer in part (d) using Newton's laws and kinematics. **[3 marks]**

Section D: Gravitational Potential Energy [24 marks]

Question 8 [**10 marks**] Explain gravitational potential energy:

(a) Define gravitational potential energy and state the formula. [**3 marks**]

(b) Explain why we can choose any reference level for potential energy. [**2 marks**]

(c) What is meant by saying that gravitational force is conservative? [**3 marks**]

(d) Show that the work done by gravity depends only on the vertical displacement, not the path taken. [**2 marks**]

Question 9 [**14 marks**] A stone of mass 1.8 kg is thrown from the top of a 45 m tall building with an initial velocity of 20 m/s at 35° above the horizontal.

(a) Taking ground level as the reference, calculate the initial potential energy. [**2 marks**]

(b) Find the initial kinetic energy. [**2 marks**]

(c) Calculate the total mechanical energy. [**2 marks**]

(d) Use conservation of energy to find the speed just before the stone hits the ground. [**3 marks**]

(e) Find the speed of the stone when it is 25 m above the ground. [**3 marks**]

(f) At what height above the ground is the kinetic energy equal to the potential energy? [**2 marks**]

Section E: Elastic Potential Energy [22 marks]

Question 10 [**12 marks**] A spring with spring constant $k = 500$ N/m is compressed by 0.18 m from its natural length.

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

(b) If a mass of 1.2 kg is attached to the spring and released, find the maximum speed achieved. [**3 marks**]

(c) At what compression will the speed of the mass be 2.5 m/s? [**3 marks**]

(d) What is the acceleration of the mass when the compression is 0.12 m? [**2 marks**]

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

Question 11 [**10 marks**] A 2.5 kg block is attached to a horizontal spring and can slide on a frictionless surface. The spring constant is 300 N/m. The block is pulled 0.25 m from equilibrium and released.

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

(b) Calculate the maximum speed of the block. [**2 marks**]

(c) Determine the speed when the displacement is 0.15 m from equilibrium. [**3 marks**]

(d) Find the acceleration when the displacement is 0.20 m from equilibrium. [**3 marks**]

Section F: Conservation of Mechanical Energy [30 marks]

Question 12 [**16 marks**] A pendulum consists of a 0.8 kg mass attached to a 1.5 m string. The mass is released from rest when the string makes an angle of 50° with the vertical.

(a) Calculate the initial potential energy (taking the lowest point as reference). [**3 marks**]

(b) Find the speed of the mass at the lowest point of its swing. [**3 marks**]

(c) Determine the speed when the string makes an angle of 25° with the vertical. [**3 marks**]

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

(e) Find the minimum initial angle required for the pendulum to complete a full circle. [**4 marks**]

Question 13 [**14 marks**] A roller coaster car of mass 600 kg starts from rest at the top of a hill 30 m high. It then goes through a valley and up another hill 18 m high.

(a) Assuming no friction, find the speed at the bottom of the valley. [**2 marks**]

(b) Calculate the speed at the top of the second hill. [**3 marks**]

(c) If there is actually friction causing a total energy loss of 25,000 J, find the actual speed at the top of the second hill. [**3 marks**]

(d) What average friction force acted on the car if the total track length is 200 m? [**3 marks**]

(e) For the car to just reach the top of the second hill, what initial height would be needed with this friction? [**3 marks**]

Section G: Power Calculations [26 marks]

Question 14 [**10 marks**] Define power and explain its relationship to work and energy:

(a) State the basic definition of power and its SI unit. [**2 marks**]

(b) Derive the relationship $P = F \cdot v$ for constant force and velocity. [**3 marks**]

(c) Explain the difference between average power and instantaneous power. [**3 marks**]

(d) Why is power important in practical applications? Give two examples. [**2 marks**]

Question 15 [**16 marks**] A crane lifts a load of mass 900 kg vertically upward at constant speed.

(a) If the crane lifts the load 15 m in 25 seconds, calculate the average power output. [**3 marks**]

(b) Find the instantaneous power when the lifting speed is 0.8 m/s. [**2 marks**]

(c) If the crane's motor has an efficiency of 80%, what electrical power input is required for part (b)? [**3 marks**]

(d) The load is then accelerated upward at 1.2 m/s^2 from rest. Find the power required after 4 seconds. [**4 marks**]

(e) Calculate the work done by the crane during the first 6 seconds of acceleration. [**4 marks**]

Section H: Power in Vehicle Motion [18 marks]

Question 16 [**10 marks**] A car engine develops a constant power of 75 kW. The car has mass 1800 kg and experiences a constant resistance force of 950 N.

(a) Find the maximum speed the car can achieve on level ground. [**2 marks**]

(b) Calculate the initial acceleration when starting from rest. [**3 marks**]

(c) Determine the speed when the acceleration is 2.0 m/s^2. [**3 marks**]

(d) How long does it take to accelerate from 15 m/s to 25 m/s? [**2 marks**]

Question 17 [**8 marks**] A cyclist with total mass 85 kg pedals at constant power 300 W on level ground against a resistance force of 25 N.

(a) Calculate the steady speed achieved. [**2 marks**]

(b) If the cyclist then goes up a 8° incline at steady speed, find the new steady speed. [**3 marks**]

(c) What power would be needed to maintain 10 m/s up the incline? [**3 marks**]

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

Question 18 [**14 marks**] A 3 kg block moving at 8 m/s collides with a stationary 4 kg block. After collision, they stick together.

(a) Find the velocity after collision using conservation of momentum. [**3 marks**]

(b) Calculate the kinetic energy before collision. [**2 marks**]

(c) Find the kinetic energy after collision. [**2 marks**]

(d) Calculate the energy lost in the collision. [**2 marks**]

(e) If the collision lasted 0.015 seconds, find the average force between the blocks. [**3 marks**]

(f) What percentage of the initial kinetic energy is lost? [**2 marks**]

Question 19 [**10 marks**] A 0.15 kg ball moving at 12 m/s strikes a wall perpendicularly and rebounds with speed 9 m/s.

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

(b) Find the energy lost in the collision. [**2 marks**]

(c) If the contact time is 0.008 seconds, calculate the average force on the ball. [**3 marks**]

(d) What fraction of the initial kinetic energy is retained? [**2 marks**]

Section J: Comprehensive Applications [30 marks]

Question 20 [**18 marks**] A 6 kg block starts from rest and slides down a curved frictionless track. At the bottom, it compresses a spring with spring constant 2500 N/m. The vertical drop is 4 m.

(a) Find the speed of the block just before hitting the spring. [**2 marks**]

(b) Calculate the maximum compression of the spring. [**3 marks**]

(c) Determine the speed of the block when the spring is compressed by 0.15 m. [**3 marks**]

(d) If there is friction with coefficient 0.15 on the horizontal section only (length 2.5 m), find the maximum compression. **[4 marks]**

(e) Calculate the speed of the block when it returns to the point where it first contacted the spring in part (d). **[3 marks]**

(f) How high up the track will the block rise on the return journey? **[3 marks]**

Question 21 [12 marks] A pumped storage power station works by pumping water uphill during low demand and releasing it through turbines during peak demand. Water is pumped from a lower reservoir to an upper reservoir 180 m higher.

(a) Calculate the potential energy gained per cubic metre of water pumped. **[2 marks]**

(b) If the pumping rate is 60 m^3/s and the pump efficiency is 88%, find the electrical power input required. **[3 marks]**

(c) During generation, water flows down at 45 m^3/s through turbines with 92% efficiency. Calculate the electrical power output. **[3 marks]**

(d) If the upper reservoir holds 1.5 million cubic metres, how long can it generate at full power? **[2 marks]**

(e) Calculate the overall efficiency of the storage system (energy out/energy in). **[2 marks]**

Physics Data and Formulae

Work and Energy:

Work done: $W = F \cdot d\cos\theta$ (constant force)

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

Gravitational potential energy: $PE = mgh$

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

Work-Energy Theorem:

$W_{net} = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

Conservation of Energy:

$KE + PE = \text{constant}$ (no friction)

$KE_i + PE_i = KE_f + PE_f + \text{energy lost to friction}$

Power:

$P = \frac{W}{t}$ (average power)

$P = F \cdot v$ (instantaneous power)

$P = \frac{dW}{dt}$ (instantaneous power)

Springs and Simple Harmonic Motion:

Hooke's Law: $F = -kx$

$a = -\frac{k}{m}x$ (acceleration in SHM)

Constants:

Acceleration due to gravity: $g = 9.8\ \text{m/s}^2$

Density of water: $\rho = 1000\ \text{kg/m}^3$

Trigonometric Values:

$\sin 20 = 0.342$, $\cos 20 = 0.940$, $\tan 20 = 0.364$

$\sin 25 = 0.423$, $\cos 25 = 0.906$, $\tan 25 = 0.466$

$\sin 35 = 0.574$, $\cos 35 = 0.819$, $\tan 35 = 0.700$
$\sin 40 = 0.643$, $\cos 40 = 0.766$, $\tan 40 = 0.839$
$\sin 50 = 0.766$, $\cos 50 = 0.643$, $\tan 50 = 1.192$
$\sin 8 = 0.139$, $\cos 8 = 0.990$, $\tan 8 = 0.141$

END OF TEST

Total marks: 270

Grade boundaries: A* 243, A 216, B 189, C 162, D 135, E 108

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