A Level Mechanics
Practice Test 2: Momentum and Impulse

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: 2 hours 20 minutes

Section A: Advanced Momentum Concepts [25 marks]

Question 1 [**15 marks**] A system consists of three particles with masses 3 kg, 5 kg, and 7 kg moving with velocities 6 m/s, -4 m/s, and 8 m/s respectively along the same straight line.

(a) Calculate the total momentum of the system. [**3 marks**]

(b) Find the velocity of the center of mass. [**3 marks**]

(c) If an external force acts on the system for 3 seconds, changing the total momentum to 120 kgm/s, calculate the average external force. [**4 marks**]

(d) After the force is removed, the 3 kg particle collides elastically with a wall and reverses direction. Find the new total momentum of the system. [**5 marks**]

Question 2 [**10 marks**] Two balls of masses 0.8 kg and 1.2 kg are connected by a light inextensible string and move together at 5 m/s. The string suddenly breaks.

(a) If the 0.8 kg ball moves at 7 m/s in the original direction after the string breaks, find the velocity of the 1.2 kg ball. [**4 marks**]

(b) Calculate the kinetic energy before and after the string breaks. [**4 marks**]

(c) Explain the source of the additional kinetic energy. [**2 marks**]

Section B: Complex Collision Analysis [30 marks]

Question 3 [**18 marks**] A ball of mass 2 kg moving at 12 m/s collides with a ball of mass 3 kg moving at 8 m/s in the same direction. After collision, the first ball moves at 6 m/s in the original direction.

(a) Find the velocity of the second ball after collision. [**4 marks**]

(b) Calculate the coefficient of restitution for this collision. [**4 marks**]

(c) Determine the kinetic energy lost in the collision. [**5 marks**]

(d) If the collision time was 0.02 seconds, calculate the average force between the balls. [**5 marks**]

Question 4 [12 marks] A trolley of mass 8 kg moves at 4 m/s and collides with a stationary trolley of mass 12 kg. The coefficient of restitution is 0.6.

(a) Calculate the velocities of both trolleys after collision. **[6 marks]**

(b) Find the percentage of kinetic energy lost in the collision. **[4 marks]**

(c) Verify your answer using the coefficient of restitution. **[2 marks]**

Section C: Variable Force and Impulse [25 marks]

Question 5 [15 marks] A force varies with time according to $F = 15t - 3t^2$ N, where t is in seconds. This force acts on a particle of mass 2.5 kg initially at rest.

(a) Calculate the impulse delivered during the first 3 seconds. **[4 marks]**

(b) Find the velocity of the particle after 3 seconds. **[3 marks]**

(c) Determine when the force becomes zero. **[2 marks]**

(d) Calculate the maximum impulse delivered and the velocity at this point. **[6 marks]**

Question 6 [10 marks] A cricket ball of mass 0.16 kg is hit by a bat. The force on the ball varies as shown in the graph: starts at 0, increases linearly to 800 N at t = 0.003 s, then decreases linearly to 0 at t = 0.006 s.

(a) Calculate the impulse delivered to the ball. **[4 marks]**

(b) If the ball was initially moving at 25 m/s toward the bat, find its velocity after being hit. **[3 marks]**

(c) Calculate the maximum force if the impulse is the same but contact time is halved. **[3 marks]**

Section D: Multi-Stage Collisions [20 marks]

Question 7 [20 marks] Three railway wagons are involved in a series of collisions. Wagon A (mass 15,000 kg) moves at 6 m/s and collides with stationary wagon B (mass 20,000 kg). After this collision, both wagons move together and collide with stationary wagon C (mass 25,000 kg).

(a) Calculate the velocity after the first collision (perfectly inelastic). **[4 marks]**

(b) Find the kinetic energy lost in the first collision. **[4 marks]**

(c) If the second collision is also perfectly inelastic, calculate the final velocity of all three wagons. **[4 marks]**

(d) Calculate the total kinetic energy lost in both collisions. **[4 marks]**

(e) Find the percentage of the original kinetic energy that remains. **[4 marks]**

Section E: Two-Dimensional Momentum [25 marks]

Question 8 [15 marks] A snooker ball moving at 8 m/s strikes an identical stationary ball. After collision, the first ball moves at 4 m/s at 30° to its original direction.

(a) Using conservation of momentum, find the velocity of the second ball after collision. **[6 marks]**

(b) Calculate the kinetic energy before and after collision. **[4 marks]**

(c) Determine whether the collision is elastic. **[3 marks]**

(d) Calculate the coefficient of restitution for this collision. **[2 marks]**

Question 10 [10 marks] Two objects collide in two dimensions. Object A (mass 4 kg) moves at 6 m/s east, and object B (mass 6 kg) moves at 4 m/s north. After a perfectly inelastic collision:

(a) Find the velocity of the combined objects after collision. **[5 marks]**

(b) Calculate the energy lost in the collision. **[3 marks]**

(c) Determine the impulse experienced by each object. **[2 marks]**

Section F: Explosions and Recoil [20 marks]

Question 9 [12 marks] A firework of mass 0.8 kg explodes while at rest, breaking into three pieces. Piece A (mass 0.3 kg) flies off at 25 m/s north, piece B (mass 0.2 kg) flies off at 30 m/s east.

(a) Find the velocity of piece C using conservation of momentum. **[5 marks]**

(b) Calculate the total kinetic energy of the three pieces after explosion. **[4 marks]**

(c) If the explosion lasted 0.0008 seconds, estimate the average force on piece A. **[3 marks]**

Question 11 [8 marks] A cannon of mass 800 kg fires a cannonball of mass 12 kg horizontally with velocity 150 m/s.

(a) Calculate the recoil velocity of the cannon. **[3 marks]**

(b) Find the ratio of kinetic energies of cannonball to cannon. **[3 marks]**

(c) Explain why the kinetic energies are different despite equal magnitude momenta. **[2 marks]**

Section G: Advanced Applications [25 marks]

Question 12 [15 marks] A rocket of initial mass 5000 kg (including fuel) burns fuel at a rate of 40 kg/s, ejecting it at 1800 m/s relative to the rocket.

(a) Calculate the thrust force produced by the rocket engine. **[3 marks]**

(b) Find the initial acceleration of the rocket (neglecting gravity). **[3 marks]**

(c) Calculate the acceleration after 25 seconds of burn time. **[4 marks]**

(d) If the rocket starts from rest, find its velocity after 25 seconds (neglecting gravity and using average acceleration). **[5 marks]**

Question 13 [10 marks] A pendulum bob of mass 2 kg hangs from a string 1.5 m long. A bullet of mass 0.01 kg moving horizontally at 400 m/s embeds in the bob.

(a) Find the velocity of the bob immediately after the bullet embeds. **[3 marks]**

(b) Calculate the maximum angle the pendulum makes with the vertical. **[4 marks]**

(c) Determine the percentage of the bullet's kinetic energy converted to other forms. **[3 marks]**

Physics Data and Formulae

Momentum and Impulse:

Momentum: $\vec{p} = m\vec{v}$

Impulse: $\vec{J} = \vec{F}\Delta t = \Delta\vec{p}$

For variable force: $J = \int F\,dt$

Conservation of momentum: $\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$

Center of Mass:

Velocity of center of mass: $v_{cm} = \frac{\sum m_i v_i}{\sum m_i}$

Elastic Collision (1D):

$v_1' = \frac{(m_1 - m_2)v_1 + 2m_2 v_2}{m_1 + m_2}$

$v_2' = \frac{(m_2 - m_1)v_2 + 2m_1 v_1}{m_1 + m_2}$

Perfectly Inelastic Collision:

$v' = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$

Coefficient of Restitution:

$e = \frac{\text{speed of separation}}{\text{speed of approach}}$

$e = \frac{v_2' - v_1'}{v_1 - v_2}$ (for direct collision)

Kinetic Energy:

$E_k = \frac{1}{2}mv^2$

Pendulum Motion:

$mgh = \frac{1}{2}mv^2$ (conservation of energy)

$h = l(1 - \cos\theta)$ (height for pendulum)

Vector Analysis:

Magnitude: $|\vec{v}| = \sqrt{v_x^2 + v_y^2}$

Direction: $\tan\theta = \frac{v_y}{v_x}$

Constants:

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

END OF TEST

Total marks: 170

Grade boundaries: A* 153, A 136, B 119, C 102, D 85, E 68

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