A Level Mechanics
Practice Test 3: 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 25 minutes

Section A: Complex Momentum Systems [30 marks]

Question 1 [20 marks] Four particles are arranged in a system: particle A (mass 2 kg, velocity 8 m/s east), particle B (mass 3 kg, velocity 6 m/s west), particle C (mass 1.5 kg, velocity 10 m/s north), and particle D (mass 2.5 kg, velocity 4 m/s south).

(a) Calculate the total momentum of the system (magnitude and direction). **[6 marks]**

(b) Find the velocity of the center of mass of the system. **[4 marks]**

(c) If all particles suddenly stick together, find their common velocity. **[4 marks]**

(d) Calculate the kinetic energy before and after they stick together. **[4 marks]**

(e) Determine what fraction of the original kinetic energy is lost. **[2 marks]**

Question 2 [10 marks] A space probe of mass 800 kg ejects a fuel pod of mass 200 kg backward at 50 m/s relative to the probe. Initially, both were moving together at 15 m/s.

(a) Calculate the velocity of the probe after ejecting the fuel pod. **[4 marks]**

(b) Find the velocity of the fuel pod relative to a stationary observer. **[3 marks]**

(c) Calculate the change in kinetic energy of the system. **[3 marks]**

Section B: Advanced Collision Dynamics [35 marks]

Question 3 [20 marks] A ball of mass 1.8 kg moving at 15 m/s collides with a ball of mass 2.2 kg moving at 10 m/s in the opposite direction. The coefficient of restitution is 0.75.

(a) Calculate the velocities of both balls after collision. **[8 marks]**

(b) Find the impulse experienced by each ball. **[6 marks]**

(c) Calculate the kinetic energy lost in the collision. **[4 marks]**

(d) Determine the percentage of kinetic energy retained. **[2 marks]**

Question 4 [15 marks] A Newton's cradle consists of five identical balls, each of mass 0.05 kg, suspended by strings. Ball 1 is pulled back and released, striking the stationary balls with velocity 3 m/s.

(a) Assuming elastic collisions, determine what happens after ball 1 strikes the group. **[5 marks]**

(b) Calculate the velocity of ball 5 immediately after the collision sequence. **[3 marks]**

(c) If ball 5 swings to a height of 0.4 m, verify energy conservation. **[4 marks]**

(d) Explain why only ball 5 moves significantly after the collision. **[3 marks]**

Section C: Variable Force Analysis [25 marks]

Question 5 [15 marks] A hammer strikes a nail with a force that varies according to $F = 500t - 2000t^2$ N, where t is in seconds. The hammer has mass 0.8 kg and initial velocity 4 m/s.

(a) Calculate the impulse delivered during the time interval from t = 0 to t = 0.2 s. **[4 marks]**

(b) Find the velocity of the hammer after 0.2 seconds. **[3 marks]**

(c) Determine when the force reaches its maximum value. **[3 marks]**

(d) Calculate the maximum force and the impulse delivered up to this point. **[5 marks]**

Question 6 [10 marks] A tennis ball bounces on the ground with coefficient of restitution 0.85. It hits the ground with velocity 18 m/s downward.

(a) Calculate the velocity immediately after bouncing. **[2 marks]**

(b) If the contact time is 0.005 seconds and the ball has mass 0.057 kg, find the average force during contact. **[4 marks]**

(c) Determine the impulse from the ground on the ball. **[2 marks]**

(d) Calculate the height the ball reaches after bouncing. **[2 marks]**

Section D: Multi-Dimensional Collision Problems [30 marks]

Question 7 [18 marks] A hockey puck of mass 0.16 kg slides across ice at 12 m/s and collides with a stationary puck of mass 0.18 kg. After collision, the first puck moves at 6 m/s at 40° to its original direction.

(a) Find the velocity components of the first puck after collision. **[3 marks]**

(b) Using conservation of momentum, calculate the velocity of the second puck. **[6 marks]**

(c) Determine if this collision is elastic by checking energy conservation. **[5 marks]**

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

Question 8 [12 marks] Two cars collide at an intersection. Car A (mass 1400 kg) traveling north at 20 m/s collides with car B (mass 1600 kg) traveling east at 15 m/s. They stick together after collision.

(a) Calculate the velocity of the combined cars immediately after collision. **[5 marks]**

(b) Find the direction of motion after collision. **[3 marks]**

(c) Calculate the kinetic energy lost in the collision. **[4 marks]**

Section E: Explosion and Fragmentation [20 marks]

Question 9 [**20 marks**] A grenade of mass 2 kg is thrown horizontally at 8 m/s and explodes at the highest point of its trajectory into three fragments. Fragment A (mass 0.6 kg) flies horizontally at 25 m/s in the original direction, fragment B (mass 0.8 kg) flies at 30 m/s at 60° above the horizontal in the original direction.

(a) Calculate the velocity of the grenade just before explosion. [**2 marks**]

(b) Find the momentum of the grenade just before explosion. [**2 marks**]

(c) Calculate the velocity components of fragments A and B. [**4 marks**]

(d) Using conservation of momentum, find the velocity of fragment C. [**6 marks**]

(e) Calculate the total kinetic energy released in the explosion. [**4 marks**]

(f) Determine the impulse experienced by fragment A during explosion. [**2 marks**]

Section F: Advanced Applications [25 marks]

Question 10 [**15 marks**] A spacecraft of mass 2000 kg approaches a space station at 50 m/s. To dock safely, it fires retro-rockets that eject gas at 3000 m/s relative to the spacecraft at a rate of 8 kg/s.

(a) Calculate the thrust force produced by the retro-rockets. [**3 marks**]

(b) Find the initial deceleration of the spacecraft. [**3 marks**]

(c) If the rockets fire for 12 seconds, calculate the final velocity using the rocket equation. [**6 marks**]

(d) Determine the total impulse delivered by the rockets. [**3 marks**]

Question 11 [**10 marks**] A ballistic pendulum consists of a wooden block of mass 5 kg suspended by strings. A bullet of mass 0.025 kg moving horizontally embeds in the block, causing it to swing to a maximum angle of 30° from vertical.

(a) Calculate the velocity of the block immediately after the bullet embeds. [**4 marks**]

(b) Find the initial velocity of the bullet. [**3 marks**]

(c) Calculate the kinetic energy lost when the bullet embeds. [**3 marks**]

Section G: Complex System Analysis [15 marks]

Question 12 [**15 marks**] A chain of mass 12 kg and length 4 m lies on a frictionless table with 1 m hanging over the edge. The chain is released from rest.

(a) When 2 m of chain has fallen off the table, calculate the velocity of the chain using energy methods. [**4 marks**]

(b) Find the momentum of the entire chain at this instant. [**3 marks**]

(c) Calculate the impulse delivered to the chain by gravity from release until 2 m has fallen. [**4 marks**]

(d) Determine the average force exerted by the table on the remaining chain during this time. [**4 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: $v_{cm} = \frac{\sum m_i v_i}{\sum m_i}$

Position of center of mass: $x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

Collision Formulas:

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

Coefficient of Restitution:

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

For direct collision: $e = \frac{v_2' - v_1'}{v_1 - v_2}$

Rocket Equation:

$v = v_0 + v_{rel} \ln\left(\frac{m_0}{m}\right)$

Thrust: $F = \frac{dm}{dt} \times v_{rel}$

Energy Relations:

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

Gravitational potential energy: $E_p = mgh$

Conservation of energy: $E_{initial} = E_{final}$

Pendulum Relations:

For pendulum: $h = l(1 - \cos\theta)$

$v = \sqrt{2gl(1 - \cos\theta)}$

Vector Analysis:

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

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

Components: $v_x = v\cos\theta,\ v_y = v\sin\theta$

Constants:

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

END OF TEST

Total marks: 180

Grade boundaries: A* 162, A 144, B 126, C 108, D 90, E 72

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stepupmaths.co.uk