Enhanced Physics Chapter 4: Laws of Motion

Multiple Choice Questions I

5.1. Uniform Translational Motion

Question: A ball is travelling with uniform translational motion. This means that:

a) it is at rest

b) the path can be a straight line or circular and the ball travels with uniform speed

c) all parts of the ball have the same velocity and the velocity is constant

d) the centre of the ball moves with constant velocity and the ball spins about its centre uniformly

Answer: c) all parts of the ball have the same velocity and the velocity is constant

Explanation: Uniform translational motion means every particle of the object moves with the same constant velocity in the same direction. This excludes rotational motion and ensures all parts move identically.

5.2. Uniform Velocity of Scale

Question: A metre scale is moving with uniform velocity. This implies:

a) the force acting on the scale is zero, but a torque about the centre of mass can act on the scale

b) the force acting on the scale is zero and the torque acting about the centre of mass of the scale is also zero

c) the total force acting on it need not be zero but the torque on it is zero

d) neither the force nor the torque need to be zero

Answer: b) the force acting on the scale is zero and the torque acting about the centre of mass of the scale is also zero

Explanation: By Newton's first law, if an object moves with uniform velocity (constant), both net force and net torque must be zero for translational and rotational equilibrium.

5.3. Cricket Ball Momentum Change

Question: A cricket ball of mass 150 g has an initial velocity $\mathbf{u} = (3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ m/s and a final velocity $\mathbf{v} = -(3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ m/s after being hit. The change in momentum is:

a) zero

b) $-(0.45\hat{\mathbf{i}} + 0.6\hat{\mathbf{j}})$ kg·m/s

c) $-(0.9\hat{\mathbf{i}} + 1.2\hat{\mathbf{j}})$ kg·m/s

d) $-5(\hat{\mathbf{i}} + \hat{\mathbf{j}})$ kg·m/s

Answer: c) $-(0.9\hat{\mathbf{i}} + 1.2\hat{\mathbf{j}})$ kg·m/s

Solution:

- Mass m = 150 g = 0.15 kg
- Initial momentum: $\mathbf{p}_i = m\mathbf{u} = 0.15(3\hat{\mathbf{i}} + 4\hat{\mathbf{j}}) = (0.45\hat{\mathbf{i}} + 0.6\hat{\mathbf{j}})$ kg·m/s
- Final momentum: $\mathbf{p}f = m\mathbf{v} = 0.15(-3\hat{\mathbf{i}} - 4\hat{\mathbf{j}}) = (-0.45\hat{\mathbf{i}} - 0.6\hat{\mathbf{j}})$ kg·m/s
- Change in momentum: $\Delta\mathbf{p} = \mathbf{p}f - \mathbf{p}_i = (-0.45\hat{\mathbf{i}} - 0.6\hat{\mathbf{j}}) - (0.45\hat{\mathbf{i}} + 0.6\hat{\mathbf{j}}) = -(0.9\hat{\mathbf{i}} + 1.2\hat{\mathbf{j}})$ kg·m/s

5.4. Magnitude of Momentum Transfer

Question: In the previous problem, the magnitude of the momentum transferred during the hit is:

a) zero

b) 0.75 kg·m/s

c) 1.5 kg·m/s

d) 14 kg·m/s

Answer: c) 1.5 kg·m/s

Solution: $|\Delta \mathbf{p}| = \sqrt{[(0.9)^2 + (1.2)^2]} = \sqrt{[0.81 + 1.44]} = \sqrt{2.25} = 1.5$ kg·m/s

5.5. Conservation of Momentum

Question: Conservation of momentum in a collision between particles can be understood from:

a) conservation of energy

b) Newton's first law only

c) Newton's second law only

d) both Newton's second and third law

Answer: d) both Newton's second and third law

Explanation: Newton's second law gives F = dp/dt, and Newton's third law ensures internal forces cancel out, leading to conservation of total momentum.

5.6. Hockey Player Force

Question: A hockey player is moving northward and suddenly turns westward with the same speed to avoid an opponent. The force that acts on the player is:

a) frictional force along westward

b) muscle force along southward

c) frictional force along south-west

d) muscle force along south-west

Answer: c) frictional force along south-west

Explanation: The change in velocity is from north to west, so $\Delta \mathbf{v}$ points northwest. By $F = m\Delta \mathbf{v}/\Delta t$, the force points northwest. The friction from ground provides this force, acting southwest on the player.

5.7. Force from Position Function

Question: A body of mass 2 kg travels according to the law $x(t) = pt + qt^2 + rt^3$ where p = 3 m/s, q = 4 m/s², and r = 5 m/s³. The force acting on the body at t = 2 seconds is:

a) 136 N

b) 134 N

c) 158 N

d) 68 N

Answer: a) 136 N

Solution:

- $x(t) = 3t + 4t^2 + 5t^3$

- $v(t) = dx/dt = 3 + 8t + 15t^2$
- $a(t) = dv/dt = 8 + 30t$
- At t = 2s: $a(2) = 8 + 30(2) = 68\ m/s^2$
- $F = ma = 2 \times 68 = 136\ N$

5.8. Velocity Along y-axis

Question: A body with mass 5 kg is acted upon by a force $\mathbf{F} = (-3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ N. If its initial velocity at t = 0 is $\mathbf{v} = (6\hat{\mathbf{i}} - 12\hat{\mathbf{j}})$ m/s, the time at which it will just have a velocity along the y-axis is:

a) never

b) 10 s

c) 2 s

d) 15 s

Answer: b) 10 s

Solution:

- $\mathbf{a} = \mathbf{F}/m = (-3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})/5 = (-0.6\hat{\mathbf{i}} + 0.8\hat{\mathbf{j}})\ m/s^2$
- $\mathbf{v}(t) = \mathbf{v}_o + \mathbf{a}t = (6\hat{\mathbf{i}} - 12\hat{\mathbf{j}}) + (-0.6\hat{\mathbf{i}} + 0.8\hat{\mathbf{j}})t$
- $v_x(t) = 6 - 0.6t$, $v_y(t) = -12 + 0.8t$
- For velocity only along y-axis: $v_x(t) = 0$
- $6 - 0.6t = 0 \rightarrow t = 10$ s

5.9. Car Acceleration Force

Question: A car of mass m starts from rest and acquires a velocity **v** along east in two seconds. Assuming the car moves with uniform acceleration, the force exerted on the car is:

a) mv/2 eastward and is exerted by the car engine

b) mv/2 eastward and is due to the friction on the tyres exerted by the road

c) more than mv/2 eastward exerted due to the engine and overcomes the friction of the road

d) mv/2 exerted by the engine

Answer: b) mv/2 eastward and is due to the friction on the tyres exerted by the road

Solution:

- a = v/t = v/2
- F = ma = mv/2 eastward
- This force comes from road friction on tires (Newton's third law pair with tire pushing road backward)

Multiple Choice Questions II

5.10. Piecewise Motion Analysis

Question: The motion of a particle of mass m is given by:

- x = 0 for t < 0 sec
- $x(t) = A \sin 4\pi t$ for 0 < t < (1/4) sec
- x = 0 for t > (1/4) sec

Which of the following statements is true?

a) the force at t = (1/8) sec on the particle is $-16\pi^2 Am$

b) the particle is acted upon by an impulse of magnitude $4\pi Am$ at t = 0 sec and t = (1/4) sec

c) the particle is not acted upon by any force

d) the particle is not acted upon by a constant force e) there is no impulse acting on the particle

Answer: a), b), and d) are correct

Solution: For $0 < t < 1/4$:

- $x(t) = A \sin 4\pi t$
- $v(t) = dx/dt = 4\pi A \cos 4\pi t$
- $a(t) = dv/dt = -16\pi^2 A \sin 4\pi t$
- $F(t) = ma(t) = -16\pi^2 Am \sin 4\pi t$

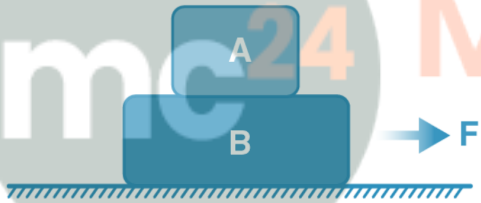
At t = 1/8: $F = -16\pi^2 Am \sin(\pi/2) = -16\pi^2 Am$ ✓

At t = 0: v changes from 0 to $4\pi A$, so impulse = $m(4\pi A) = 4\pi Am$ ✓ At t = 1/4: v changes from 0 to 0, so impulse = $4\pi Am$ ✓

Force is not constant since it varies as $\sin 4\pi t$ ✓

5.11. Friction Between Bodies

Question: The coefficient of friction between the floor and body B is 0.1. The coefficient of friction between bodies B and A is 0.2. A force F is applied on B. The mass of A is m/2 and of B is m. Which statements are true?



a) the bodies will move together if F = 0.25 mg

b) the body A will slip with respect to B if F = 0.5 mg

c) the bodies will move together if F = 0.5 mg

d) the bodies will be at rest if F = 0.1 mg e) the maximum value of F for which the two bodies will move together is 0.45 mg

Answer: a), b), d), and e) are correct

Solution: Case 1: Bodies at rest ($F \leq \mu_1 mg = 0.1mg$)

- If F = 0.1mg, static friction balances applied force ✓

Case 2: Bodies move together with acceleration a

- Total mass = m + m/2 = 3m/2
- Net force = $F - \mu_1(3m/2)g = F - 0.15mg$
- Acceleration: $a = (F - 0.15mg)/(3m/2)$

For A not to slip on B: friction force on A $\leq \mu_2(m/2)g = 0.1mg$ Force needed to accelerate A: $(m/2)a = (m/2)(F - 0.15mg)/(3m/2) = (F - 0.15mg)/3$

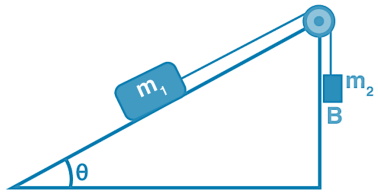
Setting equal: (F - 0.15mg)/3 = 0.1mg F - 0.15mg = 0.3mg F = 0.45mg (maximum for moving together) ✓

Checking options:

- F = 0.25mg < 0.45mg → move together ✓
- F = 0.5mg > 0.45mg → A slips on B ✓

5.12. Inclined Plane with Pulley

Question: Mass m_1 moves on a slope making angle θ with horizontal and is attached to mass m_2 by a string over a frictionless pulley. The coefficient of friction between m_1 and slope is μ. Which statements are true?



a) if $m_2 > m_1 \sin\theta$, the body will move up the plane

b) if $m_2 > m_1(\sin\theta + \mu\cos\theta)$, the body will move up the plane

c) if $m_2 < m_1(\sin\theta + \mu\cos\theta)$, the body will move up the plane

d) if $m_2 < m_1(\sin\theta - \mu\cos\theta)$, the body will move down the plane

Answer: b) and d) are correct

Solution: Forces on m_1 along the incline:

- Component of weight down the slope: $m_1 g \sin\theta$
- Friction force (opposing motion): $\mu m_1 g \cos\theta$
- Tension up the slope: T

For m_2: $m_2 g - T = m_2 a$ (if moving up) For m_1: $T - m_1 g \sin\theta - \mu m_1 g \cos\theta = m_1 a$ (if moving up)

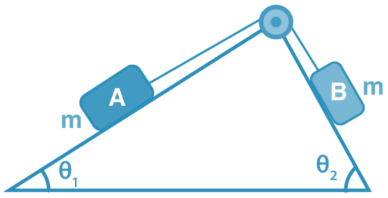
For upward motion: $m_2 g > m_1 g \sin\theta + \mu m_1 g \cos\theta$ Therefore: $m_2 > m_1(\sin\theta + \mu\cos\theta)$ ✓

For downward motion: $m_1 g \sin\theta - \mu m_1 g \cos\theta > m_2 g$

Therefore: $m_2 < m_1(\sin\theta - \mu\cos\theta)$ ✓

5.13. Two Inclined Planes System

Question: Body A (mass m) slides on plane inclined at angle θ_1 with coefficient of friction μ_1. Connected by string over pulley to body B (mass m) on frictionless plane inclined at angle θ_2. Which statements are true?



a) A will never move up the plane

b) A will just start moving up the plane when $\mu = (\sin\theta_2 - \sin\theta_1)/\cos\theta_1$

c) for A to move up the plane, θ_2 must always be greater than θ_1

d) B will always slide down with constant speed

Answer: b) and c) are correct

Solution: For equilibrium (A just starts moving up):

- Forces on A: $T = mg \sin \theta_1 + \mu_1 mg \cos \theta_1$
- Forces on B: $mg \sin \theta_2 = T$

Setting equal: $mg \sin \theta_2 = mg \sin \theta_1 + \mu_1 mg \cos \theta_1$ Therefore: $\mu_1 = (\sin \theta_2 - \sin \theta_1)/\cos \theta_1$ ✓

For A to move up: $\sin \theta_2 > \sin \theta_1 + \mu_1 \cos \theta_1$ Since $\mu_1 > 0$ and $\cos \theta_1 > 0$, we need $\theta_2 > \theta_1$ ✓

5.14. Billiard Ball Collision

Question: Two billiard balls A and B, each of mass 50 g, moving in opposite directions with speed 5 m/s each, collide and rebound with the same speed. If collision lasts 10^{-3} seconds, which statements are true?

a) the impulse imparted to each ball is 0.25 kg·m/s and the force on each ball is 250N

b) the impulse imparted to each ball is 0.25 kg·m/s and the force on each ball is 25×10^{-5} N

c) the impulse imparted to each ball is 0.5 N·s

d) the impulse and the force on each ball are equal in magnitude and opposite in direction

Answer: c) and d) are correct

Solution:

- Mass of each ball: m = 0.05 kg
- Initial velocities: $v_{1i} = +5$ m/s, $v_{2i} = -5$ m/s
- Final velocities: $v_1f = -5$ m/s, $v_2f = +5$ m/s

For ball A:

- $\Delta p_1 = m(v_1f - v_{1i}) = 0.05(-5 - 5) = -0.5$ kg·m/s
- |Impulse| = 0.5 N·s ✓

Forces are equal and opposite by Newton's third law ✓

5.15. Perpendicular Forces on Body

Question: A body of mass 10 kg is acted upon by two perpendicular forces, 6N and 8N. The resultant acceleration of the body is:

a) 1 m/s² at an angle of $\tan^{-1}(4/3)$ w.r.t 6N force

b) 0.2 m/s² at an angle of $\tan^{-1}(4/3)$ w.r.t 6N force

c) 1 m/s² at an angle of $\tan^{-1}(3/4)$ w.r.t 8N force

d) 0.2 m/s² at an angle of $\tan^{-1}(3/4)$ w.r.t 8N force

Answer: a) and c) are correct

Solution:

- Resultant force: $F = \sqrt{(6^2 + 8^2)} = \sqrt{100} = 10$ N
- Resultant acceleration: $a = F/m = 10/10 = 1$ m/s²
- Angle with 6N force: $\tan \theta = 8/6 = 4/3 \rightarrow \theta = \tan^{-1}(4/3)$ ✓
- Angle with 8N force: $\tan \phi = 6/8 = 3/4 \rightarrow \phi = \tan^{-1}(3/4)$ ✓