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Laws of Motion - Chapter 4

Class 11 CBSE Physics

Complete Study Material with Derivations & Practice Questions

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1. Introduction

The Laws of Motion, formulated by Sir Isaac Newton, form the foundation of classical mechanics. These laws explain the relationship between the motion of objects and the forces acting upon them.

Historical Context:

- **Aristotle's View (384-322 BC):** Believed that a force is necessary to keep a body in motion
- **Galileo's Contribution (17th century):** Through experiments with inclined planes, concluded that an object on a frictionless horizontal plane moves with constant velocity
- **Newton's Laws (1687):** Refined and formalized the laws of motion

2. Aristotle's Fallacy

Aristotle proposed that an external force is required to keep a body in motion. This view, though intuitive from everyday experience, is incorrect.

Why Aristotle was Wrong:

- A moving toy car comes to rest because of **friction**, not because force is required for motion
- To maintain uniform motion, an external force is needed only to **counter friction**
- In the absence of friction, no force is needed to maintain uniform motion

Key Understanding: External forces (friction, air resistance) oppose motion in real-world scenarios. In an ideal frictionless world, no force is needed to maintain uniform motion.

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3. The Law of Inertia

Based on Galileo's experiments with double inclined planes, the law of inertia states that a body continues in its state of rest or uniform motion unless acted upon by an external force.

Galileo's Double Inclined Plane Experiment:

- A ball released from one plane rolls down and climbs up the other plane
- On smooth planes, the ball reaches nearly the same height
- If the second plane's slope is decreased, the ball travels a longer distance to reach the same height
- In the limiting case (horizontal plane), the ball would travel infinitely

Definition of Inertia: Inertia is the resistance of a body to change its state of rest or uniform motion. It is directly proportional to the mass of the body.

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4. Newton's First Law of Motion

Statement:

"Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise."

Mathematical Form:

If $F_{\text{net}} = 0$, then $a = 0$

Key Points:

- The first law defines the concept of **inertial frames of reference**
- It is also called the **Law of Inertia**
- State of rest and state of uniform linear motion are equivalent
- Zero net external force means zero acceleration, not zero motion

Applications & Examples:

1. **Passenger in a Bus:** When a bus suddenly starts, passengers are thrown backward due to inertia of rest
2. **Jerking a Tree Branch:** Fruits fall when the branch is shaken due to inertia of rest

3. **Spaceship in Space:** With no external forces, a spaceship continues with constant velocity

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5. Momentum

Definition: Momentum of a body is the product of its mass and velocity.

$$p = m \times v$$

SI Unit: kg m s^{-1} or N s

Nature: Vector quantity (direction same as velocity)

Why Momentum is Important:

- For same speed, heavier bodies are harder to stop (greater mass → greater momentum)
- For same mass, faster bodies require greater force to stop (greater velocity → greater momentum)
- Momentum combines both mass and velocity effects

Key Observations:

1. **Mass Effect:** Greater force needed to push a loaded truck than a car to the same speed
2. **Velocity Effect:** A high-speed bullet causes more damage than a slow-moving one
3. **Rate of Change:** Greater change in momentum in given time requires greater force

6. Newton's Second Law of Motion

Statement:

"The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts."

Mathematical Derivation:

Step 1: Define the relationship

Force is proportional to rate of change of momentum:

$$F \propto \Delta p / \Delta t$$

Step 2: Introduce constant of proportionality

$$F = k \times (\Delta p / \Delta t)$$

Step 3: Take the limit as $\Delta t \rightarrow 0$

$$F = k \times (dp/dt)$$

Step 4: Set $k = 1$ (SI units)

$$F = dp/dt$$

Step 5: For constant mass

Since $p = mv$:

$$F = d(mv)/dt = m(dv/dt) = ma$$

Final Form:

$$\mathbf{F = ma}$$

Unit of Force:

Newton (N): One newton is the force that produces an acceleration of 1 m s^{-2} in a body of mass 1 kg.

$$1 \text{ N} = 1 \text{ kg m s}^{-2}$$

Important Points:

1. **Vector Law:** $F = ma$ is a vector equation, equivalent to three scalar equations:

$$F_x = ma_x, F_y = ma_y, F_z = ma_z$$

2. **Local Law:** Force at a point determines acceleration at that same point at that instant
3. **Consistency with First Law:** When $F = 0$, we get $a = 0$
4. **Applicability:** Valid for particles and systems of particles (where F is total external force)

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7. Impulse

Definition: Impulse is the product of force and the time duration for which it acts.

$$\text{Impulse} = F \times \Delta t = \Delta p$$

SI Unit: N s or kg m s⁻¹

Derivation of Impulse-Momentum Theorem:

From Newton's Second Law:

$$F = dp/dt$$

Multiplying both sides by dt and integrating:

$$\int F dt = \int dp = \Delta p$$

For constant force over time Δt :

$$F \times \Delta t = \Delta p = m(v - u)$$

Applications:

1. **Cricket Catch:** A cricketer moves hands backward to increase time of contact, reducing the force felt

2. **High Jump:** Thick foam mattresses increase stopping time, reducing impact force
3. **Car Safety:** Airbags increase collision time, reducing force on passengers
4. **Athlete Landing:** Bending knees on landing increases time, reducing force on joints

Key Concept: For the same change in momentum, increasing the time duration decreases the force experienced. This is why we follow through in sports and use safety devices that extend impact time.

8. Newton's Third Law of Motion

Statement:

"To every action, there is always an equal and opposite reaction."

Mathematical Form:

$$F_{AB} = -F_{BA}$$

(Force on A by B = - Force on B by A)

Important Clarifications:

1. **Simultaneous Forces:** Action and reaction occur at the same instant (no cause-effect relationship)
2. **Different Bodies:** Action and reaction act on different bodies, so they cannot cancel each other
3. **Same Nature:** If action is gravitational, reaction is also gravitational; if action is contact force, reaction is also contact force
4. **Equal Magnitude:** Action and reaction always have equal magnitude regardless of masses

Examples with Action-Reaction Pairs:

Situation	Action	Reaction
Book on table	Weight of book on table	Normal force of table on book
Gun firing bullet	Force on bullet by gun	Recoil force on gun by bullet
Swimming	Force on water by swimmer (backward)	Force on swimmer by water (forward)
Rocket propulsion	Force on gases by rocket	Thrust on rocket by gases
Walking	Force on ground by foot (backward)	Friction force on foot by ground (forward)

Common Misconception: The normal force and weight of a book on a table are NOT action-reaction pairs. They act on the same body and happen to be equal due to equilibrium, not due to the third law.

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9. Law of Conservation of Momentum

Statement:

"The total momentum of an isolated system of interacting particles is conserved."

Derivation:

For a system of two particles A and B:

By Newton's Second Law:

$$F_{AB} = dp_A/dt \text{ (force on A by B)}$$

$$F_{BA} = dp_B/dt \text{ (force on B by A)}$$

By Newton's Third Law:

$$F_{AB} = -F_{BA}$$

Therefore:

$$dp_A/dt = -dp_B/dt$$

$$dp_A/dt + dp_B/dt = 0$$

$$d(p_A + p_B)/dt = 0$$

This means:

$$p_A + p_B = \text{constant}$$

Or equivalently:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Applications:

1. Recoil of Gun:

Initial momentum = 0

Final momentum: $m_{\text{bullet}}v_{\text{bullet}} + m_{\text{gun}}v_{\text{gun}} = 0$

2. Rocket Propulsion:

Momentum of expelled gases = -Momentum gained by rocket

3. Collisions:

Total momentum before collision = Total momentum after collision

Important Note: Conservation of momentum holds true whether the collision is elastic or inelastic. In elastic collisions, kinetic energy is also conserved; in inelastic collisions, kinetic energy is not conserved.

10. Equilibrium of a Particle

Definition: A particle is in equilibrium when the net external force on it is zero.

$$\Sigma F = 0 \Rightarrow a = 0$$

Types of Equilibrium:

1. **Static Equilibrium:** Body is at rest ($v = 0$)
2. **Dynamic Equilibrium:** Body moves with constant velocity ($v = \text{constant}$)

Conditions for Equilibrium:

For Two Forces:

$$F_1 + F_2 = 0 \Rightarrow F_1 = -F_2$$

For Three Concurrent Forces:

$$F_1 + F_2 + F_3 = 0$$

The three forces can be represented by sides of a closed triangle (Lami's Theorem)

Component Form:

$$\Sigma F_x = 0$$

$$\Sigma F_y = 0$$

$$\Sigma F_z = 0$$

Note: For equilibrium of a rigid body, both translational equilibrium ($\Sigma F = 0$) and rotational equilibrium ($\Sigma \tau = 0$) are required.

11. Friction

Definition:

Friction is the component of contact force parallel to the surfaces in contact, which opposes the relative motion (actual or impending) between two surfaces.

Types of Friction:

A. Static Friction (f_s)

- Opposes **impending motion**
- Self-adjusting force: increases with applied force up to a maximum value
- Maximum value: $(f_s)_{\max} = \mu_s N$

$$0 \leq f_s \leq \mu_s N$$

B. Kinetic/Sliding Friction (f_k)

- Opposes **actual relative motion**
- Approximately constant for given surfaces
- Independent of contact area and velocity

$$f_k = \mu_k N$$

C. Rolling Friction

- Much smaller than static or kinetic friction (2-3 orders of magnitude less)
- Due to deformation of surfaces during rolling
- Reason why wheels are so effective

Laws of Friction:

Law	Description
1. Direction	Friction always opposes relative motion
2. Proportionality	$f \propto N$ (Normal reaction)
3. Independence	Independent of area of contact
4. Surface dependence	Depends on nature of surfaces (μ)
5. Inequality	$\mu_s > \mu_k$ (always)

Coefficient of Friction:

Static Coefficient:

$$\mu_s = (f_s)_{\max} / N = \tan \theta_{\max}$$

where θ_{\max} is the angle of repose (angle at which body just begins to slide)

Kinetic Coefficient:

$$\mu_k = f_k / N$$

Applications of Friction:

Beneficial	Harmful
Walking	Wear and tear of machinery
Vehicle braking	Energy dissipation as heat
Writing	Reduced efficiency
Holding objects	Noise production

Methods to Reduce Friction:

1. **Lubrication:** Oil/grease between surfaces
2. **Ball Bearings:** Convert sliding to rolling friction
3. **Streamlining:** Reduce air/fluid resistance
4. **Polishing:** Make surfaces smoother

5. **Air Cushion:** Compressed air between surfaces

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12. Circular Motion

Centripetal Acceleration:

For uniform circular motion:

A particle moving in a circle of radius R with constant speed v experiences acceleration directed towards the center.

Magnitude of centripetal acceleration:

$$a_c = v^2/R = \omega^2 R = v\omega$$

where ω is angular velocity = v/R

Centripetal Force:

By Newton's Second Law:

$$F_c = ma_c = mv^2/R = m\omega^2 R$$

Direction: Always towards the center of the circle

Sources of Centripetal Force:

Situation	Centripetal Force Provided By
Stone tied to string	Tension in string
Planet around Sun	Gravitational force
Car on level road	Friction force
Car on banked road	Component of normal force + friction
Electron around nucleus	Electrostatic force

Motion of Car on Level Road:

For a car taking a turn of radius R on a level road:

Centripetal force = Friction force

$$mv^2/R = f \leq \mu_s N = \mu_s mg$$

Maximum safe speed:

$$v_{\max} = \sqrt{(\mu_s Rg)}$$

Note: Independent of mass of car!

Motion of Car on Banked Road:

For a banked road at angle θ :

Vertical equilibrium:

$$N \cos \theta = mg + f \sin \theta$$

Horizontal (centripetal force):

$$N \sin \theta + f \cos \theta = mv^2/R$$

Optimum speed ($f = 0$):

$$v_0 = \sqrt{Rg \tan \theta}$$

At this speed, no friction is needed. This reduces tire wear.

Maximum speed ($f = \mu_s N$):

$$v_{\max} = \sqrt{[Rg(\mu_s + \tan \theta) / (1 - \mu_s \tan \theta)]}$$

Centrifugal Force: There is no outward "centrifugal force" in an inertial frame. What we feel as centrifugal force is actually the inertial tendency to move in a straight line. Centrifugal force appears only in rotating (non-inertial) reference frames.

13. Expected Home Exam Questions

Section A: Very Short Answer Questions (1 Mark)

Q1. State Newton's First Law of Motion.

Answer: Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise.

Q2. Define momentum. Is it a scalar or vector?

Answer: Momentum is the product of mass and velocity of a body. $p = mv$. It is a vector quantity.

Q3. What is the SI unit of momentum?

Answer: kg m s^{-1} or N s

Q4. State the relationship between coefficient of static and kinetic friction.

Answer: $\mu_s > \mu_k$ (coefficient of static friction is always greater than coefficient of kinetic friction)

Q5. What provides the centripetal force when a car takes a turn on a level road?

Answer: Friction force between tires and road

Section B: Short Answer Questions (2-3 Marks)

Q6. Distinguish between inertia of rest and inertia of motion with examples.

Answer:

- **Inertia of Rest:** Tendency of a body to remain at rest.
Example: When a bus starts suddenly, passengers are thrown backward.
- **Inertia of Motion:** Tendency of a body to continue its motion. Example: When a moving bus stops suddenly, passengers are thrown forward.

Q7. Why does a cricketer move his hands backward while catching a ball?

Answer: By moving hands backward, the cricketer increases the time of contact with the ball. Since impulse = Force \times time, for the same change in momentum (impulse), increasing time decreases the force experienced. This prevents injury to hands.

Q8. Derive the relation $F = ma$ from Newton's Second Law.

Answer:

Newton's Second Law: $F = dp/dt$

Since $p = mv$:

$$F = d(mv)/dt$$

For constant mass m :

$$F = m(dv/dt)$$

$$F = ma \text{ (since } a = dv/dt)$$

Q9. A body of mass 5 kg is acted upon by two forces 8 N and 6 N perpendicular to each other. Find the magnitude and direction of acceleration.

Answer:

$$\text{Net force } F = \sqrt{(8^2 + 6^2)} = \sqrt{(64 + 36)} = \sqrt{100} = 10 \text{ N}$$

$$\text{Acceleration } a = F/m = 10/5 = 2 \text{ m s}^{-2}$$

Direction: $\tan \theta = 6/8 = 0.75$, $\theta = \tan^{-1}(0.75) \approx 37^\circ$ with 8 N force

Q10. State and prove the law of conservation of momentum.

Answer:

Statement: The total momentum of an isolated system remains constant.

Proof: For two particles A and B:

$$F_{AB} = dp_A/dt \text{ and } F_{BA} = dp_B/dt$$

By Newton's Third Law: $F_{AB} = -F_{BA}$

$$\text{Therefore: } dp_A/dt = -dp_B/dt$$

$$d(p_A + p_B)/dt = 0$$

$$\text{Hence: } p_A + p_B = \text{constant}$$

Section C: Long Answer Questions (5 Marks)

Q11. (a) State and explain Newton's laws of motion. (b) Derive the expression for centripetal force in uniform circular motion.

Answer:

(a) Newton's Laws:

1. **First Law:** A body continues in its state of rest or uniform motion unless acted upon by external force.
2. **Second Law:** Rate of change of momentum is proportional to applied force: $F = dp/dt = ma$
3. **Third Law:** To every action there is equal and opposite reaction: $F_{AB} = -F_{BA}$

(b) Centripetal Force:

For uniform circular motion, acceleration $a_c = v^2/R$ directed towards center

By Newton's Second Law: $F_c = ma_c = mv^2/R$

This is the centripetal force required for circular motion.

Q12. (a) Define friction and explain types of friction. (b) A block of mass 10 kg is placed on a horizontal surface with $\mu_s = 0.5$ and $\mu_k = 0.3$. Find (i) force needed to start motion (ii) force needed to maintain uniform motion.

Answer:

(a) Friction is the force parallel to contact surfaces that opposes relative motion.

Types:

- **Static friction:** Opposes impending motion, self-adjusting, $f_s \leq \mu_s N$
- **Kinetic friction:** Opposes actual motion, $f_k = \mu_k N$
- **Rolling friction:** During rolling motion, much less than sliding friction

(b) Given: $m = 10 \text{ kg}$, $\mu_s = 0.5$, $\mu_k = 0.3$

Normal force $N = mg = 10 \times 10 = 100 \text{ N}$

(i) Force to start motion = $(f_s)_{\max} = \mu_s N = 0.5 \times 100 = 50 \text{ N}$

(ii) Force for uniform motion = $f_k = \mu_k N = 0.3 \times 100 = 30 \text{ N}$

Q13. Derive expressions for (a) maximum safe speed on a level circular road (b) optimum speed on a banked road.

Answer:

(a) Level Road:

Centripetal force = Friction force

$$mv^2/R = f \leq \mu_s N = \mu_s mg$$

$$v^2 \leq \mu_s Rg$$

$$v_{\max} = \sqrt{(\mu_s Rg)}$$

(b) Banked Road:

For optimum speed, friction is not needed ($f = 0$)

Vertical: $N \cos \theta = mg$

Horizontal: $N \sin \theta = mv^2/R$

Dividing: $\tan \theta = v^2/Rg$

$$v_0 = \sqrt{(Rg \tan \theta)}$$

14. Case Study Based Questions

Case Study 1: Road Safety and Friction

During monsoon season, road accidents increase significantly. The coefficient of friction between car tires and wet roads reduces from 0.7 (dry) to 0.4 (wet). On a particular curved road with radius 50 m, several accidents have been reported. Engineers are analyzing the situation to recommend speed limits and possible road modifications.

Q1. What is the maximum safe speed on this curve during dry conditions? (Take $g = 10 \text{ m s}^{-2}$)

- (a) 15.7 m/s (b) 18.7 m/s (c) 21.7 m/s (d) 24.7 m/s

Answer: (b) 18.7 m/s

Solution: $v_{\max} = \sqrt{(\mu_s Rg)} = \sqrt{(0.7 \times 50 \times 10)} = \sqrt{350} = 18.7$
m/s

Q2. What is the maximum safe speed on this curve during wet conditions?

- (a) 12.2 m/s (b) 14.1 m/s (c) 16.3 m/s (d) 18.7 m/s

Answer: (b) 14.1 m/s

Solution: $v_{\max} = \sqrt{(0.4 \times 50 \times 10)} = \sqrt{200} = 14.1 \text{ m/s}$

Q3. If the road is banked at angle 30° , what would be the optimum speed (requiring no friction)?

- (a) 16.9 m/s (b) 18.9 m/s (c) 20.9 m/s (d) 22.9 m/s

Answer: (a) 16.9 m/s

Solution: $v_0 = \sqrt{(Rg \tan \theta)} = \sqrt{(50 \times 10 \times \tan 30^\circ)} = \sqrt{(500 \times$

$0.577) = 16.9 \text{ m/s}$

Q4. What is the primary reason for reduced friction on wet roads?

- (a) Water increases smoothness (b) Water acts as lubricant
(c) Road becomes slippery (d) All of the above

Answer: (d) All of the above

Explanation: Water fills microscopic irregularities, reduces interlocking, and acts as a lubricant between tire and road.

Case Study 2: Rocket Propulsion

A rocket of initial mass 5000 kg is launched vertically upward. The rocket burns fuel at a rate of 50 kg/s and ejects gases downward at a relative speed of 2000 m/s with respect to the rocket. The rocket needs to overcome Earth's gravity ($g = 10 \text{ m s}^{-2}$) and air resistance during its ascent.

Q1. Which law of motion primarily explains rocket propulsion?

- (a) First Law (b) Second Law (c) Third Law (d) Conservation of Energy

Answer: (c) Third Law

Explanation: Rocket exerts force on gases (action), gases exert equal and opposite force on rocket (reaction), propelling it forward.

Q2. What is the thrust force produced by the rocket?

- (a) 50,000 N (b) 100,000 N (c) 150,000 N (d) 200,000 N

Answer: (b) 100,000 N

Solution: Thrust = $(dm/dt) \times v_{\text{rel}} = 50 \times 2000 = 100,000 \text{ N}$

Q3. What is the initial weight of the rocket?

- (a) 30,000 N (b) 40,000 N (c) 50,000 N (d) 60,000 N

Answer: (c) 50,000 N

Solution: Weight = $mg = 5000 \times 10 = 50,000 \text{ N}$

Q4. What is the initial net upward force on the rocket?

- (a) 25,000 N (b) 50,000 N (c) 75,000 N (d) 100,000 N

Answer: (b) 50,000 N

Solution: Net force = Thrust - Weight = $100,000 - 50,000 = 50,000$ N (ignoring air resistance)

Case Study 3: Collision Analysis

In a crash test facility, a car of mass 1200 kg moving at 20 m/s collides head-on with a stationary truck of mass 3000 kg. After the collision, the vehicles move together. The collision lasts for 0.2 seconds. Safety engineers need to analyze the forces and energy involved to improve vehicle safety features.

Q1. What is the velocity of the combined mass after collision?

- (a) 4.8 m/s (b) 5.7 m/s (c) 6.5 m/s (d) 7.2 m/s

Answer: (b) 5.7 m/s

Solution: By conservation of momentum:

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

$$1200 \times 20 + 3000 \times 0 = (1200 + 3000)v$$

$$24000 = 4200v$$

$$v = 5.7 \text{ m/s}$$

Q2. What is the average force experienced by the car during collision?

- (a) 85,800 N (b) 95,800 N (c) 105,800 N (d) 115,800 N

Answer: (a) 85,800 N

Solution: Change in momentum of car = $m_1(v - u_1) = 1200(5.7 - 20) = -17,160 \text{ kg m/s}$

Force = $\Delta p/\Delta t = 17,160/0.2 = 85,800 \text{ N}$ (magnitude)

Q3. Is this collision elastic or inelastic?

- (a) Perfectly elastic (b) Perfectly inelastic (c) Partially elastic
(d) Cannot determine

Answer: (b) Perfectly inelastic

Explanation: The vehicles stick together after collision, which is characteristic of perfectly inelastic collision.

Q4. What percentage of kinetic energy is lost in the collision?

(a) 57.1% (b) 67.1% (c) 77.1% (d) 87.1%

Answer: (c) 77.1%

Solution:

$$\text{Initial KE} = \frac{1}{2} \times 1200 \times 20^2 = 240,000 \text{ J}$$

$$\text{Final KE} = \frac{1}{2} \times 4200 \times 5.7^2 = 68,229 \text{ J}$$

$$\text{Loss} = (240,000 - 68,229)/240,000 \times 100 = 77.1\%$$

Case Study 4: Elevator Physics

A person of mass 60 kg stands on a weighing scale inside an elevator. The elevator can move with different accelerations: upward acceleration of 2 m s^{-2} , downward acceleration of 2 m s^{-2} , or constant velocity. The person wants to understand why the scale reading changes in different situations. (Take $g = 10 \text{ m s}^{-2}$)

Q1. What is the scale reading when the elevator is at rest or moving with constant velocity?

(a) 500 N (b) 600 N (c) 700 N (d) 800 N

Answer: (b) 600 N

Solution: When $a = 0$, Normal force $N = mg = 60 \times 10 = 600 \text{ N}$

Q2. What is the scale reading when elevator accelerates upward at 2 m s^{-2} ?

(a) 600 N (b) 660 N (c) 720 N (d) 780 N

Answer: (c) 720 N

Solution: $N - mg = ma$

$$N = m(g + a) = 60(10 + 2) = 720 \text{ N}$$

Q3. What is the scale reading when elevator accelerates downward at 2 m s^{-2} ?

(a) 420 N (b) 480 N (c) 540 N (d) 600 N

Answer: (b) 480 N

Solution: $mg - N = ma$

$$N = m(g - a) = 60(10 - 2) = 480 \text{ N}$$

Q4. What would be the scale reading if the elevator cable breaks and it falls freely?

(a) Zero (b) 300 N (c) 600 N (d) Infinite

Answer: (a) Zero

Solution: In free fall, $a = g$ (downward)

$$N = m(g - a) = m(g - g) = 0$$

This is a state of weightlessness.

15. Important Numerical Problems

Problem 1: A bullet of mass 0.02 kg moving with a speed of 500 m/s penetrates a wooden block and comes to rest after traveling 0.2 m. Calculate the average resistance offered by the block.

Solution:

Given: $m = 0.02$ kg, $u = 500$ m/s, $v = 0$, $s = 0.2$ m

Using $v^2 = u^2 + 2as$:

$$0 = (500)^2 + 2a(0.2)$$

$$a = -250000/0.4 = -625000 \text{ m/s}^2$$

$$\text{Resistance force } F = ma = 0.02 \times 625000 = 12,500 \text{ N}$$

Problem 2: Two blocks of masses 2 kg and 3 kg are connected by a massless string passing over a frictionless pulley. Find the acceleration and tension in the string when the system is released.

Solution:

$$\text{For heavier block (3 kg): } 3g - T = 3a \dots (1)$$

$$\text{For lighter block (2 kg): } T - 2g = 2a \dots (2)$$

$$\text{Adding equations: } g = 5a$$

$$a = g/5 = 10/5 = 2 \text{ m/s}^2$$

$$\text{From (2): } T = 2g + 2a = 2(10) + 2(2) = 24 \text{ N}$$

Problem 3: A stone of mass 0.5 kg is rotated in a horizontal circle of radius 1 m with a constant speed of 10 m/s. Calculate (a) centripetal acceleration (b) centripetal force (c) angular velocity.

Solution:

(a) Centripetal acceleration $a_c = v^2/R = (10)^2/1 = 100 \text{ m/s}^2$

(b) Centripetal force $F_c = ma_c = 0.5 \times 100 = 50 \text{ N}$

(c) Angular velocity $\omega = v/R = 10/1 = 10 \text{ rad/s}$

Problem 4: A 1500 kg car is moving at 72 km/h. The driver applies brakes and the car comes to rest in 5 seconds. Find (a) retardation (b) braking force (c) distance traveled.

Solution:

Given: $m = 1500 \text{ kg}$, $u = 72 \text{ km/h} = 20 \text{ m/s}$, $v = 0$, $t = 5 \text{ s}$

(a) Retardation $a = (v - u)/t = (0 - 20)/5 = -4 \text{ m/s}^2$

(b) Braking force $F = ma = 1500 \times 4 = 6000 \text{ N}$

(c) Distance $s = ut + \frac{1}{2}at^2 = 20(5) + \frac{1}{2}(-4)(25) = 100 - 50 = 50 \text{ m}$

Problem 5: A body of mass 2 kg initially at rest is acted upon by a force that varies with time as $F = (3t^2 + 2t)$ N. Find the velocity after 2 seconds.

Solution:

$$F = ma = m(dv/dt)$$

$$3t^2 + 2t = 2(dv/dt)$$

$$dv = (3t^2/2 + t)dt$$

Integrating from 0 to 2:

$$v = [t^3/2 + t^2/2] \text{ from 0 to 2}$$

$$v = [(8/2 + 4/2) - 0] = 4 + 2 = 6 \text{ m/s}$$



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16. Quick Revision - Key Formulas

Concept	Formula	Units
Momentum	$p = mv$	kg m s^{-1}
Force (Second Law)	$F = dp/dt = ma$	N or kg m s^{-2}
Impulse	$J = F\Delta t = \Delta p$	N s
Third Law	$F_{AB} = -F_{BA}$	N
Conservation of Momentum	$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$	kg m s^{-1}
Static Friction	$f_s \leq \mu_s N$	N
Kinetic Friction	$f_k = \mu_k N$	N
Angle of Repose	$\tan \theta = \mu_s$	dimensionless
Centripetal Acceleration	$a_c = v^2/R = \omega^2 R$	m s^{-2}
Centripetal Force	$F_c = mv^2/R$	N
Max speed (level road)	$v_{\max} = \sqrt{(\mu_s Rg)}$	m s^{-1}
Optimum speed (banked)	$v_o = \sqrt{(Rg \tan \theta)}$	m s^{-1}

17. Tips for Examination

Do's:

- ✓ Always draw free body diagrams for problems involving forces
- ✓ Clearly identify the system and all external forces acting on it
- ✓ Use proper sign conventions (especially for direction)
- ✓ State the law or principle before applying it
- ✓ Write final answers with proper units
- ✓ Check if your answer makes physical sense
- ✓ For derivations, start from basic principles
- ✓ Remember: Action and reaction act on different bodies

Don'ts:

- X Don't confuse mass and weight
- X Don't add action-reaction pairs (they act on different bodies)
- X Don't forget to convert units (km/h to m/s, etc.)
- X Don't assume friction is always present or always maximum
- X Don't forget that centripetal force is provided by some actual force
- X Don't write $F = ma$ without defining what F represents
- X Don't skip intermediate steps in derivations

Common Mistakes to Avoid:

1. Confusing μ_s and μ_k (remember $\mu_s > \mu_k$)
2. Wrong direction of friction in circular motion problems
3. Not considering all forces in equilibrium problems
4. Incorrect application of conservation of momentum (only for isolated systems)
5. Forgetting that impulse equals change in momentum, not final momentum



FINAL SUCCESS MANTRA

Remember These Points:

-  Master Newton's Laws - they're the foundation of all mechanics
-  Draw Free Body Diagrams for EVERY problem - it makes solving easier
-  Practice friction and circular motion problems - high weightage topics
-  Conservation of momentum questions are scoring - don't miss them!
-  Show ALL steps clearly in exam - even simple ones
-  Remember: Action-reaction pairs act on DIFFERENT bodies
-  Case study questions need careful reading - they're concept-based
-  Time management is key - this chapter has many numerical problems

 **YOU'VE GOT THIS!**

**"Force is not just a push or pull - It's the language
of motion!"**

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Study Material Information

This comprehensive study material has been prepared following the latest CBSE curriculum and examination pattern for Class 11 Physics. The content includes detailed explanations, important derivations, case study based questions aligned with the current exam format, and practice questions to help students achieve excellence in their board examinations.

Key Features:

- Complete topic coverage with conceptual clarity
- Step-by-step solved derivations
- Case study questions with detailed solutions
- Exam tips and scoring strategies
- Quick revision checklists
- Practice questions with detailed solutions

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