Chapter 4: Laws of Motion

Exercises — Exercises

Q1 Give the magnitude and direction of the net force acting on
(a) a drop of rain falling down with a constant speed,
(b) a cork of mass 10 g floating on water,
(c) a kite skillfully held stationary in the sky,
(d) a car moving with a constant velocity of 30 km/h on a rough road,
(e) a high-speed electron in space far from all material objects, and free of electric and magnetic fields.

SOLUTION

By Newton's first law, a body moving with constant velocity (or at rest) has zero net external force on it.

(a) Rain drop falling at constant speed: velocity is constant, so acceleration = 0. Net force = 0 N.

(b) Cork of mass 10 g floating at rest on water: it is in equilibrium (at rest). Net force = 0 N.

(c) Kite held stationary: velocity = 0, acceleration = 0. Net force = 0 N.

(d) Car moving at constant velocity 30 km/h on a rough road: constant velocity => acceleration = 0. Net force = 0 N. (The engine force exactly balances friction.)

(e) Electron in space, free of all fields: no force acts on it (gravity from distant objects negligible, no electric or magnetic force). Net force = 0 N.

Answer: Net force = 0 N in all five cases. In each situation the body is either at rest or moving with constant velocity, so by Newton's first law the net external force is zero.

Q2 A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction and magnitude of the net force on the pebble,
(a) during its upward motion,
(b) during its downward motion,
(c) at the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction?
Ignore air resistance.

SOLUTION

Given: mass m = 0.05 kg, g = 10 m s^{-2} (as per chapter convention).
The only force acting on the pebble (ignoring air resistance) is gravity.

Net force = mg = 0.05 × 10 = 0.5 N, directed vertically downward in all three cases.

(a) During upward motion: force = 0.5 N downward.
(b) During downward motion: force = 0.5 N downward.
(c) At highest point (momentarily at rest): force = 0.5 N downward.
(The force is not zero at the highest point even though v = 0.)

If thrown at 45° to horizontal: the answers do not change. Air resistance is still neglected, so gravity is still the only force. Net force = 0.5 N downward in all three stages regardless of the direction of throw.

Answer: 0.5 N directed vertically downward in all three cases. The answer is the same when the pebble is thrown at 45° — gravity alone acts on it throughout its flight.

Q3 Give the magnitude and direction of the net force acting on a stone of mass 0.1 kg,
(a) just after it is dropped from the window of a stationary train,
(b) just after it is dropped from the window of a train running at a constant velocity of 36 km/h,
(c) just after it is dropped from the window of a train accelerating with 1 m s^{-2},
(d) lying on the floor of a train which is accelerating with 1 m s^{-2}, the stone being at rest relative to the train.
Neglect air resistance throughout.

SOLUTION

Given: m = 0.1 kg, g = 10 m s^{-2} (chapter convention).

(a) Stone dropped from stationary train:
Once released, the only force is gravity (air resistance neglected).
Net force = mg = 0.1 × 10 = 1 N, directed vertically downward.

(b) Stone dropped from train moving at constant velocity 36 km/h:
The train's constant velocity gives no horizontal force. After release, only gravity acts.
Net force = mg = 1 N, directed vertically downward.

(c) Stone dropped from accelerating train (a_{train} = 1 m s^{-2}):
The moment the stone is released from the window it is no longer in contact with the train. The train's acceleration no longer acts on the stone. Only gravity acts.
Net force = mg = 1 N, directed vertically downward.

(d) Stone lying on floor of train accelerating at 1 m s^{-2}, stone at rest relative to train:
The stone accelerates with the train at a = 1 m s^{-2}. By Newton's second law:
Net force = ma = 0.1 × 1 = 0.1 N, in the direction of the train's acceleration (horizontal, forward).
This net force is provided by the static friction between stone and floor.

Answer: (a) 1 N downward. (b) 1 N downward. (c) 1 N downward. (d) 0.1 N in the direction of the train's acceleration (horizontal).

Q4 One end of a string of length l is connected to a particle of mass m and the other to a small peg on a smooth horizontal table. If the particle moves in a circle with speed v the net force on the particle (directed towards the centre) is:
(i) T, (ii) T − mv^2/l, (iii) T + mv^2/l, (iv) 0
T is the tension in the string. [Choose the correct alternative].

SOLUTION

The particle moves in a horizontal circle of radius l with speed v.
The only horizontal force on the particle is the tension T in the string, directed towards the centre (centripetal direction).
By Newton's second law, the net centripetal force = mv^2/l.

This net centripetal force is provided entirely by the tension T:
Net force (towards centre) = T = mv^2/l.

Option (i): T — this is correct, since T is the only horizontal force acting on the

particle and it alone provides the centripetal acceleration.

Options (ii) and (iii) are incorrect: mv^2/l is not a separate force to be added or subtracted — it equals T. Option (iv) is wrong because a net inward force is needed to maintain circular motion.

Answer: (i) T. The tension in the string is the net centripetal force on the particle.

Q5 A constant retarding force of 50 N is applied to a body of mass 20 kg moving initially with a speed of 15 m s^{-1}. How long does the body take to stop?

SOLUTION

Given: retarding force F = −50 N, mass m = 20 kg, initial speed u = 15 m s^{-1}, final speed v = 0.

Acceleration: $a = F/m = -50/20 = -2.5$ m s^{-2}

Using $v = u + at$:
$0 = 15 + (-2.5) \times t$
$t = 15/2.5 = 6.0$ s

Answer: 6.0 s

Q6 A constant force acting on a body of mass 3.0 kg changes its speed from 2.0 m s^{-1} to 3.5 m s^{-1} in 25 s. The direction of the motion of the body remains unchanged. What is the magnitude and direction of the force?

SOLUTION

Given: m = 3.0 kg, u = 2.0 m s^{-1}, v = 3.5 m s^{-1}, t = 25 s.

Acceleration: $a = (v - u)/t = (3.5 - 2.0)/25 = 1.5/25 = 0.06$ m s^{-2}

Force: $F = ma = 3.0 \times 0.06 = 0.18$ N

Since the speed increases and the direction is unchanged, the force is along the direction of motion.

Answer: 0.18 N, in the direction of motion of the body.

Q7 A body of mass 5 kg is acted upon by two perpendicular forces 8 N and 6 N. Give the magnitude and direction of the acceleration of the body.

SOLUTION

Given: $m = 5$ kg, $F_1 = 8$ N, $F_2 = 6$ N, $F_1 \perp F_2$.

Magnitude of net force:
$F_{net} = \sqrt{(8^2 + 6^2)} = \sqrt{(64 + 36)} = \sqrt{100} = 10$ N

Magnitude of acceleration:
$a = F_{net} / m = 10 / 5 = 2$ m s^{-2}

Direction of acceleration:
$\tan \theta = F_2/F_1 = 6/8 = 0.75$
$\theta = \tan^{-1}(0.75) \approx 37°$ with the direction of the 8 N force (i.e., 53° with the 6 N force).

Answer: 2 m s^{-2}, directed at approximately 37° to the 8 N force (or equivalently 53° to the 6 N force).

Q8 The driver of a three-wheeler moving with a speed of 36 km/h sees a child standing in the middle of the road and brings his vehicle to rest in 4.0 s just in time to save the child. What is the average retarding force on the vehicle? The mass of the three-wheeler is 400 kg and the mass of the driver is 65 kg.

SOLUTION

Given: initial speed $u = 36$ km/h $= 10$ m s^{-1}, final speed $v = 0$, time $t = 4.0$ s.
Total mass $m = 400 + 65 = 465$ kg.

Acceleration: $a = (v - u)/t = (0 - 10)/4.0 = -2.5$ m s^{-2}

Retarding force: $F = ma = 465 \times (-2.5) = -1162.5$ N

Magnitude of retarding force ≈ 1163 N (directed opposite to motion).

Answer: Average retarding force ≈ 1162.5 N (approximately 1163 N), directed opposite to the direction of motion.

Q9 A rocket with a lift-off mass 20,000 kg is blasted upwards with an initial acceleration of 5.0 m s^{-2}. Calculate the initial thrust (force) of the blast.

SOLUTION

Given: m = 20,000 kg, upward acceleration a = 5.0 m s^{-2}, g = 10 m s^{-2}.

Applying Newton's second law (taking upward as positive):
Thrust − Weight = ma
Thrust = m(g + a) = 20,000 × (10 + 5.0) = 20,000 × 15 = 3.0×10^5 N

Answer: Initial thrust = 3.0×10^5 N (300,000 N or 3×10^5 N).

Q10 A body of mass 0.40 kg moving initially with a constant speed of 10 m s^{-1} to the north is subject to a constant force of 8.0 N directed towards the south for 30 s. Take the instant the force is applied to be t = 0, the position of the body at that time to be x = 0, and predict its position at t = −5 s, 25 s, 100 s.

SOLUTION

Given: m = 0.40 kg, initial velocity u = +10 m s^{-1} (north, positive direction), force F = −8.0 N (southward) applied from t = 0 to t = 30 s.

Acceleration during $0 \le t \le 30$ s:
$a = F/m = -8.0/0.40 = -20$ m s^{-2}

Before t = 0 (no force acting):
Body moves uniformly at 10 m s^{-1} northward.
At t = −5 s: $x = 0 + 10 \times (-5) = -50$ m
(i.e., the body was 50 m south of the origin at t = −5 s)

At t = 25 s (force still acting, $0 \le t \le 30$ s):
$x = ut + \frac{1}{2}at^2 = 10 \times 25 + \frac{1}{2} \times (-20) \times 25^2 = 250 - 6250 = -6000$ m

Velocity at t = 30 s:
$v_{30} = u + a \times 30 = 10 + (-20) \times 30 = -590$ m s^{-1}

Position at t = 30 s:
$x_{30} = 10 \times 30 + \frac{1}{2} \times (-20) \times 30^2 = 300 - 9000 = -8700$ m

At t = 100 s (force ceased at t = 30 s; body moves at constant velocity $v_{30} = -590$ m s^{-1}):
$x_{100} = x_{30} + v_{30} \times (100 - 30) = -8700 + (-590) \times 70 = -8700 - 41300 = -50{,}000$ m

Summary:

t = −5 s: x = −50 m (50 m south of origin)
t = 25 s: x = −6000 m (6 km south of origin)
t = 100 s: x = −50,000 m (50 km south of origin)

Answer: x(−5 s) = −50 m; x(25 s) = −6000 m; x(100 s) = −50,000 m. All positions are south of the origin (negative direction).

Q11 A truck starts from rest and accelerates uniformly at 2.0 m s^{-2}. At t = 10 s, a stone is dropped by a person standing on the top of the truck (6 m high from the ground). What are the (a) velocity, and (b) acceleration of the stone at t = 11 s? (Neglect air resistance.)

SOLUTION

Given: truck starts from rest, acceleration a_{truck} = 2.0 m s^{-2}.

At t = 10 s (moment of release):
Velocity of truck (and stone) = $a_{truck} \times t = 2.0 \times 10 = 20$ m s^{-1} (horizontal, forward).

Once released, the stone is no longer in contact with the truck. No horizontal force acts on it (air resistance neglected). Only gravity (vertically downward) acts on it.

(a) Velocity of stone at t = 11 s (i.e., 1 s after release):
Horizontal component: v_x = 20 m s^{-1} (unchanged, no horizontal force)
Vertical component: $v_y = 0 + g \times 1 = 10 \times 1 = 10$ m s^{-1} (downward)

Magnitude: $|v| = \sqrt{(v_x^2 + v_y^2)} = \sqrt{(20^2 + 10^2)} = \sqrt{(400 + 100)} = \sqrt{500} \approx 22.4$ m s^{-1}

Direction: $\theta = \tan^{-1}(v_y/v_x) = \tan^{-1}(10/20) = \tan^{-1}(0.5) \approx 26.6°$ below the horizontal.

(b) Acceleration of stone at t = 11 s:
Only gravity acts. Acceleration = g = 10 m s^{-2} vertically downward.

Answer: (a) Speed ≈ 22.4 m s^{-1} at 26.6° below horizontal (resultant of 20 m s^{-1} horizontal and 10 m s^{-1} downward). (b) Acceleration = 10 m s^{-2} vertically downward (due to gravity alone).

Q12 A bob of mass 0.1 kg hung from the ceiling of a room by a string 2 m long is set into oscillation. The speed of the bob at its mean position is 1 m s^{-1}. What is the trajectory of the bob if the string is cut when the bob is (a) at one of its extreme positions, (b) at its mean position.

SOLUTION

At the extreme position, the bob is momentarily at rest (v = 0) and displaced from the vertical.

At the mean (equilibrium) position, the bob swings through with maximum speed = 1 m s^{-1} directed horizontally.

(a) String cut at extreme position:

At the instant of cutting, velocity = 0. The only force is gravity (downward).

Starting from rest under gravity, the bob falls vertically downward.

Trajectory: a straight vertical line (vertical free fall).

(b) String cut at mean (lowest) position:

At the instant of cutting, the bob has velocity = 1 m s^{-1} horizontal.

After cutting, gravity acts downward while horizontal velocity is maintained.

This is projectile motion.

Trajectory: a parabola (curving downward from the mean position).

Answer: (a) Vertical straight line (free fall from rest). (b) Parabolic trajectory (projectile motion with initial horizontal velocity 1 m s^{-1}).

Q13 A man of mass 70 kg stands on a weighing scale in a lift which is moving
(a) upwards with a uniform speed of 10 m s^{-1},
(b) downwards with a uniform acceleration of 5 m s^{-2},
(c) upwards with a uniform acceleration of 5 m s^{-2}.
What would be the readings on the scale in each case?
(d) What would be the reading if the lift mechanism failed and it hurtled down freely under gravity?

SOLUTION

Given: m = 70 kg, g = 10 m s^{-2} (chapter convention).

Weight W = mg = 70 × 10 = 700 N.

The weighing scale reads the normal reaction R (apparent weight).

Newton's second law (taking upward as positive): R − mg = ma => R = m(g + a).

(a) Upward with uniform speed (a = 0):

R = m(g + 0) = 70 × 10 = 700 N
Scale reading = 700/10 = 70 kg.

(b) Downward with uniform acceleration a = −5 m s^{-2} (a = −5, taking upward as positive):
R = m(g + a) = 70 × (10 − 5) = 70 × 5 = 350 N
Scale reading = 350/10 = 35 kg.

(c) Upward with uniform acceleration a = +5 m s^{-2}:
R = m(g + a) = 70 × (10 + 5) = 70 × 15 = 1050 N
Scale reading = 1050/10 = 105 kg.

(d) Free fall (a = −g = −10 m s^{-2}):
R = m(g − g) = 0 N
Scale reading = 0 kg (weightlessness).

Answer: (a) 70 kg (700 N). (b) 35 kg (350 N). (c) 105 kg (1050 N). (d) 0 kg (0 N) — the person is weightless during free fall.

Q14 Figure 4.16 shows the position-time graph of a particle of mass 4 kg. What is the (a) force on the particle for t < 0, t > 4 s, 0 < t < 4 s? (b) impulse at t = 0 and t = 4 s? (Consider one-dimensional motion only).

SOLUTION

From Figure 4.16: the position-time graph is made of straight-line segments.
For t < 0: x = 0 (particle at rest, horizontal line).
For 0 < t < 4 s: x increases linearly from 0 to 3 m (straight line with constant positive slope).
For t > 4 s: x = 3 m (particle at rest again, horizontal line).
Point A is at (t = 4 s, x = 3 m).

(a) Force:
A straight line in the x-t graph means constant velocity, i.e., zero acceleration.
For t < 0: particle at rest (v = 0, a = 0). Force = ma = 4 × 0 = 0 N.
For 0 < t < 4 s: uniform velocity v = 3/4 = 0.75 m s^{-1} (a = 0). Force = 0 N.
For t > 4 s: particle at rest (v = 0, a = 0). Force = 0 N.

(b) Impulse (= change in momentum):
Mass m = 4 kg.
Velocity before t = 0: v_1 = 0 m s^{-1}.
Velocity just after t = 0: v_2 = 3/4 = 0.75 m s^{-1}.

Impulse at t = 0: $J = m(v_2 - v_1) = 4 \times (0.75 - 0) = 3$ N s (in the direction of motion).

Velocity just before t = 4 s: $v_3 = 0.75$ m s^{-1}.

Velocity just after t = 4 s: $v_4 = 0$ m s^{-1}.

Impulse at t = 4 s: $J = m(v_4 - v_3) = 4 \times (0 - 0.75) = -3$ N s (opposing direction of motion).

Answer: (a) Force = 0 N for all three intervals (t < 0, 0 < t < 4 s, t > 4 s) — all are straight-line segments in the x-t graph. (b) Impulse at t = 0 is +3 N s (forward); impulse at t = 4 s is −3 N s (backward).

Q15 Two bodies of masses 10 kg and 20 kg respectively kept on a smooth, horizontal surface are tied to the ends of a light string. A horizontal force F = 600 N is applied to (i) A, (ii) B along the direction of string. What is the tension in the string in each case?

SOLUTION

Given: $m_A = 10$ kg, $m_B = 20$ kg, smooth surface (no friction), F = 600 N.

Total mass = 10 + 20 = 30 kg.

Common acceleration: $a = F/(m_A + m_B) = 600/30 = 20$ m s^{-2}.

(i) Force F applied to A (A pulls B through string):

Applying Newton's second law to body B (only tension T acts on B):

$T = m_B \times a = 20 \times 20 = 400$ N.

(ii) Force F applied to B (B pulls A through string):

Applying Newton's second law to body A (only tension T acts on A):

$T = m_A \times a = 10 \times 20 = 200$ N.

Answer: (i) When F is applied to A: tension T = 400 N. (ii) When F is applied to B: tension T = 200 N.

Q16 Two masses 8 kg and 12 kg are connected at the two ends of a light inextensible string that goes over a frictionless pulley. Find the acceleration of the masses, and the tension in the string when the masses are released.

SOLUTION

Given: $m_1 = 8$ kg, $m_2 = 12$ kg, frictionless pulley, light inextensible string, $g = 10$ m s^{-2}.

Let a be the common magnitude of acceleration ($m_2 > m_1$, so m_2 descends).

Applying Newton's second law:
For m_2 (descending): $m_2g - T = m_2a$ ... (1)
For m_1 (ascending): $T - m_1g = m_1a$ ... (2)

Adding (1) and (2):
$(m_2 - m_1)g = (m_1 + m_2)a$
$a = (m_2 - m_1)g / (m_1 + m_2) = (12 - 8) \times 10 / (8 + 12) = 40/20 = 2$ m s^{-2}

From equation (2): $T = m_1(g + a) = 8 \times (10 + 2) = 8 \times 12 = 96$ N

Verification with (1): $T = m_2(g - a) = 12 \times (10 - 2) = 12 \times 8 = 96$ N ✓

Answer: Acceleration = 2 m s^{-2} (12 kg mass descends, 8 kg mass ascends). Tension in string = 96 N.

Q17 A nucleus is at rest in the laboratory frame of reference. Show that if it disintegrates into two smaller nuclei the products must move in opposite directions.

SOLUTION

Let M be the mass of the parent nucleus, and m_1, m_2 be the masses of the two product nuclei.
Let v_1 and v_2 be the velocities of the products after disintegration.

The nucleus is at rest initially, so its initial momentum = 0.

The disintegration is an isolated process (no external force). By the law of conservation of momentum:
Total final momentum = Total initial momentum = 0

$m_1v_1 + m_2v_2 = 0$
$\Rightarrow m_1v_1 = -m_2v_2$
$\Rightarrow v_1 = -(m_2/m_1)v_2$

Since m_1 and m_2 are both positive, the negative sign means v_1 and v_2 are in

opposite directions.

Therefore, the two product nuclei must move in opposite directions. ∎

Answer: By conservation of momentum: $m_1v_1 + m_2v_2 = 0$, so $v_1 = -(m_2/m_1)v_2$. Since $m_1, m_2 > 0$, the velocities are in opposite directions.

Q18 Two billiard balls each of mass 0.05 kg moving in opposite directions with speed 6 m s^{-1} collide and rebound with the same speed. What is the impulse imparted to each ball due to the other?

SOLUTION

Given: m = 0.05 kg for each ball, speed = 6 m s^{-1}.

Take the initial direction of ball 1 as positive.

For ball 1:
Initial momentum = +m × 6 = +0.05 × 6 = +0.30 kg m s^{-1}
After rebounding, the ball reverses direction: final momentum = −0.30 kg m s^{-1}
Impulse on ball 1 = change in momentum = −0.30 − 0.30 = −0.60 N s
Magnitude = 0.6 N s (in the direction opposite to ball 1's initial motion).

For ball 2:
Initial momentum = −0.30 kg m s^{-1} (moving in negative direction)
After rebounding: final momentum = +0.30 kg m s^{-1}
Impulse on ball 2 = +0.30 − (−0.30) = +0.60 N s
Magnitude = 0.6 N s (in the direction opposite to ball 2's initial motion).

Each ball receives an impulse of magnitude 0.6 N s, directed opposite to its initial direction of motion.

Answer: Impulse imparted to each ball = 0.6 N s, directed opposite to the ball's initial velocity.

Q19 A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m s^{-1}, what is the recoil speed of the gun?

SOLUTION

Given: m_shell = 0.020 kg, m_gun = 100 kg, v_shell = 80 m s^{-1}.

Initially, both gun and shell are at rest. Total initial momentum = 0.

By conservation of momentum:

$m_{shell} \times v_{shell} + m_{gun} \times v_{gun} = 0$
$0.020 \times 80 + 100 \times v_{gun} = 0$
$1.6 + 100 \times v_{gun} = 0$
$v_{gun} = -1.6/100 = -0.016 \text{ m s}^{-1}$

The negative sign indicates the gun moves in the direction opposite to the shell.
Recoil speed of gun = 0.016 m s^{-1}.

Answer: Recoil speed of the gun = 0.016 m s^{-1} (in the direction opposite to the fired shell).

Q20 A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 km/h. What is the impulse imparted to the ball? (Mass of the ball is 0.15 kg.)

SOLUTION

Given: m = 0.15 kg, speed v = 54 km/h = 15 m s^{-1} (unchanged), deflection angle $\theta = 45°$.

The magnitude of initial and final momenta are both $p = mv = 0.15 \times 15 = 2.25$ kg m s^{-1}.

The angle between the initial and final momentum vectors = 45°.

Using the vector triangle (law of cosines) for Δp:
$|\Delta p|^2 = p^2 + p^2 - 2p^2 \cos 45°$
$= 2p^2(1 - \cos 45°) = 2p^2(1 - 1/\sqrt{2})$

$|\Delta p| = p\sqrt{[2(1 - \cos 45°)]} = 2p \sin(45°/2) = 2p \sin(22.5°)$

$|\Delta p| = 2 \times 2.25 \times \sin(22.5°) = 4.5 \times 0.3827 \approx 1.72$ N s

Answer: Impulse imparted to the ball ≈ 1.72 N s.

Q21 A stone of mass 0.25 kg tied to the end of a string is whirled round in a circle of radius 1.5 m with a speed of 40 rev./min in a horizontal plane. What is the tension in the string? What is the maximum speed with which the stone can be whirled around if the string can withstand a maximum tension of 200 N?

SOLUTION

Given: m = 0.25 kg, r = 1.5 m, n = 40 rev/min = 40/60 rev/s.

Angular velocity: $\omega = 2\pi n = 2\pi \times (40/60) = 4\pi/3$ rad $s^{-1} \approx 4.19$ rad s^{-1}

Linear speed: $v = \omega r = (4\pi/3) \times 1.5 = 2\pi$ m $s^{-1} \approx 6.28$ m s^{-1}

Tension (centripetal force):

$T = m\omega^2 r = 0.25 \times (4\pi/3)^2 \times 1.5$

$= 0.25 \times (16\pi^2/9) \times 1.5$

$= 0.25 \times 1.5 \times 16\pi^2/9$

$\approx 0.25 \times 1.5 \times 17.546$

≈ 6.57 N (≈ 6.6 N)

Maximum speed (when $T = T_{max} = 200$ N):

$T_{max} = mv_{max}^2/r$

$v_{max} = \sqrt{(T_{max} \times r / m)} = \sqrt{(200 \times 1.5 / 0.25)} = \sqrt{(1200)} \approx 34.6$ m s^{-1}

Answer: Tension at 40 rev/min ≈ 6.57 N. Maximum speed (string limit 200 N) ≈ 34.6 m s^{-1}.

Q22 If, in Exercise 4.21, the speed of the stone is increased beyond the maximum permissible value, and the string breaks suddenly, which of the following correctly describes the trajectory of the stone after the string breaks:
(a) the stone moves radially outwards,
(b) the stone flies off tangentially from the instant the string breaks,
(c) the stone flies off at an angle with the tangent whose magnitude depends on the speed of the particle?

SOLUTION

When the string is intact, the stone moves in a circle. The velocity of the stone at any instant is directed tangentially (perpendicular to the radius).

The tension in the string provides the centripetal force directed inward (radially towards the centre). When the string breaks, this centripetal force suddenly vanishes.

At the instant of breaking, the stone has a velocity directed tangentially. With no net force (neglecting gravity for horizontal motion), the stone continues in a straight line in the direction of its velocity at that instant — which is tangential.

Option (b) is correct: the stone flies off tangentially from the instant the string breaks.

Option (a) is wrong: there is no outward radial force — centrifugal force is a pseudo-force in a rotating frame; in the inertial (ground) frame, no outward force acts.
Option (c) is wrong: the tangential direction is exact at the moment of breaking; the angle is not speed-dependent.

Answer: (b) The stone flies off tangentially from the instant the string breaks.

Q23 Explain why
(a) a horse cannot pull a cart and run in empty space,
(b) passengers are thrown forward from their seats when a speeding bus stops suddenly,
(c) it is easier to pull a lawn mower than to push it,
(d) a cricketer moves his hands backwards while holding a catch.

SOLUTION

(a) A horse cannot pull a cart in empty space:

When the horse pulls the cart forward, the reaction force that propels the horse itself comes from the ground: the horse pushes the ground backward with its hooves, and the ground pushes the horse forward (Newton's third law). In empty space there is no ground, so the horse cannot exert a backward force on any surface, and receives no forward reaction. Therefore the horse cannot propel itself (or the cart) in empty space.

(b) Passengers thrown forward when bus stops suddenly:

Before the bus stops, both the bus and the passengers are moving forward at the same speed. When the bus brakes suddenly, friction from the seat and floor acts on the passengers, but if the deceleration is large and abrupt, the frictional force may be insufficient to decelerate the passengers' bodies as quickly as the bus decelerates. By Newton's first law, the passengers tend to continue moving forward due to their inertia — they are 'thrown' forward relative to the bus.

(c) It is easier to pull a lawn mower than to push it:

When you pull a lawn mower at an angle above the horizontal, the vertical component of the applied force is upward, which reduces the normal reaction of the ground on the mower and hence reduces the friction force opposing motion.

When you push it at an angle below the horizontal, the vertical component of the applied force presses the mower into the ground, increasing the normal reaction and hence increasing friction.

Since friction is less when pulling, it is easier to pull.

(d) Cricketer moves hands backwards while catching:

By Newton's second law, the force on a body equals the rate of change of momentum: $F = \Delta p/\Delta t$.

When the cricketer draws his hands backward, the time Δt over which the ball's momentum changes from its initial value to zero is increased. Since the change in momentum ($\Delta p = mv$) is fixed, a larger Δt means a smaller average force F on the hands.

This reduced force prevents injury to the cricketer's hands.

Answer: (a) No ground reaction available in empty space — Newton's third law cannot provide forward thrust. (b) Inertia (Newton's first law) keeps passengers moving forward when the bus decelerates abruptly. (c) Pulling reduces the normal force and hence friction; pushing increases both. (d) Increasing the time of contact reduces the average force (impulse-momentum theorem).