Chapter 6: How Forces Affect Motion

Exercises — Revise, Reflect, Refine

Q1 Using a horizontal force F, a table is moved across the floor at a constant velocity. How much is the frictional force exerted by the floor on the table?

SOLUTION

The table moves at constant velocity, so its acceleration is zero.
By Newton's second law, net force = mass × acceleration = 0.
The two horizontal forces acting on the table are the applied force F (forward) and friction f (backward).
Net force = F − f = 0
=> f = F

Answer: The frictional force exerted by the floor on the table equals F, the applied force, in the opposite direction.

Q2 For a ball moving on a smooth (frictionless) surface, choose the appropriate option that will make the following statements physically correct:
(i) If no net force is applied on the ball, the velocity of the ball will remain the same/increase/decrease.
(ii) If a net force is applied on the ball in the direction of its motion, the magnitude of the velocity of the ball will remain the same/increase/decrease.
(iii) If a net force is applied on the ball in a direction opposite to the direction of its motion, the magnitude of the velocity of the ball will remain the same/increase/decrease.

SOLUTION

(i) If no net force acts on the ball, Newton's first law states that the ball continues in its state of uniform motion. Its velocity remains the same.

(ii) If a net force is applied in the direction of motion, by Newton's second law the ball accelerates in that direction. The magnitude of velocity will increase.

(iii) If a net force is applied opposite to the direction of motion, the ball decelerates (negative acceleration in the direction of motion). The magnitude of velocity will decrease.

Answer: (i) remain the same; (ii) increase; (iii) decrease.

Q3 Two blocks P and Q on a smooth horizontal surface are shown in Fig. 6.36a and Fig. 6.36b. Two forces of magnitudes 4 N and 5 N are acting in opposite directions on block P, while block Q is moving with a constant velocity. Which of the following statement is correct?
(i) P experiences a net force and Q does not experience a net force.
(ii) P does not experience a net force and Q experiences a net force.
(iii) Both P and Q experience a net force.
(iv) Neither P nor Q experiences a net force.

SOLUTION

Block P has two forces acting on it in opposite directions: 5 N and 4 N.
Net force on P = 5 N − 4 N = 1 N (non-zero). So P experiences a net force.

Block Q is moving at constant velocity on a smooth (frictionless) surface.
Constant velocity => acceleration = 0 => net force = 0. So Q does not experience a net force.

Therefore statement (i) is correct.

Answer: (i) P experiences a net force and Q does not experience a net force.

Q4 While practising for the snake boat race (Vallum kalli in Kerala), 100 oarsmen are rowing a boat together. Out of these, 95 row backwards to propel the boat forward. But by mistake, 5 oarsmen row in the opposite direction. If each oarsman applies a horizontal force of 200 N, what is the net force on the snake boat? (Ignore drag forces, air friction, etc.)

SOLUTION

Force applied by 95 oarsmen rowing forward = 95 × 200 N = 19 000 N (forward).
Force applied by 5 oarsmen rowing backward (opposite direction) = 5 × 200 N = 1 000 N (backward).
Net force = 19 000 N − 1 000 N = 18 000 N in the forward direction.

Answer: The net force on the snake boat is 18 000 N in the forward direction.

Q5 When a net force acts on an object, we observe that the object accelerates:
(i) opposite to the direction of force, with acceleration proportional to the force acting on the object.
(ii) opposite to the direction of force, with acceleration proportional to the mass of the object.
(iii) in the direction of force, with acceleration inversely proportional to the force acting on the object.
(iv) in the direction of force, with acceleration proportional to the force acting on the object.

SOLUTION

Newton's second law of motion states: F = ma, i.e., a = F/m.
The direction of acceleration is the same as the direction of the net force.
The magnitude of acceleration is directly proportional to the net force (for constant mass): $a \propto F$.
Option (iv) correctly states both the direction (same as force) and the proportionality ($a \propto F$).

Option (i) is wrong — direction is opposite to force (incorrect).
Option (ii) is wrong — direction is opposite (incorrect), and $a \propto$ mass is also incorrect ($a \propto 1/m$).
Option (iii) is wrong — direction is correct but 'inversely proportional to force' contradicts a = F/m.

Answer: (iv) in the direction of force, with acceleration proportional to the force acting on the object.

Q6 The position-time graph for four objects A, B, C and D moving along a straight line are given in Fig. 6.37. A net force acts on:
(i) Object A
(ii) Object B
(iii) Object C
(iv) Object D

SOLUTION

A net force causes a non-zero acceleration, which shows up as a curved (non-linear) position-time graph.
A constant velocity (zero acceleration) gives a straight-line (sloping) position-time graph.

An object at rest gives a horizontal (flat) straight line.

From Fig. 6.37:
Object A: straight line with positive slope => constant velocity => zero net force.
Object B: horizontal (flat) line => at rest => zero net force.
Object C: curved position-time graph (position increases non-linearly, bending upward) => non-zero acceleration => net force acts on C.
Object D: straight line with negative slope => constant velocity (moving in the opposite direction) => zero net force.

Only Object C has a curved position-time graph, so only Object C has a non-zero acceleration and experiences a net force. Option (iii) is correct.

Answer: (iii) Object C — it is the only one with a curved position-time graph, indicating non-zero acceleration and hence a net force.

Q7 A sailor jumps out from a small boat to the shore (Fig. 6.38). As the sailor jumps forward, will the boat move? If yes, in which direction and why.

SOLUTION

Yes, the boat will move — in the direction opposite to the sailor's jump (i.e., away from the shore).

Reason: By Newton's third law of motion, when the sailor pushes off the boat in the forward direction (toward the shore), the boat exerts an equal and opposite force on the sailor. Equivalently, the sailor exerts a backward force on the boat.
By Newton's second law, this backward force accelerates the boat in the direction away from the shore.

Additionally, by the law of conservation of momentum: before the jump the total momentum of the sailor + boat system is zero. After the jump, the sailor moves forward, so the boat must move backward to keep the total momentum zero.

Answer: Yes, the boat moves backward (away from the shore) due to Newton's third law — the force the sailor exerts on the boat is equal and opposite to the force the boat exerts on the sailor.

Q8 During a high jump event, a landing mat or sand bed is placed for the athlete to fall upon (Fig. 6.39). Explain the reason behind it.

SOLUTION

By Newton's second law: $F = \Delta p/\Delta t$, where Δp is the change in momentum and Δt is the time over which the change occurs.
When an athlete lands, their momentum changes from a large downward value to zero. This change in momentum (Δp) is fixed regardless of the surface.

The landing mat or sand bed is soft and compressible. It increases the time Δt over which the athlete comes to rest.
Since $F = \Delta p/\Delta t$, a larger Δt means a smaller force F acts on the athlete.

A smaller stopping force reduces the risk of injury to the athlete. Hard surfaces bring the athlete to rest very quickly (small Δt), producing a large, dangerous force.

Answer: The soft landing mat increases the time over which the athlete's momentum changes to zero, thereby reducing the impact force on the athlete and preventing injury.

Q9 A hand cart loaded with vegetables collides with an identical but empty hand cart. During the collision:
(i) the loaded cart exerts a force of larger magnitude on the empty cart.
(ii) the empty cart exerts a force of larger magnitude on the loaded cart.
(iii) neither cart exerts a force on the other.
(iv) the loaded cart and the empty cart, both exert an equal magnitude of force on each other.

SOLUTION

By Newton's third law of motion, whenever two objects interact, the force exerted by object A on object B is equal in magnitude and opposite in direction to the force exerted by object B on object A.
This law holds regardless of the masses or velocities of the objects.

Therefore, during the collision, the loaded cart exerts a force on the empty cart and the empty cart exerts an equally large force on the loaded cart — the forces are equal in magnitude.

Option (i) is wrong — Newton's third law does not allow one to be larger.
Option (ii) is wrong — same reason.

Option (iii) is wrong — they do exert forces on each other during the collision.
Option (iv) is correct.

Answer: (iv) The loaded cart and the empty cart both exert an equal magnitude of force on each other (Newton's third law).

Q10 The acceleration-mass graph for the acceleration produced by a force on objects of different masses is plotted in Fig. 6.40. Plot the force-mass graph for this case.

SOLUTION

From Fig. 6.40, the acceleration-mass graph is a hyperbola: as mass increases, acceleration decreases inversely.
Reading key data points from the graph:
At mass m = 1 kg, acceleration a = 10.0 m s^{-2}
At mass m = 2 kg, acceleration a = 5.0 m s^{-2}
At mass m = 4 kg, acceleration a = 2.5 m s^{-2}

Force at each mass: F = m × a
F = 1 × 10.0 = 10 N
F = 2 × 5.0 = 10 N
F = 4 × 2.5 = 10 N

The force is constant at 10 N for all masses.

Force-mass graph: Since F = 10 N (constant) for all values of mass, the force-mass graph is a horizontal straight line parallel to the mass axis at F = 10 N.

Answer: The force is constant at 10 N. The force-mass graph is a horizontal straight line at F = 10 N for all masses from 1 kg to 5 kg.

Q11 The velocity-time graph of an object of mass 10 kg moving along a straight line is shown in Fig. 6.41. Calculate the force acting on the object by using the graph.

SOLUTION

From Fig. 6.41: the velocity-time graph is a single straight line. The velocity increases uniformly from 10 m s^{-1} at t = 0 s to 30 m s^{-1} at t = 8 s (passing through 20 m s^{-1} at t = 4 s).

A straight-line velocity-time graph means the acceleration is uniform throughout.

Acceleration $a = (v - u)/t = (30 - 10)/(8 - 0) = 20/8 = 2.5 \text{ m s}^{-2}$
Mass $m = 10 \text{ kg}$

Force $F = m \times a = 10 \times 2.5 = 25 \text{ N}$

The force is constant at 25 N throughout the motion, acting in the direction of motion.

Answer: The acceleration is uniform at 2.5 m s^{-2}, so the force acting on the object is $F = m \times a = 10 \times 2.5 = 25$ N, constant and in the direction of motion.

Q12 A bullet of mass 50 g moving with a speed of 100 m s^{-1} enters a heavy stationary wooden block and stops after penetrating a distance of 50 cm. Estimate the stopping force acting on the bullet (assume that the bullet undergoes constant acceleration within the block).

SOLUTION

Given: mass $m = 50 \text{ g} = 0.05 \text{ kg}$; initial speed $u = 100 \text{ m s}^{-1}$; final speed $v = 0$; distance $s = 50 \text{ cm} = 0.5 \text{ m}$.

Using $v^2 = u^2 + 2as$:
$0 = (100)^2 + 2 \times a \times 0.5$
$0 = 10\,000 + a$
$a = -10\,000 \text{ m s}^{-2}$

Stopping force $F = m \times |a| = 0.05 \times 10\,000 = 500 \text{ N}$

The negative sign of acceleration indicates deceleration (force opposes motion).

Answer: The stopping force on the bullet is 500 N, acting opposite to its direction of motion.

Q13 An ace footballer converted a penalty shot by kicking the football with a speed of 108 km h^{-1}. The estimated force they imparted was 800 N. The mass of the football was 0.4 kg. Calculate the time of contact between their foot and the ball.

SOLUTION

Given: mass of ball $m = 0.4 \text{ kg}$; force $F = 800 \text{ N}$; initial speed of ball $u = 0$ (ball was stationary); final speed $v = 108 \text{ km h}^{-1}$.

Convert speed to SI units: $v = 108 \times (1000/3600) = 30 \text{ m s}^{-1}$.

By Newton's second law (impulse-momentum form):

$F \times t = m \times (v - u)$
$800 \times t = 0.4 \times (30 - 0)$
$800 \times t = 12$
$t = 12/800 = 0.015$ s

Answer: The time of contact between the foot and the ball is 0.015 s (i.e., 15 ms).

Q14 An object of mass 2 kg moving with a constant velocity of 10 m s^{-1} encounters a rough patch where the force of friction on the object is 7 N. At the same time, an additional constant force of 3 N opposing the motion is applied on the object. After entering the rough patch, how much distance does the object travel before coming to rest?

SOLUTION

Given: mass m = 2 kg; initial velocity u = 10 m s^{-1}; friction force = 7 N (opposing motion); additional force = 3 N (opposing motion); final velocity v = 0.

Total retarding force = 7 + 3 = 10 N (both oppose motion).
Acceleration (deceleration): $a = -F/m = -10/2 = -5$ m s^{-2}.

Using $v^2 = u^2 + 2as$:
$0 = (10)^2 + 2 \times (-5) \times s$
$0 = 100 - 10s$
$10s = 100$
$s = 10$ m

Answer: The object travels 10 m before coming to rest.

Q15 A tractor pulls a harrow (a ploughing tool) of mass m_1 with a net force F resulting in an acceleration of a_1. The same tractor pulls a trolley of mass m_2 with a force F producing an acceleration of a_2. If the tractor now pulls the trolley with the harrow placed on it (with the same force F), then obtain an expression for the resulting acceleration in terms of a_1 and a_2. Ignore friction.

SOLUTION

From pulling the harrow alone: $F = m_1 \times a_1 \Rightarrow m_1 = F/a_1$.
From pulling the trolley alone: $F = m_2 \times a_2 \Rightarrow m_2 = F/a_2$.

When the harrow is placed on the trolley, the combined mass = $m_1 + m_2$.
With the same force F:

$F = (m_1 + m_2) \times a$
$a = F / (m_1 + m_2)$
$a = F / (F/a_1 + F/a_2)$
$a = F / [F(1/a_1 + 1/a_2)]$
$a = 1 / (1/a_1 + 1/a_2)$
$a = (a_1 \times a_2) / (a_1 + a_2)$

Answer: The resulting acceleration $a = (a_1 \times a_2)/(a_1 + a_2)$.

Q16 When the pole of a bar magnet is brought close to a magnetic compass, the bar magnet and the compass needle (which is also a magnet) exert a magnetic force on each other. As per Newton's third law of motion, both the forces are equal in magnitude and opposite in direction. However, the compass needle moves, whereas the bar magnet does not move (Fig. 6.42). Explain why.

SOLUTION

Newton's third law guarantees that the force on the compass needle from the bar magnet equals the force on the bar magnet from the compass needle in magnitude.

However, Newton's second law relates force to acceleration: $a = F/m$.
The compass needle is extremely small and light (very small mass), so even a small force produces a large acceleration, causing it to move noticeably.

The bar magnet is much more massive than the compass needle. The same force F produces an acceleration $a = F/m$ that is extremely small for the large mass of the bar magnet.
Additionally, the bar magnet is typically held in the hand or placed on a surface, where static friction and the person's grip counteract any tiny movement.

Therefore, the compass needle moves visibly while the bar magnet appears stationary — not because the forces are unequal, but because the resulting accelerations are vastly different due to the large difference in mass.

Answer: Both forces are equal (Newton's third law), but the compass needle has a very small mass, so the same force produces a large acceleration and visible motion; the bar magnet's large mass means its resulting acceleration is negligible, and it does not move perceptibly.