



### In-Test Solution

1. Which of the following has more inertia: (a) a rubber ball and a stone of the same size? (b) a bicycle and a train? (c) a five-rupee coin and a one-rupee coin?

**Answer:** Inertia is the measure of the mass of the body. The greater is the mass of the body; the greater its inertia and vice-versa.

(a) The mass of a stone is more than the mass of a rubber ball of the same size. Hence, the inertia of the stone is greater than that of a rubber ball.

(b) The mass of a train is more than the mass of a bicycle. Hence, the inertia of the train is greater than that of the bicycle.

(c) The mass of a five-rupee coin is more than that of a one-rupee coin. Hence, the inertia of the five-rupee coin is greater than that of the one-rupee coin.

2. In the following example, try to identify the number of times the velocity of the ball changes: “A football player kicks a football to another player of his team who kicks the football towards the goal. The goalkeeper of the opposite team collects the football and kicks it towards a player of his team”. Also, identify the agent supplying the force in each case.

**Answer:**

The velocity of football changes four times. First, when a football player kicks another player, second when that player kicks the football to the goalkeeper. Third when the goalkeeper stops the football. Fourth when the goalkeeper kicks the football towards a player of his team.

Agent supplying the force

First case First player

Second case Second player

Third case Goalkeeper

Fourth case Goalkeeper



**3. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.**

**Answer:** When a tree is vigorously shaken, the branches of the tree come in motion but the leaves tend to continue in their state of rest due to inertia of rest. As a result of this, leaves get separated from the branches of the tree and hence fall down.

**4. Why do you fall in the forward direction when a moving bus brakes to a stop and fall backward when it accelerates from rest?**

**Answer:** Initially, when the bus accelerates in a forward direction from a state of rest, the passengers experience a force exerted on them in the backward direction due to their inertia opposing the forward motion.

Once the bus starts moving, the passengers are in a state of motion in the forward direction. When the brakes are applied, the bus moves towards a rest position. Now, a force in the forward direction is applied to the passengers because their inertia resists the change in the motion of the bus. This causes the passengers to fall forward when the brakes are applied.

**5. If action always equals the reaction, explain how a horse can pull a cart.**

**Answer:** The third law of motion states that action is always equal to the reaction but they act on two different bodies.

In this case, the horse exerts a force on the ground with its feet while walking, and the ground exerts an equal and opposite force on the feet of the horse, which enables the horse to move forward and the horse pulls the cart.

**6. Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity.**

**Answer:** When a fireman directs a large amount of water at a high velocity on fire from a hose pipe, they have to hold the hose pipe strongly because it tends to go backward. The backward movement of the hose pipe is due to the backward reaction force of the water rushing out through it in the forward direction at a high speed as per Newton's third law of motion.



7. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 m/s. Calculate the initial recoil velocity of the rifle.

Answer:

$$(m_1) \text{ Mass of rifle} = 4 \text{ kg}$$

$$(m_2) \text{ Mass of bullet} = 50 \text{ g} = 0.05 \text{ kg}$$

$$(v_2) \text{ Velocity of bullet} = 35 \text{ m/s}$$

$$(v_1) \text{ Recoil velocity of rifle} = ?$$

According to the law of conservation of momentum

$$\text{Momentum of rifle} = \text{momentum of bullet}$$

$$m_1 v_1 = m_2 v_2$$

$$4 \text{ kg} \times v_1 = 0.05 \times 35 \text{ m/s}$$

$$\therefore v_1 = \frac{0.05 \times 35}{4} = \frac{1.75}{4}$$

$$v_1 = 0.4375 \text{ m/s}$$

$$\therefore \text{Recoil velocity of rifle} = 0.4375 \text{ m/s}$$

8. Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of  $2 \text{ ms}^{-1}$  and  $1 \text{ ms}^{-1}$ , respectively. They collide and after the collision, the first object moves at a velocity of  $1.67 \text{ ms}^{-1}$ . Determine the velocity of the second object.

Answer:

$$m_1 = 100 \text{ g} = 0.1 \text{ kg}$$

$$m_2 = 200 \text{ g} = 0.2 \text{ kg}$$

$$u_1 = 2 \text{ m/s}$$

$$u_2 = 1 \text{ m/s}$$

After collision

$$v_1 = 1.67 \text{ m/s}$$

$$v_2 = ?$$

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

$$(0.1 \times 2) + (0.2 \times 1) = (0.1 \times 1.67) + (0.2 \times v_2)$$

$$\therefore 0.2 + 0.2 = 0.167 + 0.2v_2$$

$$0.4 - 0.167 = 0.2v_2$$

$$\frac{0.4 - 0.167}{0.2} = v_2$$

$$\therefore \frac{0.233}{0.2} = 1.165 \text{ m/s}$$

$\therefore$  The velocity of the second object is 1.165 m/s.



## Exercises Questions

- 1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on the magnitude and direction of the velocity. If no, provide a reason.**

**Answer:** By Newton's First law of motion, a body remains in a state of rest or uniform motion unless an external force is applied on it. So, if the body has some initial velocity and the net force applied is zero, it will continue to move with the same initial velocity.

- 2. When a carpet is beaten with a stick, dust comes out of it. Explain.**

**Answer:** When a carpet is beaten with a stick, the dust comes out of it because of the law of inertia.

Initially, the dust particles are at rest along with the carpet. Beating the carpet with the stick makes the carpet move but the dust particles remain at rest due to the inertia of rest, thus the dust gets detached from the carpet.

- 3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?**

**Answer:** Any luggage kept on the roof of a bus should be tied with a rope. This is because when the bus starts suddenly, the luggage pieces may fall due to the inertia of motion.

While the bus is moving, luggage tends to remain in an inertia-of-motion state. When the bus stops, the luggage tends to resist the change and due to the inertia of motion, it moves forward and may fall off. That's why it is advised to tie any luggage kept on the roof of a bus with a rope. We also know, when the bus moves in forward direction, the luggage kept on the roof also moves along with the bus in forward direction. Now when the bus suddenly stops, it comes to rest but the luggage is still in a forward direction due to inertia of motion, thus the luggage falls off the roof of the bus.

- 4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because**
  - (a) the batsman did not hit the ball hard enough.**
  - (b) velocity is proportional to the force exerted on the ball.**



(c) there is a force on the ball opposing the motion.

(d) there is no unbalanced force on the ball, so the ball would want to come to rest.

**Answer:** (c) there is a force on the ball opposing the motion.

A batsman hits a cricket ball, which then rolls on level ground. After covering a short distance, the ball comes to rest because there is frictional force on the ball opposing its motion.

Frictional force always acts in the direction opposite to the direction of motion. Hence, this force is responsible for stopping the cricket ball.

**5. A truck starts from rest and rolls down a hill with constant acceleration. It travels a distance of 400 m in 20 seconds. Find its acceleration. Find the force acting on it if its mass is 7 tonnes (Hint: 1 tonne = 1000 kg.)**

**Answer:**

Given, the distance covered by the truck ( $s$ ) = 400 meters

Time taken to cover the distance ( $t$ ) = 20 seconds

The initial velocity of the truck ( $u$ ) = 0 (since it starts from a state of rest)

From the equations of motion,  $s = ut + \frac{1}{2}at^2$

Therefore,  $400 = 0(20s) + \frac{1}{2}(a)(400s^2) = 2ms^{-2}$

The acceleration of the truck is equal to  $2 \text{ ms}^{-2}$

As per the second law of motion, Force = Mass  $\times$  Acceleration

Mass of the truck = 7 tonnes = 7000kg

Force acting on the truck =  $7000kg \times 2m.s^{-2} = 14000 \text{ kg.m.s}^{-2} = 14000 \text{ N}$

Therefore, a force of 14000 N is acting on the truck.

**6. A stone of 1 kg is thrown with a velocity of  $20 \text{ ms}^{-1}$  across the frozen surface of a lake and comes to rest after traveling a distance of 50 m. What is the force of friction between the stone and the ice?**

**Answer:**



Answer:

$$m = 1 \text{ kg}$$

$$u = 20 \text{ m/s}$$

$$s = 50 \text{ m}$$

$$v = 0$$

$$F = ?$$

$$a = ?$$

$$v^2 - u^2 = 2as$$

$$(0)^2 - (20)^2 = 2a(50)$$

$$\therefore -400 = 100a$$

$$\therefore a = \frac{-400}{100} = -4 \text{ m/s}^2$$

$$\begin{aligned} \text{Force of friction, } F &= m \times a \\ &= 1 \text{ kg} \times -4 \text{ m/s}^2 \\ &= -4 \text{ N} \end{aligned}$$

7. A 40000 kg engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate:

Answer:

(a) The net accelerating force = Force exerted by the engine – friction force  
 $= 40000 \text{ N} - 5000 \text{ N}$   
 $= 35000 \text{ N}$

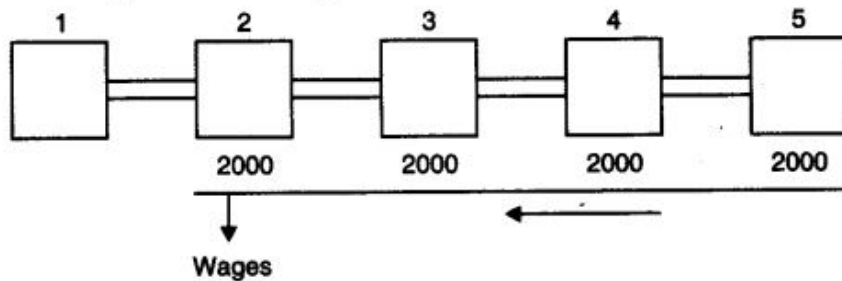
(b) The acceleration of the train  $(a) = ?$   
 $F = 35000 \text{ N}$

Mass of 5 wagons pulled by engine =  $5 \times 2000$   
 $= 10000 \text{ kg}$

$\therefore F = ma$   
 $35000 = 10000 \times a$

$\therefore a = \frac{35000}{10000} = 3.5 \text{ m/s}^2$

(c) The force of wagon 1 on wagon 2



$$F = ?$$

Mass of wagon 2  $\rightarrow (2000 \times 4)$

$$\begin{aligned} a &= 3.5 \text{ m/s}^2 \\ F &= ma \\ &= 8000 \times 3.5 \\ &= 28000 \text{ N} \end{aligned}$$



**8. An automobile vehicle has a mass of 1500 kg. What must be the force between the vehicle and the road if the vehicle is to be stopped with a negative acceleration of  $1.7 \text{ ms}^{-2}$ ?**

**Solution:**

Given, the mass of the vehicle ( $m$ ) = 1500 kg

Acceleration ( $a$ ) =  $-1.7 \text{ ms}^{-2}$

As per the second law of motion,  $F = ma$

$$F = 1500\text{kg} \times (-1.7 \text{ ms}^{-2}) = -2550 \text{ N}$$

Hence, the force between the automobile and the road is -2550 N, in the opposite direction of the automobile's motion.

**9. What is the momentum of an object of mass  $m$ , moving with a velocity  $v$ ?**

**(a)  $(mv)^2$  (b)  $mv^2$  (c)  $\frac{1}{2} mv^2$  (d)  $mv$**

**Solution:**

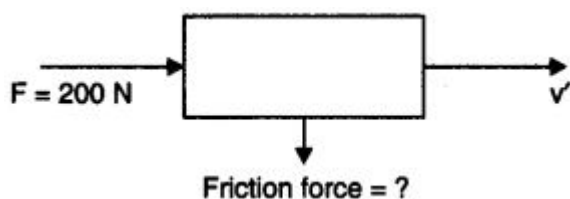
The momentum of an object is defined as the product of its mass  $m$  and velocity  $v$

Momentum = mass x velocity

Hence, the correct answer is  $mv$  i.e option (d)

**10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?**

**Answer:**



As the wooden cabinet moves across the floor at a constant velocity and the force applied is 200 N. Hence the frictional force that will be exerted on the cabinet will be less than 200 N.



11. Two objects each of mass 1.5 kg, are moving in the same straight line but in opposite directions. The velocity of each object is  $2.5 \text{ ms}^{-1}$  before the collision during which they stick together. What will be the velocity of the combined object after collision?

Answer:

$$\text{Mass of the objects } m_1 = m_2 = 1.5 \text{ kg}$$

$$\text{Velocity of first object } v_1 = 2.5 \text{ m/s}$$

$$\text{Velocity of second object } v_2 = -2.5 \text{ m/s}$$

$$\begin{aligned} \text{Momentum before collision} &= m_1 v_1 + m_2 v_2 \\ &= (1.5 \times 2.5) + (1.5 \times -2.5) = 0 \end{aligned}$$

$$\text{Momentum after collision} = m_1 + m_2 = 1.5 + 1.5 = 3.0 \text{ kg}$$

$$\text{After collision } v = ?$$

According to law of conservation of momentum

$$\text{Momentum before collision} = \text{Momentum after collision}$$

$$0 = 3 \times v$$

$$\therefore v = 0$$

12. According to the third law of motion when we push on an object, the object pushes back on us with an equal and opposite force. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.

**Answer:** According to the third law of motion when we push an object, the object pushes us back with an equal and opposite force. These two forces are called action-reaction pairs.

The student's justification is incorrect since action and reaction always operate on different bodies and hence cannot cancel each other. When two equal and opposite forces act on the same body, they cancel each other.

A truck parked on the side of the road is a heavyweight and generates greater friction between the tires and the ground than the force applied. As a result, the truck will only move if a force greater than the friction force is applied to it.



13. A hockey ball of mass 200 g travelling at  $10 \text{ ms}^{-1}$  is struck by a hockey stick to return it along its original path with a velocity of  $5 \text{ ms}^{-1}$ . Calculate the change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.

Answer:

$$\text{Mass of ball } m = 200 \text{ g} = 0.2 \text{ kg}$$

$$\text{Initial speed of ball } u = 10 \text{ m/s}$$

$$\text{Final speed of ball } v = -5 \text{ m/s}$$

$$\begin{aligned} \text{Initial momentum of the ball} &= mu \\ &= 0.2 \text{ kg} \times 10 \text{ m/s} \\ &= 2 \text{ kg m/s} \end{aligned}$$

$$\begin{aligned} \text{Final momentum of the ball} &= mv \\ &= 0.2 \text{ kg} \times (-5 \text{ m/s}) \\ &= -1 \text{ kg m/s} \end{aligned}$$

$$\begin{aligned} \text{Hence, change in momentum} &= \text{Difference in the momentum} \\ &= 2 - (-1) \\ &= 2 + 1 = 3 \text{ kg m/s} \end{aligned}$$

14. A bullet of mass 10 g traveling horizontally with a velocity of  $150 \text{ m s}^{-1}$  strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also, calculate the magnitude of the force exerted by the wooden block on the bullet.

Answer:

$$m = 10 \text{ g} = \frac{10}{1000} = 0.01 \text{ kg}$$

$$u = 150 \text{ m/s}$$

$$v = 0 \text{ m/s}$$

$$t = 0.03 \text{ s}$$

$$v = u + at$$

$$0 = 150 + a(0.03)$$

$$a = \frac{-150}{0.03} = -5000 \text{ m/s}^2$$

$$s = ?$$

$$F = ?$$

$$v^2 - u^2 = 2as$$



$$\therefore (0)^2 - (150)^2 = 2 \times 5000 \times s$$

$$\therefore s = \frac{150 \times 150}{2 \times 5000}$$

$$s = \frac{22500}{10000}$$

$$s = 2.25 \text{ m.}$$

$\therefore$  The penetration distance of the bullet in the wooden block = 2.25 m.

$$\text{Magnitude of force } F = ma$$

$$= \frac{10}{1000} \times 5000$$

$$F = 50 \text{ N.}$$

15. An object of mass 1 kg travelling in a straight line with a velocity of  $10 \text{ ms}^{-1}$  collides with, and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact just after the before impact and just after the impact. Also, calculate the velocity of the combined object.

Answer:

$$m_1 = 1 \text{ kg}$$

$$v_1 = 10 \text{ m/s}$$

$$\text{Mass of wooden block} = 5 \text{ kg}$$

$$m_2 = 5 \text{ kg} + 1 \text{ kg (combined object)} = 6 \text{ kg}$$

$$\text{Velocity of combined object} = v_2 = ?$$

$$p_1 \text{ and } p_2 = ?$$

$$\text{Momentum before impact } p = m_1 v_1$$

$$= 1 \times 10 = 10 \text{ kg m/s}$$

$\therefore$  Momentum before impact = Momentum after impact

$$m_1 v_1 = m_2 v_2$$

$$10 \text{ kg m/s} = 6 v_2$$

$$\therefore \frac{10}{6} = v_2$$

$$\therefore v_2 = 1.67 \text{ m/s}$$



16. An object of mass 100 kg is accelerated uniformly from a velocity of  $5 \text{ ms}^{-1}$  to  $8 \text{ ms}^{-1}$  in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

Answer:

$$m = 100 \text{ kg}$$

$$u = 5 \text{ m/s}$$

$$v = 8 \text{ m/s}$$

$$t = 6 \text{ s}$$

$$p_1 = ?$$

$$p_2 = ?$$

$$F = ?$$

$$\begin{aligned} \therefore \text{Initial momentum } p_1 &= mu \\ &= 100 \times 5 = 500 \text{ kg m/s} \end{aligned}$$

$$\begin{aligned} \text{Final momentum } p_2 &= mv \\ &= 100 \times 8 = 800 \text{ kg m/s} \end{aligned}$$

$$\begin{aligned} \text{Force exerted on the object } F &= ma \\ &= 100 \left( \frac{u - v}{t} \right) \\ &= 100 \left( \frac{8 - 5}{6} \right) = 100 \times \frac{3}{6} \\ F &= 50 \text{ N} \end{aligned}$$

17. Akhtar, Kiran, and Rahul were riding in a motorcar that was moving with a high velocity on an expressway when an insect hit the windshield and got stuck on the windscreen. Akhtar and Kiran started pondering over the situation. Kiran suggested that the insect suffered a greater change in momentum as compared to the change in momentum of the motorcar (because the change in the velocity of the insect was much more than that of the motorcar). Akhtar said that since the motorcar was moving with a larger velocity, it exerted a larger force on the insect. And as a result, the insect died. Rahul while putting an entirely new explanation said that both the motorcar and the insect experienced the same force and a change in their momentum. Comment on these suggestions.



**Answer:**

Kiran's statement:

The change in momentum of the insect and the motorcar is equal to the conservation of momentum. The velocity of the insect changes significantly because its mass is very small compared to the motorcar. Similarly, the velocity of the motorcar is very insignificant because its mass is very large compared to the insect. Hence, Kiran's statement is false.

Akhtar's statement:

By Newton's third law of motion, action and reaction force are equal and opposite and they act on different bodies. Hence, the motorcar and the insect both experience the same force. Since the mass of the insect is very small compared to the motorcar, it suffers a huge change in velocity as compared to the car. Due to this, the insect dies. Hence, Akhtar's statement is false.

Rahul's Statement:

As discussed before, both the motorcar and the insect experience the same force and change in momentum. Hence, Rahul's statement is correct.

**18. How much momentum will a dumbbell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be  $10 \text{ ms}^{-2}$ .**

**Answer:**

$$\text{Mass of dumb-bell} = 10 \text{ kg}$$

Height,

$$h = 80 \text{ cm} = 0.8 \text{ m}$$

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

$$u = 0$$

$$v^2 - u^2 = 2as$$

$$v^2 - (0)^2 = 2 \times 10 \times 0.8$$

$$v^2 = 16$$

$\therefore$

$$v = 4 \text{ m/s}$$

$$\text{Momentum } p = mv$$

$$= 10 \times 4$$

$$= 40 \text{ kgm/s}$$



### Additional Exercises

1. The following is the distance-time table of an object in motion:

Time (seconds)	Distance (meters)
0	0
1	1
2	8
3	27
4	64
5	125
6	216
7	343

(a) What conclusion can you draw about the acceleration? Is it constant, increasing, decreasing, or zero? (b) What do you infer about the forces acting on the object?

**Answer:**

(a) The distance covered by the object at any time interval is greater than any of the distances covered in previous time intervals. Therefore, the acceleration of the object is increasing.

(b) As per the second law of motion, force = mass  $\times$  acceleration. Since the mass of the object remains constant, the increasing acceleration implies that the force acting on the object is increasing as well

2. Two persons manage to push a motorcar of mass 1200 kg at a uniform velocity along a level road. The same motorcar can be pushed by three persons to produce an acceleration of  $0.2 \text{ ms}^{-2}$ . With what force does each person push the motorcar? (Assume that all persons push the motorcar with the same muscular effort)

**Answer:**

Given, a mass of the car ( $m$ ) = 1200kg

When the third person starts pushing the car, the acceleration ( $a$ ) is  $0.2 \text{ ms}^{-2}$ .

Therefore, the force applied by the third person ( $F = ma$ ) is given by:

$$F = 1200\text{kg} \times 0.2 \text{ ms}^{-2} = 240\text{N}$$



The force applied by the third person on the car is 240 N. Since all 3 people push with the same muscular effort, the force applied by each person on the car is 240 N.

**3. A hammer of mass 500 g, moving at 50 m s<sup>-1</sup>, strikes a nail. The nail stops the hammer in a very short time of 0.01 s. What is the force of the nail on the hammer?**

**Answer:**

Mass of hammer  $m = 500 \text{ g} = 0.5 \text{ kg}$

Initial velocity of hammer  $u = 50 \text{ ms}^{-1}$

Final velocity of hammer  $v = 0$  and time  $t = 0.01 \text{ s}$

$$\therefore \text{Acceleration of the hammer, } a = \frac{v - u}{t} = \frac{0 - 50}{0.01} = -5000 \text{ ms}^{-2}$$

$\therefore$  Force applied by the nail on hammer

$$F = ma = (0.5) \times (-5000) \\ = -2500 \text{ N}$$

-ve sign of force suggests that the force is opposing the motion of hammer.

**4. A motorcar of mass 1200 kg is moving along a straight line with a uniform velocity of 90 km/h. Its velocity is slowed down to 18 km/h in 4 s by an unbalanced external force. Calculate the acceleration and change in momentum. Also, calculate the magnitude of the force required.**

**Answer:**

$$\text{Initial velocity of car } u = 90 \text{ km/h} = 90 \times \frac{5}{18} \text{ ms}^{-1} = 25 \text{ ms}^{-1}$$

$$\text{Final velocity of car} = 18 \text{ kmh}^{-1} = 18 \times \frac{5}{18} = 5 \text{ ms}^{-1}$$

$$\text{and time } t = 4 \text{ s}$$

$$\text{Acceleration } a = \frac{v - u}{t} = \frac{5 - 25}{4} = -5 \text{ ms}^{-2}$$

Change in momentum of car

$$mv - mu = m(v - u) \\ = 1200(5 - 25) = -24000 \text{ kg ms}^{-1}$$

$$\text{Magnitude of force } F = ma = 1200 \times (-5) = -600 \text{ N}$$

-ve sign of acceleration, change in momentum and force suggests that the force is opposing the motion of motor car.



**5. A large truck and a car, both moving with a velocity of magnitude  $v$ , have a head-on collision and both of them come to a halt after that. If the collision lasts for 1 s:**

- (a) Which vehicle experiences the greater force of impact?**
- (b) Which vehicle experiences the greater change in momentum?**
- (c) Which vehicle experiences the greater acceleration?**
- (d) Why is the car likely to suffer more damage than the truck?**

**Answer:**

(a) During head-on collision forces applied by truck and car are action-reaction forces. Hence both vehicles experience the same (equal) force of impact.

(b) Here initial velocity of both car and truck is equal to  $v$  and the final velocity of both is zero. But the mass of the truck is much more than that of the car, hence change in the momentum of the truck is more than a change in the momentum of the car.

(c) For the same force of impact, the acceleration of the car will have greater magnitude because its mass is less.

(d) The car suffers more damage than the truck, as the acceleration of the car is greater, its velocity falls to zero in a shorter time, and consequently, its momentum changes in a shorter time.

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