CHAPTER

8

FORCE AND LAWS OF MOTION

Syllabus

Force and Motion, Newton's Laws of Motion, Action and Reaction forces, Inertia of a body, Inertia and mass, Momentum, Force and Acceleration. Elementary idea of Conservation of Momentum.

TOPIC-1
Force, Inertia and Laws of Motion

Revision Notes

- **Force :** It is a push or pull acting upon an object. It can change the shape of an object. It can put the object in motion, can change the direction of the object in motion or it can bring the object in motion to rest. For example, while riding a bicycle, you can set the bicycle in motion due to the force applied by peddling, you can change the direction of movement of the bicycle or you can bring it to rest by applying force in the form of brakes.
- There are mainly two types of forces : balanced forces and unbalanced forces.
- **Balanced forces :** These are the two forces that act on an object in opposite directions. They are equal in magnitude. They cancel each other. So, they do not change the state of rest or of motion of an object.
- **Unbalanced forces :** These forces are not equal in magnitude. So, they can change the state of or of motion of an object on which they are acting.
- By observing the motion of objects on an inclined plane, scientist Galileo concluded that objects move with a constant speed when no force is acting on them.
- Newton further studied Galileo's ideas on force and motion. Then he put forth three fundamental laws which govern the motion of objects. These three laws are known as Newton's laws of motion.


Newton

- **Newton's First Law of Motion :** It states that a body at rest will remain at rest and a body in motion will remain in uniform motion unless acted upon by an unbalanced force.
- It means all objects resist a change in their state of motion. Or They have a tendency to continue the state in which they are.
- **Inertia :** The tendency of undisturbed objects to stay at rest or in uniform motion is called inertia.
- Heavier the object, larger is the inertia. So, the inertia of an object is measured by its mass.
- The first law of motion indicates that when an unbalanced external force acts on an object, its velocity changes, that is, the object gets an acceleration.
- If an object is to be accelerated, we have to apply force. We know that a greater force is required to give a greater velocity.
- There must be some properties which combine the object's mass and its velocity. One such property called momentum was introduced by Newton.
- The momentum of an object is the product of its mass and velocity and has the same direction as that of the velocity. Its SI unit is kg m-s^{-1}.
- Applying an unbalanced force brings a change in the velocity of the object. It means that the applied force produces a change of momentum.

- The force necessary to change the momentum of an object depends on the time rate at which the momentum is changed.
- **Newton's second law of motion :** It states that the rate of change of momentum of a body is directly proportional to the force and takes place in the same direction as the force.
- **Mathematical Formulation of Newton's Second Law of Motion :**

  Suppose an object of mass m is moving along a straight line with an initial velocity u. It is uniformly accelerated to velocity v in time t by the application of a constant force F, throughout the time t. The initial and final momentum of the object will be, $p_1 = mu$ and $p_2 = mv$ respectively .

  The change in momentum $= p_2 - p_1$

  $= mv - mu$

  The rate of change of momentum $\propto \frac{m \times (v-u)}{t}$

  Or, the applied force, according to second law

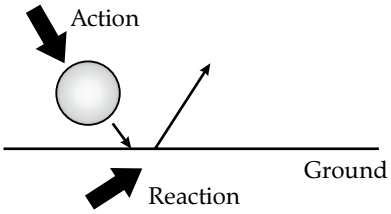
  $$F \propto \frac{m \times (v-u)}{t}$$

  $$F = \frac{km \times (v-u)}{t}$$, where k is the proportionality constant.

  $$F = kma$$, and setting k = 1 in the SI unit system, we get,

  $$F = ma$$

  where, a [$= (v-u)/t$] is the acceleration, that is the rate of change of velocity.
- Force can also be defined as the product of mass and acceleration. The SI unit of force is kg ms^{-2}. This is also known as newton and represented by the symbol N.
- Unit for force is newton, and abbreviation is N or kg m s^{-2}.
- A force of one newton produces an acceleration of 1 m s^{-2} on an object of mass 1 kg.
- When there is a force of friction between two objects, it always opposes motion of objects.
- Two forces resulting from the interaction between two objects are called action and reaction forces respectively.



- Action and reaction forces act on two different bodies but they are equal in magnitude and opposite in direction to each other. (In the above figure, they are the vertical components.)
- The first two laws of motion tell us how an applied force changes the motion. They help us to find out he method of determining the force.
- **Newton's third law of motion :** For every action there is an equal and opposite reaction; but action and reaction forces act on different bodies. For example, when a gun is fired, it exerts a forward force on the bullet. The bullet exerts an equal and opposite force on the gun. This results in the recoil of the gun.

SELF ASSESSMENT – 1

I. OBJECTIVE TYPE QUESTIONS [1 mark each]

A. Multiple Choice Questions

Ⓡ **Q. 1. What is recoil velocity of a gun?**

(a) The velocity with which a gun moves forward after firing a bullet.

(b) The velocity with which a gun moves backward after firing a bullet.

(c) The velocity with which the bullet travels.

(d) The velocity with which the bullet strikes.

Ⓚ **Q. 2. Why are the athletes in a high jump event made to fall either on a cushioned bed or on a sand bed?**

(a) To increase the rate of change of momentum and hence the force.

(b) To increase the rate of change of momentum and decrease the force.

(c) To reduce the rate of change of momentum and hence the force.

(d) To reduce the rate of change of momentum and to increase the force.

B. Diagram Based Question

Ⓐ **Q. 1. In the figure below the card is flicked with a push.**

(a) What do you observe in the above case and why?

(b) State the law involved in this case.

(c) What will be your observation if the above coin is replaced by a heavy five rupee coin. Justify your answer.

(d) State the law that provides the formula for measuring force and the law which provides the definition of force.

C. Assertion and Reason type questions

Directions : In the following questions, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as :

(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).

(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).

(c) Assertion (A) is true but reason (R) is false.

(d) Assertion (A) is false but reason (R) is true.

(K) **Q. 1. Assertion :** If a spring is stretched from one side, the size and shape of the spring changes.

Reason : Unbalanced force acting on the spring changes the size and shape of the spring in the direction of application.

(K) **Q. 2. Assertion :** When we stop pedalling a bicycle it slows down.

Reason: Force of friction always acts in the direction of motion.

D. Very Short Answer Type Questions

(U) **Q. 1.** Give one point of difference between balanced and unbalanced forces.

(K) **Q. 2.** Find the acceleration produced by a force of 12 N exerted on an object of mass 3 kg.

II. SHORT ANSWER TYPE QUESTIONS-I [2 marks each]

Q. 1. Two boys dropped sheets of paper from the top of the tower. One by dropped his sheet of paper as such, while the other boy dropped it by changing it in the shape of a ball. Which sheet of paper willreach the ground first? Explain why? (Assume air-resistance negligible).

(A) **(Board Term-I, 2014)**

Q. 2. What are the effects of the following on inertia of a body?

(i) If force is doubled

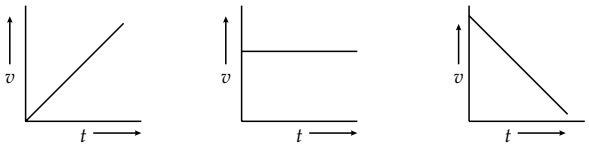
(ii) If density is halved

(iii) If volume is reduced to one third.

(A) **(Board Term-I, 2016)**

III. SHORT ANSWER TYPE QUESTIONS-II [3 marks each]

(A) **Q. 1.** What type of force is acting in the cases given below?



(i) (ii) (iii)

(U)+(A) **(Board Term-I, 2016)**

(U) **Q. 2. Read the passage carefully and answer the following questions :**

When we are travelling by a motor car, we tend to remain at rest with respect to the seat until the driver applies a braking force to stop the motorcar. With the application of brakes, the car slows down but our body tends to continue in the same state of motion because of its inertia. A sudden application of brakes may thus cause injury to us by impact or collision with the panels in front. Safety belts are worn to prevent such accidents. Safety belts exert a force on our body to make the forward motion slower.

(a) Why does our body continue in the same state of motion though brakes are applied to a moving motorcar?

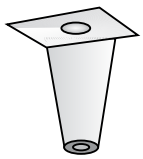
(b) Why are safety belts worn?

(c) How do safety belts help?

IV. LONG ANSWER TYPE QUESTIONS [5 marks each]

(A) **Q. 1. (i)** State Newton's second Law of Motion. Express it mathematically and find SI unit of force from it.

(ii) In the diagram given, if the card is flicked away with a jerk, what will you observe? Explain the reason for this observation.



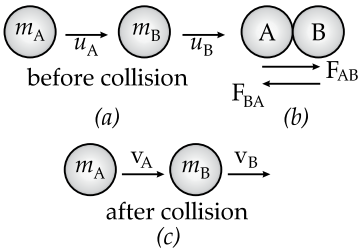
(R)+(A) **(Board Term-I, 2015)**

AI (K) **Q. 2.** Using second law of motion, derive the relation between force and acceleration.

TOPIC-2
Conservation of Momentum

Revision Notes

- Momentum is a property that combines the mass and velocity of the object together. It is the product of mass and velocity of an object.
- **Law of conservation of momentum :** The sum of momenta of the two objects before collision is equal to the sum of momenta after the collision, provided there is no external unbalanced force acting on them. Or, the total momentum of the two objects is unchanged or conserved by the collision.
- Suppose two objects (two balls A and B, say) of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B, respectively [Fig. (a)]. And there are no other external unbalanced forces acting on them. Let $u_A > u_B$ and the two balls collide with each other as shown in Fig. (b). During collision which lasts for a time t, the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A. Suppose v_A and v_B are the velocities of the two balls A and B after the collision, respectively [Fig.(c)].



Momentum of ball A before and after the collision are $m_A\ u_A$ and $m_A v_A$, respectively. The rate of change of its

momentum (or F_{AB}) during the collision will be $m_A \frac{(v_A - u_A)}{t}$

Similarly, the rate of change of momentum of ball B (= F_{BA}) during the collision will be $m_B \frac{(v_B - u_B)}{t}$

According to the third law of motion, the force F_{AB} exerted by ball A on ball B and the force F_{BA} exerted by the ball B on ball A must be equal and opposite to each other.

Therefore,

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

or $$m_A \frac{(v_A - u_A)}{t} = -m_B \frac{(v_B - u_B)}{t}$$

This gives,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

Thus, we can generalize this equation, by law of conservation of momentum, as, $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ where m_1 , m_2 are the masses of the colliding bodies, u_1, u_2 are their initial velocities while v_1, v_2 are there final velocities respectively.

SELF ASSESSMENT – 2

I. OBJECTIVE TYPE QUESTIONS [1 mark each]

A. Multiple Choice Questions

Q. 1. Which of the following accidents will be most damaging ?

(a) Collision between two cars moving with a speed of 50 km/hr.
(b) Collision between two bicycles.
(c) Collision between two scooters moving with a speed of 50 km/hr.
(d) Collision between two trucks moving with a speed of 50 km/hr.

Q. 2. A ball is thrown vertically upwards. What will be its momentum at the highest point ?

(a) 1 kg m s^{-1} as $v = 1$ **(b)** Zero as $v = 0$
(c) 10 kg m s^{-1} as $v = 0$ **(d)** 100 kg m s^{-1} as $v = 10$

B. Passage Based Questions

Q. 1. Read the given passage and answer the following questions.

Akhtar, Kiran and Rahul were riding in a motorcar that was moving with a high velocity on an express-way 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.

(a) Whose suggestion is correct?
(b) Define momentum.
(c) What is the SI unit of momentum?
(d) Find the momentum of a man of mass 75 kg when he walks with a velocity of 2 m/s.

C. Assertion and Reason type questions

Directions : In the following questions, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:

(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).
(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
(c) Assertion (A) is true but reason (R) is false.
(d) Assertion (A) is false but reason (R) is true.

(K) **Q. 1. Assertion :** Momentum of an object which is the product of mass and velocity is a vector quantity.
Reason : Momentum has both direction as well as magnitude.

(K) **Q. 2. Assertion :** If a balanced force is applied on a wooden block it will move.
Reason : Unbalanced force changes the state of motion or rest while balanced force does not.

D. Very Short Answer type questions

(R) **Q. 1.** Name the physical quantity which is measured by rate of change of momentum.

(AI) (A) **Q. 2.** Which has more inertia, a cricket ball or a rubber ball of the same size? Give reason for your answer.

II. SHORT ANSWER TYPE QUESTIONS-I [2 marks each]

Q. 1. Which accident will be more damaging, collision between two trucks moving with a speed of 50 km/hr or collision between two cars moving with a speed of 50 km/hr? Explain.

(A) **(Board Term-I, 2014)**

Q. 2. (i) Which one has more inertia : a five rupee coin or a one rupee coin? Why?
(ii) Two objects P and Q of masses 'm' and '4m' move with velovitles 'v' and '4v' respectively. Calculate the ratio of their llnear momenta.

(A) **(Board Term-I, 2012)**

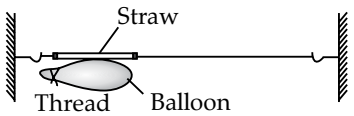
III. SHORT ANSWER TYPE QUESTIONS-II [3 marks each]

(AI) (K) **Q.1. (i)** A ball is allowed to roll down from an inclined plane. It reaches the foot of the plane and continues to roll on the ground. It stops after travelling some distance. Is this the violation of law of inertia? Give reasons for your answer. **(DDE 2014)**
(ii) A player lowers his hand while catching a ball. Explain reason behind his action.

(A) **Q. 2.** A body of mass 4 kg is dropped from a height of 20 m. Calculate the initial momentum and the momentum just before it strikes the ground. ($g = 10\ m/s^2$)

IV. LONG ANSWER TYPE QUESTIONS [5 marks each]

(R)+(A) **Q. 1. (a)** State the law of conservation of momentum.
(b) Observe the following diagram and answer the questions given below :



(i) Which direction does the balloon move when the thread tied to its neck is removed and why ?
(ii) State the conclusion drawn from this activity.

(A) **Q. 2.(i)** Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of 2 m/s and 1 m/s respectively. They collide and after the collision, the first object moves at a velocity of 1.67 m/s. Determine the velocity of second object.
(ii) If a man jumps out from a boat, the boat moves backwards. Why ?

NCERT CORNER

Intext Question

Q. 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-rupees coin and a one-rupee coin.

[NCERT Q. 1, Page 118]

[KVS, Patna Region, SA-I, 2015-16]

Ans. Inertia is the measure of the mass of the body. The greater is the mass of the body, the greater is its inertia and vice-versa.

(a) Mass of a stone is more than the mass of a rubber ball for the same size. So, inertia of the stone is greater than that of a rubber ball.

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

(c) Mass of a five-rupee coin is more than that of a one-rupee coin. So, inertia of the five-rupee coin is greater than that of the one-rupee coin.

Q. 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 own team".

Also identify the agent supplying the force in each case. **[NCERT Q. 2, Page 118]**

Ans. The velocity of football changes four times in following ways:

(i) First, when a football player kicks the football to another player.

(ii) Second, when that player kicks the football to the goalkeeper.

(iii) Third, when the goalkeeper stops the football.

(iv) Fourth, when the goalkeeper kicks the football towards a player of his own team.

As a football player kicks the football, its speed changes from zero to a certain value. So that, the velocity of the ball gets changed. In this case, the player applied a force to change the velocity of the ball. Another player kicks the ball towards the goal post. As a result, the direction of the ball gets changed.

Therefore, its velocity also changes. In this case, the player applied a force to change the velocity of the ball. The goalkeeper collects the ball. In other words, the ball comes to rest. So, its speed comes to zero from a certain value. The velocity of the ball has changed. In this case, the goalkeeper applied an opposite force to stop/change the velocity of the ball.

The goalkeeper kicks the ball towards his team players. Hence, the speed of the ball increases from zero to a certain value. Hence, its velocity changes once again. In this case, the goalkeeper applied a force to change the velocity of the ball.

Agent supplying the force are-

(i) First case – First player

(ii) Second case – Second player

(iii) Third case – Goalkeeper

(iv) Fourth case – Goalkeeper

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

[NCERT Q. 3, Page 118]

Ans. Some leaves of a tree get detached when we shake its branches vigorously. This is due to the Newton's first law of motion.

Initially, leaves and tree both are in rest. So, when the branches of a tree are shaken, it moves to and fro, but its leaves tend to remain at rest.

This is because the inertia of the leaves tends to resist the 'to and fro' motion. Due to this reason, some leaves fall down from the tree when shaken some vigorously.

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

[NCERT Q. 4, Page 118]

Ans. According to the Law of inertia- "If a body is at rest, then it tries to remain at rest. If a body is moving, then it tries to remain in motion".

In a moving bus, passengers are in motion along with bus. When brakes are applied to stop a moving bus, it comes to rest. So the lower of a person in contact with the bus also stops. But the upper body remains in motion due to inertia, caused the person fall forwards.

Similarly, when a bus is accelerated from rest, the lower body is contact with the bus gets dragged forward, while the upper body remains in a state rest due to inertia. So the person falls backwards.

Q. 5. If action is always equal to the reaction, explain how a horse can pull a cart.

[NCERT Q. 1, Page 126]

Ans. Horse pushes the ground in backward direction. In reaction to this, the ground pushes the horse moves forward and cart moves along with horse in forward direction.

According to Newton's third law of motion, a reaction force is exerted by the ground on the horse in the forward direction.

Q. 6. Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity. **[NCERT Q. 2, Page 126]**

Ans. According to the Newton's third law of motion, when large amount of water is ejected from a

hose at a high velocity, water pushes the hose in backward direction with the same force.

As a result of the backward force, the stability of the fireman decreases. Hence, it is difficult for him to remain stable while holding the hose.

Q. 7. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 m s^{-1}. Calculate the initial recoil velocity of the rifle.

[NCERT Q. 3, Page 126]
[KVS, Patna Region, SA-I, 2015-16]

Ans. Given that,

Mass of the rifle, $m_1 = 4$ kg

Mass of the bullet, $m_2 = 50$ g $= 0.05$ kg

Recoil (final) velocity of the rifle $= v_1$

Bullet is fired with an initial velocity, $v_2 = 35$ m/s

Initially, the rifle and bullet are at rest, so $u_1 = u_2 = 0$

Total initial momentum of the rifle and bullet system

$$= m_1u_1 + m_2u_2$$
$$= 0$$

Total momentum of the rifle and bullet system after firing :

$$= m_1v_1 + m_2v_2$$
$$= 4(v_1) + 0.05 \times 35$$
$$= 4v_1 + 1.75$$

According to the law of conservation of momentum :

Total momentum after the firing

= Total momentum before the firing

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$
$$4v_1 + 1.75 = 0$$
$$\Rightarrow \quad v_1 = -1.75/4$$
$$= -0.4375 \text{ m/s}$$

The negative sign indicates that the rifle recoils backwards with a velocity of 0.4375 m/s.

Q. 8. Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of 2 m s^{-1} and 1 m s^{-1}, respectively. They collide and after the collision, the first object moves at a velocity of 1.67 m s^{-1}. Determine the velocity of the second object. **[NCERT Q. 4, Page 127]**

Ans. Given that,

Mass of one of the objects, $m_1 = 100$ g $= 0.1$ kg

Mass of the other object, $m_2 = 200$ g $= 0.2$ kg

Velocity of m_1 before collision, $u_1 = 2$ m/s

Velocity of m_2 before collision, $u_2 = 1$ m/s

Velocity of m_1 after collision, $v_1 = 1.67$ m/s

Velocity of m_2 after collision $= v_2$

According to the law of conservation of momentum :

Total momentum before collision

= Total momentum after collision

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$
$$\Rightarrow 0.1 \times 2 + 0.2 \times 1 = 0.1 \times 1.67 + 0.2 \times v_2$$
$$\Rightarrow \quad 0.4 = 0.67 + 0.2 \times v_2$$
$$\Rightarrow \quad v_2 = 1.165 \text{ m/s}$$

Hence, the velocity of the second object becomes 1.165 m/s after the collision.

Exercise Questions

Q. 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.

Ans. Yes, it is possible, but only when the object has been moving with a constant velocity in a particular direction.

Then, there is no net unbalanced force applied on the body. The object will keep moving with a non-zero velocity. To change the state of motion, a net non-zero external unbalanced force must be applied on the object.

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

Ans. According to the law of inertia, when a carpet is beaten with a stick, then the carpet comes to motion.

But the dust particles try to resist any change to their inertia. Hence the dust particles come out of the carpet, as they do not move with the carpet.

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

Ans. When the bus accelerates and moves forward, it acquires a state of motion. However, the luggage kept on the roof, owing to its inertia, tends to remain in its state of rest.

So, with the forward movement of the bus, the luggage tends to remain at its original position and ultimately falls from the roof of the bus. To avoid this, it is advised to tie any luggage kept on the roof of a bus with a rope.

Q. 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.

Ans. Correct option : (c)

Explanation : A batsman hits a cricket ball, which then rolls on a 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.

Q. 5. A truck starts from rest and rolls down a hill with a 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 metric tonnes (Hint : 1 metric tonne = 1,000 kg.)

Ans. Given that,

Initial velocity of the truck, $u = 0$ m/s

Time taken, $t = 20$ s

Distance covered by the stone, $s = 400$ m

According to the second equation of motion :

$$s = ut + \frac{1}{2}at^2$$

We have,

$$400 = 0 \times 20 + \frac{1}{2} \times a \times (20)^2$$

$\Rightarrow 400 = 200a$

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

Now, Force = mass × acceleration

$\Rightarrow \qquad F = 7{,}000 \times 2 = 14{,}000$ N

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

Ans. Given that,

Initial velocity of the stone, $u = 20$ m/s

Final velocity of the stone, $v = 0$ m/s

Distance covered by the stone, $s = 50$ m

According to the third equation of motion :

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

$(0)^2 = (20)^2 + 2 \times a \times 50$

or $\quad a = -4 \text{ m/s}^2$

The negative sign indicates that acceleration is acting against the motion of the stone.

Mass of the stone, $m = 1$ kg

From Newton's second law of motion :

Force,

F = Mass x Acceleration

F = ma

$F = 1 \times (-4) = -4$ N

Hence, the force of friction between the stone and the ice is –4 N.

Q. 7. An 8,000 kg engine pulls a train of five wagons, each of 2,000 kg, along a horizontal track. If the engine exerts a force of 40,000 N and the track offers a friction force of 5,000 N, then calculate :

(a) the net accelerating force;

(b) the acceleration of the train; and

(c) the force of wagon 1 on wagon 2.

Ans. (a) Given that,

Force exerted by the engine, F = 40,000 N

Frictional force offered by the track, $F_f = 5{,}000$ N

Net accelerating force, $F_a = F - F_f$
$= 40{,}000 - 5{,}000 = 35{,}000$ N

Hence, the net accelerating force is 35,000 N.

(b) Given that,

Acceleration of the train = a

The engine exerts a force of 40,000 N on all the five wagons.

Net accelerating force on the wagons, $F_a = 35{,}000$ N

Mass of the wagons, m = Mass of a wagon × Number of wagons

Mass of one wagon = 2,000 kg

Number of wagons = 5

$\therefore m = 2{,}000 \times 5 = 10{,}000$ kg

Total mass (including the mass of engine), $M = m + 8{,}000 = 18{,}000$ kg

$F_a = M_a$

$$\Rightarrow a = \frac{F_a}{M} = \frac{35{,}000}{18{,}000} = 1.944 \text{ m/s}^{-2}$$

(c) Given that,

Mass of four wagons (excluding wagon 1),

$m = 2{,}000 \times 4 = 8{,}000$ kg

Acceleration of the train = 1.944 m/s^2

$\therefore$ The force of wagon 1 on, wagon 2

$ma = 8{,}000 \times 1.944 = 15{,}552$ N

Q. 8. An automobile vehicle has a mass of 1,500 kg. What must be the force between the vehicle and road if the vehicle is to be stopped with a negative acceleration of 1.7 m s^{-2} ?

Ans. Given that,

Mass of the automobile vehicle, $m = 1{,}500$ kg

Final velocity, $v = 0$ m/s

Acceleration of the automobile, $a = -1.7 \text{ m s}^{-2}$

From Newton's second law of motion :

Force = Mass × Acceleration

$= 1{,}500 \times (-1.7) = -2{,}550$ N

So, the force between the automobile and the road is –2,550 N, in the direction opposite to the motion of the automobile.

Q. 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.

Ans. Correct option : (d)

Explanation :

If,

Mass of the object = m

Velocity = v

Momentum = Mass × Velocity

Momentum = mv

Q. 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 ?

Ans. A force of 200 N is applied in the forward direction. An equal amount of force will act in the opposite direction, so that the net force will be zero.

This opposite force is the fictional force exerted on the cabinet. So, a frictional force of 200 N is exerted on the cabinet.

Q. 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 m s^{-1} before the collision during which they stick together. What will be the velocity of the combined object after collision ?

Ans. Given that,

Mass of one of the objects, m_1 = 1.5 kg

Mass of the other object, m_2 = 1.5 kg

Velocity of m_1 before collision, u_1 = 2.5 m/s

Velocity of m_2, moving in opposite direction before collision, u_2 = −2.5 m/s

(Negative sign arises because mass m_2 is moving in an opposite direction)

After collision, the two objects stick together.

Total mass of the combined object = $m_1 + m_2$

Velocity of the combined object = v

According to the law of conservation of momentum :

Total momentum before collision = Total momentum after collision

$m_1u_1 + m_2 u_2 = (m_1 + m_2) v$

$1.5(2.5) + 1.5(–2.5) = (1.5 + 1.5) v$

$3.75 - 3.75 = 3 v$

$v = 0$

Hence, the velocity of the combined object after collision is 0 m/s.

Q. 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.

Ans. The truck has a large mass. So, the static friction between the truck and the road is also very high. To move the car, one has to apply a force more than the static friction.

When someone pushes the truck and the truck does not move, then it can be said that the applied force in one direction is cancelled out by the frictional force of equal amount acting in the opposite direction.

Therefore, the student is right in justifying that the two opposite and equal cancel each other.

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

Ans. Given that,

Mass of the hockey ball, m = 200 g = 0.2 kg

Hockey ball travels with velocity, v_1 = 10 m/s

Initial momentum = mv_1

Hockey ball travels in the opposite direction with velocity, v_2 = −5 m/s

Final momentum = mv_2

Change in momentum = $mv_2 - mv_1$

= 0.2 [–5 –10] = 0.2 (–15)

= –3 kg m s^{-1}

So, the change in momentum of the hockey ball is 3 kg m s^{-1}.

Q. 14. A bullet of mass 10 g travelling horizontally with a velocity of 150 m s^{-1} strikes a stationary wooden block and comes to rest in 0.03 seconds. 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.

Ans. Given that,

The bullet is travelling with a velocity of 150 m/s.

Thus, when the bullet enters the block, its velocity = Initial velocity, u = 150 m/s

Final velocity, v = 0 (since the bullet finally comes to rest)

Time taken to come to rest, t = 0.03 second

According to the first equation of motion,

$v = u + at$

Acceleration of the bullet, a

$0 = 150 + (a \times 0.03 \text{ s})$

$a = \frac{-150}{0.03} = -5{,}000 \text{ m/s}^2$

(Negative sign indicates that the velocity of the bullet is decreasing.)

According to the third equation of motion :

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

$0 = (150)^2 + 2(-5{,}000)\, s$

$s = -(150)^2/-2(5{,}000)$

$= 22{,}500/1{,}000 = 2.25$ m

Hence, the distance of penetration of the bullet into the block is 2.25 m.

From Newton's second law of motion :

Force, F = Mass × Acceleration

Mass of the bullet, $m = 10$, (g) = 0.01 kg

Acceleration of the bullet, $a = -5{,}000$ m/s^2

$F = ma = -0.01 \times 5{,}000 = -50$ N

Hence, the force exerted by the wooden block on the bullet is 50 N, opposing bullet's motion.

Q. 15. An object of mass 1 kg travelling in a straight line with a velocity of 10 m s^{-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 and just after the impact. Also, calculate the velocity of the combined object.

Ans. Given that,

Mass of the object, $m_1 = 1$ kg

Velocity of the object before collision,

$v_1 = 10$ m/s

Mass of the stationary wooden block, $m_2 = 5$ kg

Velocity of the wooden block before collision,

$v_2 = 0$ m/s

$\therefore$ Total momentum before collision

$= m_1v_1 + m_2v_2$

$= 1(10) + 5(0) = 10$ kg m s^{-1}

It is given that after collision, the object and the wooden block stick together.

Total mass of the combined system = $m_1 + m_2$

Velocity of the combined object = v

According to the law of conservation of momentum :

Total momentum before collision

= Total momentum after collision

$m_1v_1 + m_2v_2 = (m_1 + m_2)\, v$

$1(10) + 5(0) = (1 + 5)v$

$$v = \frac{10}{6} = \frac{5}{3} \text{ m s}^{-1}$$

The total momentum after collision is 10 kg m s^{-1} and velocity of combined object is 5/3 m/s.

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

Ans. Given that,

Initial velocity of the object, $u = 5$ m/s

Final velocity of the object, $v = 8$ m/s

Mass of the object, $m = 100$ kg

Time take by the object to accelerate, $t = 6$ s

Initial momentum, $mu = 100 \times 5$

$= 500$ kg m s^{-1}

Final momentum, $mv = 100 \times 8$

$= 800$ kg ms^{-1}

Force exerted on the object,

$$F = \frac{[mv - mu]}{t}$$

$$= \frac{[800 - 500]}{6}$$

$$= \frac{300}{6} = 50 \text{ N}$$

Initial momentum of the object is 500 kg ms^{-1}. Final momentum of the object is 800 kg ms^{-1}. Force exerted on the object is 50 N.

Q. 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.

Ans. According to the law of conservation of momentum :

Momentum of the car and insect system before collision = Momentum of the car and insect system after collision

Hence, the change in momentum of the car and insect system is zero. The insect gets stuck on the wind screen. This means that the direction of the insect is reversed. As a result, the velocity of the insect changes to a great amount. On the other hand, the car continues moving with a constant velocity.

Hence, Kiran's suggestion that the insect suffers from a great change in momentum as compared to the car is correct. The momentum of the insect after collision becomes very high because the car is moving at a high speed.

Therefore, the momentum gained by the insect is equal to the momentum lost by the car. Akhtar made a correct conclusion because the mass of the car is very large as compared to the mass of the insect.

Rahul gave a correct explanation as both the car and the insect experienced equal forces caused by the Newton's action-reaction law. But, he made an incorrect statement as the system suffers a change in momentum because the momentum before the collision is equal to the momentum after the collision.

Q. 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 m s^{-2}.

Ans. Given that,

Mass of the dumbbell, $m = 10$ kg

Distance covered by the dumbbell,

$s = 80$ cm $= 0.8$ m

Acceleration in the downward direction, $a = 10$ m/s^2

Initial velocity of the dumbbell, $u = 0$

Final velocity of the dumbbell (when it was about to hit the floor) $= v$

According to the third equation of motion :

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

$$v^2 = 0 + 2(10)\ 0.8$$

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

Hence, the momentum with which the dumbbell hits the floor is

$$= mv$$

$$= 10 \times 4 \text{ kg m s}^{-1}$$

$$= 40 \text{ kg m s}^{-1}$$

So, the momentum with which the dumbbell hits the floor is 40 kg m s^{-1}.

Additional Exercise

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

Time (in seconds)	Distance (in 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 ?

Ans. **(a)** There is an unequal change of distance in an equal interval of time.

Thus, the given object is having a non-uniform motion. The equation of motion with constant decleration is

$s = ut + \frac{1}{2}at^2 = \frac{1}{2}at^2$ for $u = 0$, requiring $s \propto t^2$. But here we see $s \propto t^3$. $\therefore$ a is not constant, but increasing.

(b) According to Newton's second law of motion, the force acting on an object is directly proportional to the acceleration produced in the object.

In the given case, the increasing acceleration of the given object indicates that the force acting on the object is also increasing.

A. 2. Two persons manage to push a motorcar of mass 1,200 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 ms^{-2}. With what force does each person push the motorcar? (Assume that all persons push the motorcar with the same muscular effort)

Ans. Given that,

Mass of the motor car = 1,200 kg

Only two persons manage to push the car. So, the acceleration acquired by the car is given by the third person alone.

Acceleration produced by the car, when it is pushed by the third person will be, $a = 0.2$ m/s^2

Let the force applied by the third person be F

From Newton's second law of motion :

Force = Mass × Acceleration

$F = 1{,}200 \times 0.2 = 240$ N

Thus, the third person applies a force of magnitude 240 N.

So, each person applies a force of 240 N to push the motor car. 480 N was used to overcome friction.

A. 3. A hammer of mass 500 g, moving at 50 ms^{-1}, 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 ?

Ans. Given that,

Mass of the hammer, $m = 500\ g = 0.5$ kg

Initial velocity of the hammer, $u = 50$ m/s

Time taken by nail to stop the hammer, $t = 0.01$ s

Final velocity of the hammer, $v = 0$ (because the hammer finally comes to rest)

From Newton's second law of motion :

$$F = \frac{m(v-u)}{t}$$

$$= 0.5\ (0 - 50)/0.01$$

$$= -2{,}500 \text{ N}$$

The hammer stop due to this force acting on it, which means that the nail exerts a force of 2500 N on the hammer, in a direction opposite to the motion of the hammer.

A. 4. A motorcar of mass 1,200 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 seconds by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of the force required.

Ans. Given that,

Mass of the motor car, $m = 1{,}200$ kg

Initial velocity of the motor car,

$$u = 90 \text{ km/h} = 90 \times \frac{5}{18} = 25 \text{ m/s}$$

Final velocity of the motor car,

$v = 18 \text{ km/h} = 18 \times \frac{5}{18} = 5 \text{ m/s}$

Time taken, $t = 4$ seconds

Using the first equation of motion :

$v = u + at$

Put the values,

$5 = 25 + a\,(4)$

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

Negative sign indicates that it's a retarding motion. So, the velocity is decreasing.

Change in momentum $= mv - mu = m(v - u)$

$= 1{,}200\,(5 - 25) = -24{,}000 \text{ kg m s}^{-1}$

Newton's second law:

Force = Mass × Acceleration

$= 1200 \times (-5) = -6000$ N

Acceleration of the motor car $= -5 \text{ m/s}^2$

Change in momentum of the motor car $= -24{,}000 \text{ kg m s}^{-1}$

Hence, the force required to decrease the velocity is 6,000 N.

(Negative sign indicates retardation, decrease in momentum and retarding force)

NCERT Exemplar

Multiple Choice Questions

Q. 1. Which of the following statement is not correct for an object moving along a straight path in an accelerated motion ?

(a) Its speed keeps changing.

(b) Its velocity always changes.

(c) It always goes away from the Earth.

(d) A force is always acting on it.

Ans. Correct option : (c)

Explanation : For an object moving along a straight path in an accelerated motion, it is not necessary that it always goes away from the earth.

Q. 2. According to the third law of motion, action and reaction :

(a) always act on the same body.

(b) always act on different bodies in opposite directions.

(c) have same magnitude and directions.

(d) act on either body at normal to each other.

Ans. Correct option : (b)

Explanation : According to the third law of motion, action and reaction always act on different bodies in opposite directions.

Q. 3. A goalkeeper in a game of football pulls his hands backwards after holding the ball shot at the goal. This enables the goal keeper to :

(a) exert larger force on the ball.

(b) reduce the force exerted by the ball on hands.

(c) increase the rate of change of momentum.

(d) decrease the rate of change of momentum.

Ans. Correct option : (b)

Explanation : The goalkeeper pulls his hands backwards after holding the ball to decrease the rate of change of momentum by increasing the time. By doing this, less force is exerted on his hands (Force is directly proportional to the rate of change of momentum).

Q. 4. The inertia of an object tends to cause the object :

(a) to increase its speed.

(b) to decrease its speed.

(c) to resist any change in its state of motion.

(d) to decelerate due to friction.

Ans. Correct option : (c)

Explanation : The inertia of an object tends to cause the object to resist any change in its state of rest or motion.

Q. 5. A passenger in a moving train tosses a coin which falls behind him. It means that motion of the train is :

(a) accelerated **(b)** uniform

(c) retarded **(d)** along circular tracks

Ans. Correct option : (a)

Explanation : If the coin falls behind the passenger it means that the train is accelerated. When the coin is tossed it has same velocity as that of train but during the same time it is in air its velocity becomes less than that of train (because the train is accelerated), so it falls behind the passenger.

Q. 6. An object of mass 2 kg is sliding with a constant velocity of 4 m s^{-1} on a frictionless horizontal table. The force required to keep the object moving with the same velocity is :

(a) 32 N **(b)** 0 N

(c) 2 N **(d)** 8 N

Ans. Correct option : (b)

Explanation : Given that,

Mass, $m = 2$ kg

Velocity, $v = 4$ m/s

As the object is moving with a constant velocity, *i.e.*, 4 m/s. so the acceleration of the object is zero ($a = 0$) and according to the property of inertia if there is no external force acting on the body, then body remains as it is, *i.e.*, if the body is at rest, remains and if it is in motion remains in motion.

Q. 7. Rocket works on the principle of conservation of :

(a) mass **(b)** energy

(c) momentum **(d)** velocity

Ans. Correct option : (c)

Explanation : Rocket works on the conservation of momentum. In a rocket, the fuel burns and produces gas at high temperature. These gases are ejected out of the rocket from a nozzle at the back side of the rocket. The ejecting gas exerts a forward force on the rocket which helps in accelerating the object.

The mass of gases escaping per second is very small and their momentum is very large due to their tremendous velocity of escape, an equal and opposite momentum is imparted to the rocket which despite its large mass builds up a high velocity.

Q. 8. A water tanker filled up to two-thirds of its height is moving with a uniform speed. On sudden application of the brake, the water in the tank would :

(a) move backwards **(b)** move forwards

(c) be unaffected **(d)** rise upwards

Ans. Correct option : (b)

*Explanatio*n : On the sudden application of brake, the tanker will come in the state of rest but the water remains in the state of motion, so the water will move forward.

Short Answer Questions

Q. 9. There are three solids made up of aluminium, steel and wood, of the same shape and same volume. Which of them would have the highest inertia ?

Ans. As the mass is a measure of inertia, steel has the highest inertia.

As the mass is a measure of inertia, the ball of same shape and size, having more mass than other balls will have the highest inertia.

Since steel has greatest density and greatest mass, therefore, it has highest inertia.

Q. 10. Two balls of the same size but of different materials, rubber and iron are kept on the smooth floor of a moving train. The brakes are applied suddenly to stop the train. Will the balls start rolling? If so, in which direction ? Will they move with the same speed ? Give reasons for your answer.

Ans. Yes, the balls will start rolling in the direction in which the train was moving.

When the train is stopped suddenly, then the train comes in the state of rest, but the balls remain in the state of motion and they begin to roll.

So, due to inertia of motion, the balls move in the forward direction. As the balls are of same size but of different materials that means their mass will be different and the frictional force will be different. So, both the balls will move with different speeds.

Q. 11. Two identical bullets are fired one by a light rifle and another by a heavy rifle with the same force. Which rifle will hurt the shoulder more and why ?

Ans. According to law of conservation of momentum, the momentum of bullet forward will be equal to the momentum of backward in case of light rifle, velocity with be more than the velocity of heaving rifle because of mass so that momentum product of mass and velocity for bod shall not be equal. Due this, the light rifle will hurt the shoulder more, In cases it has been called second.

Q. 12. A horse continues to apply a force in order to move a cart with a constant speed. Explain why ?

Ans. When the cart starts moving, frictional force starts working on the wheel of cart in opposite to the motion.

So, horse need to apply continuous force in forward direction to maintain constant speed.

Therefore, the cart will move with the constant speed only when the force applied by horse is equal to the force of friction.

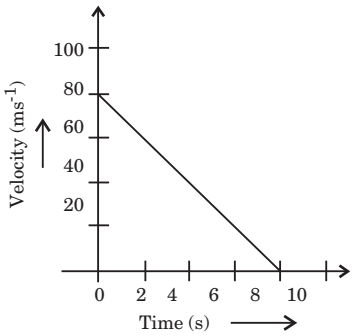
Q. 13. Suppose a ball of mass *m* is thrown vertically upward with an initial speed '*v*', its speed decreases continuously till it becomes zero. Thereafter, the ball begins to fall downwards and attains the speed '*v*' again before striking the ground. It implies that the magnitude of initial and final momentums of the ball are same. Yet, it is not an example of conservation of momentum. Explain why ?

Ans. Law of conservation of linear momentum applies only to isolated systems where there is no external force is applied on the body.

In this case, there is gravitational force acting on the ball which is an external force, change in velocity of ball (upwards and downwards) is due to gravitational pull of earth.

That is why this motion of ball is not an example of conservation of momentum.

Q. 14. Velocity versus time graph of a ball of mass 50 g rolling on a concrete floor is shown in Figure. Calculate the acceleration and frictional force of the floor on the ball.



Ans. Given that,

Mass, $m = 50\text{ g} = \dfrac{50}{1000} = 0.05\text{ kg}$ [1 kg = 1,000 g]

Initial velocity, $u = 80\text{ m s}^{-1}$

Final velocity, $v = 0\text{ m s}^{-1}$

Time taken, $t = 8\text{ s}$

From first equation of motion :

$$v = u + at$$

$$\Rightarrow \quad at = v - u$$

$$\text{Acceleration, } a = \frac{v-u}{t} = \frac{0-80}{8} = \frac{-80}{8} = -10\text{ ms}^{-2}$$

[negative sign shows retardation]

Now, friction force of the floor on the ball

$F = ma = 0.05 \times (-10) = -0.5\text{ N}$

[Negative sign shows against the direction of motion]

The acceleration and frictional force of the floor on the ball is -10 m/s^2 and -0.5 N, respectively.

Q. 15. A truck of mass M is moved under a force F. If the truck is then loaded with an object equal to the mass of the truck and the driving force is halved, then how does the acceleration change ?

Ans. Let initial mass, $m_1 = M$

Initial force, $F_1 = F$

According to the question, new mass, $m_2 = M + M = 2M$

and new force, $F_2 = \dfrac{F}{2}$

From, Newton's second law, $F = ma$

$$\Rightarrow \quad a = \frac{F}{m}$$

Change in acceleration

$$\frac{a_1}{a_2} = \frac{F_1}{F_2} \times \frac{m_2}{m_1} = \frac{F}{\frac{F}{2}} \times \frac{2M}{M} = \frac{2F}{F} \times \frac{2m}{m} = 4$$

$$\Rightarrow \frac{a_1}{a_2} = 4 \qquad \Rightarrow 4a_2 = a_1$$

$$\Rightarrow a_2 = \frac{a_1}{4} = \frac{1}{4} \times a_1$$

another method :

$$a_2 = \frac{F_2}{M_2} = \frac{\frac{1}{2}F_1}{2M_1} = \frac{1}{4}\frac{F_1}{M_1} = \frac{1}{4}a$$

Hence, the new acceleration will be one fourth of previous acceleration.

Q. 16. Two friends on roller-skates are standing 5 m apart facing each other. One of them throws a ball of 2 kg towards the other, who catches it. How will this activity affect the position of the two? Explain your answer.

Ans. Separation between them will increase. Initially the momentum of both of them is zero as they are at rest. In order to conserve the momentum, the one who throws the ball would move backward. The second will experience a net force after catching the ball and therefore will move backwards that is in the direction at the force.

Q. 17. Water sprinkler used for grass lawns begins to rotate as soon as the water is supplied. Explain the principle on which it works.

Ans. The rotation of the sprinkler is explained by the Newton's third law.

As soon as water comes out from the nozzle of the sprinkler, it exerts an equal force to the nozzle in the opposite direction and the sprinkler starts rotating.

Long Answer Questions

Q. 18. Using second law of motion, derive the relation between force and acceleration. A bullet of 10 g strikes a sand-bag at a speed of 10^3 m s^{-1} and gets embedded after travelling 5 cm. Calculate :

(i) the resistive force exerted by the sand on the bullet.

(ii) the time taken by the bullet to come to rest.

Ans. If a body of mass m, moving with the speed u, accelerates uniformly at a, for time t. so that its speed changes to v, then-

Initial momentum, $p_1 = mu$

And final momentum, $p_2 = mv$

$\therefore$ Change in momentum $= p_2 - p_1$

$= mv - mu = m(v - u)$

According to the second law of motion, force $\propto \dfrac{\text{Change in momentum}}{\text{Time}}$

$$F \propto \frac{p_2 - p_1}{t}$$

$$F \propto \frac{m(v-u)}{t}$$

$$F \propto ma \qquad \left[\text{where, } \frac{v-u}{t} = a\right]$$

$F = kma$, k being he proportionality constant.

setting $k = 1$ in the SI system, we get,

$F = ma$

Given that,

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

$u = 10$

$v = 0$ [$\therefore$ 1 kg = 1000 g]

and $s = 5\text{ cm} = \frac{5}{100}\text{m} = 0.05\text{ m}$

$[\because 1\text{ m} = 100\text{ cm}]$

(i) From third equation $v^2 = u^2 + 2as$

$\Rightarrow \quad v^2 - u^2 = 2as$

$$\Rightarrow a = \frac{v^2 - u^2}{2s} = \frac{(0)^2 - (10^3)^2}{2 \times 0.05}$$

$$a = \frac{-10^6}{0.1} - 10^7 \text{ m/s}^2$$

Now, force applied by the bullet,

$F = ma$

$= 0.01 \times (-10^7) = -10^5$ N

[Negative sign shown against the direction of motion]

The resistive force extends by the sand on the bullet $= 10^5$ N

(ii) From the equation of the motion,

$v = u + at$

$\Rightarrow \quad at = \underline{v} - u$

Now, time taken by bullet to come to rest

$$\Rightarrow \quad t = \frac{v - u}{a}$$

$$\Rightarrow \quad t = \frac{0 - 10^3}{-10^7}$$

$$\Rightarrow \quad t = \frac{-10^3}{-10^7} = 10^3 \times 10^{-7}$$

$$\Rightarrow \quad t = 10^{-4}\text{ s}$$

Hence, force $(F) = 10^5$ N and time $t = 10^{-4}$ s.

Q. 19. Derive the unit of force using the second law of motion. A force of 5 N produces an acceleration of 8 m s^{-2} on a mass m_1 and an acceleration of 24 m s^{-2} on a mass m_2. What acceleration would the same force provide if both the masses are tied together ?

Ans. As we know that,

S.I. unit of mass, $m = 1$ kg

S.I. unit of acceleration, $a = 1$ m/s

According to Newton's second law of motion-

$$F = m.a$$

S.I. unit of force, $F = 1\text{ kg} \times 1\text{ m s}^{-2}$

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

And, 1 Newton $= 1$ kg -m s^{-2}

So, for condition 1 : Given that, $F_1 = 5$ N

$$a = 8\text{ m s}^{-2}$$

m_1 = mass of first body

According to Newton's second law— F = ma

Put the values—$m_1 = 5/8$ kg

For condition 2 : Given that,

$$F_2 = 5\text{ N}$$

$$a_2 = 24\text{ m s}^{-2}$$

m_2 = mass of second body

Again, using Newton's second law, $F = m.a$

put the values,

$$5 = M_2 \times 24$$

$$m_2 = \frac{5}{24}\text{kg}$$

Sum of two masses,

$$m_1 + m_2 = \frac{5}{8} + \frac{5}{24}$$

$$= \frac{15+5}{24} = \frac{20}{24} = \frac{5}{6}$$

Acceleration produced by the same force provided both the masses are tied together

$$F = \text{same combined mass,}$$

$$M = m_1 + m_2$$

$$a = \frac{F}{(m_1 + m_2)}$$

$$= \frac{5}{5/6}$$

$$= 6\text{ m/s}^2$$

So that, the acceleration is 6 m/sec^2.

Q. 20. What is momentum? Write its SI unit. Interpret force in terms of momentum. Represent the following graphically :

(a) momentum versus velocity when mass is fixed.

(b) momentum versus mass when velocity is constant.

Ans. Momentum can be defined as "mass in motion". All objects have mass, so if an object is moving, then it has momentum - it has its mass in motion. Mathematically, momentum of an object is defined as the product of mass and velocity of the object.

$p = m \times v$

where,

p = momentum

m = mass

v = velocity

The standard metric unit of momentum is the kg. m/s.

As we know from Newton's second law-

$F = m \,.\, a$ Thus, the rate of change of momentum is equal to the force exerted.

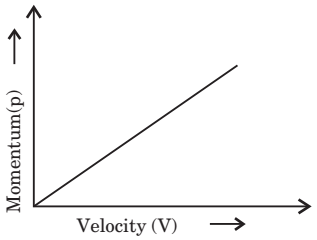
$$= \frac{m\,(v-u)}{t} = \frac{mv - mu}{t} = \frac{\text{change in momentum}}{\text{time}}$$

(a) Momentum versus velocity when mass is fixed.

$p = mv$

If m is fixed, then $p \propto v$

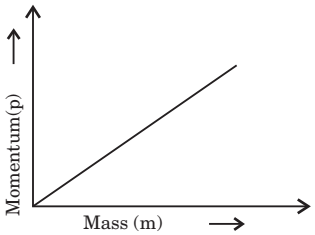
$\therefore$ Momentum versus velocity graph will be a straight line passing through the origin (if $v = 0$, then $p = 0$).



(b) Momentum versus mass graph when velocity is constant for the p = mv

If velocity is constant for different masses, then

$p \propto m$



So, the momentum versus mass graph will be a straight line passing through the origin (if $m = 0$, then $p = 0$).

BOARD CORNER

Short Answer Questions

Q. 1. When a carpet is beaten with a stick, dust comes out of it. Explain. [KVS, 2018, Agra Region]

Ans. According to the law of inertia, when a carpet is beaten with a stick, then the carpet comes to motion, but the dust particles stay at rest due to inertia not experiencing the drag by the carpet due to the fast motion of the carpet. Hence, the dust particles come out of the carpet. **[2]**

Q. 2. A bullet of mass 10 g travelling horizontally with a velocity of 150 m/s strikes a wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of bullet into the block. Also calculate the magnitude of force exerted by the wooden block on the bullet.

[KVS, 2018, Agra Region]

Ans. Mass of bullet $m = 10\text{g} = \frac{10}{1000} = 0.01$ Kg

Initial Velocity $u = 150$ m s^{-1}

Final Velocity $v = 0$

Time $t = 0.03$ s

From equation of motion

$$v = u + at$$

$$0 = 150 + a \times 0.03$$

$$a = \frac{-150}{0.03}$$

$$= -5000 \text{ m s}^{-2}$$

Distance covered by the bullet before coming to rest is given by :

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

$$0 = (150)^2 + 2(-5000)\, s$$

$$s = \frac{150 \times 150}{10000} = 2.25\ m.$$

Magnitude of the force applied by the bullet on the block

$$F = ma$$

$$= 0.01 \times -5000 = -50\text{N}$$ **[1+1+1]**

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

[KVS, 2018, Agra Region]

Ans. When the bus stops suddenly, the luggage on roof top will fall forward due to motion. Similarly, when the bus starts, the luggage will fall backwards due to inertia of rest. To avoid this, any luggage kept on the roof of a bus is tied with a rope. **[2]**

Q. 4. State Newton's second law of motion. Mathematically derive Newton's second law of motion. Also, give one application of second law of motion.

Ans. The force acting on a body is directly proportional to the rate of charge of momentum of the body. This is newton's second law of motion.

Let P_i and P_f be the initial and final momentum respectively.

According to newton's second law,

$$\frac{P_f - P_i}{t} \propto \text{F}$$

We know momentum (P) = mv

Let v be the final and u be the initial velocity.

Now, $\frac{m(v-u)}{t} \alpha \text{F}$

$$\text{F} \propto \frac{m(v-u)}{t}$$

$$\text{F} \alpha ma$$

$$\text{F} = \text{K}ma$$

Here, K is the proportionality constant. It's value is

1. Units of Force are given by the units of mass and acceleration. Units of force is Kg m/s^2

In accordance to honour the contributions of Newton, 1 Kg m/s^2 is termed as 1 newton.

Newton's second law of motion, establishes the ground rules for how every thing moves. For example, if you use the same force to push a truck and push a car, the car will have more acceleration than the truck, because the car has less mass. **[3]**

Answering Tip

- Students should understand and learn the statements of laws of motion.

Commonly Made Error

- Students get confused in the statements of the three laws of motion.