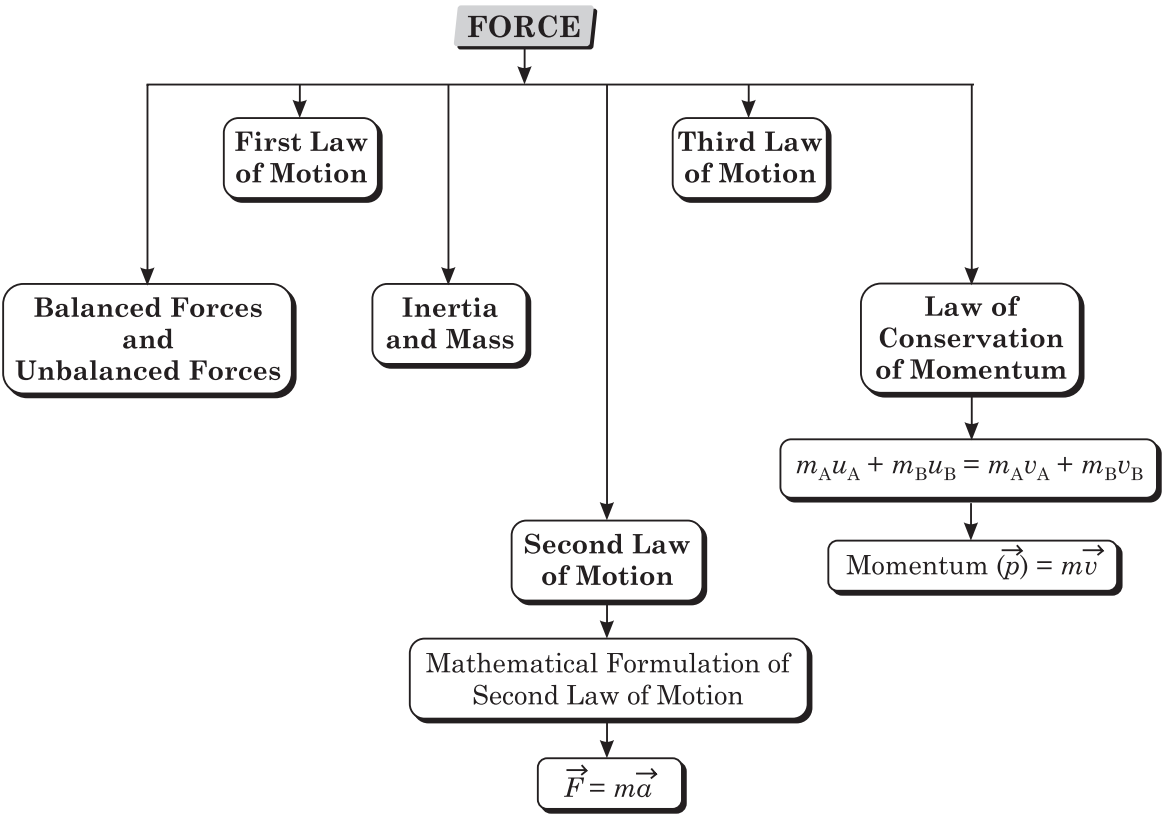
9 Force and Laws of Motion

Topics Covered

9.1 Balanced and Unbalanced forces, First law of motion, Inertia and Mass
9.2 Second Law of Motion
9.3 Third Law of Motion, Law of Conservation of Momentum

CHAPTER MAP



QUICK REVISION NOTES

- **Force** is an external cause which either changes or try to change the state, position, shape and size and direction of motion of an object.
- We need a force to change the direction of motion. We need to apply a force in order to stop a moving ball.
- Force cannot change the mass of a body. It can change the shape, size, velocity and direction of motion of that body.
- Force can change the speed of an object.
- Machine helps us to reduce the effort or force required to do a work.
- The S.I unit of force is kg m s^{-2}. 1 Newton (N) = 1 kg ms^{-2}.
- **1 Newton** force produces an acceleration of 1 m s^{-2} in a body of mass of 1 kg.
- Dyne is the CGS unit of force. (1 dyne = 1 g cm s^{-2}).
- 1 N = 10^5 dyne.
- If the resultant of forces applied on a body is zero, it is called balanced force. If the resultant force is not zero, then the force applied is called unbalanced force.
- **First law of motion:** It states that the object remains in the state of rest or in uniform motion until or unless an unbalanced force is applied on it.
- **Inertia** is the natural tendency of an object to resistant any change in its state of rest or in uniform motion.
- The mass of an object is a measure of inertia. Greater the mass, more will be inertia, more will be the effort needed to move it. Its S.I unit is kg.
- Greater the inertia, more will the force required to change its position or velocity, e.g. it requires a lot of effort to drive a road roller as it has more inertia.
- The product of mass and velocity is called linear momentum. It is a vector quantity. $\boxed{\vec{p} = m\vec{v}}$
- **Second law of motion:** It states that the rate of change of momentum is directly proportional to the force applied on the object in the direction of the force. $\boxed{\vec{F} = \vec{ma}}$ where 'F' is force, 'm' is mass, 'a' is acceleration.
- The direction of both linear momentum and velocity is the same. The S.I unit of momentum is kg ms^{-1}.
- **Third law of motion:** To every action, there is equal and opposite reaction action and reaction acting on two different bodies. When we walk we apply some force on the ground and frictional force acts on our body.
- The total momentum of an insolated system remains conserved. It is the **law of conservation of momentum**.
- Force of friction always acts opposite to motion. Vehicle stops on applying the breaks due to increase in force of friction.
- **Friction** exists between rough surfaces. It provides resistance to motion. It can be a help or a nuisance. It can be reduced by adding lubricants, graphite, water or by layers of air. Direction of friction is always opposite to the direction of motion.
- Friction is independent of surface area in contact. It is directly proportional to the normal force between the surfaces.
- Mass and weight of an object are different quantities.
- **Mass** always remains constant whereas weight depends upon the value of 'g', e.g. our weight will be $\frac{1}{6}$ th at moon than earth due to $\frac{1}{6}$ th gravity (*i.e.* smaller g) on moon than earth but the mass of the body will remain the same.
  $W = mg$, where 'W' is weight, 'm' is the mass, 'g' is gravity or gravitational field strength which varies from place to place.

- SI unit of mass is kg and that of weight is Newton.
- There are three types of inertia, namely, Inertia of rest, Inertia of motion and Inertia of direction.

1. Balanced and Unbalanced forces, First law of motion, Inertia and mass

Force

It is a push or pull which either about the changes or try to change in position, direction, velocity, shape and size of the body.

- **Balanced forces:** When the resultant of all the forces acting on the body is zero, these are called balanced forces, e.g. in tug of war, when equal force is applied by both the sides, the rope does not move in a any direction. They are equal and opposite in direction.
  Balanced forces can changes the shape and size of an object, e.g. if we apply equal forces on both sides of the balloon, the size and shape of balloon is changed because balloon is elastic in nature.
- **Unbalanced forces:** When the resultant of all the forces acting on the body is not equal to zero, then the forces are unbalanced forces. The body moves in the direction of the larger force, e.g. the team which applies more force in the game of tug of war wins the game and rope will move in their direction.

First Law of Motion

'An object remains in the state of rest or uniform motion unless and until an external force is applied on it to change its state of rest and uniform motion. It is also called law of inertia.

Inertia: The tendency of an object to stay at rest or keep moving with the same velocity is called inertia.

- When a driver apply breaks suddenly, we fall in front because vehicle slows down but our body continues to move in the same state of motion because of inertia. That is why seat belts are must for the safety of the driver and passengers in vehicle. These safety belts exert a force on the body to make forward motion slower.
- **Inertia and Mass:** Heavier objects have more mass and more inertia. More inertia means more will be force needed to change its position, speed and direction of motion. The mass of an object is the measure of its inertia.

Exercise 9.1

I. Very Short Answer Type Questions (1 Mark)

1. Can a force be measured in negative value and units. When? [*DOE*]
2. What is the tendency of a body to resist its change of state called? [*DOE*]
3. Which factor affects inertia?
4. When a carpet is beaten with a wooden stick, dust comes out of it. Explain. [*NCERT*]
5. Why is it advised to tie the luggage kept on the roof of a bus with a rope? [*NCERT*]
6. What is the SI unit of momentum?
7. Define 1 Newton.
8. Name the physical quantities whose units are:
   (*i*) kg ms^{-2} (*ii*) kg ms^{-1}
9. Which of the following has more inertia:
   (*a*) a rubber ball and a stone of the same size.
   (*b*) a bicycle and a train? [*NCERT*]

10. A batsman hits a cricket ball which then rolls on a level ground. After covering a certain distance, the ball comes to rest. Why?
(*a*) the batsman did not hit the ball hard enough.
(*b*) velocity is proportional to the force exerted on the ball.
(*c*) first law of motion.
(*d*) there is no unbalanced force acting on the ball, so the ball would come to rest. [*NCERT*]

11. Why is it difficult to stop a truck suddenly than a motor bike?

12. A water tank filled up to two-thirds of its height is moving with water with a uniform speed. What will happen to the water in the tank on applying sudden brakes?

13. A ball is moving over a horizontal smooth surface with a constant velocity. What kind of forces are acting on the ball?

14. Which law of motion defines force?

15. Name the type of force which acts on the body when the resultant force is not equal to zero.

16. A passenger in a moving train tosses a coin which falls behind him. State the type of motion of the train.

17. What is the role of inertia?

18. While riding a bicycle if we stop paddling, why does the bicycle begin to slow down? [HOTS]

II. Short Answer Type Questions–I (2 Marks)

19. Why do we fall in the forward direction when a driver of a moving bus applies brakes to stop it and we fall backwards when it accelerates from the rest? [*NCERT*]

20. 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. [*NCERT*]

21. When a bus takes a right turn on a road your body moves in opposite direction. Give reason.

22. Look at the diagram given and answer the following questions. In which case will the object will move and in which direction? Give reason in support of your answer.

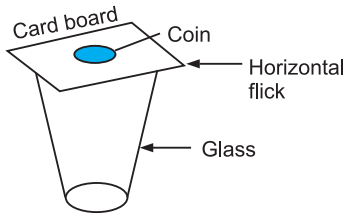
(*i*) 

(*ii*) 

23. 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 opposition 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*]

24. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch? [*NCERT*]

25. In the given experimental set up, a student gives sharp and fast horizontal flick to the cardboard with a finger.
(*a*) What will happen to the coin? (*b*) Write the reason for your answer.



III. Short Answer Type Questions–II (3 Marks)

26. State the effect of force in each of the following cases:
(*i*) A light spring is stretched. (*ii*) A hockey player hits an incoming ball.
(*iii*) A football lying on a ground is kicked.

27. While driving a vehicle how the use of safety belt prevents accidents? To show a body remains at rest unless acted upon by an unbalanced force, mention one situation from everyday life. [*CBSE* 2016]

Answers 9.1

1. Yes, force can be negative if it is in the opposite direction of the motion, e.g. frictional force is negative wrt to the force of motion.

2. Inertia

3. Inertia is affected by the mass of a body. more mass, more will be the inertia.

4. When a carpet is beaten, carpet's comes to motion and dust falls down due to inertia of rest.

5. It is because when bus brakes are applied suddenly luggage will move forward due to inertia of motion and may fall down if it is not tied.

6. kg ms^{-1} is the SI unit of momentum.

7. **1** Newton may be defined as the force which produces an acceleration of 1 m s^{-2} in a body of mass 1 kg.

8. (*i*) Force (*ii*) Momentum

9. (*a*) A stone has more inertia due to more mass than rubber ball.
(*b*) A train has more inertia than a bicycle.

10. (*c*) Force of friction and air resistance act in opposite direction of motion of ball and these opposing forces bring the ball to rest.

11. It is because a truck has more mass and more inertia than a motor bike.

12. The water in the tank will move forward because of the inertia of motion. The vehicle will come to rest on applying brakes but water will remain in the state of motion, so it will move forward.

13. Balanced forces

14. First law of motion

15. Unbalanced force

16. The motion of the train is accelerated.

17. The role of inertia is to resist any change in the body's state of motion or state of rest.

18. It is because the forces that bring about the motion of bicycle is opposed by the unbalanced forces of friction between the tyres of bicycle and the road.

19. When brakes are applied on a moving, the bus will comes to rest along with the lower part of our body but our upper part of the body continues to be in the state of motion due to inertia of motion and we fall in the forward direction.

When the bus starts all of a sudden, bus and lower part of our body in contact with bus comes into motion but our upper part of body tends to remain at rest due to inertia of rest and we fall backwards as inertia works in the opposite direction to the motion.

20. Yes, it is possible for the object to be travelling with a non-zero velocity because the body experiences a net zero unbalanced force.

The magnitude of velocity should be constant and direction should remain the same according to the first law of motion.

21. When motor car takes a sharp turn at a high speed, we tend to get thrown to one of the sides due to inertia of direction.

22. In the first case, net force is zero. So, the object will not move.
Net force applied = 25 N – 15 N = 10 N.
In case (*ii*) the unbalanced forces are acting on the body. The object will move towards the left, i.e. in the direction of greater force.

23. (*i*) When first player kicks the ball, velocity changes.
(*ii*) When second player kicks the ball, the initial velocity again changes.
(*iii*) When the goalkeeper stops the ball, velocity will become zero.
(*iv*) When goalkeeper kicks the ball towards its own team player, the velocity will again change.

24. When we shake the branch of a tree vigorously, the branch attains motion but leaves tends to stay at rest due to inertia.
The leaves thus opposes the motion and try to remain at rest and hence get detached away from the tree and fall down.

25. (*a*) The coin will fall into the glass.
(*b*) We are applying force on the cardboard and not on the coin. The coin will fall into the glass due to its inertia of rest, it will remain at rest because no external force is applied on it and hence fall into the glass.

26. (*i*) Its length will increase.
(*ii*) It changes the speed and direction of the incoming ball.
(*iii*) It brings the football from rest to motion.

27. Safety belts exert a force on our body to make the forward motion slower during accidents. When we strike a pile of carrom coins with a striker by a horizontal hit at the bottom of the pile, if our hit is strong, the bottom coin moves out quickly. Once the bottom coin is removed, the inertia of other coins makes them fall vertically on the table. It means other coins will not move unless and until we hit them directly with an unbalanced force.

2. Second Law of Motion

Momentum

The product of velocity and mass is called the momentum.

- Momentum is denoted by 'p'. It is a vector quantity
  $\vec{p} = m \times \vec{v}$, where '$p$' is momentum, '$m$' is mass, '$v$' is velocity.
- Momentum is regarded as the power of motion of an object.
- Due to linear velocity momentum is called linear momentum.

Examples

- A person gets injured by a moving vehicle or a stone, etc. because of momentum.
- A bullet can kill a person due to its momentum.
- Momentum is directly proportional to the mass and velocity of an object.
- Momentum increases with increase in mass or velocity or both.
- Heavier vehicles moving with the same velocity will have more momentum than lighter vehicles.
- Lighter object with higher velocity may have more momentum than heavier vehicles moving with less velocity.

Momentum of an Object at Rest

It is equal to zero because 'v' is zero.

$$\vec{p} = m\vec{v} = m \times 0 = 0$$

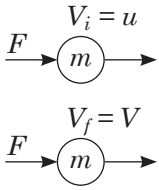
Thus momentum of an object at rest is equal to zero.

SI Unit of momentum: $\vec{p} = m\vec{v} = \text{kg} \times \text{m s}^{-1} = \text{kg m s}^{-1}$

Newton's Second Law of Motion

The rate of change of momentum is directly proportional to the applied unbalanced force in the direction of force.

Mathematical Expression



Let mass of the an object $= m$

Initial velocity $= u$

Final velocity $= v$

Its initial momentum $= mu$

and Final momentum $= mv$

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

$$\text{Rate of change of momentum} = \frac{\text{Change in momentum}}{\text{Time taken}}$$

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

According to Newton's second equation of motion

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

$\because$ $\frac{v-u}{t} = a$

$\therefore$ $F \propto ma$

or $F = k\, ma$

where 'k' is a proportionality constant and its value is equal to 1

$$F = ma$$

Unit of force $= \text{kg ms}^{-1}$ or **Newton**

Proof of Newton's First Law of Motion from Second Law

Newton's First law of motion states that if external force F = 0, then a moving body keeps on moving with the same velocity or a body continues to be at rest if it is in moving or at rest respectively.

$$F = 0$$

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

$\therefore$ $0 = \frac{m(v-u)}{t}$

$(v - u) = 0$

$v = u$

That is final velocity is equal to the initial velocity i.e. there is no change in velocity.

When body is at rest i.e. $u = 0$

Therefore, from the above relation $u = v = 0$

So, the body will continue to be at rest.

This expression is also valid for a finite value of 'u' in case of uniform motion, thus Newton's first law of motion holds true.

Exercise 9.2

I. Very Short Answer Type Questions (1 Mark)

1. What will be the momentum of a stone having the mass of 10 kg when it is thrown with a velocity of 4 m s^{-1}?
2. Calculate the momentum of a bullet of 20 g when it is fired from a gun with a velocity of 100 m/s.
3. A ball of mass 150 g moving with a velocity of 15 m s^{-1} is brought to rest by a player in 0.1 s. Calculate the force acting on the hands of the player.

II. Short Answer Type Questions–I (2 Marks)

4. The mass of a goods truck is 4000 kg and mass of goods loaded is 2000 kg. If the truck is moving with a velocity of 40 km/hour, what will be its momentum?
5. An automobile vehicle has a mass of 1500 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}? [*NCERT*]
6. A force is applied on the object of 2 kg on a frictionless surface. It produces an acceleration of 3 m s^{-2}. How much will be the force applied?
7. Which would require a greater force — accelerating a 2 kg mass at 5 m s^{-2} or a 4 kg mass at 2 m s^{-2} ? [*NCERT*]
8. Two similar trucks were moving with the same velocity on a road. One of them is loaded while the other is empty. Which of two will require larger force to stop? [*DOE*]
9. Identify whether it is balanced or unbalanced force that causes the following different types of movements.
   (*a*) A person resting on an arm chair. [*DOE*]
   (*b*) A cyclist braking.
   (*c*) A vehicle travelling at a constant speed on a straight road.
   (*d*) A car that that has a deceleration of 10 m s^{-2}.
10. A force of 5 N produces an acceleration of 8 m s^{-2} on mass m_1 and an acceleration of 24 m s^{-2} on mass m_2. What acceleration will provide the same force if both the masses are tied together? [*CBSE* 2011] [*NCERT Exemplar Problem*]
11. A motorcycle is moving with a velocity of 90 km/hour and it take 5 seconds to stop after the brakes are applied. Calculate the force exerted by the brakes on the motorcycle if its mass along with the rider is 200 kg. [*CBSE* 2011, 2012]

III. Short Answer Type Questions–II (3 Marks)

12. A constant force acts on an object of mass 5 kg for a duration of 2 s. It increases the object's velocity from 3 m s^{-1} to 7 m s^{-1}. Find the magnitude of the applied force. Now, if the same force was applied for a duration of 5 s, what would be the final velocity of the object? [*NCERT*]
13. 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. Also find the force acting on it, if its mass is 7 metric tonnes. (*Hint:* 1 metric tonne = 1000 kg.) [*NCERT*] [*CBSE* 2010]
14. A stone of 1 kg is thrown with a velocity of 20 m s^{-1} across the frozen surface of a lake and it come to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice? [*NCERT*] [*CBSE* 2011, 2012]
15. A 8000 kg engine pulls a train of 5 wagons, each of mass 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a frictional force of 5000 N, then calculate: [*NCERT*]

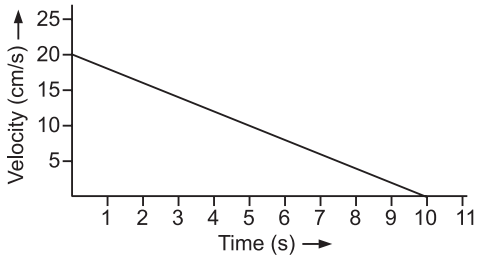
(*a*) the net accelerating force (*b*) the acceleration of the train and
(*c*) the force of wagon 1 on wagon 2. [*CBSE* 2010]

16. A car accelerates uniformly from rest to a speed of 20 m s^{-1} in 8 seconds. The mass of the car is 1200 kg.
(*a*) Calculate the acceleration of the car.
(*b*) (*i*) Calculate the minimum force needed to produce the acceleration in (*a*).
(*ii*) Explain why the engine must produce a larger force if this acceleration is to be achieved?

17. A motorcar is moving with a velocity of 108 km/h and it takes 4 s to stop after the brakes are applied. Calculate the force exerted by the brakes on the motorcar if its mass along with the passengers is 1000 kg. [*NCERT*]

18. A force of 5 N gives a mass m_1, an acceleration of 10 m s^{-2} and a mass m_2, an acceleration of 20 m s^{-2}. What acceleration would be given by the same force if both the masses were tied together?

19. The velocity-time graph of a ball of mass 20 g moving along a straight line on a long table is given in the Figure.

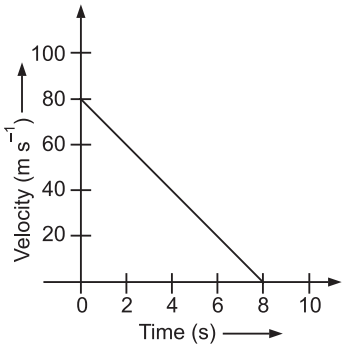


How much force does the table will exert on the ball in order to bring it to rest? [*NCERT*]

20. (*a*) Define SI unit of force.
(*b*) The force of 2 N acting on the body changes its velocity uniformly from 2 m s^{-1} to 5 m s^{-1} in 10 s. Calculate the mass of the body. [*CBSE* 2016]

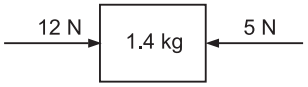
21. Explain how Newton's second law of motion can be used to define the unit of force. Define the SI unit of force. [*DOE*]

22. Velocity versus time graph of a ball of mass 50 g rolling on a concrete floor is shown in the given figure. Calculate the acceleration and frictional force of the floor on the ball.
[*NCERT Exemplar*]



IV. Long Answer Type Questions (5 Marks)

23. An object of mass 1.4 kg rests on a horizontal surface, as shown in figure below:



The object is pulled to the left by a force of 12.0 N and towards the right by a force of 5.0 N

(*a*) Assuming no other horizontal force acts on the object, calculate:

(*i*) the resultant force

(*ii*) the acceleration produced by the resultant force in (*i*)

(*b*) In practice, the object accelerates from rest and reaches a level of 8.0 m s^{-1} in 2.0 seconds

(*i*) Calculate the actual acceleration.

(*ii*) Using your answer (*b*) (*i*) and (*a*) (*ii*), suggest the reason whether forces act on the object or not.

24. (*a*) Derive Newton's first law of motion from the second law of motion.

(*b*) Find the force required to stop a car of mass 100 kg with two passengers of 50 kg each sitting inside, if it is moving at 60 km/hr speed and take 5 s to stop.

Answers 9.2

1. $p = mv \Rightarrow 10 \text{ kg} \times 4 \text{ m s}^{-1} \Rightarrow 40 \text{ kg m s}^{-1}$

2. $p = mv \Rightarrow \frac{20}{1000} \text{ kg} \times 100 \text{ m s}^{-1} \Rightarrow 2 \text{ kg m s}^{-1}$

3. $m = 150 \text{ g} = \frac{150}{1000} \text{ kg} = 0.15 \text{ kg}$

$u = 15 \text{ m s}^{-1} \quad v = 0$

$a = \frac{v-u}{t} = \frac{0-15 \text{m s}^{-1}}{0.1} = -150 \text{ m s}^{-2}$

$F = m \times a = 0.15 \text{ kg} \times -150 \text{ m s}^{-2} = -22.5 \text{ newton}$

$F = 22.5 \text{ N}$

4. Total mass = 4000 kg + 2000 kg = 6000 kg

$v = \frac{40 \times 1000}{60 \times 60} = \frac{400}{36} = \frac{100}{9} \Rightarrow 11.11 \text{ m s}^{-1}$

$p = mv = 6000 \text{ kg} \times \frac{100}{9} = \frac{200000}{3} \text{ kg ms}^{-1} = 66666.66 \text{ kg m s}^{-1}$

5. $m = 1500 \text{ kg} \quad F = ? \quad a = -1.7 \text{ m s}^{-1}$

$F = m \times a$

$F = 1500 \text{ kg} \times -1.7 \text{ m s}^{-1}$

$F = -2550 \text{ Newton}$

The force between vehicle and road is –2550 Newton.

6. $F = ma$

$F = 2 \text{ kg} \times 3 \text{ m s}^{-1} \Rightarrow 6 \text{ N}$

7. $F_1 = m_1 a_2 = 2 \text{ kg} \times 5 \text{ m s}^{-2} = 10 \text{ N}$

$F_2 = m_2 a_2 = 4 \text{ kg} \times 2 \text{ m s}^{-1} = 8 \text{ N}$

$\therefore$ F_1 is greater than F_2.

8. The loaded truck will require larger force to stop as the momentum of the loaded truck is greater than the momentum of the empty truck.

Momentum depends upon the mass and velocity of the body.

9. (*a*) Balanced force (*b*) Unbalanced force (*c*) Unbalanced force (*d*) Balanced force

10. $F = m_1 a_1$

$5 \text{ N} = m_1 \times 8 \text{ m s}^{-2}$

$m_1 = \frac{5}{8} \Rightarrow 0.625$ kg

$F = m_2 a_2$

$5\text{ N} = m_2 \times 24\text{ m s}^{-2}$

$m_2 = \frac{5}{24}\text{ kg} \Rightarrow 0.208\text{ kg}$

Total mass $= m_1 + m_2 = \frac{5}{8} + \frac{5}{24} = \frac{20}{24}\text{kg}$

$F = m \times a$

$5 = \frac{20}{24} \times a \Rightarrow a = \frac{5 \times 24}{20} \Rightarrow \frac{120}{20}$

$a = 6\text{ m s}^{-2}$

11. $u = 90$ km/hour $= \frac{90 \times 1000}{60 \times 60} = \frac{900}{36} = \frac{100}{4}\ \text{ms}^{-1}$

$u = 25\text{ m s}^{-1}$

$t = 5$ seconds

$v = 0$

$a = \frac{v-u}{t} = \frac{0-25}{5} = -5\text{ m s}^{-2}$

$F = ma = 200\text{ kg} \times -5\text{ m s}^{-2} = -1000$ Newton.

The force applied by the brakes on the motorcycle is 1000 Newton.

12. $m = 5$ kg, $t = 2$ s, $u = 3\text{ m s}^{-1}$, $v = 7\text{ m s}^{-1}$

F = ? $t = 5$ s

$F = \frac{m(v-u)}{t} = \frac{5\text{ kg} \times (7-3)\text{ m s}^{-1}}{2} = 10\text{ N}$

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

$10\text{ N} = \frac{5\text{ kg } (v-3)\text{ m s}^{-1}}{5}$

$5(v-3) = 50\text{ N}$

$5v - 15 = 50$

$5v = 65\text{ m s}^{-1}$

$v = 13\text{ m s}^{-1}$

13. $u = 0$ $s = 400$ m $t = 20$ s $a = ?$

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

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

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

F = ma

Given: m = 7 metric tonnes

$= 7 \times 1000 = 7000$ kg

$F = 7000\text{ kg} \times 2\text{ m s}^{-2}$

$= 14000\text{ kg m s}^{-2}$

F = 14000 Newton

14. $m = 1$ kg $\quad u = 20$ m s^{-1} $\quad v = 0 \quad s = 50$ m

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

$$0 - (20 \times 20) = 2 \times a \times 50$$

$$a = \frac{400}{100}\,\text{ms}^{-1} = -4\text{m s}^{-2}$$

$\because$ F = ma $\Rightarrow$ 1 kg $\times$ ($-$ 4 m s^{-2}) $= -$ 4 N

$\therefore$ Force of friction = 4 N.

15. (*a*) Mass of engine = 8000 kg

Mass of 5 wagons = 5 $\times$ 2000 kg = 10000 kg

Total mass = 10000 + 8000 = 18000 kg

Force = 40000 N

Frictional free = 5000 N

Net accelerating Force = 40000 $-$ 5000 = 35000 N

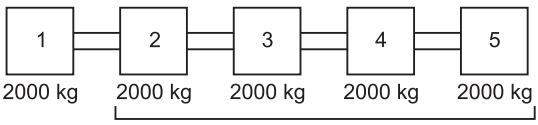
(*b*) F = *ma*, *a* = acceleration of train

35000 N = 18000 kg $\times$ *a*

$$a = \frac{35000}{18000} = 1.9 \text{ m s}^{-2}$$

(*c*) Let F′ be the force an wagon 2 due to 1.

M′ is the mass of wagons (2 to 5) = 4 $\times$ 2000 kg = 8000 kg



Mass of Wagon 2 to 5 = 2000 $\times$ 4 = 8000 kg

$a = 1.9$ m s^{-2}

F = *ma*

F = 8000 $\times$ 1.9 = 15200 N

16. $m = 1200$ kg, $t = 8$ second, $a = 0$, $u = 0$, $v = 20$ m s^{-1}

(*a*) $a = \dfrac{v-u}{t} \Rightarrow \dfrac{20-0}{8} \Rightarrow \dfrac{20}{8} \Rightarrow 2.5$ m s^{-1}

(*b*) (*i*) F = *ma* $\Rightarrow$ 1200 kg $\times$ 2.5 $\Rightarrow$ 3000 N

(*ii*) Extra force needs to be applied by the engine so as to overcome the force of friction and the air resistance.

17. $u = 108$ km/h $\Rightarrow \dfrac{108 \times 1000\,\text{m}}{60 \times 60} \Rightarrow \dfrac{1080}{36} = 30$ m s^{-1}

$m = 1000$ kg

$t = 4\ s, \quad v = 0$

$$a = \frac{v-u}{t} \Rightarrow \frac{0-30}{4} \Rightarrow -7.5 \text{ m s}^{-1}$$

F = *ma* $\Rightarrow$ 1000 kg $\times$ $-$7.5 m s^{-2} $= -$7500 Newton

The negative sign shows that the force exerted by brakes is in opposite direction to the direction of the movement of car.

18. F = 5 N, $\quad a_1 = 10$ m s^{-2}, $\quad m_1 = ?, \quad m_2 = ?,$

$a_2 = 20$ m s^{-2}

$F_1 = m_1 a_1$

$5 = m_1 \times 10 \Rightarrow m_1 = \frac{5}{10} = 0.50$ kg

$F_2 = m_2 a_2$

$5 = m_2 \times 20 \Rightarrow m_2 = \frac{5}{20} = 0.25$ kg

Total mass = 0.50 + 0.25 = 0.75 kg

$F = ma$

$5 = 0.75 \times a$

$a = \frac{5}{0.75} = \frac{500}{75} = \frac{20}{3} = 6.67 \text{ m s}^{-2}$

19. $u = 20 \text{ cm s}^{-1}$, m = 20 g, $m = \frac{200}{1000}$ kg

$v = 0 \quad t = 10$ s

$a = \frac{v-u}{t} \Rightarrow \frac{0 - 20 \text{ cm s}^{-1}}{10s} = -2 \text{ cm s}^{-2} \Rightarrow \frac{-2}{10} \text{ m s}^{-2}$

$a = -0.02 \text{ m s}^{-2}$

$F = ma \Rightarrow \frac{20}{1000} \text{ kg} \times (-0.02 \text{ m s}^{-2})$

$= \frac{-40}{100000} = -4 \times 10^{-4}$ N

The negative sign shows that the force is acting against the direction of motion, i.e. is frictional force.

20. (*a*) **SI unit of force is newton:** One Newton is the force which when applied on a body of mass of 1 kg produces an acceleration of 1 m s^{-2} on a body of mass 1 kg.

(*b*) $a = \frac{v-u}{t} = \frac{5-2}{10} = \frac{3}{10} = 0.3 \text{ m s}^{-2}$

$m = \frac{F}{a} = \frac{2\text{N}}{0.3 \text{m s}^{-2}} = \frac{2 \text{ kg m s}^{-2}}{0.3 \text{ m s}^{-2}} = \frac{20}{3} = 6.67$ kg

21. **Second law:** The force acting on the body is directly proportional to the product of its mass and acceleration.

$F = m \times a$

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

then $F = 1 \times 1 = 1$ Newton

Newton is the one unit force which produces an acceleration of 1 m s^{-2} in a body of mass 1 kg.

22. $u = 80$ m/s, $v = 0$, $t = 8$s

$a = \frac{v-u}{t} = \frac{0-80}{8} = -10 \text{ m s}^{-2}$

$F = ma = \frac{50}{1000}$ kg $\times (-10 \text{ m s}^{-2})$

$= -0.5$ Newton.

Frictional force of the floor acting on the ball = 0.5 Newton.

23. (*a*) (*i*) Net force F acting on the mass

F = 12 – 5 = 7 N, $m = 1.4$ kg

(*ii*) $F = ma \Rightarrow a = \frac{F}{m} \Rightarrow \frac{7N}{1.4\,kg} \Rightarrow 5\ m\ s^{-2}$.

(*b*) (*i*) $a = \frac{v-u}{t} \Rightarrow \frac{8\,ms^{-1} - 0}{2} \Rightarrow 4\ m\ s^{-2}$

(*ii*) The actual acceleration is less than as calculated value of a (*ii*). It is because frictional force is also acting on the object and the net force is less than 7 N which is acting on the body.

24. (*a*) First law of motion states that if an external force F = 0 is there on a body, then a moving body keeps on moving with the same velocity or a body continues to be at rest.

$F = 0$

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

$0 = \frac{m(v-u)}{t}$

$(v-u) = 0$

$v = u$

That is, final velocity is equal to the initial velocity, i.e. there is no change in the velocity of the moving body.

If it is at rest $u = 0$, then it remains at rest if it is moving with velocity u then it keeps moving with the same velocity.

When body is at rest, i.e. $u = 0$

Then, from above $u = v = 0$

So, the body will continue to be at rest.

(*b*) Total mass = mass of car + mass of passengers

= 100 kg + 50 × 2 ⇒ 200 kg

$u = 60\ km\ hour^{-1} \Rightarrow \frac{60 \times 1000\,m}{60 \times 60\,s} \Rightarrow \frac{50}{3} m\ s^{-1}$

$v = 0$

$a = \frac{v-u}{t} \Rightarrow \frac{0 - \frac{50}{3}}{5} \Rightarrow \frac{-50}{10} \Rightarrow \frac{-10}{3} = -3.33\ m\ s^{-2}$

$F = ma = 200\ kg \times \left(\frac{-10}{3}\right) \Rightarrow \frac{-2000}{3} \Rightarrow -666.66\ N$

Applications of Frictional Force

- Frictional force enables us to hold a pen and write on a surface of paper.
- Frictional force enables us to walk without slipping.
- Friction helps the vehicles to slow down and come to stop.
- We can light matchstick by frictional force which generates heat and light.
- A boat moves back when we deboard in it due to the validity of third law.
- A gun recoils.
- Rowing of a boat is based on third law of motion.

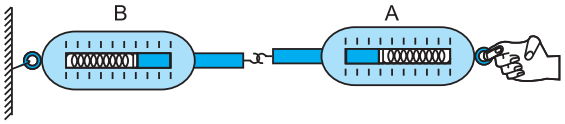
3. Third Law of Motion, Law of Conservation of Momentum

Third Law of Motion

It states 'To every action, there is an equal and opposite reaction'.

Activity: To prove that action and reaction are equal and opposite.

- Take two spring balances connected to each as shown in the figure.
- The fixed end of 'B' is attached to a fixed support.



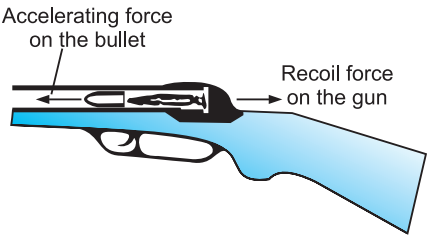
- When force is applied on free end of a spring balance 'A', observe the readings in spring balance A and B.

Observation: The reading is same in both the spring balances.

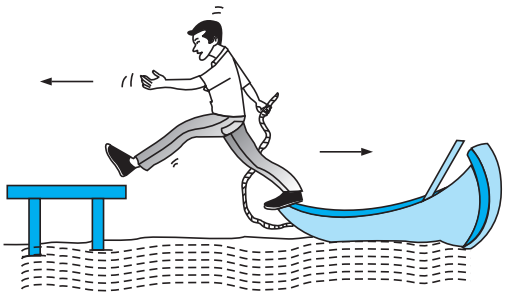
Conclusion: It means that force exerted by 'A' is equal and opposite in direction to the force exerted by 'B' on 'A' (reaction).

Action and Reaction always Acts on Two Different Objects

- We need muscular effort to move forward. We push the road backwards, the road exerts an equal and opposite force on our feet to make us move forward.
- Although action and reaction are equal in magnitude but they may not produces the same acceleration because each force acts on different objects of different masses.
- When we fire a gun, it exerts a forward force on the bullet. The bullet exerts an equal and opposite force on the gun which results in recoil of the gun.



- When a sailor jumps forward from a boat, boat moves backward due to third law of motion.



Law of Conservation of Momentum

The total linear momentum of an isolated system remains constant (or conserved) provided no external forces are acting on them, *i.e.*

Initial momentum = Final momentum

Let the initial velocity of body 'A' of mass m_1 be u_1 and that of body 'B' of mass m_2 be u_2.

Initial momentum = $m_1u_1 + m_2u_2$

When these two bodies strikes each other after then time 't' they start moving with velocity v_1 and v_2, respectively.

Final momentum = $m_1v_1 + m_2v_2$

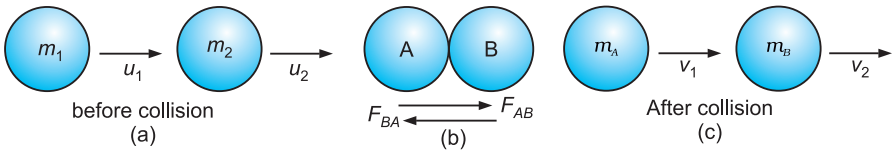
F_1 = Rate of change of momentum in body 'A' = $\frac{m_1v_1 - m_1u_1}{t} = \frac{m_1(v_1 - u_1)}{t}$

F_2 = Rate of change of momentum in body 'B' = $\frac{m_2v_2 - m_2u_2}{t} = \frac{m_2(v_2 - u_2)}{t}$

According to the 3rd law of motion:

$$F_1 = -F_2$$

$$\frac{m_1(v_1 - u_1)}{t} = -\frac{m_2(v_2 - u_2)}{t}$$



$$m_1v_1 - m_1u_1 = -m_2v_2 + m_2u_2$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2, \quad i.e.$$

Initial momentum = Final momentum.

Exercise 9.3

I. Very Short Answer Type Questions (1 Mark)

1. 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 m s^{-2}. With what force does each person push the motorcar? (Assume that all persons push the motorcar with the same muscular effort.) [*NCERT*]
2. When a person hits a stone, his foot gets injured, why? [*CBSE* 2011]
3. State the S.I unit of inertia.
4. Which has highest inertia: solids made up of Aluminium, steel and wood of same shape and same volume? [*CBSE* 2011, 2012]
5. Name the physical quantity which is determined by the rate of change of linear momentum. [*CBSE* 2010, 2012]
6. State third law of motion. [*CBSE* 2010, 11, 12]
7. State the action and reaction when a person walks on the ground. [*CBSE* 2011]
8. An object is thrown vertically upwards. What is its momentum at the highest point? [*CBSE* 2012]
9. State the law of Conservation of momentum. [*CBSE* 2010, 2012]
10. State the action and reaction forces in case when bullet is fired from the gun? [*CBSE* 2011]
11. Name the principle on which rocket works. [*CBSE* 2012]
12. What happens when a wet piece of cloth is shaken? [*CBSE* 2011]

II. Short Answer Type Questions–I (2 Marks)

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. [*NCERT*]
14. 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 objects after collision? [*NCERT*]

15. A bullet of mass 20 g is horizontally fired with a velocity 150 m s^{-1} from a pistol of mass 2 kg. What is the recoil velocity of the pistol? [*NCERT*]

16. Two hockey players 'A' of mass 50 kg is moving with a velocity of 4 m s^{-1} and another one 'B' belonging to the opposite team with mass 60 kg is moving with velocity 3 m s^{-1}, entangled while chasing and fell down. Find the velocity with which they fall down? **[HOTS]** [*DOE*]

17. How much momentum will a dumb-bell 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}. [*NCERT*]

18. A hammer of mass 500 g, moving at 50 m s^{-1}, strikes a nail. The nail stops the hammer in a very short time of 0.01 s. How much force is applied by the nail on the hammer? [*NCERT*] [*CBSE* 2011, 2012]

19. Write the principle on which bullet trains operate? **[HOTS]**

III. Short Answer Type Questions–II (3 Marks)

20. A cricket player lowers his hand while catching a fast moving ball. Explain why? [*CBSE* 2011, 12]

21. 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 seconds by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of the force required. [*NCERT*]

22. 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 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. [*NCERT*]

23. Using Newton's 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 [*NCERT Exemplar*]

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

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

24. A man has mass 60 kg and is moving with a speed of 18 km/hour. He jumps into a trolley weighing 1 quintal which was stationary. Calculate the final velocity of the trolley after the man jumps into trolley. [*CBSE* 2016]

25. Two balls 'A' and 'B' of masses 40 g and 50 g are moving at the speeds of 40 m s^{-1} and 30 m s^{-1} respectively. If after colliding, B starts moving with a velocity of 25 m s^{-1}, what is the velocity of 'A'? [*DOE*]

26. A girl of mass 30 kg with a velocity 10 m s^{-1} jumps on a stationary cart of mass 5 kg. Find the velocity with which she and cart will start moving after she jumps on it. [*NCERT*] [*DOE*]

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

IV. Long Answer Type Questions (5 Marks)

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

(*a*) momentum versus velocity when its mass is fixed.

(*b*) momentum versus mass when its velocity is kept constant. [*NCERT Exemplar*]

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

30. A large truck and a car, both moving with a velocity of magnitude v, have an head-on collision and both of them come to halt after that. If the collision lasts for 1 second:
(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? **[HOTS]**

Answers 9.3

1. $m = 1200$ kg
$a = 0.2$ m s^{-2}
$F = ma = 1200 \text{ kg} \times 0.2 = 240$ N

Therefore force exerted by each person = $\frac{240\text{N}}{3} = 80$ N.

2. Every action has an equal and opposite reaction so when a person exerts force on the stone, the stone also exerts equal force on his foot, that is why the foot gets hurt.

3. kg is S.I. unit of inertia because it depends upon the mass of object.

4. Solid made up of steel because it will have higher mass due to higher density.

5. Force

6. To every action there is an equal and opposite reaction.

7. **Action:** Force exerted by the person on the ground.
Reaction: Frictional force acting by the ground on the feet of the person.

8. It is equal to zero, since final velocity (v) = 0

9. The total momentum of a system remains conserved if no external force is applied.

10. **Action:** Force exerted by the gun on the bullet.
Reaction: Force exerted on the gun by the gun.

11. It works on the principle of law of conservation of momentum.

12. It brings the cloth in motion and water droplets remain at rest due to inertia and fall down.

13. $m = 200$ g $= 0.2$ kg
$u = 10$ m s^{-1}
$v = -5$ m s^{-1}

Initial momentum = $mu = 0.2 \times 10$
$= 2$ kg m s^{-1}

Final momentum = $mv = 0.2 \times (-5)$
$= -1$ kg m s^{-1}

Change in momentum = Final – Initial
$= -1 - 2 = -3$ kg m s^{-1}

14. $m_1 = 1.5$ kg, $m_2 = 1.5$ kg
$u_1 = 2.5$ ms^{-1}, $u_2 = -2.5$ ms^{-1} [$\because$ direction is opposite]

Initial momentum = $m_1u_1 + m_2u_2$
$= 1.5 \times 2.5 - 1.5 \times 2.5 = 0$

Final momentum after collision
$= (m_1 + m_2) \times v$

As per conservation of linear momentum.
$\because$ Initial momentum= Final momentum
$0 = (m_1 + m_2) \times v$
$\therefore$ Final velocity will be zero.

15. $m_1 = 20$ g, $v_1 = 150$ ms^{-1},
m_2 = mass of pistol = 2 kg $v_2 = ?$
$u_1 = 0$ $u_2 = 0$
$\because m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$$0.02 \times 0 + 2\text{ kg} \times 0 = \frac{20}{1000} \times 150 + 2\text{ kg} \times v_2$$

$$0 = 3 + 2v_2$$

$$2v_2 = -3$$

$$v_2 = -1.5\text{ m s}^{-1}$$

Negative sign shows that the direction in which pistol will recoil i.e. opposite to that of the bullet.

16. $m_1 = 50$ kg, $u_1 = 4$ m s^{-1}
$m_2 = 60$ kg, $u_2 = 3$ m s^{-1}
Initial momentum $= m_1u_1 + m_2u_2$
$= 50 \times 4 + 60 \times 3$
$= 200 + 180$
$= 380$ kg m s^{-1}
Final momentum $= (m_1 + m_2) \times v$
$= (50 + 60) \times v$
$= 100\ v$ kg m s^{-1}
Initial momentum = Final momentum
380 kg m s$^{-1} = 110 \times v$

$$v = \frac{380}{110}\text{ m s}^{-1}$$

$$= 3.45\text{ m s}^{-1}$$

17. $m = 10$ kg, $h = 0$, $s = 80\text{ cm} = \frac{80}{100}\text{ m} = 0.8\text{ m}$
$a = 10$ m s^{-1}

$$v^2 - u^2 = 2gs$$

$$v^2 - 0 = 2 \times 10 \times 0.8 = 16\ m^2\ s^{-2}$$

$$v = 4\text{ m s}^{-1}$$

Momentum before it touches the ground, $mv = 10\text{ kg} \times 4\text{ m s}^{-1} = 40$ kg m s^{-1}

18. $m = 500\text{ g} = \frac{500}{1000}\text{ kg} = 0.5$ kg
$u = 50$ m s^{-1}
$t = 0.01$ s
F = ?
$v = 0$

$$a = \frac{v-u}{t} = \frac{0-50}{0.01} = -5000\text{ m s}^{-2}$$

F $= ma = 0.5\text{ kg} \times (-5000\text{ m s}^{-2}) = -2500$ N.

19. It works on the principle that with the help of super magnetic field (magnetic levigation) train is lifted above its track. This reduces the frictional force and enables the train to move faster than the normal train. The train ride in such a case is smoother and less noisy.

20. He lowers his hand in order to increase the time to stop the ball, so less force has to be applied to reduce the velocity of the ball to zero, i.e. to decrease the momentum of the ball and he does not get hurt.

21. $m = 1200$ kg

$u = 90$ km/hour $= \dfrac{90\times1000}{60\times60} = \dfrac{900}{36}$ m s^{-1} $= 25$ m s^{-1}

$v = 18$ km/hour $= \dfrac{18\times1000}{60\times60} = \dfrac{180}{36}$ m s^{-1} $= 5$ m s^{-1}

$t = 4$ seconds

$a = \dfrac{v-u}{t} = \dfrac{5-25}{4} = \dfrac{-20}{4} = -5$ m s^{-2}

F $= ma = 1200$ kg $\times -5$ m s^{-2}

F $= -6000$ N

6000 N force will be required.

22. $m = 10$ g $= \dfrac{10}{1000} = 0.01$ kg

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

$v = 0$

$t = 0.03$ s

$v = u + at$

$0 = 150$ m s$^{-1} + a \times 0.03$

$a = \dfrac{-150}{0.03} = -5000$ m s^{-2}

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

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

$$s = \frac{-(150\times150)}{-10{,}000} = \frac{22500}{10{,}000}$$

$= 2.25$ m

$$F \propto \frac{\text{Change in Momentum}}{\text{Time}}$$

$$\Rightarrow \quad F \propto \frac{m(v-u)}{t} \quad \text{or} \quad F \propto ma \quad \text{or} \quad F = kma$$

Here $k = 1$, $\therefore$ $\boxed{F = ma}$

23. (*i*) $m = 10$ g $= \dfrac{10}{1000} = 0.01$ kg

$u = 10^3$ ms^{-1}

s $= 5$ cm $= \dfrac{5}{100} = 0.05$ m

$v = 0$

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

$0 - (1000)^2 = 2 \times a \times 0.05$

$a = \dfrac{-1000\times1000}{2\times0.05} = -10^7$ m s^{-2}

$F = ma = 0.01 \text{ kg} \times (-10^7 \text{ m s}^{-2}) \quad \Rightarrow \quad F = -10^5 \text{ Newton} = -100{,}000 \text{ Newton.}$

(*ii*) $t = \dfrac{v-u}{a}$

$t = \dfrac{0-1000}{-10^7} = 10^{-4}$ seconds

$t = 0.0001$ seconds.

24. Mass of man = 60 kg

Initial velocity of man

$u_1 = 18 \text{ km/hour} = \dfrac{18 \times 1000}{60 \times 60} = \dfrac{180}{36} = 5 \text{ m s}^{-1}$

Mass of trolley = 1 Quintal = 100 kg

Initial velocity of trolley = 0

After the man jumps into the trolley, common velocity of trolley and man is 'V'

Total momentum after jump

= Total momentum before jump

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

$(60 + 100)V = 60 \times 5 + 100 \times 0$

$V = \dfrac{300}{160} = 1.88 \text{ m s}^{-1}$

25. $m_1 = 40 \text{ g} = \dfrac{40}{1000} \text{ kg}$

$u_1 = 40 \text{ m s}^{-1}$

$m_1u_1 = \dfrac{40}{1000} \times 40 = 1.6 \text{ kg m s}^{-1}$

$m_2 = 50 \text{ g} = \dfrac{50}{1000} \text{ kg}$

$u_2 = 30 \text{ m s}^{-1}$

$m_2u_2 = \dfrac{50}{1000} \times 30 = 1.5 \text{ kg m s}^{-1}$

Initial momentum = $m_1u_1 + m_2u_2 = (1.6 + 1.5) \text{ kg m s}^{-1}$

$= 3.10 \text{ kg m s}^{-1}$

Final momentum = $m_1v_1 + m_2v_2 = \dfrac{40}{1000} \times v_1 + \dfrac{50}{1000} \times 25$

Initial momentum = Final momentum

$0.04v_1 + 1.25 = 3.10$

$0.04v_1 = 3.10 - 1.25$

$0.04v_1 = 1.85$

$v_1 = \dfrac{1.85}{0.04} = \dfrac{185}{4}$

$v_1 = 46.25 \text{ m s}^{-1}$

26. $m_1 = 30$ kg, $m_2 = 5$ kg

$u_1 = 10 \text{ m s}^{-1}$, $u_2 = 0$

Initial momentum = $m_1u_1 + m_2u_2 = 30 \times 10 + 5 \times 0 = 300$ kg ms^{-1}

Final momentum = $(m_1 + m_2) \times v = (30 + 5) \times v$

Initial momentum= Final momentum

$$300 = 35 \times v$$

$$v = \frac{300}{35} \text{ m s}^{-1}$$

$$v = 8.57 \text{ m s}^{-1}$$

27. Mass of object, m= 100 kg

Initial velocity (u) = 5 ms^{-1}

Final velocity (v) = 8 ms^{-1}

time (t) = 6s

Initial momentum = mu = 100 kg × 5 m s^{-1} = 500 kg m s^{-1}

Final momentum = mv = 100 kg × 8 m s^{-1} = 800 kg m s^{-1}

$$\text{Force} = \frac{\text{Change in momentum}}{\text{time}} = \frac{(800 - 500)\text{kg m s}^{-1}}{6\text{s}}$$

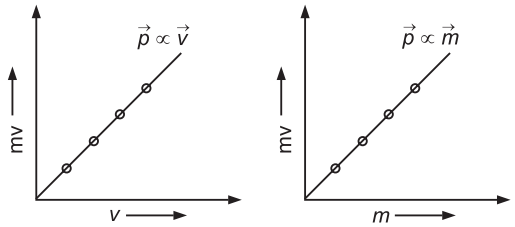
$$\text{F} = \frac{300}{6} \text{ kg m s}^{-2} = 50 \text{ Newton.}$$

28. Momentum is defined as the product of mass and velocity.

Its S.I unit is kg m s^{-1}.

$$\vec{P} = m\vec{V}$$

Force is directly proportional to momentum.



29. Initial moment turn of two friends = 0, as both are at rest. When one of them throw a ball of mass 2 kg towards the other, who catches it, the total linear momentum is zero because no external force is acting on them.

Thus both friends must move in opposite directions and distance between them will increase.

30. (*a*) Car will experiences greater force of impact because momentum of the truck is more due to higher mass.

(*b*) Truck will experience greater change in momentum because its mass is higher

$\therefore$ $m(v - u)$ will be higher.

(*c*) Car will experience greater acceleration because force of impact is more and its mass is less.

(*d*) It is because transfer of momentum from the truck to car will be greater so damage will `be more.

Value Based Questions

1. Harpreet was not wearing seat belt in the car. Her husband Shiraj asked her to wear the seat belt otherwise she will get hurt if he has to apply the emergency brakes. She followed his advice and now travels safely.
   (*i*) What values are associated with Shiraj?
   (*ii*) Why should we wear seat belt in the car?
   (*iii*) How does it saves us from accidents?
2. Neha was wearing a sandal having pencil heel. She was feeling difficulty in walking. Gaurav asked her to change her sandal, otherwise she may fall down. She followed his advice and had walked safely.
   (*i*) What values are associated with Gaurav?
   (*ii*) Why is it difficult to walk wearing a sandal with pencil heel?
   (*iii*) Why do we fall on a slippery floor?

Answers

1. (*i*) He is concerned about the safety of his wife.
   (*ii*) It is for the safety purpose.
   (*iii*) When brakes are applied suddenly, safety belt exerts force on our body and we do not fall forward and thus remains safe.
2. (*i*) He is concerned about the safety of Neha.
   (*ii*) It is because it exerts force on the ground and ground exerts less force due to less area of contact, which makes walking difficult.
   (*iii*) It is because water does not allow our body to exert force on the floor whereas floor exerts force on us and we fell down.

IMPORTANT FORMULAE

1. $\boxed{1 \text{ Newton} = 1 \text{ kg ms}^{-2}}$ newton (N) is the SI unit of force.
2. $\boxed{\vec{p} = m\vec{v}}$ '$\vec{p}$' is momentum, 'm' is mass, 'v' is velocity.
3. $\vec{F} = \dfrac{\vec{p_f} - \vec{p_i}}{t} = \dfrac{m\vec{v} - m\vec{u}}{t} = \dfrac{m(\vec{v} - \vec{u})}{t} = m\vec{a}$, where a = acceleration. $\left[\because \dfrac{v-u}{t} = a\right]$
4. $\boxed{\vec{F} = m\vec{a}}$
   Impulse= force × time = change in momentum
5. $\boxed{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$: Law of conservation of momentum.
6. **Recoil of gun:** $V = \dfrac{-mv}{M}$ where 'm' is the mass of bullet, M is the mass of gun, 'V' is the velocity of gun, 'v' is the velocity of bullet.
7. $\dfrac{\text{Rocket propulsion}}{\text{Velocity of rocket}} = V = \dfrac{-mV}{M}$, where '$m$' is mass of burnt fuel, 'v' is velocity of burnt fuel 'M' is the mass of rocket at any instant.

IMPORTANT NUMERICAL PROBLEMS

Q1. Find the force acting on a rocket and its acceleration if its velocity is 600 m s^{-1} at t = 60 s and 1000 ms^{-1} at t = 80s, presuming its mass remains unchanged during this time interval and its mass is 1.67×10^7 kg. The total weight of the rocket at t = 80 seconds is 1.6×10^7 kg. Calculate the upward force acting on the rocket at this time caused by the burning of fuel.

Sol. (*i*) $a = \dfrac{v-u}{t} = \dfrac{1000-600}{200} = \dfrac{400}{20} = 20 \text{ m s}^{-1}$

$F = ma = 1.67 \times 10^7 \text{ kg} \times 20 \text{ m s}^{-1} = 3.34 \times 10^8$ Netwon

(*ii*) $F = ma = 1.6 \times 10^7 \text{ kg} \times 20 \text{ m s}^{-1} = 32 \times 10^7$ Newton $= 3.2 \times 10^8$ Newton.

Q2. A body of 10 kg initially at rest is subjected to force of 20N. Calculate the kinetic energy acquired by the body at the end of 10 seconds.

Sol. m = 10 kg $\quad u = 0, \quad F = 20 \text{ N} \quad KE = ? \quad t = 10 \text{ sec}$

$F = ma \quad \Rightarrow \quad a = \dfrac{F}{m} = \dfrac{20\text{N}}{10\text{kg}} = 2 \text{ m s}^{-1}.$

$a = \dfrac{v-u}{t} \Rightarrow \dfrac{v-0}{10} = 2 \quad \Rightarrow \quad v = 20 \text{ m s}^{-1}$

$K.E = \dfrac{1}{2} mv^2 = \dfrac{1}{2} \times 10 \text{ kg} \times (20 \text{ m s}^{-1})^2 = 2000 \text{ J} = 2 \text{ kJ}$

Q3. A truck starts from the rest and rolls down a hill with constant acceleration. It travels 200 m in 20 s. Find its acceleration. Find the force acting on it, if its mass is 5 metric tonnes. (1 metric tonne = 1000 kg)

Sol. $u = 0, \quad t = 20 \text{ s}, \quad s = 20 \text{ m}, \quad a = ?, \quad F = ?, \quad m = 5000 \text{ kg}$

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

$$200 \text{ m} = 0 + \frac{1}{2} \times a \times 20 \times 20$$

$$a = \frac{400}{400} = 1 \text{ m s}^{-1}$$

$F = ma \quad \Rightarrow \quad F = 5000 \text{ kg} \times 1 \text{ m s}^{-1}$

$F = 5000$ Newton

Q4. A bullet of mass 10 g is horizontally fired with a velocity of 100 m s^{-1} from pistol of mass 1 kg. What is the recoil velocity of the pistol?

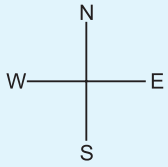
Sol. $m = 10 \text{ g} = \dfrac{10}{1000}$ kg, $v = 100 \text{ m s}^{-1}, \quad M = 1 \text{ kg}, \quad V = ?$

$$V = -\frac{mv}{M} = -\frac{10}{1000} \text{ kg} \times \frac{100 \text{ m s}^{-1}}{1 \text{ kg}}$$

$$V = -1 \text{ m s}^{-1}$$

Velocity of gun will be 1 m s^{-1} in the opposite direction to the bullet being fired.

COMMON ERRORS

Errors	Corrections
• Children take mass in g instead of kg.	☞ Mass should always be taken in kg.
• Children do not put sign before writing velocity depending upon its direction.	☞ If the direction is changed or becomes opposite, velocity will become negative.
• Children do not write formula in numericals.	☞ Formula must be written before starting the numericals.
• Children do not write proper unit of Force.	☞ The proper unit of force is Newton (N).
• Children do not have proper idea of direction.	☞ The following diagram will helps to remember the direction. Always draw the diagram when numerical involves direction: 

REVISION CHART

Force

A push or a pull which brings change in position, direction velocity, shape and size of a body.

Balanced and Unbalanced Forces

- When the resultant of the forces acting on the body is zero, it is called **balanced forces**.
- When the resultant of the forces acting on the body is not equal to zero, it is called **unbalanced forces**.

First Law of Motion

An object remains in the state of rest or uniform motion unless and until an external force is applied on it to the change the state.

Inertia and Mass

- **Inertia** is the tendency of an object to stay at rest or keep moving with same velocity.
- **Mass** of an object is a measure of inertia.
- Heavier objects have higher mass and more inertia.

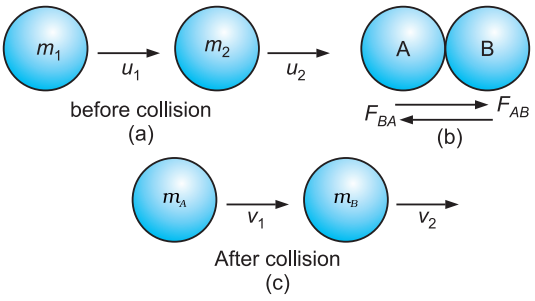
Second Law of Motion

The rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.

Mathematical Formulation of Second Law of Motion

$F = ma$

Conservation of Momentum



$m_A u_B + m_B u_B = m_A v_B + m_B v_B$

Third Law of Motion

It states that when one object exerts a force on another object, the second object instantaneously exerts a force back on the first. i.e., 'To every action, there is equal and opposite reaction.'