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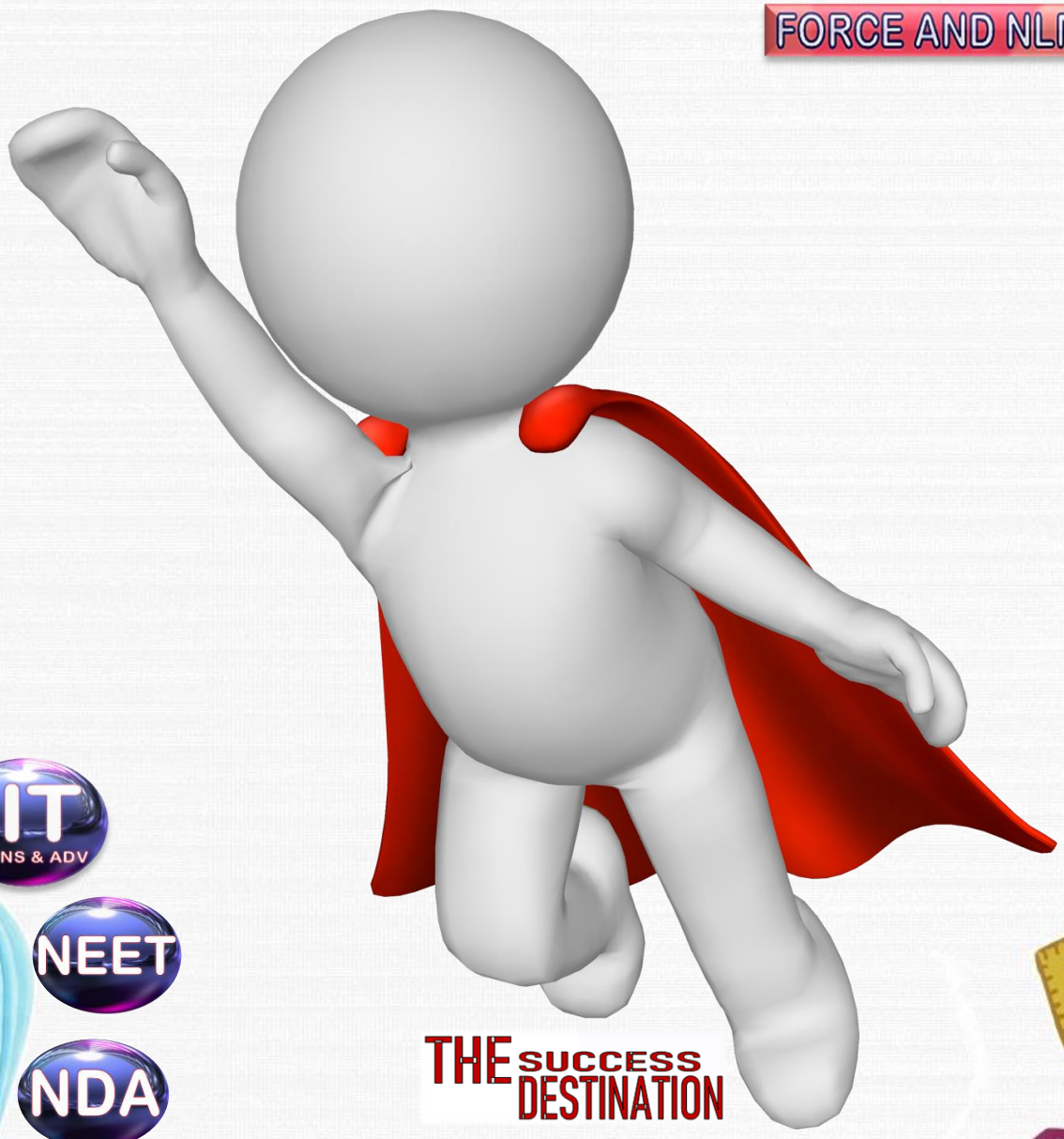

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FORCE & N L M

FORCE

Consider a ball kept on a table, we can move it by pulling or pushing. We can increase its speed by pushing it in the direction of motion. If we push it opposite to the direction of motion its speed will decrease. If the ball is in motion towards east, we push it towards north, the direction of will change.

Take a soft rubber ball between your palms and push the ball from both sides, the shape of the ball is distorted. In all the above cases we have applied the force on the ball.

So force in a push or pull which can move the object. It can change the speed of the object, it can change the direction of motion, it can change the shape of the object. In all the above cases we have applied the force on the ball and the ball is accelerated so we can define force as follows :

"Force is the cause which can produce acceleration in the body on which is acts".

(a) Effects of Force :

The force or a set of forces acting on a body, can do three things :

(i) A force or a set of forces can change the speed of the body.

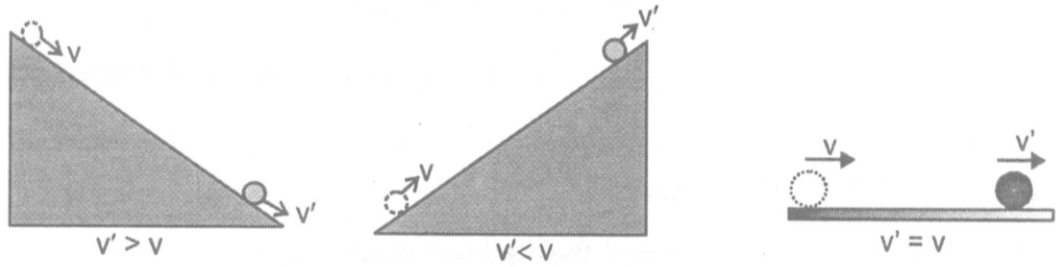
(ii) A force or a set of forces can change the direction of motion.

(iii) A force can change the shape of the body.

GALILEO'S EXPERIMENTS

Experiment 1 :

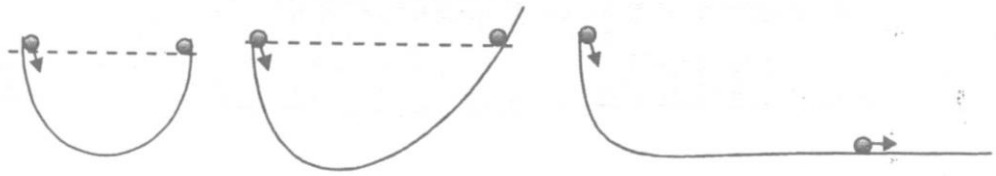
It was observed by Galileo that when a ball is rolled down on an inclined plane it speed increases, whereas if it is rolled up an inclined plane its speed decreases. If it is rolled on a horizontal plane the result must be between the cases describe above i.e. the speed should remain constant. If can be explain as -



moving down : speed increase **moving up : speed decreases** **moving horizontal : speed remains constant**

Experiments 2 :

When a ball sin released on the inner surface of a smooth hemisphere, it will move to the other side and reach the same height before coming to rest momentarily. If the hemisphere is replaced by a surface shown in figure (b) in order to reach the same height ht ball will have to move a larger distance.



(a) **(b)** **(c)**

if the other side is made horizontal, the ball will never stop because it will never be able to reach the same height, it means its speeds will not decrease. It will have uniform velocity on the horizontal surface. Thus, if unbalances forced do not act on a body, the body will either remain at rest or will move with a uniform velocity. It will remain uncelebrated.

(a) Conclusion of Galileo's Experiments :

(i) A body is at rest and no unbalanced forced acts on it, remains at rest.

(ii) A body is moving and no unbalance force acts on it, it will continue to move at constant speed in a fixed direction.

(iii) If unbalance forces act on a body the body will accelerated. The idea was suggested by Galileo and was later formulated into laws by Newton.

NOWTON'S FIRST LAW OF MOTION

We have learnt so far that :

(i) If a body is at rest and no unbalanced force acts on it, it remains at rest.

(ii) If a body is moving and no unbalanced force acts on it, it will continue to move at constant speed in a fixed direction.

(iii) If an unbalanced force acts on a body, the body will accelerated.

These facts are taken together from Galileo's law of inertia on Newton's' first law of motion. The idea was suggested by Galileo and was later formulated into a law by Newton. We can state Newton's first law motion as follows :

(a) Statement of Newton's First law of Motion :

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.

This law also be stated as follows :

A body remain uncelebrated if and only if, the resultant force on it is zero.

In such a case the body is said to be in equilibrium.

INERTIA

Description :

If follows from first law of motion that is absence of any eternal force, a body continues to be in its state of rest or of uniform motion along a straight line. In other words, the body cannot change by itself its position of rest or of uniform motion.

The inability of the body to change by itself its states of rest or uniform motion is a straight line is called inertia. Newton's' first law of motion is also called law of inertia.

(a) Inertia Depends upon Mass :L

We know that it is difficult to move a heavier body than the lighter one. Similarly it is difficult to stop a moving heavier body that a lighter body moving with the same velocity. Thus, we conclude that mass of the body is the measure of inertia, more the mass, more the inertia.

TYPES OF INERTIA

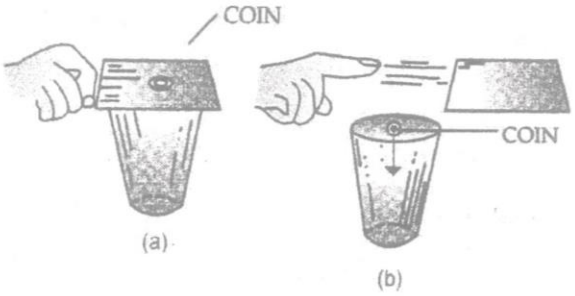
Inertia is of the three types :

(a) Inertia of Rest :

The tendency of the body to continue is state of rest even when some external unbalance force is applied on it, is called the inertia of rest.

Description :

(i) A person sitting in a bus falls backwards when the bus suddenly starts. The reason is the lower part of his body begins to move along with the bus but the upper part of his body tends to remain at due to inertia of rest.



(iii) We beat a carpet with a stick to remove dust particles. When the carpet is beaten, it is suddenly set into motion. The dust particles tend to remain at rest due to inertia of rest and hence fall off.

(iv) When a branch of tree is shaken the fruits get separated from the tree due to inertia of rest.

(b) Inertia of Motion :

The tendency of the body to continue in its state of motion even when some unbalance forces are applied on it, is called in the inertia of motion.

Description :

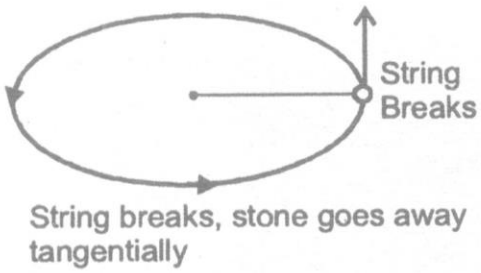
(i) A man carelessly getting down a moving bus falls forward, the reason being that his feet come to rest suddenly, whereas the upper part of his body retains the forward motion.

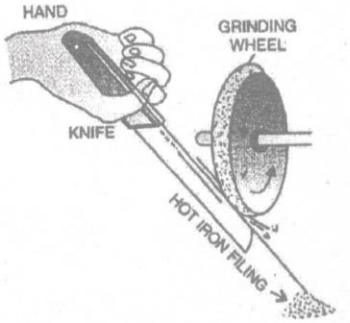
Man jumping carelessly from a moving bus falls forward.

(ii) An athlete runs a certain distance before taking a leap so that the inertia of motion of his body at the time of leaping may help him in his muscular efforts.
(iii) We remove snow or mud from our shoes by striking them against wall. On striking the wall, the feet comes to rest whereas the snow which is still in motion separates from the shoes.

(c) Inertia of Direction :

The tendency of a body to oppose any change in its direction of motion is known as inertia of direction.
(i) If a car takes a turn along a curved track, the passengers experience a force acting away from the centre of the curved track. This is the result of tendency of the passenger to continue moving along a straight path.
(ii) Tie a stone to one end of a string and holding other end of the string in hand. rotate the stone in a horizontal circle. if during rotation, the string breaks at certain stage, the stone is found to fly off tangentially at that point of the circle.





Sparks produced during sharpening of knife go tangential.

(iii) The water drops sticking to cycles tyre are found to fly off tangentially.
(iv) The sparks produced during sharpening of a knife or a razor against a grinding wheel, leave the rim of the wheel tangentially.

DEFINITION OF FORCE FROM FIRST LAW OF MOTION

Description :

A according to first law of motion, if there is no force, there is no change in state of rest or of uniform motion. In other words, if a force is applied, it may change the state of rest or of uniform motion. If the force is not sufficient, it may not produce a change but only try to do so.
Hence force is that which changes or tries to change the state of rest or of uniform motion of a body in straight line.

EXERCISE

OBJECTIVE DPP - 6.1

1. If A and B two objects with masses 10 kg and 30 kg respectively then :

(A) A has more inertia than B (B) B has more inertia than A

(C) A and B have the same inertia (D) none of the two have inertia

2. First law of motion defines :

(A) inertia (B) force

(C) both inertia and force (D) neither inertia nor force

3. Newton's first law of motion is :

(A) qualitative (B) quantitative

(C) both qualitative and quantitative (D) neither qualitative nor quantitative

4. Inertia depends upon :

(A) acceleration of the body (B) velocity of the body

(C) shape of the body (D) mass of the body

5. Which of the following has largest inertia ?

(A) A pin (B) An in pot

(C) Your physics book (D) Your body

6. When a bus starts suddenly the passengers standing on it, lean backwards in the bus. This is an example of :

(A) Newton's first law (B) Newton's second law

(C) Nekton's third law (D) none of Newton's law

7. The law which defines force is :

(A) Newton's third law (B) Newton's first law

(C) Newton's second law (D) none of these

8. Inertia of rest is the property by virtue of which the body is unable to change by itself :

(A) the state of rest only

(B) the state of uniform linear motion

(C) the direction of motion only

(D) the steady state of rest

9. An iron ball and aluminium ball has same mass :

(A) inertia of iron is greater than aluminium (B) both the ball have same inertia

(C) inertia of iron is less than that on Aluminium (D) none of these

10. Mass measure amount of ____ in a body :

(A) inertia (B) motion (C) velocity (D) acceleration

SUBEJCTIVE DPPT - 6.2

1. Name the property of the bodies to resist the change in their velocities.
2. With which law of motion, the same of Galileo is associated ?
3. A ball is moving on a frictionless horizontal surface and no force is applied on it. Will its speed decrease, increase or remain same.
4. What causes motion ?
5. Define force.
6. Define inertia and name its three types.
7. State Newton's first law of motion.
8. Which of the following has more inertia ? Explain :
   (a) A rubber ball and stone of the same size.
   (b) A bicycle and a train.
   (c) A five rupee coin and a one rupee coin.
9. Why do you fall in forward direction when a moving bus brakes to stop and fall backward when it acceleration from rest ?

MOMENTUM

Description :

It is the combined effect of mass and velocity of the body. Mathematically, momentum of the body is defined as the product of mass and the velocity of the body. If m is the mass of the body and v is its velocity then momentum, p = mv

Momentum is a vector quantity and its direction is in the direction of velocity.

Unit of momentum :

(In **C.G.S. system)** $\rightarrow$ p = mv $\rightarrow$ gram × cm/s = dyne × s

(In **M.K.S. system)** $\rightarrow$ p = mv $\rightarrow$ kg × m/s = Newton × s

NEWTON'S SECOND LAW OF MOTION

The rate of change of momentum of a body is directly proportional to the applied unbalanced forces i.e.

Rate of change of momentum $\propto$ Force applied

Let a body is moving with initial velocity u and after applying a force F on it, its velocity becomes v in time t.

Initial momentum of the body $p_1 = mu$

Final momentum of the body $p_2 = mv$

Change in momentum in time t is mv - mu

So rate of change of momentum $= \frac{mv - mu}{t}$

But according to Newton's second law, $\frac{mv - mu}{t} \propto F$

Or $F \alpha \frac{m(v-u)}{t}$ Here, $\frac{v-u}{t} = a$ (acceleration)

So $F \alpha ma$

or $F = kma$ Here is proportionality constant.

if 1N force is applied on a body of mass 1 kg and the acceleration produced in the body is 1 $ms/^2$, then 1 = k × 1 × 1 or k = 1.

So the magnitude of the resultant force acting on body is equal to the product of mass of the body and the acceleration produced. Direction of the force is same as that of the acceleration.

UNITS OF FORCE

(a) In C.G.S. System :

$\therefore$ F = ma $\rightarrow$ gm × cm/s^2 = Dyne

Definition of one dyne :

If m = 1 gm, a = 1 cm/s^2, then F = 1 dyne.

When a force is applied on a body of mass 1 gram and the acceleration produced in the body in 1 cm/s^2 then the force acting on the body will be one dyne.

(b) In S.I. System :

F = ma $\rightarrow$ kg × m/s^2 = Newton

Definition of one Newton :

If m = 1 kg and a = 1 m/s^2 then by, F = ma

F = 1 × 1 = 1 kg m/s^2 = 1 N.

If a force is applied on a body of a mass 1 kg and acceleration produced in the body in 1 m/s^2, then the force acting on the body will be one Newton.

Other units :

There are two other units of force called gravitational units.

(c) Kilogram Force (kgf) :

Kilogram force (kf) or Kilogram weight (kg. wt.) is force with which a mass of 1 kg is attracted by the earth towards its centre.

1 kgf = 9.8 N

(d) Gram Force (gf) :

Gram force or gram weight is the force with which a mass of 1 gram is attracted by the earth towards its centre.

1 gf = 981 dyne

Relation between Newton and dyne.

We know :

1 N = 1kg = 1 ms^{-2}

or 1 N = 1000 g × 100 cms $\rightarrow$

or 1 N = 10^5 g cms $\rightarrow$ = 10^5 dyne

$\therefore$ 1 N = 10^5 dyne

FIRST LAW OF MOTION BY SECOND LAW OF MOTION

Description :

According to first law of motion, if there is no force, there is no change in state of rest or of uniform motion. In other words, if a force is applied, it may change the state of rest or of uniform motion. If the force is not sufficient, if may not produce a change but only try to do so. Hence force is that which changes o tries to change the state of rest or of uniform motion of a body in straight line.

Hence we get the definition of force from Newton's first law of motion.

Newton's first law of motion can be deduced from Newton's' second law of motion.

According to second law of motion,

$F = ma$

if $F = 0$, then $a = 0$

Since $m \neq 0$

So $a = \frac{v-u}{t} = 0$

or $mv = mu$

or $v - u = 0$ or $v = u$

or $v = u$ [after more time]

Which means that the velocity of the body cannot change in absence of external force. If the body is initially at rest i.e., if $u = 0$, $v = 0$ and if $u = 5\ ms^{-1}$, $v = 5ms^{-1}$.

Thus, it follows that a body will continue to be in the state of rest or of uniform motion along a straight line if no external force acts on it and this is the first law. thus, first law can be deduced from second law of motion.

ILLUSTRATIONS

1. A force F_1 acting on a body of 2 kg produces an acceleration of 2.5 ms^2. An other force F_2 acting on the another body of mass 5 kg produces an acceleration of 2 m/sec^2. Find the ratio $\frac{F_2}{F_1}$.

Sol. For fist body $F = ma$

$F_1 = 2 \times 2.5 = 5N$

For second body $F_2 = 5 \times 2 = 10N$

So $\frac{F_2}{F_1} = \frac{10}{5} = 2.$

2. A force of 20N acting on amass m_1 produces an acceleration of 4 ms^{-2}. The same force is applied on mass m_2 then the acceleration produced is 0.5 ms^{-2}. What acceleration would the same force produce, when both masses are tied together ?

Sol. **For mass m_1 :** $F = 20N$, $a = 4\ ms^{-2}$

then $m_1 = \frac{F}{a} = \frac{20}{4} = 5\,kg$

For mass m_2 : $F = 20N$, $a = 0.5\ ms^{-2}$

then $m_2 = \frac{F}{a} = \frac{20}{0.5} = 40\,kg$

When m_2 and m_2 are tied together :

Total mass = $m_1 + m_2 = 45$ kg. $F = 20N$

then $a = \frac{F}{(m_1 + m_2)} = \frac{20}{45} = 0.44\,ms^{-2}$

IMPULSES OF FORCE

(a) Introduction :

In previous article, we leant that a moving body has momentum and that on effect (a force) is needed to stop it. It is our common experience that a smaller force takes more time to stop the body whereas a bigger force does the same in lesser time. This observation gives concept of a new quantity, force × time, which is named a impulse.

(b) Definition :

The product of the magnitude of a force applied on a body and the time for which it is applied, is called impulse of the force. It is represented by the symbol (I).

i.e., Impulse = Force × Time

or I = F. t

The S.I. unit of impulse is Newton-second (N-s) and the C.G.S unit is dyne - second (dyne -s)

(c) Impulse and Momentum :

From Newton's second law of motion

Force, $F = \frac{p_2 - p_1}{t}$ or $F.t = p_2 - p_1$

i.e., Impulse = Change in momentum

This relation is called impulse equation or momentum-impulse theorem. It has an important application in our everyday life.

APPLICATIONS OF IMPULSE EQUATION IN DAILY LIFE

(i) Catching the ball by a cricketer :

While catching a fast moving cricket ball, the player moves his hands backward after catching the ball. By moving his hands, the cricketer increases the time. As a result he has to apply a small force on the ball. In reaction, the ball also applies lesser force and the hands of the player are not injured.

(ii) Jumping on heap of sand :

If someone jumps from a height on a heap of sand below, his feet move inside the sand very slowly. His momentum changes slowly requiring a lesser force of action from the sand. The man is not injured.

(iii) Jumping down of a passenger from a moving train or bus :

A passenger sitting in a moving train or bus has momentum, When the jumps down and stands on platform or road, his momentum becomes zero.

If he jumps down suddenly from the moving train or bus and tries to stand on his feet, his body will fall forward due to inertia of motion. He will be injured.

He is advised to run over some distance on the platform or road along with (in direction f) the train or bus. This will slow down his rate of change of momentum and lesser force will be involved.

(vi) Springs in vehicles :

The vehicles are fitted with springs to reduce the hardness of the shock. When vehicles more over an uneven road, they experience impulses exerted by the road. The springs increase the duration of impulse and hence reduce the force.

(v) Springs in seats :

The seats are also fitted with springs to reduce their hardness. When we sit on them all of a sudden, the seats are compressed. The compression increases duration of our coming to rest of the seat. They reaction force of seats become negligible.

(vi) Soft material packing :

China and glass wares are packed with soft material when transported. They collide during transportation but soft packing material slows down their rate of change of momentum. The force of impact is reduced and the items are not broken.

(vii) Atheists :

Athletes are advised to come to stop slowly after finishing a fast race. In general, all changes of momentum must be brought slowly to involve lesser force of action and reaction to avoid injury.

IMPULSE DURING AN IMPACT OR COLLISION

The impulsive force acting on the body produces a change in momentum of the body on which it acts. We know, Ft = mv - mu, therefore maximum force needed to produce a given impulse depends upon time. If time is short, the force required in a given impulse or the change in momentum is large and vice - versa.

EXERCISE

OBJECTIVE DPP - 7.1

1. Newton's second law of motion :

(A) defines force (B) defines inertia

(C) gives measure of force (D) none of these

2. Newton's second law of motion is :

(A) qualitative (B) quantitative

(C) both qualitative and quantitative (D) neither qualitative nor quantitative

3. Momentum measures amount of _____ in a body :

(A) inertia (B) motion (C) velocity (D) acceleration

4. Force measures rate of change of ____ of a body :

(A) mass (B) inertia (C) velocity (C) momentum

5. C.G.S. unit of force is :

(A) m/s (B) s/ m (C) dyne (D) Newton

6. Momentum has same unit as :

(A) impulse (B) torque (C) moment of force (D) couple

7. When force of 1N acts on mass of 1kg. which is able to move freely, the object moves with a /an:

(A) speed of 1 ms^{-1} (B) speed of 1 kms^{-1}

(C) acceleration of 10 ms^{-2} (D) acceleration of 1ms^{-2}

8. The net force acting on a body of mass of 1 kg moving with a uniform velocity of 5 ms^{-1} is :

(A) 5N (B) 0.2 N (C) 0 N (D) None of these

9. A body of mass 20 kg moves with an acceleration of 2ms^{-2}. The rate of change of momentum is S.I. unit is :

(A) 40 (B) 10 (C) 4 (D) 1

10. A body of mass M strikes against wall with a velocity v and rebounds with the same velocity. Its change in momentum is :

(A) zero (B) Mv (C) -Mv (D) -2 Mv

11. Gram weight is a unit of :

(A) mass (B) weight (C) A and B both (D) neither A nor B

12. 9.8 N is equal to :

(A) 1 kgf (B) 1 kgwt (C) A and B both (D) Neither A nor B

13. A body of mass 5 kg undergoes a change in speed from 20 m/s to 0.20 m/s. The momentum :

(A) increases by 99 kgm/s (B) decreases by 99 kgm/s

(C) increases by 101 kgm/s (D) decreases by 101 kgm/s

14. The combined effect of mass and velocity is taken into account by a physical quantity called :

A) torque (B) moment of force (C) momentum (D) all of them

15. How many dynes are equal to 1N ?

(A) 10^8 (B) 10^4 (C) 10^5 (D) 10^3

16. Choose correct relation :

(A) $a = \frac{F}{m}$ (B) aF = m (C) m = F × a (D) none of these

SUBJECTIVE DPP - 7.2

1. Name of quantities on which momentum of a body depends.
2. What is S.I. unit of momentum ?
3. Is momentum vector or scalar ?
4. Two similar trucks are moving with same velocities on a road. One of them is loaded while another one is empty. Which of the two ill require a larger force to stop it in same time ?
5. Explain meaning of the following equation F = ma. Symbol have their usual meaning.
6. Explain how Newton's second law of motion can be explained to define the unit of force and also name the unit.
7. A 1000 kg vehicle moving with a speed of 20 ms^{-1} is brought to rest in a distance of 50 metre by applying brakes :

   (i) Find the acceleration.

   (ii) Calculate the unbalanced force acting on the vehicle.

   (iii) The actual force applied by the brakes will be slightly less than that calculated in, why ? Give reasons.
8. Write the expression for impulse.
9. Name a quantity which has same unit as that of impulse.
10. Derive relation between impulse and momentum.
11. A 5 quintal car is moving with a velocity of 54 kmh^{-1}. What is its impulse if it is stopped within 0.5s by application of backward force ? Also determine the force applied.

NEWTON'S THIRD LAW

(a) Introduction :

When a force is applied to stop a moving body, we ourselves experience some force from the body being stopped. When a cricketer used his hands to stop a moving ball, his hands also experience some force from the ball and sometimes the force is unbearable. When we jump on a cemented road from some height, our feet get injured by the impact of the road.

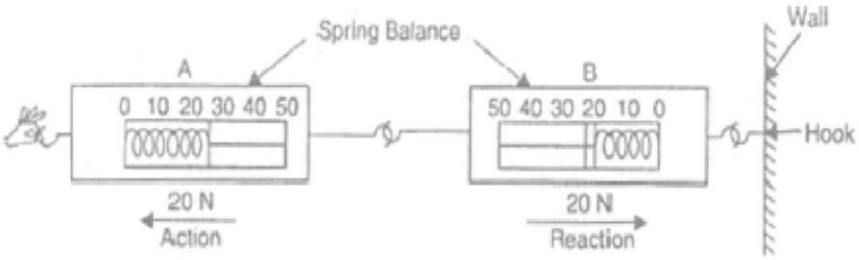
From above examples we find that whenever one body exerts a force on another body, the second body exerts an equal and opposite force on the first body. The force exerted by the first body on the second body is called 'action' and the force exerted by the second body on the first body is called 'reaction'/

(b) Statement :

The law states the "To every action there is an equal and opposite reaction". Moreover, action and reaction act on different bodies.

(c) Demonstration :

Two similar spring balances A and B joined by hook as shown in the figure, The other of the spring balance B is attached to a hook rigidly fixed in a rigid wall.



Demonstration - Newton's third law of motion.

The other end of the spring balance A is pulled out to the left. Both the balances show the same reading (20 N) for the force.

The pulled balance A exerts a force of 20N on the balance B. It acts as action, B pulls the balance A in opposite direction with a force of 20 N. This force is known as reaction.

We conclude that action-reaction forces are equal and opposite and act on two different bodies.

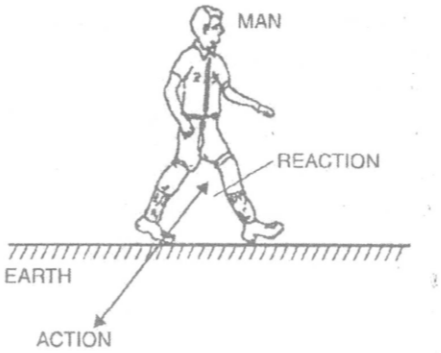
(b) Explanation :

If may be noted that action and reaction occur simultaneously. Action and reaction never act on same body. Had this been the case, there would have been no (accelerated) motion, Since action and reaction occur in pairs and act on two different bodies, it is impossible to have single isolated force.

(e) Examples :

(i) Swimming of a man : The man swims because he pushes water behind (action), water pushes man forward (reaction).

(ii) Walking of man : man pushes the earth behind from right foot (action). Earth pushes the man forward (reaction). Then the man walks.



Walking man

(iii) Flight of jet or rocket : The burnt gases are exhausted from behind with high speed giving the gases backward momentum (action). The exhausted gages impart the jet or rocket a forward momentum (reaction). Then jet or rocket moves.

(iv) Gun and bullet : A loaded gun has a bullet inside it. When the gun's trigger is pressed, the powder inside cartridge explodes. A force of action acts on the bullet and makes the light bullet come out of the barrel with a high velocity. The heavy gun moves behind (recoils) with a small velocity due to force of reaction.

This is also an example of law of conservation of linear momentum.

(v) Man and boat : A man is boat near river bank is at rest. To reach the bank, the man pushes the boat behind (action), the boat pushes the man forward (reaction). The man lands on the bank.

(vi) Hose pipe : Water rushes out of the hose pipe with a large velocity due to force of action of the compressor from behind. The rushing out jet of water pushes the hose pipe behind due to force of reaction. Then pipe has to be held tightly.

NO ACTION IS POSSIBLE WITHOUT REACTION

Examples :

(i) A nail cannot be fixed on a suspended wooden ball.

(ii) A paper cannot be cut by scissors of single blade.

(iii) A hanging piece of paper cannot be cut by blade.

(iv) Writing on a hanging page is impossible.

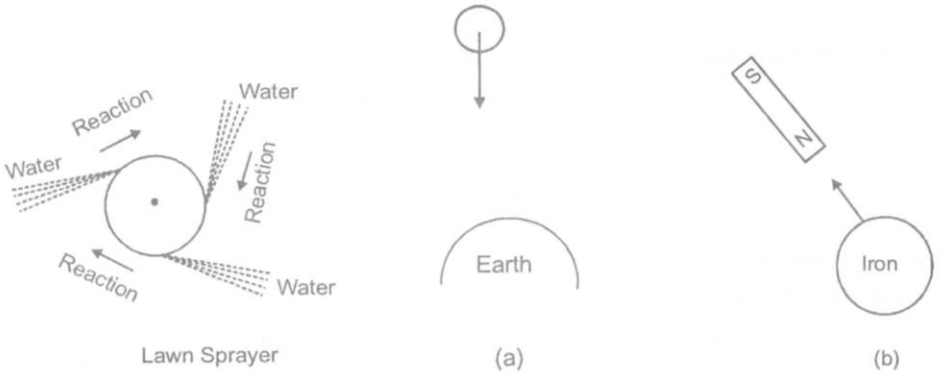
(v) Hitting on a piece of sponge does not produce reaction. You do not enjoy hitting.

ACTION AND REACTION ARE NOT BALANCED

Action and reaction, through equal and opposite are not balanced because they act on two different bodies. If case when they act on two different bodies forming a single system, they become balanced.

INTERACTION BETWEEN BODOIS AT A DISTANCE

We have uptill now considered examples where the two bodies are in direct contact with each other but. But interaction takes place even when the two bodies are not in actual contact with each other. For example, a comb rubbed with dry hair can interact with a piece of paper from a distance. Similarly a magnet can interact with an iron piece from a distance. Interaction between a falling stone and the earth also takes place although these are not in actual contact with each other. Thus when one body influences another body by applying force with or without contact, we say that the first body is interacting with the second body.



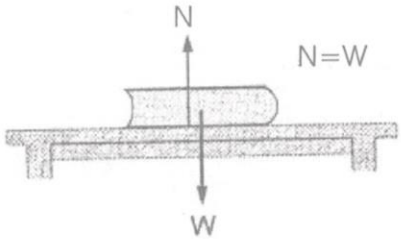
Lawn Sprayer

(a) Earth attracts a body at a distance

(b) Magnet attracts iron at a distance

ANY PAIR OF EQUAL AND OPPOSITE FORCES IN NOT AN ACTION - REACTION PAIR

Consider a book kept on a table. We have seen that the table pushes the book in the upward direction. They why does not the book fly up ? It does not fly up because there is another force on the book pulling it down. This is the force exerted by the earth of the book, which we call the weight of the book. So, there are two forces on the book-the normal force, N acting upwards, applied by the table and the force, W acting downwards, applied by the earth. As the book does not accelerate, we conclude that these two forces are balanced. In other words, they have equal magnitudes but opposite direction.



Can call N the action and W the reaction ? We cannot. This is because, although they are equal and opposite, they are not forces applied by two bodies on each other. The force N is applied by the table on the book, its reaction will be the force applied by the book on the table. Weight W is the force applied by the earth on the book, its reaction will be the force applied by the book on the earth.
So, although N and W are equal and opposite, they do not form an action - reaction pair.

PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

By Newton's second law, the rate of change of momentum is equal to the applied force.

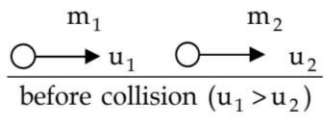
$$\frac{\text{Change in momentum}}{\text{time}} = \text{Force}$$

Change is momentum = F × t
If F = 0 then,
Change is momentum = 0
If the force applied on the body is zero then its momentum will be conserved, this law is also applicable on the system. If in a system the momentum of the objects present in the system are P_1 , P_2, P_3 ..... and external force on the system is zero, then -
$P_1 + P_2 + P_3 + ... = \text{Constant}$

❖ **NOTE :** If only internal forces are acting on the system then its linear momentum will be conserved.

(a) The Law of Conservation of Linear Momentum by Third Law of Motion :

Suppose A and B are two objects of masses m_1 and m_2 are moving in the same direction with velocity u_1 and u_2 respectively ($u_1 > u_2$). Object A collides with object B and after time t both move in their original direction with velocity v_1 and v_2 respectively.



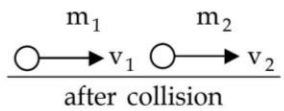
The change in momentum of object A = $m_1v_1 - m_1u_1$

The force on B by A is $F_1 = \dfrac{\text{Change in momentum}}{\text{time}}$

$$F_1 = \frac{m_1v_1 - m_1u_1}{t} \qquad .....(1)$$

The change is momentum of object B = $m_2 v_2 - m_2u_2$

The force on A by B is $F_2 = \dfrac{\text{Change in momentum}}{\text{time}} = \dfrac{m_2v_2 - m_2v_2}{t}$ .....(2)



By Newton third law, $F_1 = - F_2$

$$\frac{m_1v_1 - m_1u_1}{t} = -\left(\frac{m_2v_2 - m_2u_2}{t}\right) \Rightarrow m_1v_1 - m_1u_1 = -m_2v_2 + m_2u_2$$

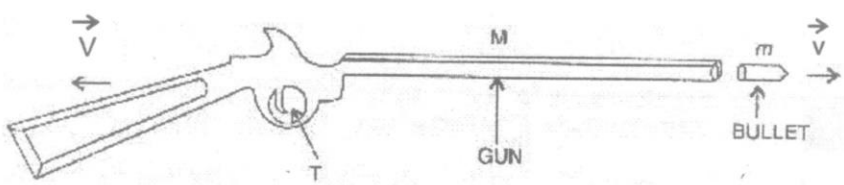
or $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

or Initial momentum = Final momentum

SOME ILLUSTRATION ON CONSERVATION OF MOMENTUM

(a) Recoil of Gun :

A loaded gun (rifle) having bullet inside it forming one system is initially at rest. The system has zero initial momentum.



When the trigger (T) is pressed, the bullet is fired due to internal force of explosion of powder in cartridge inside.
The bullet moves forward with a high velocity and the gun move behind (recoils) with a lesser velocity.
Let the bullet and the gun have masses m and M respectively. Let the bullet move forward with velocity v and the gun recoils with velocity V.

Then final momentum of the gun and bullet is MV + mv
By the law of conservation of momentum :
Initial momentum of the system = Final momentum of the system.

$0 = MV + mv$ or $V - \frac{mv}{M}$

Hence the recoil velocity of gun $= \frac{mv}{M}$

and the velocity of the gun is $= -\frac{mv}{M}$

(a) Flight of Jet Rocket :

Jet planes and rockets are provided with chemical fuels. Combustion of these fuels produces a high velocity blast of hot gases. These gases move outward and escape through nozzle (a narrow opening) with very high velocity and large momentum. (they escape horizontally backward in case of jet planes and vertically downwards in case of rocket). The escaping gases impart their momentum to the jet plane and the rocket. They move forward or upward with a high velocity.

In general, all cases involving action and reaction, are examples of law of conservation of momentum. Action and reaction being equal and acting simultaneously for same duration, have equal and opposite impulses. They produce equal and opposite changes of momentum in the pair of bodies involved. It keeps the total momentum of the two body system constant (conserved).

ILLUSTRATIONS

1. A field gun a mass 1.5 t fires a shell of mass 15 kg with a velocity of 150 m/s. Calculate the velocity of the recoil of the gun.

Sol. Mass of gun = 1.5 t = 1.5 × 1000 kg = 1500 kg
Mass of shell = 15 kg
Velocity of shell = 150 m/s.
Velocity of recoil of the gun = ?
Momentum of gun = Mass of gun × velocity of recoil of the gun = 1500 V kg m.s
Momentum of shell = Mass of shell × velocity of shell = 15 × 10 kg m/s.
By the law of conservation of momentum :
Momentum of gun = Momentum of shell

$1500\,V = 15 \times 150$ or $V = \frac{15 \times 150}{1500} = 1.5\,m/s.$

The recoil velocity of gun = 1.5 m/sec.

2. A hunter of 45 kg is standing on ice fires a bullet on 100 gram with a velocity of 500 ms^{-1} by a gun of 5 kg. Find the recoil velocity of the hunter.

Sol. The initial momentum of the system, P_1 = Momentum of hunter + momentum of gun + momentum of bullet

or $P_1 + 45 \times 0 + 5 \times 0 + 0.1 \times 0 = 0$ ..... (1)

Final momentum of the system, P_1 = Momentum of hunter + Momentum of gun + momentum of bullet

$P_2 = 45\,V + 5\,V + 0.1 \times 500$ (Here V is the recoil velocity of gun with hunter).

$P_2 = 50\,V + 50$ .....(2)

By the conservation of momentum

$P_1 = P_2$

$0 = 50\,V + 50$ or $V = -1$ m/s.

The recoil velocity of gun with hunter is 1 m/s.

EXERCISE

OBJECTIVE DPP - 8.1

1. If a moving ball A collides with another moving ball B, then :

(A) momentum of A = momentum of B

(B) (momentum + A + momentum of B) before collision = (momentum A + momentum of B) after collision

(C) neither A nor B

(D) A or B both are possible

2. When a bullet is fired from a gun. The gun recoils to :

(A) conserve mass

(B) conserve momentum

(C) conserve K.E.

(D) none of these

3. A bullet is motion hits and gets embedded in a solid resting on a frictionless table. What is conserved ?

(A) Momentum and K.E. (B) Momentum alone (C) K.E. alone (D) None of these

4. A bullet of mass 0.01 kg is fired from a gun weighing 5.0 kg. If the initial speed of the bullet is 250 m/s, calculate the speed with which the gun recoils :

(A) -0.50 m/s (B) -0.25 m/s (C) + 0.05 m/s (D) + 0.25 m/s

5. Forces of action and reaction are :

(A) equal and in same direction

(B) equal and in opposite direction

(C) unequal and in same direction

(D) unequal and opposite.

6. Forces of action and reaction act :

(A) one after the other on same body

(B) simultaneously on same body

(C) one after the other on different bodies

(D) simultaneously on different bodies

7. A man is standing on a boat in still water. If he walks towards the shore the boat will :

(A) more away from the shore (B) remain stationary

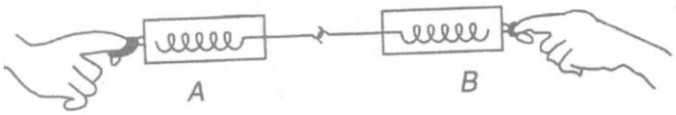
(C) move towards the shore (D) sink

8. In the action and direction were to act on the same body :

(A) the resultant would be zero (B) the body would not move at all

(C) both A and B are correct (D) neither A nor B is correct

9. Consider two spring balances hooked as shown in the figure. We pull them in opposite directions. If the reading shown by A is 1.5 N, the reading shown by B will be :



(A) 1.5 N (B) 2.5 N (C) 3.0 N (D) Zero

10. Newton used, quantity of motion' for :

(A) momentum (B) force

(C) acceleration due to gravity (D) none of these

11. A cannon after firing recoils due to :

(A) conservation of energy (B) backward thrust of gases produced

(C) Newton's first law of motion (D) Newton's' third law of motion

12. A Diwali rocket is ejecting 0.05 kg of gases per second at a velocity of 400 ms^{-1}. The accelerating force on the rocket is :

(A) 20 dyne (B) 20 Newton (C) 20 kg wt. (D) sufficient data not given

13. The forces of action and reaction have ____ magnitude but _____ direction :

(A) same, same (B) same, opposite (C) opposite, same (D) opposite, opposite

14. Choose correct statement :

(A) Action and reaction forces act on same object.

(B) Action and reaction forces act on different objects.

(C) A and B both are possible.

(D) Neither A nor B is correct.

SUBJECTIVE DPP - 8.2

1. What is total momentum of the gun and bullet just before firing ?

2. Explain of application of law of conservation of momentum.

3. State Newton's third law of motion.

4. Explain why it is difficult for a fireman to hold a hose, which ejects large amount of water at a high speed.

5. State third law of motion. Give two examples in support of this law.

6. If someone jumps to the shore from boat, the boat moves in the opposite direction. Explain why ?

7. (i) What is the physical principle involved in the working of a jet plane ?

(ii) Do the action and reaction act on the same body or direction bodies ? How are they related in magnitude and direction ? Are they simultaneous or not ?

8. Two cars A and B are moving towards each other on a horizontal surface. The can A has mass 60 g and moves towards the right with speed of 60 cms^{-1} The car B has a mass of 100 g and moves towards the left with a speed of 20 cms^{-1}. The two cars collide and get stuck to each other. With what velocity will they move after the collision ?

ANSWER KEY

(Objective DPP # 6.1)

Qus.	1	2	3	4	5	6	7	8	9	10
Ans.	B	C	A	D	D	A	B	D	B	A

(Objective DPP # 7.1)

Qus.	1	2	3	4	5	6	7	8	9	10
Ans.	C	B	B	D	C	A	D	C	A	D
Qus.	11	12	13	14	15	16				
Ans.	B	C	B	C	C	A				

(Subjective DPP # 7.2)

7. (i) - 4 m/s^2 (ii) 4000 N (iii) Because friction also apply force in opposite direction of motion.

11. Impulse = 7500 N-second
Backward Force = 1500 N

(Objective DPP # 8.1)

Qus.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ans.	B	B	B	A	B	D	A	C	A	A	D	B	B	B

(Subjective DPP # 8.2)

8. 10 cms^{-1}

MODEL NUMERICAL PROBLEMS

1. A bullet of mass 100g is fired from a gun of mass 20 kg with a velocity of $100 ms^{-1}$. Calculate the velocity of recoil of the gun

Solution. Mass of bullet, $m = 100g = \frac{100}{1000}kg = \frac{1}{10}kg$

Velocity of bullet, $\upsilon = 100 ms^{-1}$

Mass of gun, $M = 20kg$

Let recoil velocity of gun = V

Step 1. Before firing, the system (gun+bullet) is at rest, therefore, initial momentum of the system = 0

Final momentum of the system = momentum of bullet + momentum of gun

$$= m\upsilon + MV = \frac{1}{10} \times 100 + 20V = 10 + 20V$$

Step 2. Apply law of conservation of momentum

Final momentum = Initial momentum

i.e., $10 + 20V = 0$

$20V = -10$

Or $V = -\frac{10}{20} = -0.5 ms^{-1}$

Negative sign shows that the direction of recoil velocity of the gun is opposite to the direction of the velocity of the bullet.

2. An iron sphere of mass 10 kg is dropped form a height of 80 cm. If the downward acceleration of the ball is $10 ms^{-2}$, calculate the momentum transferred to the ground by the ball.

Solution. Here, Initial velocity of sphere, u = 0

Distance travelled, S = 80 cm = 0.8 m

Acceleration of sphere, $a = 10 ms^{-2}$

Step 1. Final velocity of sphere when it just reaches the ground can be calculated using

$$\upsilon^2 - u^2 = 2aS$$

$$\therefore \upsilon^2 - 0 = 2 \times 10 ms^{-2} \times 0.8 m$$

$$= 16 m^2 s^{-2}$$

Or $\upsilon = \sqrt{16 m^2 s^{-2}}$

$$= 4 ms^{-1}$$

Momentum of the sphere just before it touches the ground = $m\upsilon$

$$= 10kg \times 4 ms^{-1}$$

$$= 40 kg\ ms^{-1}$$

Step 2. On eaching the ground, the iron sphere comes to rest, so its final momentum = 0
According to the law of conservation of momentum

Momentum transferred to the ground = momentum of the sphere just before it comes to rest $= \mathbf{40\ kg}\, ms^{-1}$

3. Two small glass spheres of mases 10g and 20g are moving in a straight line in the same direction with velocities of $3ms^{-1}$ and $2ms^{-1}$ respectively. They collide with each other and after collision, glass sphere of mass 10g moves with a velocity of $2.5ms^{-1}$. Find the velocity of the second ball after collision.

Solution. Here, $m_1 = 10g = \frac{10}{1000}kg = 10^{-2}kg$

$$m_2 = 20g = 2\times10^{-2}kg$$

$$u_1 = 3ms^{-1};\ u_2 = 2ms^{-2}$$

$$\upsilon_1 = 2.5\ ms^{-1};\ \upsilon_2 = ?$$

Momentum of first sphere before collision = m_1u_1

$$= 10^{-2}kg\times3ms^{-1}$$

$$= 3\times10^{-2}\ kg\ ms^{-1}$$

Momentum of second sphere before collision = m_2u_2

$$= 2\times10^{-2}kg\times2ms^{-1} = 4\times10^{-2}kg\ ms^{-1}$$

$\therefore$ Total momentum of both the spheres before collision = $m_1u_1 + m_2u_2$

$$= 3\times10^{-2}kg\ ms^{-1} + 4\times10^{-2}kg\ ms^{-1} = 7\times10^{-2}kg\ ms^{-1}$$

Now, momentum of first sphere after collision = $m_1\upsilon_1$

$$= 10^{-2}kg\times2.5ms^{-1} = 2.5\times10^{-2}kg\ ms^{-1}$$

Momentum of second sphere after collision = $m_2\upsilon_2$

$$= 2\times10^{-2}kg\times\upsilon_2\ ms^{-1} = 2\times10^{-2}\ \upsilon_2\ kg\ ms^{-1}$$

$\therefore$ Total momentum of both the spheres after collision

$$= m_1\upsilon_1 + m_2\upsilon_2 = 2.5\times10^{-2}kg\ ms^{-1} + 2\times10^{-2}\upsilon_2\ kg\ ms^{-1}$$

Now, according to the law of conservation of momentum
Total momentum after collision = Total momentum before c ollision
$\therefore$ Total momentum after collision = Total momentum before collision

$$\therefore\ 2.5\times10^{-2} + 2\times10^{-2}\upsilon_2 = 7\times10^{-2}$$

$$\text{Or } 2\times10^{-2}\upsilon_2 = 7\times10^{-2} - 2.5\times10^{-2} = 4.5\times10^{-2}$$

$$\therefore\ \upsilon_2 = \frac{4.5\times10^{-2}}{2\times10^{-2}} = 2.25ms^{-1}$$

4. Two bodies each of mass 0.5 kg are moving in a straight line but opposite in direction with the same velocity of $2ms^{-1}$. They collide with each other and stick to each other aftrer collision. What is the common velocity of these bodies after collision ?

Solution. Let one body is moving towards left side and second body is moving to the right side. So velocity of the body to the left side is taken as positive and velocity of body moving to the right side is taken as negative.

Momentum of body moving to left side before collision = $m\upsilon$

$$= 0.5kg\times2ms^{-1} = 1kg\ ms^{-1}$$

Momentum of body moving to right side before collision = $-m\upsilon$

$$= -0.5kg\times2ms^{-1}$$

$$= -1kg\ ms^{-1}$$

$\therefore$ Total momentum of both the bodies before collision

$$= 1kg\ ms^{-1} - 1kg\ ms^{-1} = 0$$

Let V = common velocity of both the bodies after sticking to each other

$\therefore$ Total momentum of both the bodies after collision

$$= (m_1 + m_2)V$$

$$= (0.5 + 0.5)V = V\ kg\ ms^{-1}$$

According to the law of conservation of momentum

Total momentum after collision = Total momentum before collision

i.e, V = 0

thus, the combination of two bodies comes to rest after collision.

5. A body of mass 100 kg is accelerated uniformly from a velocity of $5ms^{-1}$ to $10ms^{-1}$ 5s.Calculate (i) the initial momentum of the body, (ii) finla momentum of the body and (iii) the force acting on the body

Solution.

Here, $m = 100kg$

Initial velocity, $u = 5\ ms^{-1}$

Final velocity, $\upsilon = 10ms^{-1}$

Time, t = 5s.

(i) Initial momentum, $pi = mu$

$$= 100kg \times 5ms^{-1}$$

(ii) Final momentum $pf = m\upsilon$

$$= 100kg \times 10ms^{-1} = 1000kg\ ms^{-1}$$

(iii) According to Newton's second law of motion,

$$\text{Force} = \frac{Change\ in\ momentum}{Time\ taken} = \frac{pf - pi}{t}$$

$$\text{Or } F = \frac{(1000 - 500)\ kg\ ms^{-1}}{5s} = 100N$$

6. An object of mass 1.5kg travelling in a straight line with a velocity of $5ms^{-1}$ collides with a wooden blocks of mass 5 kg resting on the floor. This object sticks with the wooden block after collision and both move together in a striaght line. Calculate (i) the total momentum before collision, (ii) the total momentum after collision and (iii) the velocity of the combination of these objects after collision.

Solution.

Mass of object, $m_1 = 1.5kg$

Mass of wooden block, $m_2 = 5kg$

Initial velocity of the object $u_1 = 5ms^{-1}$

Initial velocity of the wooden block, $u_2 = 0$

(i) Total momentum of the object and wooden block before collision = $m_1u_1 + m_2u_2$

$$= 1.5kg \times 5ms^{-1} + 5kg \times 0 = 7.5\ kg\ ms^{-1}$$

(ii) Let $\upsilon =$ velocity of the combination after collision

$\therefore$ Total momentum of the combination after collision = $(m_1 + m_2)\upsilon = (1.5 + 5)\upsilon$

$$= 6.5\upsilon\ kg\ ms^{-1}$$

(iii) According to the law of conservation of momentum:

Total momentum before collision = Total momentum after collision

i.e., $7.5 = 6.5\upsilon$

$$\text{or } \upsilon = \frac{7.5}{6.5} = 1.15\, ms^{-1}$$

Thus, velocity of the combination of the objects after collision = $1.15\, ms^{-1}$

(iv) From equation (i), total momentum of the objects after collision = $6.5 \times 1.15 = 7.5\, kg\, ms^{-1}$

UNSOLVED NUNSOLVED NUMERICALS

1. A gun of mass 1000 kg fires a shell of mass 2 kg with a velocity of $200\, ms^{-1}$. Calculate the velocity of recoil of the gun.

Ans. $0.4\, ms^{-1}$

2. A gun of mass M kg fires a shell of mass 1.5 kg with a velocity of $150\, ms^{-1}$ and recoils and with a velocity of $1.5\, ms^{-1}$. Calculate the mass of the gun.

Ans. **150 kg**

QUICK REVISION OF THE CHAPTER

FORCE

A pull or a push acting on the body which changes or tends to change the speed of the body or direction of motion of the body or the shape and size of the body.

•**Balanced forces** When two forces of equal magnitude but acting in opposite directions on an object simultaneously, then the object continues in its state of rest or of uniform motion in a straight line. Such forces acting on the object are known as balanced forces.

Unbalanced forces. When two forces of unequal magnitudes and acting in opposite directions on an object simultaneously, then the object moves in the direction of a large force. These forces acting on the object are known as unbalanced forces.

Newton's first law of motion. Everybody continues in its state of rest or uniform motion in a straight line unless compelled by some external force to change that state.

Inertia. The tendency of a body to oppose any change in its state of rest or uniform motion is called inertia of the body.

Inertia of a body is equal to the mass of the body.

•**S.I. unit of inertia** is same as that of mass i.e. **kilogram** (kg).

•**Types of inertia,** (i) Inertia of rest (ii) Inertia of motion and (iii) Inertia of direction.

•**Momentum** of a body is defined as the product of mass and velocity of the body.

That is $\vec{p} = m\vec{\upsilon}$

•Momentum is a **vector quantity.** Its SI unit is $kg\ ms^{-1}$

•**Law of conservation of momentum**. The total momentum of a system remains constant if no external force acts on the system.

Newton's second law of Motion. The rate of change of momentum of a body is directly proportional to the force acting on the body and the change in momentum of the body takes place in the direction of applied force

$$F \propto \frac{dp}{dt} \text{ or } F = ma$$

•**Units of Force**

Absolute units : S.I. unit of force is **newton** (N).

$$1N = 1kg \times 1\, ms^{-2}$$
$$= 1kg\ ms^{-2}$$

In CGS system, the unit of force is dyne.

$$1 \text{ dyne} = 1g\ \times 1cm\ s^{-2}$$
$$1g\ cm\ s^{-2}$$

$$1N = 10^5\ dyne$$

•NEWTON'S THIRD LAW OF MOTION

"To every action, there is an equal and opposite reaction."
• Action and reaction forces exist in pairs.
• Action and reaction act on two different bodies.

Very Short Answer Type Questions

1. Define the term force.
Ans. A force is a physical quantity which causes or tends to cause a motion in an object at rest or changes or tends to change the direction of motion of a moving object or the shape or size of the object.

2. Define balanced forces.
Ans. Two equal and opposite forces acting simultaneously on an object are known as balanced forces.

3. Define unbalanced forces.
Ans. Two forces of unequal magnitudes and acting in opposite directions on an object simultaneously are known as unbalanced forces.

4. A ball is moving over a horizontal smooth surface with a constant velocity. What type offerees are acting on the hall?
Ans. Balanced forces are acting on the ball.

5. State Newton's first law of motion.
Ans, Everybody continues in its state of rest or uniform motion in a straight line unless some external force acts on it.

6. What do you mean by inertia?
Ans. The tendency of a body to oppose any change in its state of rest or uniform motion is called inertia of the body.

7. On what factor does inertia of a body depend?
Ans. Inertia of a body is directly proportional to its mass.

8. State S.I. unit of inertia.
Ans. S.I. unit of inertia is kilogram (kg.)

9. Which has more inertia: a man or a child?
Ans. A man has more inertia than a child.

10. Which has more inertia: a rubber ball or a stone of same size?
Ans. Stone has move inertia.

11. Which has more inertia: a twenty five paisa coin or a one rupee coin?
Ans. A one rupee coin has more inertia than a twenty five paisa coin.

12. Which has more inertia: a train or a car?
Ans. A train has more inertia than a car.

13. State Newton's second law of motion.
Ans. The rate of change of momentum of a body is directly proportional to the unbalanced force acting on it.

14. Force = mass x ..... .

Ans. Acceleration.

15. Define unit force.
Ans. A force is said to be unit force if it produces unit acceleration in the unit mass of a body.

16. Name the unit of force in SI.
Ans. newton (N).

17. Name the unit of force in CGS system.
Ans. dyne.

18. The rate of change of momentum of a particle is 5 kg ms^{-2}. How much force acts on this body?
Ans. F = rate of change of momentum = 5 N.

19. 1 newton = ...dyne.
Ans. 10^5.

20. Define 1 newton force.
Ans. Force is said to be 1 newton if it produces 1 ms^{-2} acceleration in a body of 1 kg.

21. What is the relationship between force and acceleration?
Ans. F = ma, where m is the mass of a body.

22. What is the name given to the product of mass and acceleration of a body?
Ans. Force (F = ma)

25. State Newton's third law of motion.
Ans. To every action, there is equal and opposite reaction.

26. Are action and reaction forces exist in pairs?
Ans. Yes.

27. Are action and reaction forces act on same body or different bodies?
Ans. Action and reaction act on the different bodies.

28. State whether the following statement is true or false. If false, correct it. "Action and reaction are equal in magnitude and act in the same direction."
Ans. Action and reaction are equal in magnitude but opposite in reactions.

29. State law of conservation of momentum.
Ans. The total momentum of a system remains constant if no external force acts on the system.

30. How much force acts on a body whose momentum is constant (i.e. P = constant) ?
Ans. F = dp/dt. It p = constant, then no force acts on the body.

31. A fast moving truck loses momentum equal to 2 kg after colliding with a stationary car. Will the car lose or gain momentum? How much momentum is lost or gained by the car if the truck comes to the rest after collision?
Ans. The car will gain momentum. Momentum gained by the car = $2\,kg\ ms^{-1}$

32. What do you mean by recoil velocity of a gun?
Ans. The velocity with which a gun moves backward after firing bullet is called the recoil of the gun.

SHORT ANSWER TYPE QUESTIONS

1. If A and B are two bodies with masses 10 kg and 50 kg respectively, then which body has more inertia? Also calculate the ratio of the inertia of two bodies.

Ans. Inertia of body B is more than the inertia of body A.

$$\frac{Inertia\ of\ body\ B}{Inertia\ of\ body\ A} = \frac{50\ kg}{10\ kg} = \frac{5}{1}$$

2. A passenger falls backward when a bus suddenly starts moving in the forward direction. Explain, why?

3. Dust can be removed from the carpet by beating it with a stick. Explain, why ?

4. A bullet fired from a gun makes a fine hole in the window pane, while a stone smashes the window pane into pieces. Explain, why?

5. Some of the apples may get detached from an apple tree if we vigorously shake its branch. Explain, why?

6. What happens when a wet piece of cloth is shaken?

Ans. When a wet piece of cloth is shaken, fibres of the cloth come in motion and water droplets in the cloth fall down due to inertia of rest.

7. A luggage is usually tied with a rope on the roof of bus. Explain, why?

8. A passenger falls forward when the moving bus stops suddenly. Explain, why ?

9. A person getting down from the moving bus falls in the direction of the bus. Explain, why ?

10. A stone tied to a string whirls in a horizontal circle. It flies off tangentially when the string breaks suddenly. Explain, why?

11. Why, no force is required to move an object with a constant velocity?

Ans. We know, F = ma
When, velocity is constant, then acceleration, a = 0
Hence, F = 0

12. When a person hits a stone, his foot is injured. Why?

Ans. When a person hits a stone, the stone exerts equal force on his foot. Due to this force, his foot get injured.

13. According to Newton's third law of motion, a ball falling towards earth exert a force on the earth but the motion of earth towards the ball is not noticed. Explain why?

Ans. The acceleration produced in the earth is very small as its mass is very large. Hence, the motion of the earth towards ball is not noticed.

14. Why a rubber ball rebounds when it hits a wall?

15. Explain, how can we walk easily on a hard and rough surface than on a slippery surface?

16. Explain, how a man can swim in water ?

17. When a person jumps out of a boat, the boat moves backward. Explain, why ?

18. Why a boatman pushes the bank of the river with a pole to take his boat into the river?

19. Why does a gun recoil backward when a bullet is fired from it?

20. A gun recoils backward with small speed than the bullet moving forward. Explain why?

21. It is difficult for a fireman to hold a pipe through which a large amount of water comes out with a large velocity. Explain. why?

22. A bullet fired from a gun is more dangerous than an air molecule hitting a person, though both bullet and air molecule are moving with same velocity. Explain.

Ans. The momentum of a bullet is very large than the momentum of the air molecule as the mass of bullet is very large than that of air molecule. When bullet and air molecule hit a person, then the momentum transferred to person by a bullet is very large than the momentum transferred by the air molecule. Hence, large force is exerted on the person by the bullet.

23. Explain, why a gun recoils after firing a bullet?

Ans. A gun recoils after firing a bullet to conserve the momentum of the system (gun + bullet).

24. Explain, why an inflated balloon lying on the surface of a floor moves forward when pierced will a needle.

LONG ANSWER TYPE QUESTIONS

1. State Newton's second law of motion. Prove hat F= ma, where symbols have their usual meaning.

2. State the law of conservation of momentum. Prove the law of conservation of momentum

TEXT QUESTIONS

1. Which of the following has more Inertia?

(a) a rubher ball and a stone of the same size?
(b) a bicycle and a train?
(c) a five rupee coin and a one rupee coin?

Ans. (a) Stone has more inertia than the ball as the mass of the stone is greater than the mass of the ball.
(b) A train has more inertia than a bicycle.
(c) A five rupees coin has more inertia than a one-rupee coin.

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

Ans. (i) Velocity of the football changes when first player kicks the ball towards another player of his team.
(ii) Velocity of the football also changes when another player kicks the football towards the goal.
(iii) Velocity of the football also changes when the goalkeeper of the opposite team stops the football by collecting it.
(iv) Velocity of the football changes when the goalkeeper kicks it towards a player of his team.
Thus, the velocity of the ball changes four times in this case. In first and second cases, the force is supplied by the foot of players. In third case, force is supplied by the hands of the goalkeeper. In fourth case, as the goalkeeper hits the football with his foot, so the foot of the goalkeeper supplies the force.

3. Explain why some of the leaves may get detached from a tree If we vigorously shake Its branch.

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?

Ans. (i) When a moving bus brakes to a stop, the lower portion of our body also comes to rest but the upper part of our body remains in motion due to inertia of motion. Hence, we fall in the forward direction.

(ii) When a bus accelerates from rest, the lower portion of our body also comes in motion with the bus but the upper part of our body remains at rest due to inertia of rest. Hence we fall backwards.

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

6. Explain, why is it difficult for a fireman to hold a hose, which eject large amount of water at a high velocity?

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

Ans. Before firing, both rifle and bullet are at rest. Therefore, linear momentum of the rifle and bullet before firing is zero.

Let V = recoil velocity of the rifle after firing

Linear momentum of the rifle after firing = MV = (4V) $kg\ ms^{-1}$

Linear momentum of the bullet after firing $= m\upsilon = 50g \times 35 ms^{-1}$

$= \frac{50}{1000} kg \times 35 ms^{-1} = 1.75\ kg\ ms^{-1}$

∴ Linear momentum of the rifle and the bullet after firing = (4V + 1.75) **kg** ms^{-1}

According to the law of conservation of momentum:

$4V + 1.75 = 0$ or $V = -\frac{1.75}{4} = -0.44\ ms^{-1}$

-ve sign shows that velocity of rifle is in the direction opposite to the direction of the velocity of the bullet.

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

Ans. Here, mass of first object, m_1 =100g = 0.1 kg

Mass of second object, m_2 = 200 g = 0.2 kg

Velocity of first object before collision, $u_1 = 2 m s^{-1}$

Velocity of second object before collision, $u_2 = 1 ms^{-1}$

Velocity of first object after collision, $\upsilon_1 = 1.67\ m s^{-1}$

Let, velocity of second object after collision = υ_2

Momentum of both objects before collision = $m_1u_1 + m_2u_2 = 0.1 \times 2 + 0.2 \times 1 = 0.4 kg\ ms^{-1}$

Momentum of both objects after collision

$= m_1\upsilon_1 + m_2\upsilon_2 = 0.1 \times 1.67 + 0.2\ \upsilon_2 = 0.167 + 0.2\ \upsilon_2$

According to the law of conservation of momentum:

Momentum after collision = Momentum before collision

i.e. $0.167 + 0.2\upsilon_2 = 0.4$

or $\upsilon_2 = \frac{0.4 - 0.167}{0.2} = 1.165\ ms^{-1}$

CHAPTER EXCERCISES

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be traveling 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. According to Newton's first law of motion, no net external force is needed to move an object with constant velocity. So an object travels with a constant velocity (non-zero) when it experiences a net

zero external unbalanced force. The magnitude of this velocity is constant and the direction is same. An object may also not move at all if it experiences a net zero external unbalanced force. This is because, the object may be at rest.

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

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

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 to come to rest.

Ans. (c)

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

Ans. Here, $u = 0,\ S = 400m$

$t = 20s,\ m = 7\,metric\ tonnes = 7000\ kg$

(i) Using, $S = ut + \frac{1}{2}at^2$

$400 = 0 + \frac{1}{2}a \times 400 = 200a$

$\therefore\ a = 2ms^{-2}$

(ii) $F = ma = 7000 \times 2 = 14000\,N$

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

Ans. Here, $m = 1kg,\ u = 20\ ms^{-1}$

$\upsilon = 0,\ S = 50m$

(i) Using $\upsilon^2 - u^2 = 2aS$, we get

$a = \frac{\upsilon^2 - u^2}{2S} = \frac{0 - 400}{2 \times 50} = -4\,ms^{-2}$

(ii) Using, $F = ma$, we get

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

$\therefore$ Force of friction = 4N

7. A 8000 kg engine pulls a train of 5 wagons, each of 2000 kg along a horizontal track. If the engine exerts a force of 40,000 N and the track offers a friction force of 5000 N, then calculate:
(a) the net acceleration force
(b) the acceleration of the train and
(c) the force of wagon 1 on wagon 2

Ans. (a) Net acceleration force = Force exerted by engine Frictional force
= 40,000 – 5,000 = 35,000 N

(b) Acceleration, $a = \frac{Acceleration\ force}{Mass\ of\ train} = \frac{35000\,N}{10000\,kg} = 3.5\,ms^{-2}$

(c) Force of wagon 1 on wagon 2 = 8000 kg × 3.5 ms^{-2} = $28,000N$

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

Ans. Here, $m = 1500\,kg$,

$a = -1.7\ ms^{-2}$

$\therefore\ F = ma = -1500 \times 1.7 = -2550\,N$

9. What is the momentum of an object of mass m, moving with velocity υ ?

(a) $(m\upsilon)^2$ **(A)** $m\upsilon^2$ **(c)** $\frac{1}{2}m\upsilon^2$ **(d)** $m\upsilon$

Ans. $m\upsilon$

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. The cabinet will move with constant velocity, if net external force acting on it is zero. Since a horizontal force of 200 N acts on the cabinet in the forward direction, therefore, net external force acting on it will be zero if frictional force of 200 N acts on it. Thus frictional force = 200 N will be exerted on the cabinet.

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 $2.5\ ms^{-1}$ before the collision during which they stick together. What will be the velocity of the combined object after collision?

Ans. Let the two objects are A and B.

Mass of object A, m_1 = 1.5 kg

Mass of object B, m_2 = 1.5 kg

Velocity of object A before collision, u_1 = 2.5 ms^{-1}

Velocity of object it before collision, u_2 = -2.5 ms^{-1}

$\therefore$ Total momentum of objects A and B before collision = $m_1u_1 + m_2u_2 = 1.5 \times 2.5 - 1.5 \times 2.5 = 0$

Mass of combined object after collision = $(m_1 + m_2) = 3.0\,kg$

Let, velocity of combined object after collision = $V\,m\,s^{-1}$

$\therefore$ Total momentum of combined object after collision = $(m_1 + m_2)V = (3V)\,kg\ ms^{-1}$

According to the law of conservation of momentum:
Momentum after collision = Momentum before collision
i.e. 3V =0 or V = 0

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

Ans. Student's justification is not correct. Two equal and opposite forces cancel each other if they act on the same body. According to the third law of motion, action and reaction forces are equal and opposite but they both act on different bodies. Hence, they cannot cancel each other.
When we push a massive truck, then the force applied on the truck is not sufficient to overcome the force of friction between the tyres of the truck and ground. Hence the truck does not move. The truck will move only if the force applied on it is greater than the frictional force.

13. A hockey ball of mass 200g travelling at 10 ms^{-1} is struck by a hockey stick so as to return it

along its original path with a velocity at $5\,ms^{-1}$. Calculate the change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.

Ans. Mass of hockey ball, m = 200 g = 0.2 kg

Velocity of hockey ball before striking the hockey stick, $\upsilon_1 = 10\ ms^{-1}$

Velocity of hockey ball after striking the hockey stick, $\upsilon_2 = -5\ m\,s^{-1}$

$\therefore$ Change of momentum = $m\upsilon_1 - m\upsilon_2 = m(\upsilon_1 - \upsilon_2) = 0.2(10+5) = 0.2\times 15$

= $3.0\ kg\ ms^{-1}$

14. A bullet of mass 10 g travelling horizontally with a velocity of 150 ms^{-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.

Ans. Mass of bullet, m = 10g = 0.01 kg

Initial velocity of bullet, u = $150\,ms^{-1}$

Final velocity of bullet, $\upsilon = 0$

Time taken, $t = 0.03\,s$

(i) Using, $\upsilon = u + at$

Or $a = \dfrac{\upsilon - u}{t} = \dfrac{(0-150)\,ms^{-1}}{0.03s} = -5000\ ms^{-2}$

Using, $S = ut + \dfrac{1}{2}at^2$, we get

$S = 150\times 0.03 - \dfrac{1}{2}\times 5000\times 0.03\times 0.03 = 4.5 - 2.25 = 2.25m$

$\therefore$ Distance of penetration of bullet into the block = $2.25m$

(ii) Using, $F = ma$, we get

$F = 0.01\times(-5000) = -50N$

$\therefore$ Magnitude of force = $50\,N$

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

Ans. Mass of object, $m_1 = 1\,kg$

Velocity of object before collision, $u_1 = 10\ ms^{-1}$

Mass of wooden block, $m_2 = 5\,kg$

Velocity of wooden block before collision, $u_2 = 0$

(i) $\therefore$ Total momentum before the impact = $m_1u_1 + m_2u_2 = 1\times 10 + 5\times 0 = 10\,kg\ ms^{-1}$

According to the law of conservation of momentum (as no net external force acts on the system):

Total momentum after the impact = Total momentum before the impact = $10\,kg\ ms^{-1}$

(ii) Mass of combined object, M = mass of object + mass of block = 1+5= 6kg

Let, V = velocity of the combined object after collision

$\therefore$ Momentum of combined object = MV = (6V) $kg\ ms^{-1}$

Now, momentum of combined object = Total momentum after the impact

i.e., $6V = 10$

or $V = \frac{10}{6} = 1.67\ ms^{-1}$

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

Ans. Mass of object, m = 100 kg

Initial velocity, $u = 5ms^{-1}$

Final velocity, $\upsilon = 8ms^{-1}$

Time, $t = 6s$

(i) Initial momentum of the object = mu

$= 100 \times 5 = 500\,kg\ ms^{-1}$

Final momentum of the object = $m\upsilon = 100 \times 8 = 800\ kg\ ms^{-1}$

(ii) Force = $\frac{Change\ in\ momentum}{Time} = \frac{(800-500)}{6} = 50N$

17. 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 wind screen. 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 change in their momentum. Comment on these suggestions.

Ans. Rahul was correct.

18. 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 ms^{-2}

Ans. Here, u = 0, m = 10 kg

S = 80 cm = 0.8 m,

a = 10 ms^{-2}

(i) Using, $\upsilon^2 - u^2 = 2aS$, we get

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

or $\upsilon = \sqrt{16} = 4ms^{-1}$

Momentum of the dumb-bell just before it touches the floor $= m\upsilon = 10 \times 4 = 40\,kg\ ms^{-1}$

(ii) The momentum of the dumb-bell becomes zero as it touches the floor and the entire momentum is transferred to the floor.

$\therefore$ Momentum transferred to the floor = 40 kg ms^{-1}.

ADDITIONAL EXERCISES

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

Time in seconds	Distance in metres
0	0
1	1
2	8
3	27
4	64
5	125

6	216
7	343

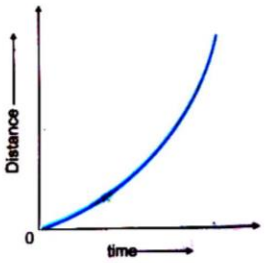
(a) What conclusion can you draw about the acceleration? Is it constant, increasing, decreasing or zero?

(b) What do you infer about the forces acting on the object?

Ans. (a) Distance-time graph for the given data is as shown in figure.

In this case, speed of the object is increasing with time as the object travels more and more distance in unit time (1s) but the velocity may not change. Thus, acceleration of the object is zero because velocity is not changing.

(b) We know, F = ma, Therefore, as the acceleration is zero, so the force acting on the object is also zero.



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

Ans. Here, mass, m = 1200 kg

acceleration, $a = 0.2\ ms^{-2}$

Using, $F = ma$, we get

$F = 1200 \times 0.2 = 240N$

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

3. A hammer of mass 500g moving at $50\,ms^{-1}$, strikes a nail. The nail stops the hammer in a very short time of 0.01s. What is the force of the nail on the hammer?

Ans. Here, mass, m = 500 g = 0.5 kg

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

Final velocity of hammer, $\upsilon = 0$

Time, t = 0.01s

$\therefore$ Force of hammer on nail, F = ma = $m\frac{(\upsilon - u)}{t}$

$= -\frac{0.5 \times 50}{0.01}$

$= -2500N$

According to Newton's third law of motion, Force of the nail on the hammer = 2500 N

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

Ans. Here, mass, m = 1200 kg

Initial velocity, u = 90 km/h

$= 90 \times \frac{5}{18} = 25\,ms^{-1}$

Final velocity, $\upsilon = 18\,km/h$

$= 18 \times \frac{5}{18} = 5\ ms^{-1}$

Time, $t = 4s$

(i) Acceleration, $a = \dfrac{Change\ in\ velocity}{Time}$

$= \dfrac{\upsilon - u}{t} = \dfrac{5-25}{4} = -5\ ms^{-2}$

(ii) Change in momentum = $m\upsilon - mu = m(\upsilon - u) = 1200(5-25) = -2400\,kg\ m\,s^{-1}$

Magnitude of change in momentum = $24000\,kg\,m\ s^{-1}$

(iii) Force, $F = ma = 1200(-5) = -6000N$

$\therefore$ Magnitude of force = $6000N$

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

Ans. (a) Car will experience the greater force of impact exerted by the truck because truck has greater momentum.

(b) Change in momentum = Initial momentum - Final momentum = m($u - \upsilon$).

Since, mass (m) of truck is greater than the mass of the car, so the truck experiences the greater change in momentum.

(c) Acceleration, $a = \dfrac{(\upsilon - u)}{t}$. Since, υ, u and t are the same for both the vehicles, so both will have the same acceleration.

(d) The momentum transferred to the car by the truck is more, so the car damages more than the truck.

CHOOSE THE CORRECT OPTION

1. When a balanced forces act on a body, the body is
(a) either at rest or moving with constant velocity (b) moving with variable speed
(c) moving with variable velocity (d) accelerating.

2. A body is accelerating in a straight line. The unbalanced force acts
(a) in the direction of motion of the body
(b) in a direction opposite to the direction of motion
(c) in a direction perpendicular to the direction of motion of the body
(d) none of these.

3. If an object experiences a net zero unbalanced force, then the body
(a) can be accelerated (b) moves with constant velocity
(c) cannot remain at rest (d) none of these.

4. A hockey player pushes the ball on the ground. It comes to rest after travelling certain distance because
(a) the player stops pushing the ball (b) no unbalanced force acts on the ball
(c) the ball moves only when pushes (d) the opposing force acts on the ball.

5. A force of 100 N acts on a ball moving on a surface. The force of friction that must act between the surface of the ball and the surface so that the ball keeps on moving with constant velocity over the surface must be
(a) zero (b) 100 N (c) 200 N (d) 300 N.

6. The law which gives the definition of force is
(a) Newton's first law of motion (b) Newton's second law of motion
(c) Newton's third law of motion (d) None of these.

7. Inertia of a body is
(a) directly proportional to the mass of the body
(b) inversely proportional to the mass of the body

(c) independent of the mass of the body (d) directly proportional to the weight of the body.

8. A father has mass 60 kg and the mass of his son is 30 kg. The ratio of the inertia of the father to the inertia of his child is
(a) 1:1 (b) 1:2 (c) 2:1 (d) 1:3

9. The momentum of a body of mass m and velocity υ is
(a) m/υ (b) υ/m (c) $m\upsilon^2$ (d) $m\upsilon$

10. The physical quantity which is the product of mass and velocity of a body is known as
(a) inertia (b) momentum (c) force (d) change in momentum

11. The relation between force, mass and acceleration is found by
(a) Newton's first law of motion (b) Newton's second law of motion
(c) Newton's third law of motion (d) Law of conservation of momentum.

12. The change in the momentum of a body in 0.01s is $10\,kg\,ms^{-1}$. The force acting on this body is
(a) 10N (b) 0.1N (c) 100N (d) 1000N

13. A force of 100N applied on an object accelerates it with an acceleration of $2ms^{-2}$. How much force is required to produce the same acceleration when identical object of same mass is tied with the first object?
(a) 50 N (b) 100 N (c) 200 N (d) 300 N

14. A book of weight 10 N is placed on a table. The force exerted by the surface of the table on the book will be
(a) zero (b) 10N (c) 20 N (d) none of these

15. The earth attracts a stone towards itself with a force of 10N. Then the force with which the stone attracts the earth is
(a) Zero (b) 20N (c) 10 N (d) none of these

16. Action and reaction are equal and opposite and they act
(a) on the same body (b) on the different bodies
(c) such that their resultant effect is zero (d) such that their resultant effect is added.

17. A gun recoils after firing to conserve
(a) velocity (b) momentum (c) force (d) speed

Answer

1.(a) 2.(a) 3.(b) 4.(d) 5.(b) 6.(a) 7.(a) 8.(c) 9.(d) 10.(b) 11.(b) 12.(d) 13.(c) 14.(b) 15.(c) 16.(b) 17.(b)

Hints to typical MCQs

12. F = change in momentum/time

13. m = F/a = 100/2 = 50 kg
F = (m+m)a = 100× 2 = 200 N

14. $F_1 = -F_2$

HIGHER ORDER THINKING QUESTIONS

1. " Action and rection are equal opposite but even then they do not cancel each other." Explain, why?

Ans. Two equal and opposite force can cancel each other if they act on the same body.
But action and reaction do not act on the same body. Action acts on one body and the reaction acts on another body. Hence they cannot cancel each other.

2. If is difficult to balance our body when we accidently step on a peel of banana. Explain, why?

Ans. When we walk on the ground, our foot pushes the ground in the backward direction (Action). On the other hand, ground pushes our foot in the forward direction (Reaction). This reaction of the ground helps us to move in the forward direction.
But, when our foot falls on a peel of banana, then our foot slips on the peel of banana and cannot push the ground in the backward direction. Consequently, no reaction force acts on our foot. Hence we lose the balance and fall down.

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

Ans. The horse pushes the ground with its foot in the backward direction by pressing the ground in a slanting direction. As a result of this action, the ground pushes the horse in the forward direction. Hence, the horse pulls a cart.

CONSERVATION OF MOMENTUM

CONSERVATION OF MOMENTUM

1. The force of friction between the surface of a floor and the surface of a box in contact with the floor in 200 N. We wish to move the box on the floor with constant velocity. How much force has to be applied on the box?

Ans. The box will move with a constant velocity if no external force acts on the body. Thus, the effect of force of friction has to be balanced. So a force equal to the force of friction (i.e., 200 N) but opposite in direction has to be applied on the box to move it with a constant velocity. So the applied force on the box = 200 N.

2. A force of 100 N acts on a body moving with a constant velocity of $20 ms^{-1}$ on a floor in a straight line. What is the force of friction between the body and the floor ?

Ans. Since, body is moving with a constant velocity, so no net force acts on the body. Hence, the force of 100N acting on the body must be balanced by the force of friction between the body and the floor in contact. Therefore, force of friction between the body and the floor = 100 N.

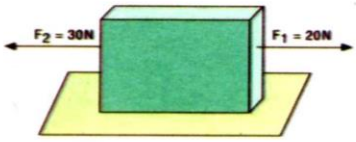
3. Is it possible for an object to be travelling with a non-zero velocity if the object experiences a net zero external unbalanced force? If yes, what is the magnitude and direction of the velocity of the object?

Ans. The object moves with a non-zero velocity if it experiences a net zero external unbalanced force. The magnitude of such velocity is constant and its direction remains unchanged i.e. such velocity is known as constant velocity.

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. Any object moving on a level ground comes to rest if some force acts on it to oppose its motion. So correct option is (c).

5. Two forces F_1 = 20 N and F_2 = 30 N are acting on an object as shown in figure.
(i) What is the net force acting on the object?
(ii) What is the direction of the net force acting on the object,
(iii) How much extra force is acting on the object if the object is not moving due to the application of these two forces? Name that force. Where that force acts and what is the direction of that force?



Ans. (i) Net force acting on the object = $F_2 - F_1$ = 30 N - 20 N = 10 N

(ii) Net force acts in the direction of the force F_2.

(iii) Since the object is not moving, so net external force acting on it is zero. If extra force = F_3, then

$F_1 + F_2 + F_3 = 0$

or $20N - 30N + F_3 = 0$

(Direction of F_1 is taken as +ve and direction of F_2 is taken as -ve).

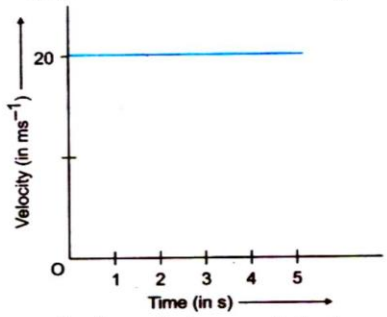
or $-10N + F_3 = 0$

or F3 = 10 N

This force F_3 is known as force of friction.

Force of friction acts between the lower surface of the object and the upper surface of the floor. Direction of force of friction is same as the direction of force F^.

6. Velocity-time graph of a moving particle is shown in figure. How much force acts on the partile?

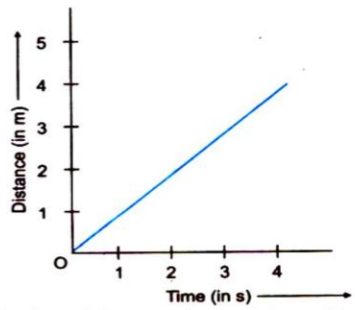


Ans. From the graph, it is clear that velocity of the particle is constant. Since, velocity is not changing with time, so the acceleration of the particle is zero. According to Newton's second law of motion,

$F = ma \equiv m \times 0 = 0$

Thus, force acting on the particle is zero

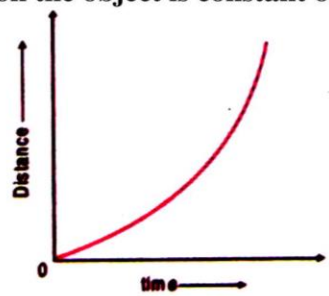
7. Distance-time graph of a moving body is shown in figure. How much force is acting on the body?



Ans. From the graph, it is clear that the boyd is moving with uniform velocity i.e., constant velocity. Hence acceleration of body is zero. Therefore, force acting on the body is zero.

$$[\because F = ma]$$

8. Distance-time graph for the motionof an object is shown in figure.
(i) State whether the acceleration of the object is constant or variable.
(ii) State whether force acting on the object is constant or variable



Ans. (i) W e known, distance, $S = ut + \frac{1}{2}at^2$

Since $u = 0$ (i.e., velocity is zero at t = 0)

$\therefore\ S = \frac{1}{2}at^2$

The given graph is possible if $S \propto t^2$ or $a = cons\tan t$
Thus, acceleration of the obejct is constant
(ii) Since, F = ma, therefore, force F is constnat because both m and a are constant.

9. Two similar buses are moving with same velocity on the road. One of them is empty and the other is loaded with passengers. Which of the two will be stopped by the application of less force? Explain.

Ans. Momentum = $m\upsilon$. Loaded bus has greater mass than the empty bus. So loaded bus has greater momentum than the empty bus. The rate of change momentum is directly proportional to the force applied. Therefore, the empty bus will be stopped by applying less force.

MODEL NUMERICAL PROBLEMS

1. A motorcycle of mass of 2000 kg is moving over a horizontal road, with uniform velocity. If this motorcycle has to be stopped with a negative acceleration of $1.5ms^{-2}$, then what is the force of friction between the tyres of the motorcycle and the road?

Sol. Here, $m = 2000\,kg$; $a = -1.5\,ms^{-2}$; $F = ?$

Using, $F = ma$, we get

$F = -2000\,kg \times 1.5\,ms^{-2} = -3000\,kg\ ms^{-2}$

$= -3000\,N$

Negative sign shows that force of friction (F) acts in a direction opposite to the motion of the motorcycle.

Note. Force of friction is also known as a retarding force.

2. Find the acceleration produced by a force of 20 N acting on a body of 5 kg.

Solution. Here, mass, m = 5 kg; Force, F =20N; $a = ?$

Using, $F = ma$, we get

$a = \frac{F}{m} = \frac{20N}{5kg} = \frac{20\,kg\ ms^{-2}}{5\,kg}$ $\quad [\because 1N = 1\,kg\ ms^{-2}]$

$= 4\ ms^{-2}$

3. A bus of mass 5000 kg starts from rest and rolls down a hill. If it travels a distnace of 200 m in 10s. Calculate (i) acceleration of the bus and (ii) the force acting on the bus.

Sol. Here, $m = 5000\,kg$; $u = 0$; $s = 200\ m$; $t = 10s$;

$a = ?$; $F = ?$

Step 1. Using, $s = ut + \frac{1}{2}at^2$, we get

$200\,m = 0 + \frac{1}{2}a \times 100s^2$ s

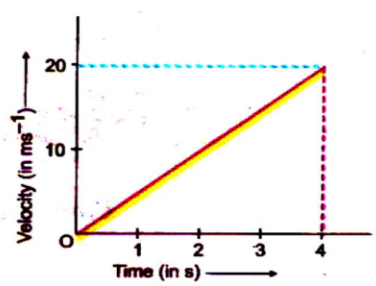
Or $a = 4\,ms^{-2}$

Step 2. Using, $F = ma$, we get

$F = 5000\,kg \times 4\,ms^{-2} = 20,000\ kg\ ms^{-2}$

$= 20,000\ N \quad (\because 1\,kg\ ms^{-2} = 1N)$

4. The velocity-time graph of a ball moving on the surface of floor is shown in figure. Calculate the force acting on the ball, if mass of the ball is 20g.



Sol. The velocity-time graph shows that the velocity of the ball at $t = 0$ is zero. That is initial velocity of ball, u = 0

Velocity of ball at $t = 4s$ is $20\ ms^{-1}$

That is, final velocity, $\upsilon = 20\ ms^{-1}$

Time, $t = 4s$

$a = ?\ ;\ F = ?$

Step 1. Acceleration of the ball, $a = \dfrac{\upsilon - u}{t}$

Or $a = \dfrac{20\,ms^{-1} - 0}{4s}$

Or $\therefore\ a = 5\,ms^{-2}$

Step 2. Also mass of ball, $m = 20\,g = \dfrac{20}{1000}kg = \dfrac{1}{50}kg$

$\therefore$ Force acting on the ball, F = ma

Or $F = \dfrac{1}{50}kg \times 5\,ms^{-2} = 0.1\ kg\ ms^{-2}$

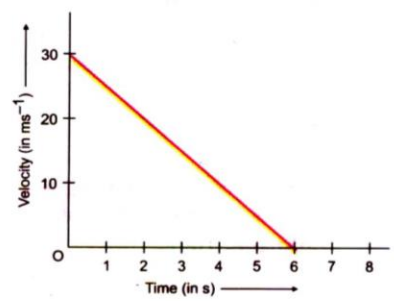
$= 0.1N$ $\left[\because 1kg\ ms^{-2} = 1N\right]$

5. The velocity-time graph of a ball moving on the surface of a floor is shown in figure. Find the force acting on the ball if the mass of the ball is 50g.

Sol. The velocity-time graph shows that velocity of the ball at t= 0 is $30\,ms^{-1}$

That is, final velocity of the ball, $\upsilon = 0$

Time, $t = 6s;\ F = ?$



Step 1. Acceleration of the ball,

$a = \dfrac{\upsilon - u}{t}$ s

$= \dfrac{0 - 30\ ms^{-1}}{6s}$

$= -5\,ms^{-2}$

Negative sign shows that the ball is retarded or decelerated.

Step 2. Also, mass of ball, $m = 50\,g = \dfrac{50}{1000} = \dfrac{1}{20}kg$

$\therefore$ Force acting on the ball, F = ma

$= \left(\dfrac{1}{20}kg\right)(-5\ ms^{-2}) = -0.25\ kg\ ms^{-2}$

$= -0.25\,N$ $\left[\because 1kg\ ms^{-2} = 1N\right]$

Negative sign shows that the force is acting on the ball in a direction opposite to the direction on the motion of the ball. Such force is known as **retarding force** or opposing force.

6. An iron sphere of 1kg is moving a velocity of $20\,ms^{-1}$ on a cemented floor. It comes to rest after travelling a distance of 50m. Find the force of friction between the sphere and the floor.

Sol. Here, $m = 1kg;\ u = 20\,ms^{-1};\ \upsilon = 0;\ s = 50\,m;\ F = ?$

Step 1. Using, $\upsilon^2 - u^2 = 2as$, we get

$$a = \frac{\upsilon^2 - u^2}{2s} = \frac{0-(-20\,ms^{-1})^2}{2\times 50\,m} = -\frac{400\,m^2s^{-2}}{100m}$$

$= -40\,ms^{-2}$

Step 2. Using $F = ma$, we get

$F = -1\,kg \times 4\,ms^{-2}$

$= -4\,kg\ ms^{-2} = -4N$

Negative sign shows that the force is retarding force.

$\therefore$ Force of friction $= 4N$

7. A wooden block of mass m_1 kg acceleration at $10\,ms^{-2}$ when a force of 5 Newton acts on it. Another block of mass m_2 kg accelerates at $20\,ms^{-2}$ when the same force acts on it. Find the acceleration, if both the blocks are tied together and same force acts on this combination.

Sol. For First Block:

$m = m_1\ kg;\ a = 10\,ms^{-2};\ F = 5N$

Using, $F = ma$, we get

$$m_1 = \frac{F}{a}$$

Or $m_1 = \dfrac{5N}{10\ ms^{-2}} = \dfrac{5\,kg\ ms^{-2}}{10\ ms^{-2}} = 0.5\,kg$

For Second Block:

$m = m_2 kg;\ a = 20\,ms^{-2};\ F = 2N$

Using, $F = ma$, we get

$$m_2 = \frac{F}{a} = \frac{5N}{20\ ms^{-2}} = \frac{5kg\ ms^{-2}}{20\ ms^{-2}} = 0.25\,kg$$

When both the blocks are tied together

Mass of the combination, $m = (m_1 + m_2) = (0.5\,kg + 0.25\,kg) = 0.75\,kg$

$F = 5N$

Using, $F = ma$, we get

$$a = \frac{F}{m} = \frac{5N}{0.75\,kg} = \frac{5kg\ ms^{-2}}{0.75\,kg} = \mathbf{6}.67\,ms^{-2}$$

8. A car of mass 1000 kg moving with a velocity of $36\ km/h$ hits a wall and comes to rest in 5s. Find the force exerted by the car on the wall.

Sol. Here, $m = 1000kg$

Initial velocity, $u = 36\,km/h = 36\times\dfrac{5}{18}ms^{-1} = 10\,ms^{-1}(\because 1km/h = \dfrac{5}{18}ms^{-1})$

Final velocity, $\upsilon = 0$

Time, $t = 5s$

$F = ?$

Using, $F = ma$, we get

$$F = m\left(\frac{\upsilon - u}{t}\right) = 1000\left(\frac{0-10}{5}\right) = -2000\,N$$

Thus, force exerted by the car on the wall = 2000N

9. A ball of mass 100g moving with velocity of $10\,ms^{-1}$ is stopped by a boy in $0.2\,s$. Calculate the force applied by the boy to stop the ball.

Sol. Here, mass of ball, $m = 100\,g = \frac{100}{1000}kg = 0.1kg$

Initial velocity of ball, $u = 10\,ms^{-1}$

Final velocity of ball, $\upsilon = 0$

Time, t = 0.2s

F=?

Step. 1 Using $a = \frac{\upsilon - u}{t}$ we get

$a = -\frac{10}{0.2} = -50\,ms^{-2}$

Step 2. Using, $F = ma$, we get

$F = 0.1kg(-50\,ms^{-2}) = -5\,kg\ ms^{-2} = -5N$

Negative sign shows that force applied by the boy is the opposing force i.e., a force in a direction opposite to the direction of motion of the ball.

Alternate Method

Mass of ball, $m = 100\,g = 0.1kg$

Initial velocity of ball, $u = 10\,ms^{-1}$

Final velocity of ball, $\upsilon = 0$

Time, t = 0.2s

Change in momentum = $m\upsilon - mu$

$= 0.1kg \times 0 - 0.1kg \times 10\,ms^{-1} = -1\,kg\ ms^{-1}$

Force applied by the boy, $F = \frac{Change\ in\ momentum}{Time\ taken} = \frac{-1kg\ ms^{-2}}{0.2\,s}$

$= -5\,kg\ ms^{-2} = -5N$

10. A car of mass 1000 kg and a bus of mass 8000 kg are moving with same velocity of $36\,km\ h^{-1}$. Find the forces to stop both the car and the bus in 5s.

Sol. Here, initial velocity, $u = 36\,km\,h^{-1} = 36 \times \frac{5}{18}ms^{-1} = 10\,ms^{-1}$

Final velocity, $\upsilon = 0$

Time t = 5s

Step 1. $a = \frac{\upsilon - u}{t}$, we get

$a = \frac{(0-10)\,ms^{-1}}{5s} = -2\,ms^{-2}$

Mass of car, $m = 1000kg$

$\therefore$ Force required to stop the car,

$F = ma = 1000kg(-2\,ms^{-2}) = -2000N$

Step 2. Mass of the bus, $m = 8000\,kg$

$\therefore$ s Force required to stop the bus,

$F = ma = 8000kg\,(-2\,ms^{-2}) = -16000N$

Negative sign with force shows that the force is applied in a direction opposite to the directions of the motion of the car and the bus. Such a force is known as **retarding force.**

11. A body of mass 100g is at rest on a smooth surface. A force of 0.2 newton acts on it for 5 secons. Calculate the distance travelled by the body.

Solution. Here, $m = 100g = \frac{100}{1000}kg = \frac{1}{10}kg$

$F = 0.2N$

$t = 5s$

$u = 0$

$S = ?$

Step 1. F = ma, we get

$$a = \frac{F}{m}\frac{0.2N}{\frac{1}{10}kg} = \frac{0.2kg\ ms^{-2}}{\frac{1}{10}kg} = 2ms^{-2}$$

Step 2. To find distance travelled, using

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

$$S = 0 + \frac{1}{2}(2ms^{-2})(25s)^2 = 625m$$

12. A gun fires a bullet of mass 50g. The bullet moving with a velocity of $100ms^{-1}$ strikes a wooden plank and comes to rest in $0.05s$. Calculate (i) the force exerted by the wooden plank on the bullet and (ii) the distance of penetration of the bullet in the wooden plank.

Sol. Here, $m = 50g = \frac{50}{1000} = \frac{1}{20}kg$

$u = 100\ ms^{-1}$

$\upsilon = 0$

$t = 0.05\,s$

$F = ?;\ S = ?$

(i) Using, $F = ma$, we get

$$F = m\left(\frac{\upsilon - u}{t}\right) \qquad \left(\because a = \frac{\upsilon - u}{t}\right)$$

$$= \frac{1}{2}kg\left(\frac{0 - 100ms^{-1}}{0.05s}\right) = -100kg\ ms^{-2} = -100N$$

Thus, force exerted by the wooden plank on the bullet = 100 N

(ii) Using, $S = ut + \frac{1}{2}at^2$

Or $S = ut + \frac{1}{2}\left(\frac{\upsilon - u}{t}\right)t^2$, we get

$$S = 100ms^{-1} \times 0.05s + \frac{1}{2}(0 - 100ms^{-1}) \times 0.05s = 5m - 2.5m = 2.5m$$

13. A mechanic strikes a nail with a hammer of mass 500g moving with a velocity of $20ms^{-1}$. The hammer comes to rest in $0.02s$ after striking the nail. Calculate the force exerted by the nail on the hammer

Sol. Here, $m = 500\,g = \frac{1}{2}kg;\ u = 20ms^{-1}$

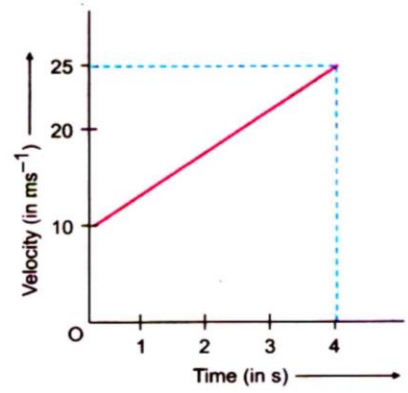
$\upsilon = 0;\ t = 0.02\,s;\ F = ?$

Using, $F = ma$

Since $a = \left(\frac{\upsilon - u}{t}\right)$ so

$$\therefore \quad F = m\left(\frac{\upsilon - u}{t}\right) = \frac{1}{2}kg\left(\frac{0 - 20ms^{-1}}{0.02s}\right) = -500N$$

Therefore, force exerted by nail on the hammer = $500N$

UNSOLVED NUMERICALS

1. Find the force acting on a body of mass 5 kg accelerating with an acceleration of 2 ms^{-2}.
[Ans. 10 N]
2. The engine of a car of mass 1000 kg produces a force of 10,000N. Find the acceleration of the car.
[Ans. $10ms^{-2}$**]R**
3. Same amount of force is acting on a car and bus. If the ratio of the mass of the bus and the car is 25:1, calculate the ratio of the acceleration produced in the car to the acceleration produced in the bus.
[Ans. 25:1]
4. A body A of mass 1 kg has acceleration 2 ms^{-2}. Another body B of mass 0.5 kg has acceleration $5ms^{-2}$. On which body greater force acts ?
[Ans. On body B]
5. A force of 5N acting on a body A produces an acceleration of $2ms^{-2}$. The same force acting on the body B produces an acceleration of 5 ms^{-2}. Find the mass of the bodies A and B. What will be the acceleration produced if both the bodies are tied together and same force (i.e. 5N) acts on it?
[Ans. Mass of body A = 2.5 kg; Mass of body B =1 kg; a = 1.43 ms^{-2}**]**
6. A ball of mass 150 g moving with a velocity of 15 ms^{-1} is brought to rest by a player in 0.1s. Calculate the force acting on the hands of the players. **[Ans. 22.5 N]**
7. The velocity of a body of mass 100g is increased from $5ms^{-1}$ to 10 ms^{-1} in 5 seconds. Calculate the force acting on the body.
[Ans. 0.1 N]
8. A bullet of mass 10 g travelling with a velocity of 100 ms^{-1} penetrates in a wooden plank and is brought to rest in 0.01s. Find (i) the distance through which the bullet penetrates in the wooden plank and (ii) the force exerted on the bullet.
[Ans. 0.5 m; 100 N]
9. The velocity-time graph of a particle moving on the ground is shown in figure. If the mass of the particle is 100 g, find the force acting on the particle.
[Ans. 0-375 N]
10. A truck of mass 5000 kg moving with a velocity of 54 km h^{-1} hits against a hill and comes to rest in 2 s. How much force is exerted on the truck by the hill?
[Ans. - 37500 N]
11. The mass of a scooter along with its rider is 150 kg. The scooter moving at a velocity of 72 $km\ h^{-1}$ is stopped in 10s after brakes were applied. Find the force required by the brakes to stop the scooter.
[Ans. - 300 N]