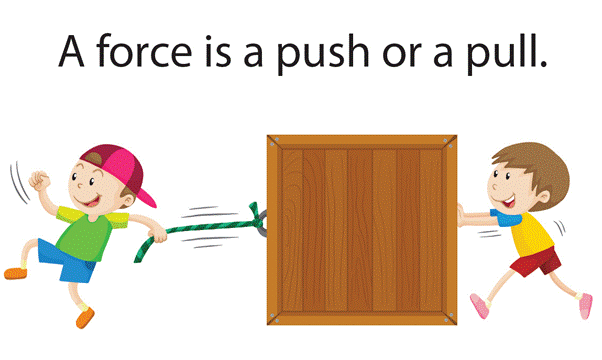
**Introduction to Force**

A force is an effort that changes the state of an object at rest or at motion. It can change an object’s direction and velocity. Force can also change the shape of an object.

## ****What is a force?****

To move a stationary object from one place to another, we need to put some effort. This effort is known as force. For Example, a push, a hit or a pull.



**Effects of Force**

Some effects of force include the following:

* Force moves stationary objects
* Force stops objects from moving
* Force changes the shape of a body
* Force changes the direction of motion

Push is defined as an action of force which causes an object to move from its place. The following are examples of push:

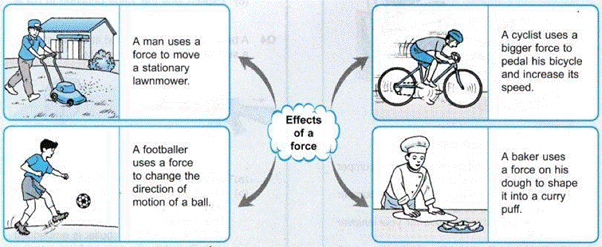
* Opening and closing the door
* Pushing the table
* Pushing a car
* Pushing of thumb pins
* Walking

Pull is defined as an action to make something move by either tugging or dragging. The following are examples of pull:

* Plucking the string of a guitar
* Pulling ropes while playing tug of war
* Opening the drawer
* Pulling the window curtain
* Opening and closing the doors

Whenever we push or pull an object a force acts upon them and makes them move from one place to another. Hence, the force can do the following to stationary objects –

* initiate motion in a motionless object
* change (increase or decrease) the velocity of the moving object
* alter the direction of a moving object
* change the shape and size of an object

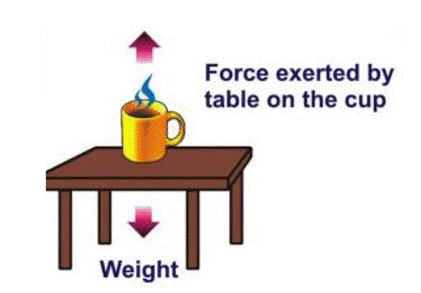


### Balanced and Unbalanced Forces

When balanced forces are applied to an object, there will be no net effective force acting on the object. Balanced forces do not cause a change in motion.

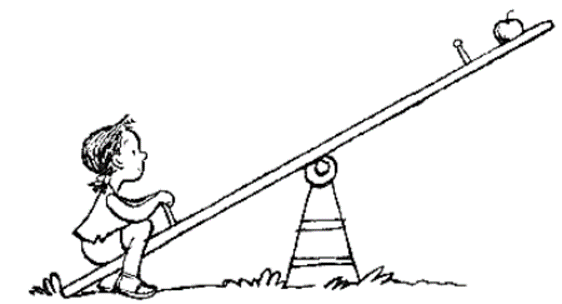
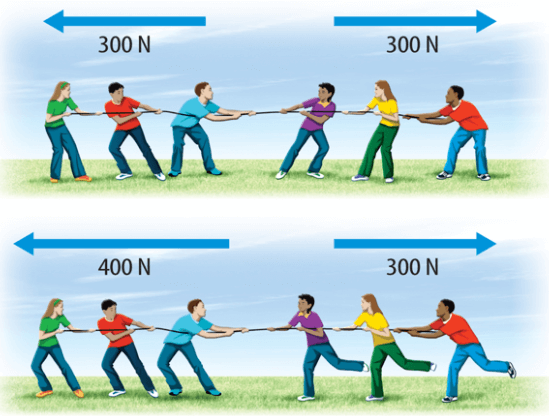
**Balanced Forces –** When equal amounts of forces are applied to an object from different directions such that they cancel out each other, such forces are known as **balanced forces**.

* Balanced forces do not change the state of rest or motion of an object.
* Balanced forces may change the shape and size of an object.



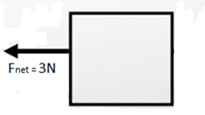
**Unbalanced Force –** When forces applied to an object are of different magnitude (or not in opposite directions to cancel out each other), such forces are unbalanced forces.  Unbalanced forces acting on an object change its speed and/or direction of motion. It moves in the direction of the force with the highest magnitude.

* Unbalanced forces can alter the state of rest or motion of an object.
* Unbalanced forces can cause acceleration in an object.
* Unbalanced forces can change the shape and size of an object.

### Net Force

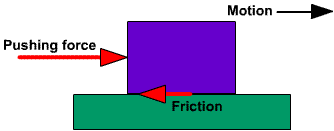
When multiple forces act on a body, they can be resolved into one component known as the net force acting on the object. The net force decides the direction of motion.



**Frictional Force**

It is a force extended when two surfaces are in contact with each other. It always acts in a direction opposite to the direction of motion of the object. The force that opposes relative motion is called friction. It arises between the surfaces in contact.

Example: When we try to push a table and it does not move is because it is balanced by the frictional force.



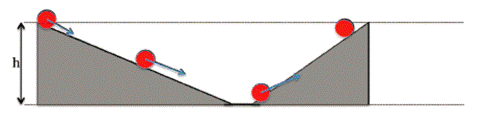
### First Law of Motion

**Galileo’s Observation**

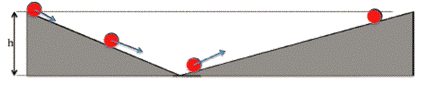
* He observed the motion of objects on an inclined plane.
* When marble is rolled down an inclined plane its velocity increases.

**Galileo’s Arguments**

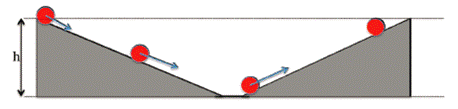
* When marble is rolled down from the left – It will go up on the opposite side up to the same height at which it is dropped down.



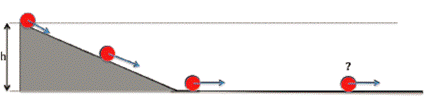
* If the inclination of planes is equal – The marble would travel equal distances while climbing up as travelled while rolling down.



* If we decrease the angle of inclination of the right plane – The marble would travel further until it reaches its original height.

****

If the right side plane is made flat – Marble would travel forever to achieve the same height.



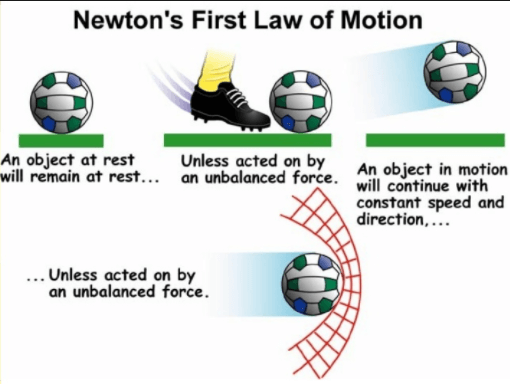
**Galileo's Inference**

* We need an unbalanced force to change the motion of the marble but no force is required when the marble is moving uniformly.
* In other words, objects move at a constant speed if no force acts upon them.

**Based on Galileo’s ideas Newton presented the three Laws of Motion**

**The First Law of Motion or The Law of Inertia**

### Whether an object is moving uniformly on a straight path or is at rest, its state would not change until and unless an external force is applied to it A body continues to be in the state of rest or uniform motion in a straight line unless acted upon by an external unbalanced force. The First Law is also called the Law of Inertia.



### Inertia

we can say that objects oppose a change in their state of motion or rest. This tendency of objects to remain in the state of rest or to keep moving uniformly is called **Inertia.**

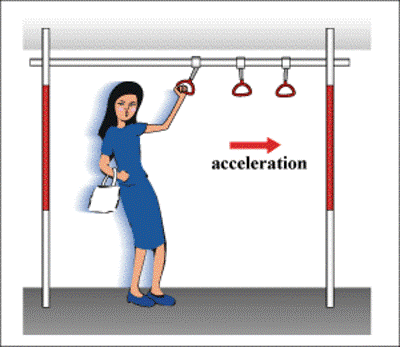
Basically, all objects have a tendency to resist the change in the state of motion or rest. This tendency is called inertia. All bodies do not have the same inertia. Inertia depends on the mass of a body. The mass of an object is the measure of its inertia.

More the mass → more the inertia and vice versa.

#### Inertia of Rest

An object stays at rest, and it remains at rest until an external force affects it. Example: When a car accelerates, passengers may feel as though their bodies are moving backwards. In reality, inertia is making their bodies stay in place as the car moves forward.

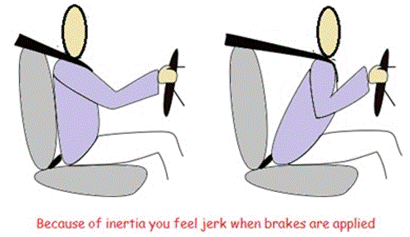
* We fall back when a vehicle starts moving in the forward direction because our body is in the rest state and it opposes the motion of the vehicle.



**Inertia of Motion**

An object will continue to be in motion until a force acts on it. Example: A hockey puck will continue to slide across the ice until acted upon by an outside force.

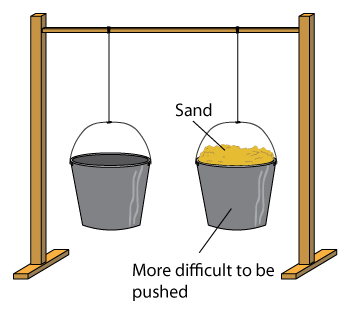
* We fall forward when brakes are applied in a car because our body is opposite the change of state of motion to rest.



**Inertia and Mass**

* The inertia of an object is dependent upon its mass.
* Lighter objects have less inertia, that is, they can easily change their state of rest or motion.
* Heavier objects have large inertia and therefore they show more resistance.
* Hence ‘Mass’ is called a measure of the inertia of an object.

Consider the image given below; it is easier for a person to push the empty bucket rather than the one that is filled with sand. This is because the mass of an empty bucket is less than that of the bucket filled with sand.



## Second Law of Motion

In order to understand the Second Law, we need to first understand momentum.

### Momentum

Impacts produced by objects depend on their mass and velocity. The momentum of an object is defined as the product of its mass and velocity. p = mv. Vector quantity has direction and magnitude. An example of momentum is a baseball flying through the air and a bullet fired from a gun.

### Second Law of Motion

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

Here, a [ = (v – u)/t ] is the acceleration, which is the rate of change in velocity.

F = kma

For 1 unit of force on 1 kg mass with the acceleration of 1m/s2, the value of k = 1.

Therefore, F = ma.

**Conservation of Momentum**

**Concept of System**

* The part of the universe chosen for analysis is called a system.
* Everything outside the system is called an environment.
* For example, a car moving with constant velocity can be considered a system. All the forces within the car are internal forces, and all forces acting on the car from the environment are external forces like friction.

## ****The Second Law of Motion****

* The impact produced by a moving object depends upon its mass and velocity.
* **For Example**, a small bullet fired at a high velocity can kill a person.
* **Momentum** – The product of mass and velocity is called Momentum.
* It is a vector quantity. Its direction is the same as that of the object’s velocity.
* Denoted by – p
  + SI unit – kg metre per second
* p = mv, where m is the mass of the object and v is the velocity of the object

**The momentum of a stationary object –**

Let the mass of a stationary object be ‘m’,

Let the velocity of a stationary object be ‘v’,

The stationary object has no velocity, so v = 0,

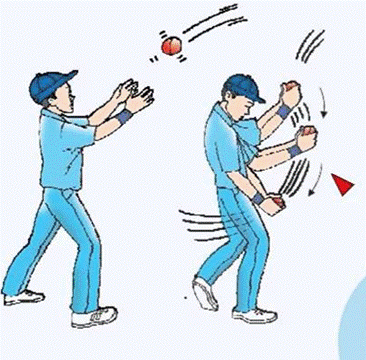
Therefore, p = m\*v = m\*0 = 0

So, the **momentum of a stationary object is zero**.

* We know that the velocity of an object can be changed by applying an unbalanced force to it. Similarly, the momentum of an object can change by applying an unbalanced force.
* **According to the second law of motion** – The rate of change of momentum of an object is directly proportional to the applied unbalanced force on the object in the direction of the force.

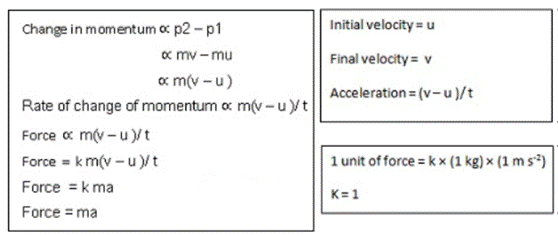
**For Example –**

A cricketer when catches a ball pulls his hands in the backward direction to give some time to decrease the velocity of the ball. As the acceleration of the ball decreases the force exerted on catching the moving ball also decreases. If the cricketer would try to stop a moving ball suddenly he would have to apply a larger force.



**Mathematical Formulation of the Second Law of Motion**

Based on the definition of the second law of motion, we can infer that -



Therefore, with help of the second law of motion, we can evaluate the amount of force that is being exerted on any object. From the formula stated above, we can see that the force is directly proportional to acceleration. So the acceleration of an object can change depending upon the change in force applied.

**Force = ma**

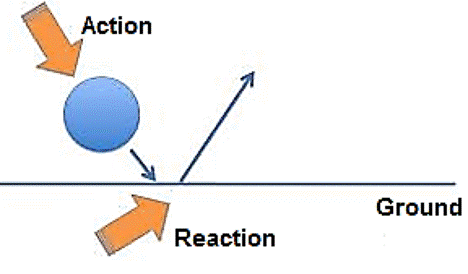
**SI Unit: kg m s2 or N (Newton)**

## Third Law of Motion

**Action and Reaction Forces**

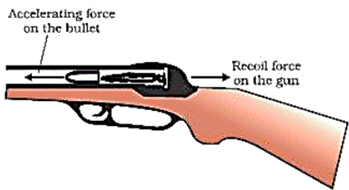
Two forces acting from opposite directions are called **Action** and **Reaction Forces**.

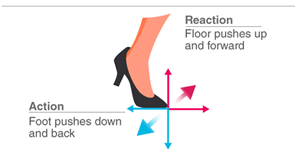
**For Example**, a ball when it hits the ground (action) bounces back with a certain force reaction.



**The Third Law of Motion states that –**

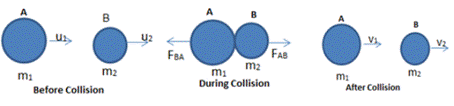
* When an object exerts a force on another object, the second object instantly exerts a force back onto the first object. These forces are always equal in magnitude but opposite in direction. These forces always act on two different objects.
* Newton’s 3rd law states that every action has an equal and opposite reaction. Action and reaction forces are equal, opposite and acting on different bodies.
* Or in other words, every action has an equal and opposite reaction.
* The magnitudes of forces acting upon the objects are the same but the acceleration produced in them may or may not be the same because the objects can differ in masses.
* **For Example**, when a bullet is fired from a gun, the gun only moves a little backwards (recoils) while the bullet can travel a large distance. This is because of the difference in the mass of the bullet and the gun.

** **

**Conservation of Momentum**

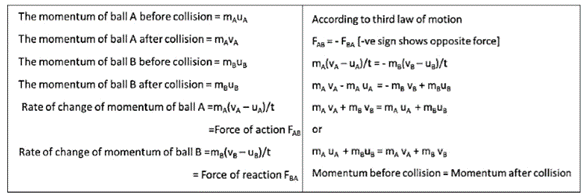
As per the law of conservation of momentum, the sum of momenta of two objects before the collision and after collision remains the same given that no external unbalanced force acts upon them. In another way, collision conserves the total momentum of two objects.



Consider the figure given above. Two balls A and B having certain initial velocities collide with each other. Conditions before the collision-

* There is no unbalanced force acting upon them
* The initial velocity of A is greater than the initial velocity of B

The figure below explains how the momentum of the balls is conserved after the collision.



* The total momentum of an isolated system is conserved.
* Isolated system → net external force on the system is zero.
* Example: Collision of 2 balls, A and B.

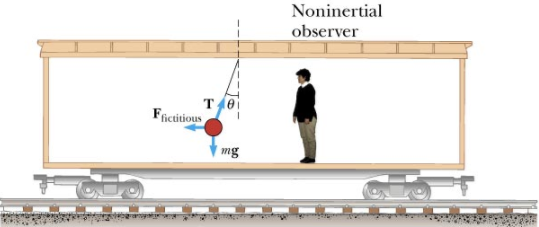
From Newtons 3rd law F\_{AB} = -F\_{BA}

**Facts about Conservation Laws**

* They are considered the fundamental laws in physics.
* They are based on observations and experiments.
* They cannot be proved but can be verified or disproved with the help of experiments.
* A single experiment is enough to disprove a law, while a single experiment is not enough to prove the same.
* It requires a large number of experiments to prove the law.
* The law of conservation of momentum was formulated 300 years ago.
* There is no single situation present until now that disproves this law.
* Other laws of conservation are – the law of conservation of energy, the law of conservation of angular momentum, the law of conservation of charge.

**Inertial and Non-Inertial Frames**

* A non-inertial frame of reference is a frame of reference in which Newton’s laws of motion do not hold. A non-inertial reference frame is a frame of reference that is undergoing acceleration with respect to an inertial frame. An accelerometer at rest in a non-inertial frame will, in general, detect a non-zero acceleration.
* A frame of reference where Newton’s Laws hold is known as an inertial frame of reference.



**Question** Name the scientist who proved for the first time that objects move with constant speed when no force acts on them.

**Answer** Galileo.

**Question** Why do bicycles begin to slow down when we stop pedalling?

**Answer** This is because of the frictional forces acting opposite to the direction of motion.

**Question** Which law of motion gives the measure of force?

**Answer** Newton’s second law of motion.

**Question** Write the C.G.S unit of force.

**Answer** Dyne.

**Question** Can every force produce motion in every object?

**Answer** No.

**Question** When a force is applied to a body, what are the two essential effects it can produce?

**Answer**

* It can bring about the change in the state of motion of a body or
* It can deform a body, i.e., it can change its shape.

**Question** Define 1 newton force.

**Answer** 1 newton is the magnitude of force which produces an acceleration of 1 m/s2 in a body of mass 1 kg.

**Question** What do you mean by an impact force?

**Answer** The force produced by the impact of a fast moving object on another is called impact force.

**Question** Define force of friction.

**Answer** The force acting between any two surfaces in contact and tending to oppose motion is called force of friction.

**Question** Define electrostatic force.

**Answer** The force exerted by an electrically charged body is called electrostatic force.

**Question** If the body is found to be accelerated, is the force acting on it balanced or unbalanced?

**Answer** Unbalanced.

**Question** What do balanced forces usually do to a body?

**Answer** Balanced forces usually produce a change in the shape of the body.

**Question** When a body moves on flat surface, will its speed change?

**Answer** No.

**Question** What did Galileo conclude on the basis of his experiments on the motion of objects?

**Answer** A body continues to move with the same velocity if no unbalanced force acts on it.

**Question** What do you mean by a resultant force?

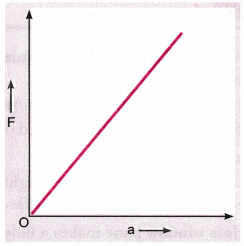
**Answer** When two or more forces act on a body simultaneously, then the single force which produces the same effect as produced by all the forces acting together is known as the resultant force.

**Question** Do action and reaction act on the same body?

**Answer** No, action and reaction act on different bodies.

**Question** Plot a graph between force applied on a body and the acceleration produced in the given mass, assuming that the magnitude of force is constantly changing.

**Answer**



**Question** Write the SI unit of impulse.

**Answer** Ns.

**Question** What is the total momentum of a bullet and a gun before firing?

**Answer** Zero.

**Question** Name the principle on which a rocket works.

**Answer** Newton’s third law of motion

**Question** Body A is heavier than body **Question** Which has more inertia?

**Answer** A has more inertia.

**Question** A body is moving with uniform acceleration. Is its momentum constant?

**Answer** No.

**Question** Name the physical quantity that corresponds to the rate of change of momentum.

**Answer** Force.

**Question** Which principle is involved in the working of a jet plane?

**Answer** Newton’s third law of motion.

**Question** Why mass is sometimes called coefficient of linear inertia?

**Answer** It is easier to pull a lighter body than a heavier body. Therefore, more the mass more will be the inertia. That is why mass is sometimes termed as coefficient of linear inertia.

**Question** When a force acting on a body has equal and opposite reaction, then why should the body move at all?

**Answer** The action and reaction act on different bodies. Therefore, the body moves under the action of the acting force.

**Question** Does Newton’s third law apply to a system where bodies do not actually touch each other?

**Answer** Yes, whenever the bodies are in actual contact or even if there is an interaction between the bodies (e.g., attraction or repulsion between two magnets charges, etc.), Newton’s third law is applicable.

**Question** Suppose a ball of mass m is thrown vertically upwards with an initial speed v, its speed decreases continuously till it becomes zero. Therefore, the ball begins to fall downward and attains the speed v again before striking the ground. It implies that the magnitude of initial and final momenta of the ball are same. Yet, it is not an example of conservation of momentum. Explain why.

**Answer** Law of conservation of momentum is applicable to isolated system (no external force is applied). In this case, the change in velocity is due to the gravitational force of earth.

**Question** What is the ratio of SI units to CGS units of momentum? How do you measure the effect of an impulsive force on the body?

**Answer** A ratio of SI units to CGS units of momentum is (kg m/s)/(g cm/s) i.e., 10s.  
The effect of an impulse force on the body is measured only in terms of impulse.

**Question** On which factors does friction depend?

**Answer** The force of friction is directly proportional to the weight of the body sliding over the surface. The force of friction also depends on the nature of the surfaces in contact.

**Question** A bullet fired against a glass window pane makes a hole in it, and the glass pane is not cracked. But on the other hand, when a stone strikes the same glass pane, it gets smashed. Why is it so?

**Answer** When the bullet strikes the glass pane, the part of the glass pane which comes in contact with the bullet immediately shares the large velocity of bullet and makes a hole, while the remaining part of the glass remains at rest and is therefore not smashed due to inertia of rest.

But when a slow moving stone strikes the same glass pane, the various parts of the glass pane gets enough time to share the velocity of the stone, and the glass is smashed.

**Question** Why can a small mass such as a bullet kill a person when fired from a gun?

**Answer**  It is so because even if the mass of the bullet is small, it moves out of the gun with a very high velocity, due to which the momentum produced is high (p = mv). This high momentum of the bullet kills a person.

**Question** Why does a boat tend to leave the shore, when passengers are alighting from it?

**Answer** When the passengers alight from the boat, they push the boat in backward direction. As a result, the boat has a tendency to slip back into water. This difficulty is usually overcome by the boatman by tying the boat to some rigid support.

**Question** Describe our walking in terms of Newton’s third law of motion.

**Answer** When we walk on the ground or road, our foot pushes the ground backward (action) and the ground pushes our foot forward (reaction). Thus, the forward reaction exerted by the ground on our foot makes us walk forward.

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

**Answer** Steel has the highest inertia. As the mass is a measure of inertia, the ball of same shape and size, having more mass than other balls will have highest inertia. Since steel has greatest density and greatest mass, therefore, it has highest inertia.

**Question** Why does a cricket player moves his hand backward while catching the ball?

**Answer** A fast moving cricket ball has a large momentum. In stopping or catching this ball, its momentum has reduced to be zero. Now, when a cricket player moves back his hands on catching the fast ball, then the time taken to reduce the momentum of ball to zero is increased. Due to more time taken to stop the ball, the rate of change of momentum of ball is decreased and hence a small force is exerted on the hands of player. So, the hands of player do not get hurt.

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

**Answer** According to conservation of momentum, the rifle recoils with same momentum as that of bullet. As momentum = mass X velocity; so light rifle will recoil with larger velocity and hence, will hurt the shoulder more.

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

**Answer** The working of the rotation of sprinkler is based on third law of motion. As the water comes out of the nozzle of the sprinkler, an equal and opposite reaction force comes into play. So the sprinkler starts rotating.

**Question** Deduce Newton’s first law from the second law.

**Answer** According to second law, F = ma

If F = 0, a =0 since m ≠ 0,

But a = *v*−*ut*

or, v – u =0 so, v = u for whatever time t is taken.

This means that the object will continue moving with uniform velocity, u throughout the time, t. If u is zero then v will also be zero. That is, the object will remain at rest.

**Question** When small boy is trying to push a heavy stone, mention various forces acting on the stone.

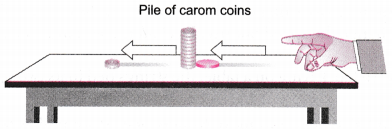
**Answer** The various forces acting on the stone are:

* The gravitational force exerted by the earth which pulls the stone downwards.
* The force of reaction exerted by the ground on the stone vertically upwards.
* The force of pushing exerted by the boy.
* The force of friction exerted by the stone.

When a small boy tries to push a heavy stone, then all these forces are balanced, and therefore the stone does not move.

**Question** Describe in brief an activity to illustrate the property of inertia of rest.

**Answer**

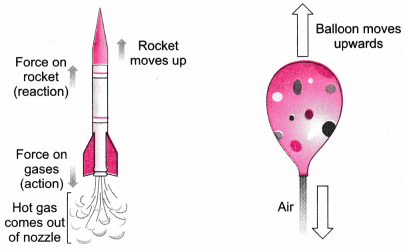


Make a pile of similar carom coins on a table, as shown in figure.

* Attempt a sharp horizontal hit at the bottom of the pile using another carom coin or the striker. If the hit is strong enough, the bottom coin moves out quickly. Once the lowest coin is removed, the inertia of the other coins makes them ‘fall’ vertically on the table.
* The inertia of coins tries to maintain its state of rest even when one of the coin moves out.

**Question** Give few examples of Newton’s third law of motion.

**Answer**

* Jet aeroplanes and rockets work on the principle of third law of motion.  
  In this case, the hot gases come out of a nozzle with great force, i.e., action and the rocket moves ‘ with high speed upwards as a reaction.
* If we fill a balloon with air and hold it with its mouth downwards, then when release the balloon, the air rushes out vertically downwards (action). The balloon moves vertically upwards (reaction).
* 

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

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

**Question** Why does an athlete puts some sands or cushion on the ground while high jumping?

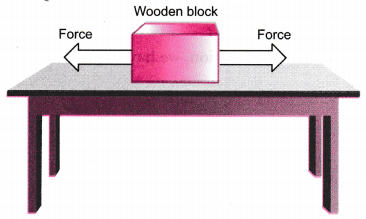
**Answer**  When a high jumper falls on a soft landing site(such as cushion or a heap of sand), then the jumper takes a longer time to come to stop. The rate of change of momentum of athlete is less due to which a smaller stopping force acts on the athlete. And the athlete does not get hurt. Thus, the cushion or sand, being soft, reduces the athlete’s momentum more gently. If however, a high jumping athlete falls from a height on to hard ground, then his momentum will be reduced to zero in a very short time. The rate of change of momentum will be large due to which a large opposing force will act on the athlete. This can cause serious injuries to the athlete.

**Question** Describe balanced forces with the help of two examples.

**Answer** If the resultant of various forces acting on a body is zero, the forces are said to be ‘balanced forces’. These forces do not change the speed but usually change the shape of an object.

Examples: (a) Consider a wooden block lying on a table, the strings tied to its two opposite faces, as shown in the figure.

If we pull at point P, it begins to move towards left. If we pull at point Q, it begins to move . towards right. But if we pull from both the sides with equal force, the block does not move. The two forces have now balanced each other.



(b) In a tug-of-war, the two teams pull the rope with equal effort; the rope is not moved in any direction. This is clearly because the forces exerted by the two teams are equal and opposite and thus get balanced.

**Question** Why do the driver and the person seated in front seat need a seat belt?

**Answer** In a car accident, a fast running car stops suddenly. Due to this the car’s large momentum is reduced to zero in a very short time. The stretchable seat belts tightened by the passengers of the car increases time taken by the passengers to fall forward. Due to longer time, the rate change of momentum of passengers is reduced and hence less stopping force acts on them. So, the passengers may either not get injured at all or may get less injuries. It is obvious that seat belts reduce the passengers’ momentum more gently and hence prevent injuries.

**Question** Describe Newton’s first law of motion in detail, giving examples.

**Answer** According to Newton’s first law of motion, a body at rest or in uniform motion will remain at rest or in uniform motion unless an unbalanced force acts upon it. This law consists of three parts:

* The first part says that a body at rest continues in its state of rest. For instance, a boy standing in a train falls backward when the train suddenly starts moving forward. This is because when the bus moves, the lower part of his body begins to move along with the train while the upper part of his body continues to remain at rest due to inertia.
* The second part says that a body in uniform motion continues to move in straight line path with a uniform speed, e.g., when a moving train stops suddenly a person sitting in it falls forward. This is because as the train stops, the lower part of the person’s body comes to rest along with the bus while upper part of his body continues to remain in ^notion due to inertia of motion and thus he falls forward.
* Third part says that a body moving with a uniform speed in a straight line cannot change its direction of motion by itself. For example, when a bus takes a sharp turn, a person sitting in the bus gets force acting away from the centre of the curved path due to his tendency to move in the original direction.

**Question** Derive the mathematical relation of Newton’s second law of motion.

**Answer** Consider an object of mass m moving along a straight line with an initial velocity u (say). It is uniformly accelerated to velocity u in time t by the application of a constant force F in time t.

Then, initial momentum of the object = mu

p1 =mu

Final momentum of the object = mv

p2 = mv

∴ Change in momentum = mv – mu = m(v – u)

The rate of change in momentum = *m*×(*v*−*u*)*t*

According to Newton’s second law of motion, we have

F ∝ *m*(*v*−*u*)*t*

F = km(*v*−*u*)*t*

F = kma ……….(1)

Here, a = *v*−*ut* = the rate of change of velocity.

= acceleration

k = a constant of proportionality

Putting m = 1kg, a = 1 ms-2

F becomes 1 N.

So, 1 N = 4 × 1kg × 1 ms-2

∴ k = 1

From equation (1), we have

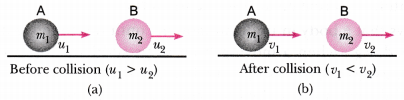
F = ma

This represents the second law of motion.

Thus, the second law of motion gives a method to measure the force acting on an object as a product of its mass and acceleration.

**Question** Derive the mathematical formula of conservation of momentum.

**Answer** To explain conservation of momentum, let us take the following example. Consider two balls A and B having masses ml andm, respectively. Let the initial velocity of ball A be u1, and that of ball B be u2 (u1 > u2). Their collision takes place for a very short interval of time t and after that A and B start moving with velocities v1 and v2 (now v1 < v2) respectively as shown in Figure.



The momentum of ball A before and after the collision is miul and mlvl respectively. If there are no external forces acting on the body, then the rate of change of momentum of ball A, during the collision will be

= *m*1(*v*1−*u*1)*t*

and, similarly the rate of change in momentum of ball B

= *m*2(*v*2−*u*2)*t*

Let F12 be the force exerted by hall A on B F21 be the force exerted by hall B on A

Then, according to Newton’s second law of motion

F12 = *m*1(*v*1−*u*1)*t* and F21 = *m*2(*v*2−*u*2)*t*

According to Newton’s third law of motion, we have

F12 = -F21

or *m*1(*v*1−*u*1)*t*=−*m*2(*v*2−*u*2)*t*

or m1v1 – m1u1 = -m2v2 + m2u2 or m1u1 + m2u2 =m1v1 + m2v2

i.e..Total momentum before collision = Total momentum after collision

Thus, we find that in a collision between the two balls the total momentum before and after the collision remains unchanged or conserved provided no net force acts on the system. This result is law of conservation of momentum.

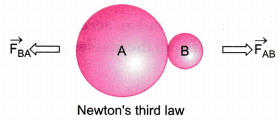
**Question** What is the relationship between mass and inertia? Explain with the help of examples.

**Answer** The mass of a body is a measure of its inertia. It means larger the mass of a body, larger will be the inertia offered by the body to change its state of motion. The following examples will clarify the concept:

* When we kick a football, it flies a long way but at the same time if we kick a stone of the same size, it hardly moves, as the stone resists a change in its motion better than the football because of its more mass.
* We can increase the velocity of our bicycle by pedaling harder, i.e., on applying more force. But the same force will produce a negligible change in the motion of a bus, because in comparison to the bicycle, a bus has more tendency to oppose any change in its state of motion because of its larger mass i.e., the bus has more inertia than the bicycle.
* The SI unit of mass and inertia is kilogram (kg).

**Question** Describe Newton’s third law of motion.

**Answer** According to this law, to every action, there is an equal and opposite reaction.  
When an object, say A, exert a force (action) on another object, say B, then B also exerts a force (reaction) on the A. These two forces are always equal in magnitude but opposite in direction.



As shown in the above figure, if **F**→AB be the force exerted by body A on B and **F**→BA is the force exerted by B on A, then according to Newton’s third law,

**F**→BA = – **F**→AB

or Force on A by B = – Force on B by A

or Reaction = – Action

This law clarifies that a single force can never exist and that the forces always exist in pairs. The two opposing forces are known as action and reaction. The forces of action and reaction always act on two different bodies.

**Question** A bullet of 10 g strikes a sand bag at a speed of 103 ms-1 and gets embedded after travelling 5 cm. Calculate

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

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

**Answer**

(i) m = 10 g = 10100 kg, u = 103 m / s, v = 0, s = 5100 m

v2 – u2 = 2as

0 – (103)2 = 2.a.5100

a = −1000×10002×5 × 100

= -107 ms-2

F = m . a = -105 N

(ii) v = u + at

0 = 103 – 107t

107t = 103

t = 103107 = 10-4 s

**Question** A body of mass 300 g kept at rest breaks into two parts due to internal forces. One part of mass 200 g is found to move at a speed of 12 m/s towards the east. What will be the velocity of the other part?

**Answer**  Initially the body was at rest. The linear momentum of the body is thus p = mu = 0. The body breaks due to internal forces. As the external force acting on it is zero, its linear momentum will remain constant, that is, zero.

p1 = m1v1 = (200 g) × (12 m/s), towards the east.

The linear momentum of the other part must have the same magnitude and should be opposite in direction. It therefore moves towards the west. If its speed is v2, its linear momentum is

p2 = m2v2 = (100 g) × v2.

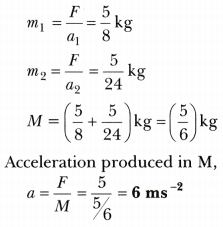
Now, m1v1 = m2v2.

Thus, (200 g) × (12 m/s) = (100 g) × v2 or, v2 = 24m/s.

The velocity of the other part is 24 m/s towards the west.

**Question** A force of 5 N produces an acceleration of 8 ms-2 on a mass m1 and an acceleration of 24 ms-2 on a mass m2. What acceleration would the same force provide if both the masses are tied together?

**Answer** We know, T=m a = 5 N or 5kg ms-2



**Question** The velocity-time graph of a ball moving on the surface of floor is shown in the figure. Calculate the force acting on the ball, if mass of the ball is 100 g.

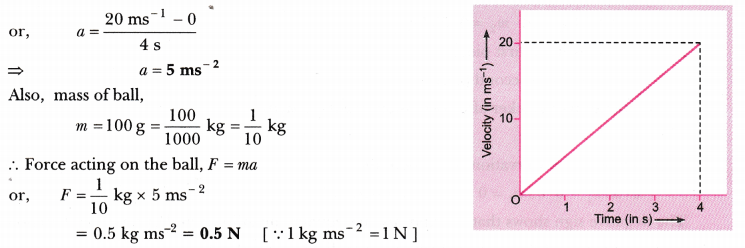
**Answer** The velocity-time graph shows that the velocity of the ball at t = 0 is zero. Initial velocity of ball, u = 0

Velocity of ball at t = 4 s is 20 ms-1

That is, final velocity, v = 20 ms-1

Time, t = 4 s

∴ Acceleration of the ball, a = *v*−*ut*



**Question** A bullet of mass 4 g when fired with a velocity of 50 ms-1, can enter a wall up to a depth of 10 cm. How much will be the average resistances offered by the wall?

**Answer** The hindrance offered by the wall to the motion of bullet is called the resistance offered by wall.

Mass of the bullet, m = 4 × 1-3 kg

Initial velocity, Depth, u = 50 ms-1

Depth, s = 10cm = 110 m

Final velocity, v = 0,

Force, F = ?

We know

v2 = u2 + 2as

v2 – u2 = 2as

0 – (50)2 = 2a × 110

or, -2500 = *a*5

⇒ a = -12500ms-1

Force, F = ma = 4 × 10-3 × (-12500)

= -50N

Thus, the average resistance offered = 50 N

Negative sign indicates that the force is acting opposite to the motion.

**Question** What is the acceleration produced by a force of 12 newton exerted on an object of mass 3 kg?

**Answer** In this problem, force, F = 12 N

Mass, m = 3 kg

We know that F = m × a,

Putting the given values, we have

12 = 3 × a

a = 123 m/ s2

or, Acceleration, a = 4 m/s2.

**Question** A cracker of mass 100 g explodes into two pieces of equal mass. Show that these two pieces of the cracker fly in opposite direction.

**Answer** Mass of a cracker, m = 100 g = 1001000 kg = 0·1 kg.

Initially, cracker is at rest, i.e. ,u = 0

Therefore, initial momentum of the cracker = mu = 0

After explosion, mass of each piece = 0⋅12 kg = 0·05 kg

∴ m1 = 0·05 kg and m2 = 0·05 kg

Let, v1 = velocity of first piece

v2 = velocity of second piece Momentum of cracker after explosion = m1v1 + m2v2

= 0·05 v1 + 0·05 v2

Applying law of conservation of momentum

0·05 v1 + 0·05 v2 = 0 or v1 = -v2

The negative sign shows that v1 and v2 are equal in magnitude and opposite in direction.

Thus, two pieces of the cracker fly in opposite directions with same speed.

**Question** An iron sphere of mass 1 kg is dropped from a height of 10 m. If the acceleration of sphere is 9.8 ms-2, calculate the momentum transferred to the ground by the ball.

**Answer** Here, initial velocity of sphere, u = 0

Distance travelled, s = 10 m

Acceleration of sphere, a = 9.8 ms-2

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

v2 – u2 = 2as

or, v2 – 0 = 2 × 9·8 ms-2 × 10 m = 196 m2s-2

or, v = 196m2s−2−−−−−−−−√ = 14 ms-1

Momentum of the sphere just before it touches the ground = mv

= 1 kg × 14 ms– 1 = 14 kg ms-1

On reaching the ground, the iron sphere comes to rest, so its final momentum is equal to zero according to the law of conservation of momentum.

Momentum transferred to the ground = Momentum of the sphere just before it comes to rest = 14 kg ms-1

**Question** A bullet of mass 0.02 kg is fired from a gun weighing 7.5 kg. If the initial velocity of the bullet is 200 m/s, calculate the speed with which the gun recoils.

**Answer** Here, the mass of the bullet, m1 = 0.02 kg

Mass of gun, m2 = 7.5 kg

Velocity of bullet, v1 = 200 m / s and the speed of gun, v2 = ?

According to law of conservation of momentum, we have

Total momentum of system after firing = Total momentum of system before firing

i.e., m1v1 + m2v2 = 0

(since initial velocities of gun and bullet before firing is zero.)

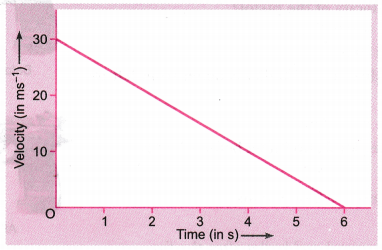
or, 0.02 × 200 + 7.5 × v2 = 0

or,7.5 × v2 =- 0.02 × 200

or, v2 = −47⋅5 = – 0.533

or v2 = – 0.53 m/s

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



**Answer** The velocity-time graph shows that velocity of the ball at t = 0 is 30 ms-1. That is, initial velocity of the ball, w = 30 ms-1

The velocity of the ball at t = 6 s is zero.

That is, final velocity of the ball, v = 0

Time, t = 6 s

Acceleration of the ball,

a = *v*−*ut*=0−30ms−16s

= – 5 ms -2

Negative sign shows that the ball is retarded or decelerated.

Also, mass of ball, m = 50 g = 501000=120 kg

∴ Force acting on the ball, F =ma

= (120kg)(−5ms−2) = – 0.25 kg ms-2 = – 0.25 N [∵ 1 kg ms-2 = 1 N]

Here -ve sign indicates that the force is retarding or stopping force.

**Question** A man throws a ball of mass 0.4 kg vertically upwards with a velocity of 10 m/s. What will be its initial momentum? What would be its momentum at the highest point of its reach?

**Answer** Here, m = 0.4 kg, u = 10 m/s

Initial momentum of the ball = mu = 0.4 × 10 = 4 kg m/s At the highest point, velocity of ball is zero,

So momentum of the ball = 0 × 4 × 0 = 0

**Question** Which would require a greater force—accelerating a 2 kg mass at 5 ms-2 or a 4 kg mass at 2 ms-2 ?

**Answer**  Here, m1 = 2 kg , a1 = 5 ms-2, m2 = 4 kg, a2 = 2 ms-2

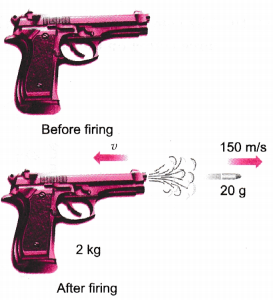
F1 = m1a1 = 2 × 5 = 10N

F2 = m2a2 = 4 × 2 = 8 N

F1 > F2

Thus, accelerating a 2 kg mass at 5 ms-2 acceleration would require a greater force.

**Question** A bullet of mass 20 g is horizontally fired with a horizontal velocity 150 ms-1 from a pistol of mass 2 kg. What is the recoil velocity of the pistol?



**Answer** For bullet: m1 = 20g = 0.02 kg,

u1 = 0 ms-1, v1 = + 150 ms-1

[By convention, the direction of bullet is taken from left to right (positive)]

For pistol: m2 = 2kg, u2 = 0 ms-1,

Total momenta of the pistol and bullet before the fire= m1u1 + m2u2

= 0.02 kg × 0 ms-1 + 2kg × 0 ms-1 = 0 kg ms-1

Total momenta of the pistol and bullet after the fire

= m1v1 + m2v2 = 0.02 kg × (+ 150 ms-1) + 2kg + v2 ms-1 = (3+ 2v2) kg ms-1

According to the law of conservation of momentum,

Total momenta after the fire = Total momenta before the fire

3 + 2v2 = 0

⇒ 2v2 = – 3

⇒ v2 = —1.5 ms-1

Negative sign indicates that the direction in which the pistol would recoil is opposite that of bullet (right to left).

Total momenta of the pistol and bullet before the fire

= m1u1 + m2u2 = 0.02 kg × 0 ms-1 + 2 kg × 0 ms-1 = 0 kg ms-1

Total momenta of the pistol and bullet after the fire = m1v1 + m2v2

= 0.02kg × (+150ms-1) + 2kg + v2 ms-1

= (3 + 2v2)kg ms-1

According to the law of conservation of momentum, we have

Total momenta after the fire = Total momenta before the fire

3 + 2v2 = 0

⇒ 2v2 = – 3

⇒ v2 = – 1.5 ms-1

Negative sign indicates that the direction in which the pistol would recoil is opposite to that of bullet (right to left).

**Question** A boy of mass 40 kg jumps with a horizontal velocity of 5 ms-1 onto a stationary cart with frictionless wheels. The mass of the cart is 3 kg. What is his velocity as the cart starts moving? Assume that there is no external unbalanced force working in horizontal direction.

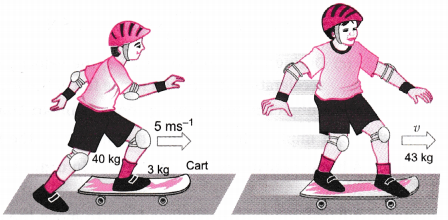
**Answer**  Suppose the velocity of the boy on the cart, as the cart starts moving is v.

∴ The total momenta of the boy and cart before the interaction

= 40 kg × 5 ms-1 + 3 kg × 0 ms-1 = 200 kg ms-1

Also, the total momenta after the interaction

= (40 + 3) kg × v ms-1 = 43v kg ms-1



As per the law of conservation of momentum, the total momentum is conserved during the interaction.

In other words,

43 v = 200

or, v = 20043 = 4.65 ms-1

Thus, the boy on cart would move with a velocity of 4.65 ms-1 in the direction in which the boy jumped onto the cart.

**Question** Why does an athlete run a certain distance before taking a leap?

**Answer** 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.

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

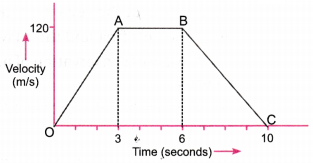
**Answer** Yes, the balls will start rolling in the direction in which the train was moving. Due to the application of the brakes, the train comes to rest but due to inertia the balls try to remain in motion, therefore, they begin to roll. Since the masses of the balls are not the same, therefore, the inertial forces are not same on both the balls. Thus, the balls will move with different speeds.

**Question** The velocity-time graph of an object of mass m = 50 g is shown in figure. Observe the graph carefully and answer the following Questions.

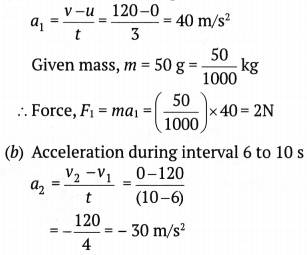
(a) Calculate the force on the object in time interval 0 to 3 s.

(b) Calculate the force on the object in the time interval 6 to 10 s.

(c) Is there any time interval in which no force acts on the object? Justify your answer.



**Answer** (a) Acceleration during interval 0 to 3 s



Force, F2 = ma2 = 50∘1000×(−30) = – 1.5 N

(c) During time interval 3 to 6 s, the velocity of object is constant, so in this time interval, acceleration is zero and hence force, F (= ma) is zero.]

**Question** If an object is not moving, does it mean that no force is acting on it?

**Answer**  No, it implies that all the forces acting on the body are balanced.

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

**Answer** A horse exerts a continuous force to move the cart with a constant velocity to overcome the force of friction between ground and cart.