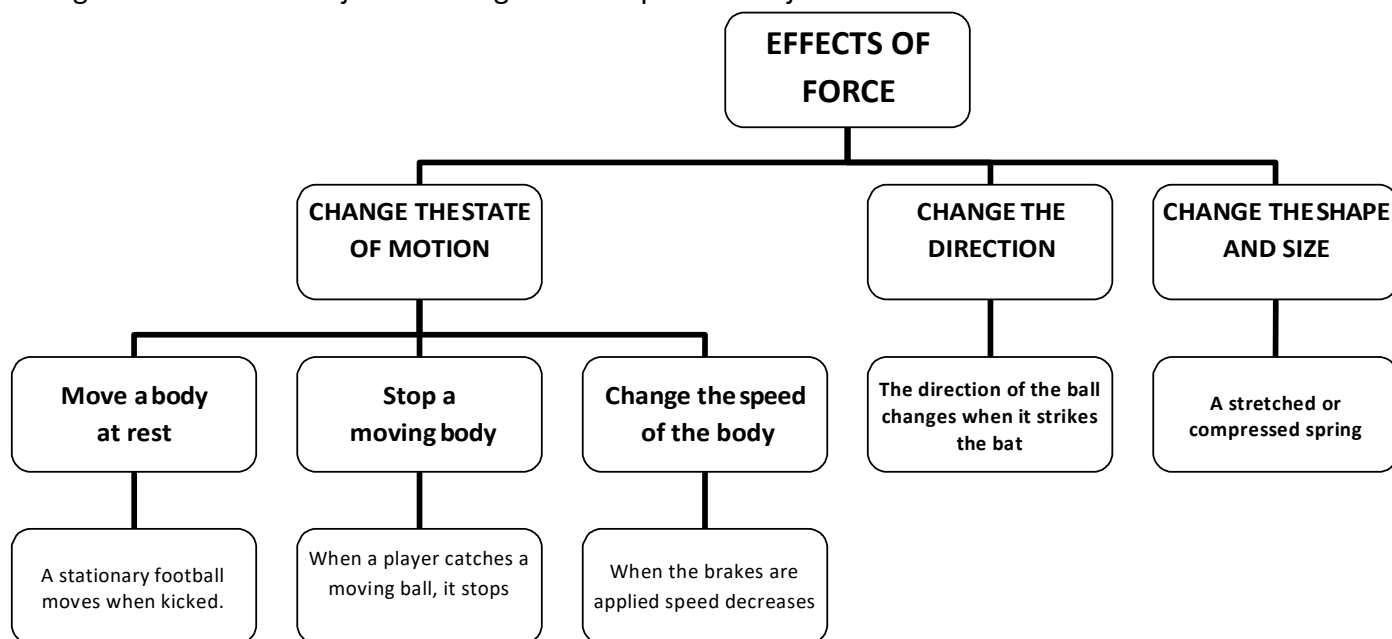


CHAPTER-9

FORCE AND LAWS OF MOTION

Force is a push or a pull which changes or tries to change the state of rest or uniform motion or change direction of an object or changes the shape of an object.

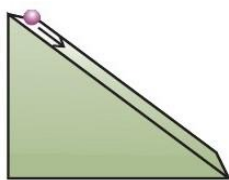


BALANCED AND UNBALANCED FORCES

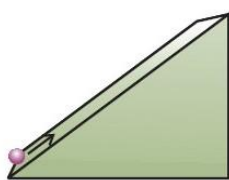
BALANCED FORCES	UNBALANCED FORCES
If the resultant of all the forces acting on a body is equal to zero, the forces are called <i>balanced forces</i> .	If the resultant of all the forces acting on a body is not zero, the forces are called <i>unbalanced forces</i> .
Balanced forces do not cause any change in state of motion of an object. Balanced forces are equal in magnitude and opposite in direction. * Balanced force can change the shape and size of an object.	Unbalanced forces always cause a change in the state of motion of an object.

Galileo's observations

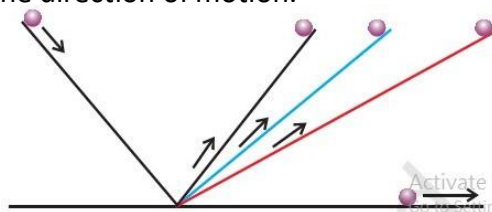
- Objects move with a constant speed when no force acts on them.
- Unbalanced force is required to change the state of motion of an object but no net force is needed to sustain the uniform motion of an object.
- In practical situations it is difficult to achieve a zero unbalanced force. This is because of the presence of frictional force acting opposite to the direction of motion.



(a)



(b)



(c)

Newton studied Galileo's ideas on force and motion and presented three fundamental laws that govern the motion of objects
These three laws are known as Newton's laws of motion.

LAWS OF MOTION

Newton's First Law of Motion

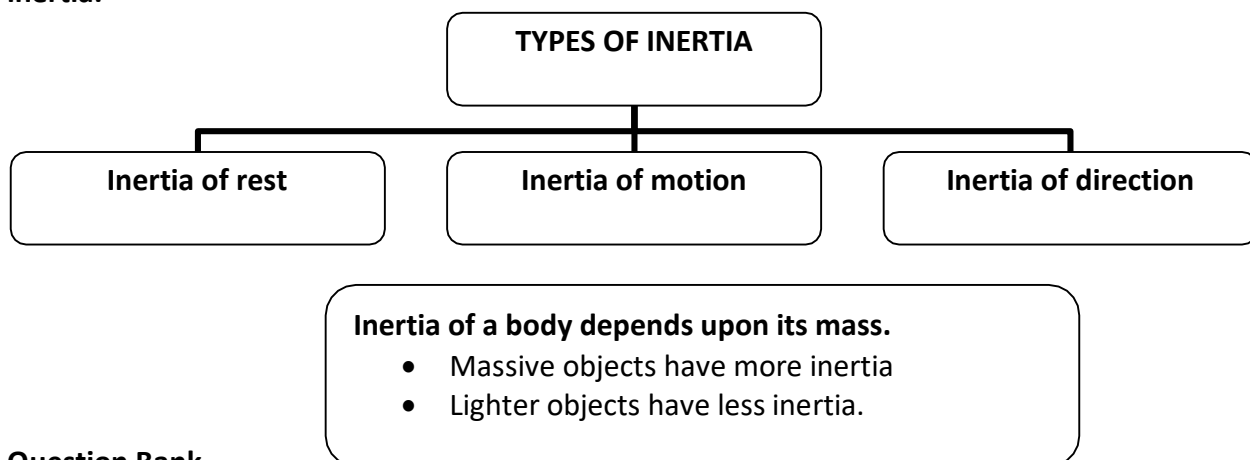
The first law of motion states that:

An object remains in a state of rest or of uniform motion in a straight line unless an external force (i.e. unbalanced force) acts upon it.

- All objects resist any change in their state of rest or motion.
- This tendency is inertia. This law is also known as law of inertia.

Inertia

Tendency of an object to resist any change in its state of rest or of uniform motion is called **inertia**.



Question Bank

Q1. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.

Ans. When the branch of a tree is shaken, it moves to and fro, but its leaves tend to remain at rest due to inertia of rest and get detached.

Q2. 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. In a moving bus, a passenger moves with the bus. As the driver applies brakes, the bus comes to rest. But the passenger tries to maintain his state of motion due to inertia of motion. As a result, he falls forward.

Similarly, the passenger tends to fall backwards when the bus accelerates from rest. This is because when the bus accelerates, the inertia of the passenger tends to oppose the forward motion of the bus due to inertia of rest.

Q3. When a carpet is beaten with a stick, dust comes out of it. Explain.

Ans. When a carpet is beaten with a stick, then the carpet comes in motion, but dust particles maintain their state of rest due to inertia of rest and hence come out.

Q4. Why is it advised to tie any luggage kept on the roof of a bus with a rope?

Ans. This is because when the bus starts suddenly, the luggage may fall backward due to inertia of rest or when the moving bus stops suddenly, the luggage may fall forward due to inertia of motion and if the bus changes its direction or take a sharp turn the luggage may fall down due to inertia of direction.

Q5. Why on striking the coin at the bottom of a pile of carrom coins with a striker, only the coin at the bottom moves away, while the rest of the pile remains intact?

Ans. The reason is that as the striker hits the lowest coin, it moves (i.e., changes its state of rest), while the remaining pile remains intact at rest due to inertia of rest

Q6. Why do we jerk clothes before spreading them on clothes line?

Ans. Before jerking water droplets present in the cloth are at rest and tend to remain at rest due to inertia of rest. So while jerking they leave the surface of the cloth.

Q7. If an object is to accelerate what must act on the object?

Ans. Unbalanced Force

Q8. 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?

Ans. Steel ball having highest density will have highest mass and hence the highest inertia.

MOMENTUM

“An object in motion has momentum “

Momentum is defined as the product of mass and velocity of an object.

If m = mass of an object

v = velocity of the object

momentum (p) = mass (m) x velocity (v)

$$p = mv$$

- Momentum is a vector quantity i.e. it has both magnitude and direction
- Direction of momentum is same as that of direction of velocity.
- S.I unit of momentum is kg m/s
- If the body is at rest, its velocity = 0, therefore $p = 0$

Newton's Second Law of Motion

- The second law of motion states that the rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.

$\frac{\text{Change in linear momentum}}{\text{Time taken}} \propto \text{force applied}$

Mathematical formulation of Newton's Second law of motion

Suppose an object of mass, m is moving along a straight line with an initial velocity, u . It is uniformly accelerated to velocity, v in time, t by the application of a constant force, F throughout the time, t .

The initial momentum of the object, $p_1 = mu$

and final momentum of the object, $p_2 = mv$

$$\begin{aligned}\text{The change in momentum of the object} &= p_2 - p_1 \\ &= mv - mu \\ &= m(v - u)\end{aligned}$$

The rate of change of momentum

$$= m(v-u)/t$$

Newton's second law states that

F is proportional to $m(v-u)/t$

$$\text{Or } F = \frac{km \times (v - u)}{t}$$

$$\text{or } F = kma \quad \left(a = \frac{v - u}{t} \text{ is the acceleration} \right)$$

The quantity, k is a constant of proportionality.

The unit of force is so chosen that the value of the constant, k becomes one, so $F = ma$

One Newton: One Newton force is defined as the amount of force that produces an acceleration of 1 m s^{-2} in an object of 1 kg mass.

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2$$

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

APPLICATIONS OF NEWTON'S SECOND LAW OF MOTION

1 . A Fielder Moves his Hands Backward While Trying to Catch a Ball

$$\text{As we know, } F = \frac{m(v - u)}{t}$$

He increases time to reduce Force

By doing so, the fielder increases the time during which the high velocity of the moving ball decreases to zero.

The rate of change of momentum of ball will decrease, thereby decreasing the force exerted on his hands.

2 . High jump on sand

In a high jump athletic event, the athletes are made to fall either on a cushioned bed or sand bed. This is to increase the time (t) of the athlete's fall to stop after making the jump. This decreases the rate of change of momentum $\frac{m(v - u)}{t}$ and hence the force (F).

3 . Seat belts in cars/aeroplanes

In case of an accident or sudden application of brakes the large momentum of car/aeroplane reduces to zero in a very short interval of time and this results in developing a large force that causes injury. The stretchable safety belts exert a force on the body of the passenger and thus

slow the forward motion. The time taken by the passenger to fall forward increases. Thus, rate of change of momentum of the passenger decreases and hence force acting on the passenger is reduced.

4 . Karate player breaks a slab of ice with a single blow.

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

He decreases time to increase Force

By doing so, the karate player decreases the time during which the momentum of his hand decreases to zero.

The rate of change of momentum of his hand will increase, thereby increasing the force exerted by his hands. So, he is able to break the slab of ice with a single blow.

Deduction of Newton's First law of motion from Newton's Second law of motion

According to Newton's second law of motion,

$$\begin{aligned} F &= ma \\ \text{or } F &= \frac{m(v - u)}{t} \\ \text{or } F &= \frac{mv - mu}{t} \end{aligned}$$

- That is, when $F = 0$, is, $v = u$ 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.

Newton's Third Law of Motion

The third law of motion states that when one object exerts a force on another object, the second object instantaneously exerts a force back on the first.

In other words, **"To every action there is always an equal and opposite reaction"**.

- The two forces are always equal in magnitude but opposite in direction.
- *It is also called the law of action and reaction force*

Applications of Newton's Third Law of Motion

1 . Walking of a person

When we walk on the ground, then our foot pushes the ground backward (action force) and the ground in turn exerts a force on the foot (reaction force) pushing us forward.

2 . Recoil of a gun

When a gun is fired, it exerts a forward force on the bullet. The bullet exerts an equal and opposite reaction force on the gun. This results in the recoil of the gun.

Since the gun has a much greater mass than the bullet, the acceleration of the gun is much less than the acceleration of the bullet.

3 . Jumping of a man from a diving board

When a man jumps from a diving board he pushes the board in the backward direction (action force) and the board in turn pushes the man in the forward direction (reaction force).

4 . Jumping of man from the boat

When a man jumps from a boat he pushes the boat in the backward direction (action force) and the boat in turn pushes the man forward (reaction force).

5 . Swimming of the swimmer

A swimmer pushes the water in the backward direction (action force) and the water exerts a force on the swimmer (reaction force) which pushes him forward.

6 . Motion of rockets and jet aeroplanes

The rocket or jet aeroplanes expel hot gases (produced due to burning of fuel) in downward direction (action) and the rocket flies off in the upward direction due to the reaction of the escaping hot gases.

Question Bank

Q1. If action is always equal to the reaction, explain how a horse can pull a cart.

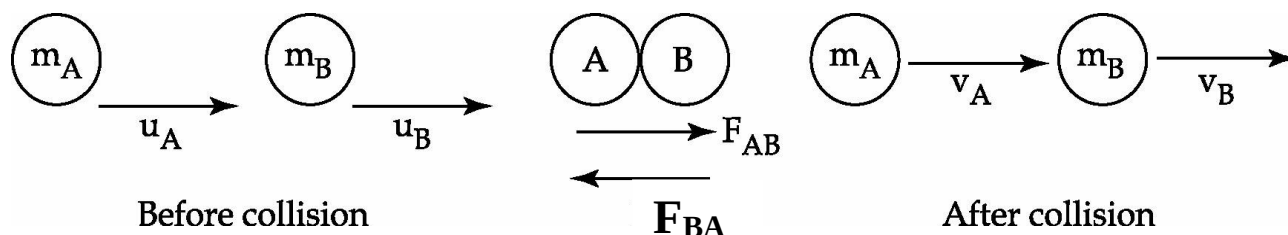
Ans. The cart is pulled by the horse. Horse pushes the ground in the backward direction (action force). According to Newton's third law of motion, a reaction force is exerted by the Earth on the horse in the forward direction. As a result, the cart moves forward.

Q2. Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity.

Ans. It is based on Newton's third law of motion i.e. to every action there is an equal and opposite reaction.

The ejection of large amount of water at high velocity results in the development of an equal force of reaction on the hose - pipe in the backward direction, so it tends to move back making it difficult for the fireman to hold it.

CONSERVATION OF MOMENTUM



Two objects of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B respectively. No other external unbalanced forces acting on them.

Let $u_A > u_B$ and the two balls collide with each other.

During collision which lasts for a time t the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A.

Suppose v_A and v_B are the velocities of the two balls A and B after the collision respectively.

$$F_{AB} = m_B \left(\frac{v_B - u_B}{t} \right)$$

$$F_{BA} = m_A \left(\frac{v_A - u_A}{t} \right)$$

By Newton's Third Law of Motion:

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

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

$$\boxed{m_A u_A + m_B u_B = m_A v_A + m_B v_B}$$

Total initial momentum = total final momentum

Law of conservation of momentum: The sum of momenta of the two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them.

Application of Law of Conservation of Momentum : Recoil of gun

If m = mass of the bullet

v = velocity of the bullet

M = mass of the gun

V = velocity of the gun

Then total momentum of the bullet and the gun before firing = 0, because initial velocity of gun and bullet before firing is zero.

And the total momentum of the bullet and the gun after firing = $mv + MV$

As no external force is acting on them, so according to law of conservation of momentum:

$$mv + MV = 0$$

or

$$\boxed{V = -\frac{mv}{M}}$$

Negative sign shows that V is in the opposite direction i.e. the gun recoils or move backwards as the bullet moves forward.