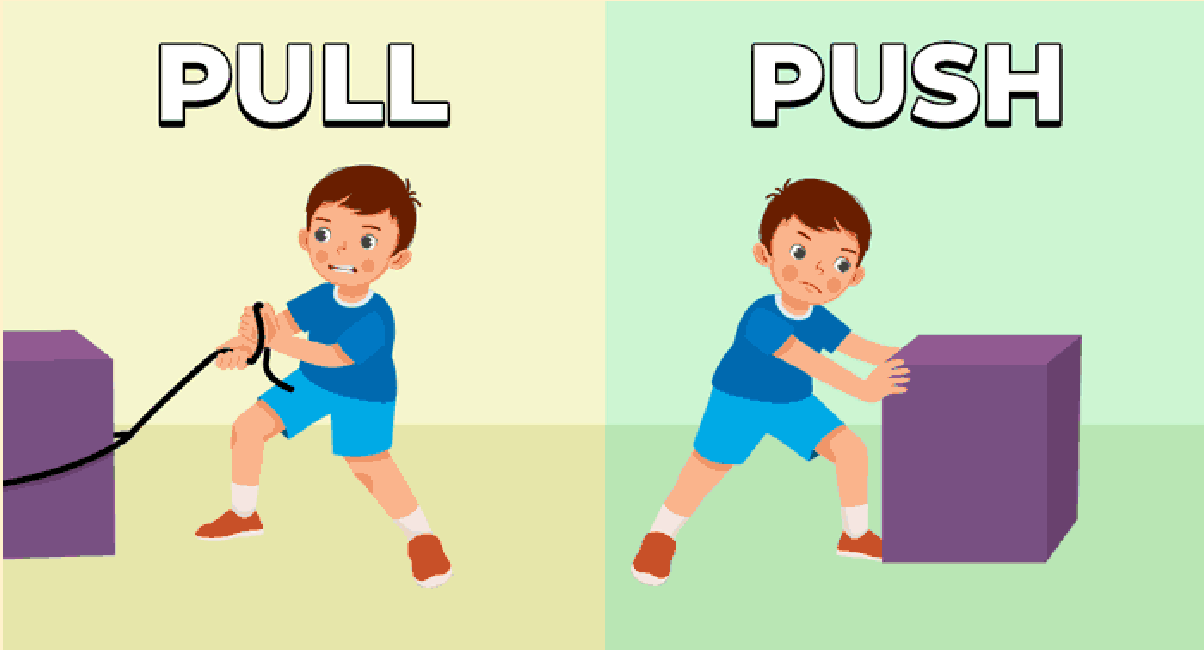
Chapter-09 : Force and laws of motion

Force : Force is an external effort which may move a body at rest or stop a moving body or change the speed of a moving body or change the direction of a moving body or change the shape and size of a body.



Effects of force :

- Force can move a body at rest.
- Force can stop a moving body.
- Force can change the speed of a moving body.
- Force can change the direction of a moving body.
- Force can change the shape and size of a body.

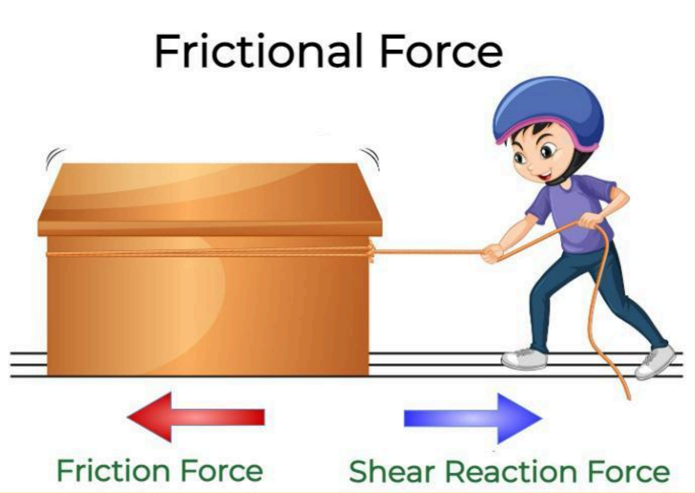
Balanced forces : If two forces act on a body in opposite direction and if both the forces are equal, then the resultant force acting on the body is zero. Such forces are called balanced forces.

- Balanced forces cannot change the state of rest or motion of a body.

Unbalanced forces : If two forces act on a body in opposite direction and if one force is greater than the other, then the resultant force is not equal to zero. Such forces are called unbalanced forces.

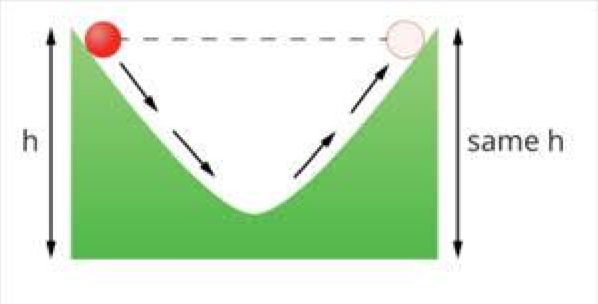
- An unbalanced force changes the state of rest or the motion of a body.

Force of friction : Force of friction is the force which opposes the motion of an object over a surface. E.g.- A ball rolling on ground gradually slows down and comes to a stop due to force of friction. If we stop pedaling a bicycle, it gradually slows down and comes to a stop due to force of friction.

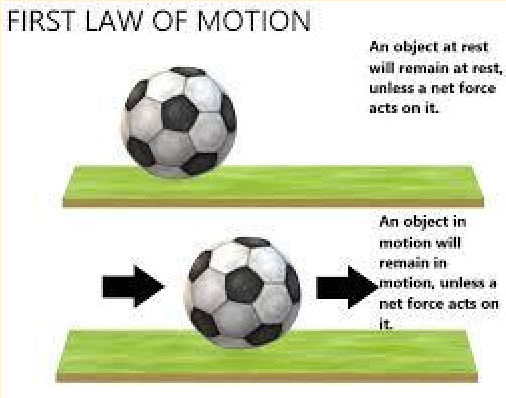


- An object with uniform motion will continue to move with uniform motion if the forces acting on it (pushing force and frictional force) are balanced.
- If an unbalanced force acts on the moving body, then its speed or direction of motion changes.
- If the unbalanced force is removed, then it will continue to move with the speed it had acquired till then.

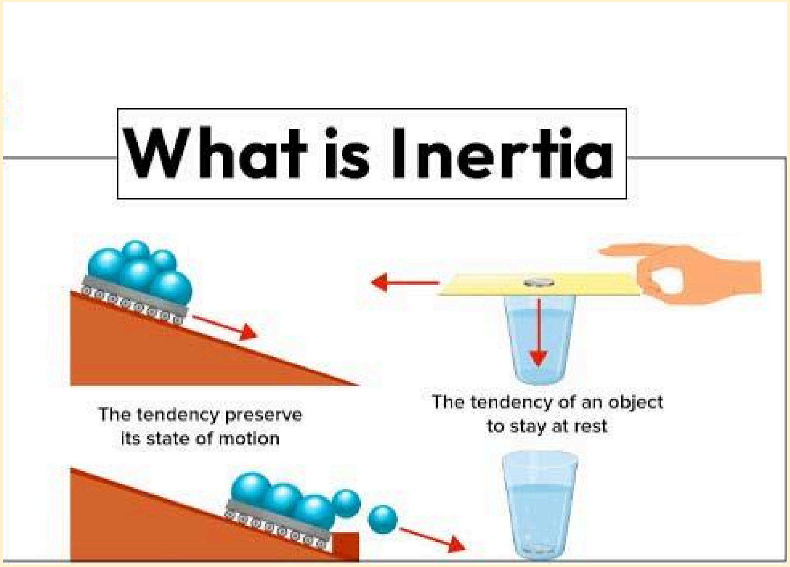
Galileo's experiment of motion of an object on an inclined plane : When a marble rolls down an inclined plane, its velocity increases and when it goes up on the second inclined plane, its velocity decreases. If the inclinations of both the planes are equal, then the marble will reach the same height which it rolled down. If the inclination of the second plane is decreased, it will travel more distance to reach the original height. If the inclination of the second plane is made horizontal, the marble will travel forever trying to reach the same height. An Unbalanced force is required to change the motion of the marble but no force is needed to sustain the uniform motion of the marble.



Newton's first law of motion : An object remains in a state of rest or in uniform motion in a straight line unless compelled to change that state by an applied unbalanced force.



Inertia : The natural tendency of objects to remain in a state of rest or in uniform motion is called inertia. This is why the first law of motion is also known as the 'law of inertia'.



Examples of inertia :

- If a striker hits a pile of coins on a carom board, the lowest coin moves out and due to inertia of rest, the other coins fall down.
- If a coin placed on a playing card over a tumbler is flicked with the finger, due to inertia of rest, the coin falls down into the tumbler.
- When we travel in a car and the driver applies the brakes suddenly, we tend to fall forward due to inertia of motion.

- When we are standing in a bus and the bus begins to move suddenly, we tend to fall backward because our feet in contact with the floor moves forward but the upper part of the body continues to remain at rest due to inertia of rest.

Inertia and Mass :

- A body at rest continues to be at rest and a body in motion continues to be in motion. This property of a body is called its inertia.
- The inertia of a body is measured by the magnitude of force required to change the state of the body. The force required to change the state of a heavier body is more than the force required to change the state of the lighter body. This is because the mass of the heavier body is more than the mass of the lighter body.
- The mass of a body is a measure of its inertia.

Momentum of a body : The momentum of a body is the product of its mass and velocity.

Momentum = mass x velocity

$$p = mv$$

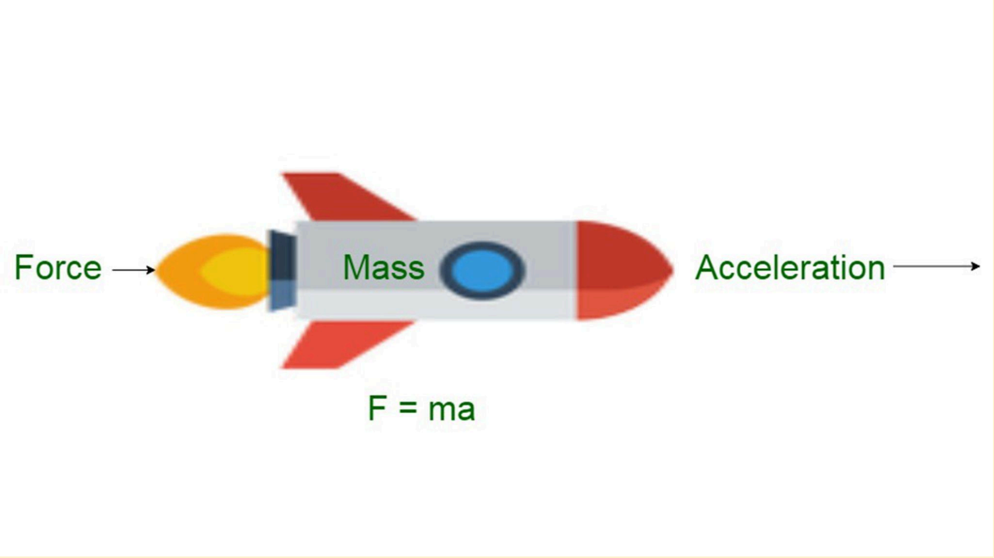
where 'p' is the momentum of a body.

'm' is the mass of the body.

'v' is the velocity of the body.

- If a body is at rest its velocity is zero and so its momentum is also zero.
- The SI unit of momentum is kilogram metre per second or kg m/s or kg ms^{-1}
- A truck moving at a very low speed can kill a person standing in its path because of the heavy mass of the truck.
- A bullet of small mass when fired from a gun can kill a person because of the large velocity of the bullet.
- So, the impact of a body depends upon its mass and velocity.

Newton's second law of motion : The rate of change of momentum of an object is proportional to the applied force in the direction of force.



Mathematical formulation of Second law of motion : If an object of mass 'm' is moving along a straight line with initial velocity 'u' and is accelerated to velocity 'v' in time 't' by applying a force 'F', then

Initial momemtum = p_1 = mu
Final momentum = p_2 = mv
Change in momentum = $p_2 - p_1$ = mv – mu = m (v – u)
Rate of change of momentum = m (v – u) / t
Or the applied force, F α m (v – u) / t

F = k.m (v – u)

[but (v – u) / t = a]

So, F = kma
where k is a constant of proportionality.

F = ma

- The SI unit of mass is kg and acceleration is m/s^2 or ms^{-2}

. So, the unit of Force is kg ms^{-2} or
newton and its symbol is N.
Newton's third law of motion : To every action there is an equal and opposite reaction and they act on two different bodies.

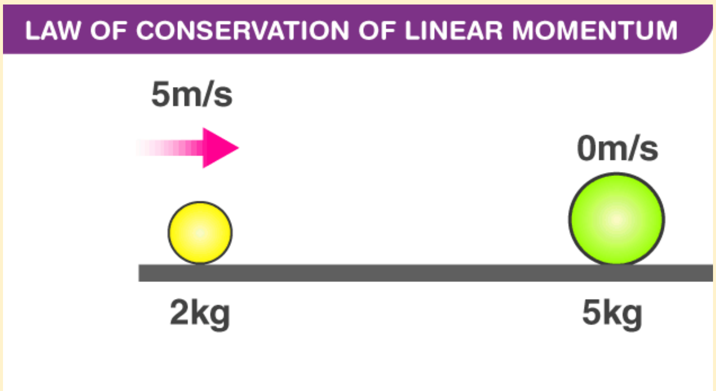
To prove that action and reaction are equal and opposite : Take two spring balances A and B connected together. Fix the spring balance B to a rigid support. When a force is applied by pulling the free end of the spring balance A, both the spring balances show the same readings. This shows that the force exerted by the spring balance A on B is equal but opposite indirection to the force exerted by spring balance B on A. The force exerted by the spring balance A on B is action and the force exerted by the spring balance B on A is reaction.

Examples of action and reaction :

- When a bullet is fired from a gun, it exerts a forward force (action) on the bullet and the bullet exerts an equal and opposite force on the gun (reaction) and the gun recoils.
- When a sailor jumps out of a boat, he exerts a backward force of the boat (action) and the boat exerts an equal and opposite force on the sailor (reaction) and the sailor jumps forward.
- When an air filled balloon is released, the force of the air coming out of the balloon (action) exerts an equal and opposite force on the balloon (reaction) and it moves upward.
- When a rocket is fired, the force of the burning gases coming out (action) exerts an equal and opposite force on the rocket (reaction) and it moves upward.

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

- This means that the total momentum of the two objects is unchanged or conserved by collision.
- If two balls A and B of masses m_A and m_B are travelling in a straight line with initial velocities u_A and u_B and if $u_A > u_B$, the two balls will collide with each other. During collision at a time t, ball A exerts a force F_{AB} on ball B and ball B exerts a force F_{BA} on ball A. If v_A and v_B are the velocities of balls A and B after collision. The momenta of ball A before and after collision are m_Au_A and m_Av_A and the momenta of ball B before and after collision are m_Bu_B and m_Bv_B.



Change in momentum of ball A during collision = $m_A v_A - m_A u_A$

Rate of change of momentum of ball A (F_{AB}) = $m_A(v_A - u_A) / t$

Change in momentum of ball B during collision = $m_B v_B - m_B u_B$

Rate of change of momentum of ball B (F_{BA}) = $m_B (v_B - u_B) / t$

According to Newton's third law of motion, the force F_{AB} exerted by ball A on ball B is equal and opposite to the force F_{BA} exerted by ball B on ball A. Therefore, $F_{AB} = - F_{BA}$

$m_A(v_A - u_A) / t = - m_B(v_B - u_B) / t$

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

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

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

- Momentum of the two balls before collision is equal to the momentum of the two balls after collision.