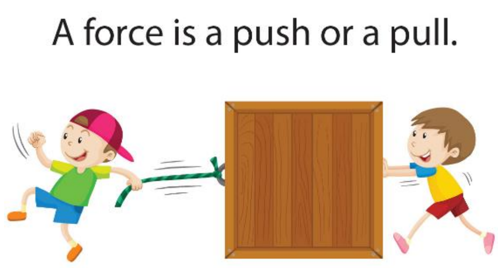
Force
A push or pull on a body is called force.

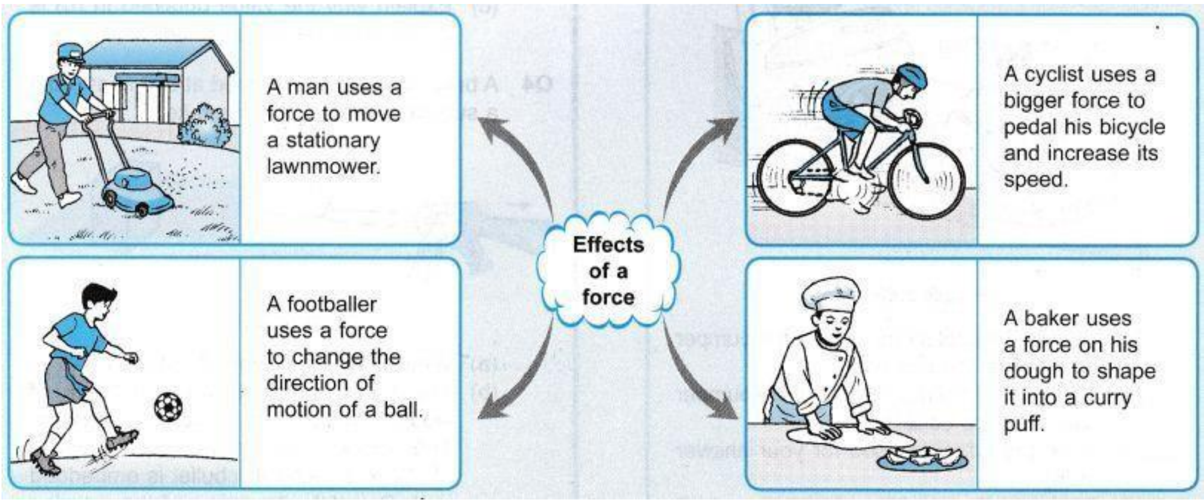
Characteristics of force:



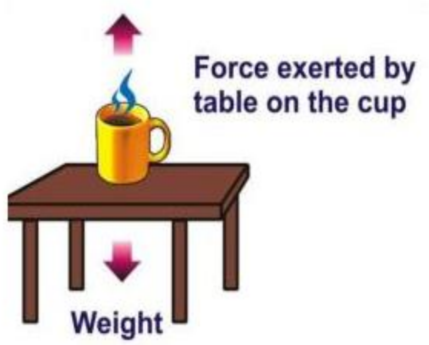
- Force has both magnitude and direction, making it a vector quantity.
- It is measured in the SI unit of Newton
- It is represented by the symbol F.

Effects of Force:

- It can change the speed of a body.
- It can change the direction of Force and Laws of Motion of a body.
- It can change the shape of a body.



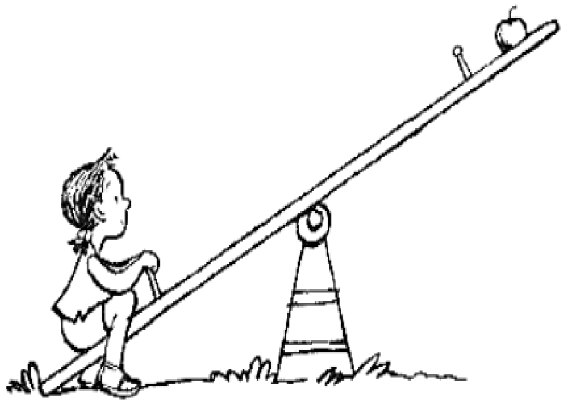
Balanced and Unbalanced Forces
(i) Balanced Forces: If the resultant of applied forces is equal to zero, it is called balanced forces.
For example: In the tug of war game when the force applied by both teams is equal in magnitude then the rope does not move in either side. This is due to the balanced forces in which resultant of applied forces comes out to be zero.



Characteristics:

- Balanced forces do not cause any change of state of an object.
- Balanced forces are equal in magnitude and opposite in direction.
- Balanced forces can change the shape and size of an object. For example: When we press a balloon from opposite sides, the size and shape of balloon is changed.

(ii)Unbalanced Forces: If the resultant of applied forces are greater than zero, the forces are called unbalanced forces.
To move an object unbalanced forces are to be applied from the opposite directions. In case of unbalanced forces acting on a body, it moves a in the direction of the greater force.



Unbalanced forces can:

- Change the speed and position of an object.
- Change the shape and size of an object.

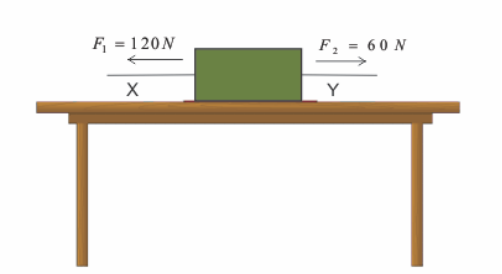


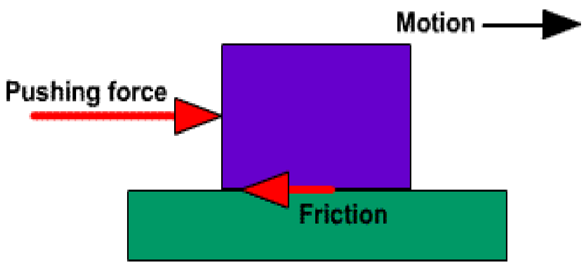
Figure 2. Unbalanced forces acting on the block

- Let us now pull the block using this string in two different directions such that two opposite forces of different magnitudes acts on the block.
- Since two forces acting on the block are of different magnitude the block would begin to move in the direction of the greater force.
- Thus, the two forces acting on the block are not balanced and the unbalanced force acts in the direction the block moves.
- So unbalanced forces can move a stationary body and they can stop a moving body.

- The size of the overall force acting on an object is called the resultant force. If the forces are balanced, this is zero. In the example above, the resultant force is the difference between the two forces F_1 and F_2, which is 120 - 60 = 60 N.
- If all the forces acting on a body result in an unbalanced force, then the unbalanced force can accelerate the body. It means that a net force or resulting force acting on a body can either change the magnitude of its velocity or change the direction of its velocity.
- The force that opposes the relative motion between the surfaces of two objects in contact and acts along the surfaces in contact is called the force of friction or simply friction.

What is the force of friction?

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.



Some Common Forces

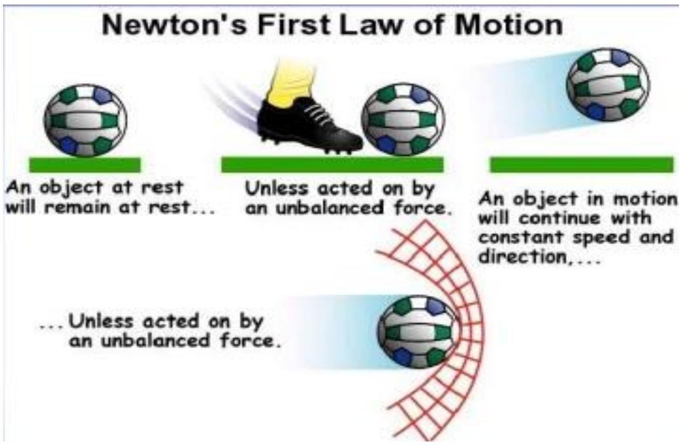
- Muscular Force: The force exerted by the human body muscles is called muscular force.
- Gravitational Force: The attractional force applied by earth on an object in downward direction is called gravitational force.
- Frictional Force: The force which opposes the Force and Laws of Motion of an object while being in contact with the other object, is known as frictional force.
- Air Resistance: Force which is exerted on the objects while flying in air is named as air resistance. It acts in a direction opposite to the velocity of the object.

Laws of motion

- Newton gave three laws of motion that describe the motion of bodies. These laws are known as Newton's Laws of motion.
- They describe the relationship between the forces acting on a body and its motion due to those forces.
- The three laws of motion were first compiled by Sir Isaac Newton in his work Principia Mathematica, first published in 1687. Newton used these laws to explain and investigate the motion of many physical objects and systems

i) Newton's First Law of Force and Laws of Motion or Law of Inertia

It states that any object will remain in the state of rest or in uniform Force and Laws of Motion along a straight line until it is compelled to change the state by applying external force.

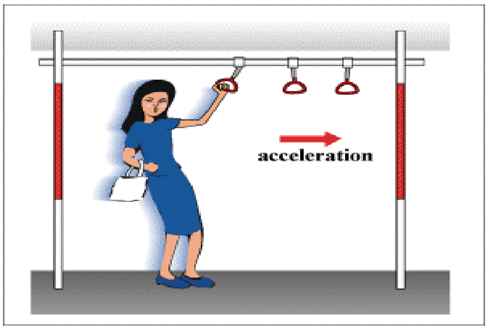


Inertia

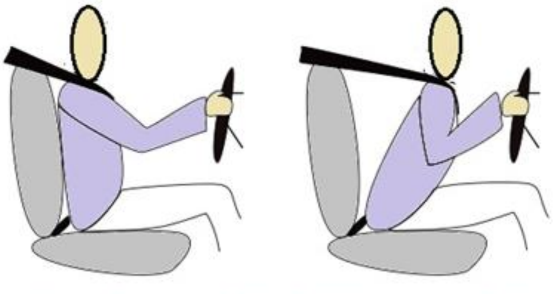
Definition: Inertia is a property or tendency of every object to resist any change in its state of rest or of uniform Force and Laws of Motion.

It is measured by the mass of an object. The heavier the object, the greater will be its inertia.

Examples of Inertia



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

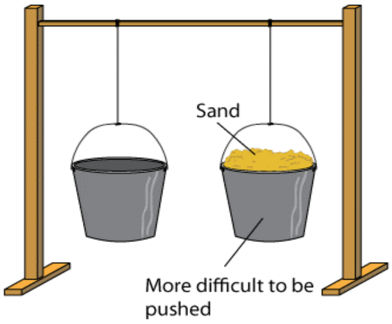


Because of inertia you feel jerk when brakes are applied

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 bucket that is empty 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.



Application of Newton's first law of Force and Laws of Motion:

- When a straight moving bus suddenly stops down, the passengers sitting inside fall in the forward direction. This is because the body of the passenger initially moving in a straight line tends to move the same way even after the brakes are applied, making the passenger fall in the forward direction.
- When we hit a carpet it loses inertia of rest and moves. But the dust in it retains inertia of rest and is left behind. Thus dust and carpet are separated.
- When a tree is shaken, it moves to and fro. But fruit remains at rest due to its inertia of rest. Due to this fruit breaks off the tree.

Momentum

- Before discussing about second law of motion we shall first learn about momentum of a moving object.
- From our daily life experiences like during the game of table tennis if the ball hits a player it does not hurt him. On the other hand, when a fast moving cricket ball hits a spectator, it may hurt him.
- This suggests that impact produced by moving objects depends on both their mass and velocity.
- So, there appears to exist some quantity of importance that combines the object's mass and its velocity called momentum and was introduced by Newton.
- Momentum can be defined as "mass in motion". All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion.
- The momentum, p of an object is defined as the product of its mass, mm and velocity, vv. That is,
  momentum p=mv

- Momentum has both direction and magnitude so it is a vector quantity. Its direction is the same as that of velocity, vv.
- The SI unit of momentum is kilogram-meter per second (kg m s^{-1}).
- Since the application of an unbalanced force brings a change in the velocity of the object, it is therefore clear that a force also produces a change of momentum.
- We define the momentum at the start of the time interval is the initial momentum and at the end of the time interval is the final momentum.
- When the object moves then it gains momentum as the velocity increases. Hence greater the velocity greater is the momentum.

Newton's Second Law of Motion
It states that the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.
Mathematical formulation of Newton's Second Law of Motion:
Let mass of an moving object be m.
Let is initial velocity be u and final velocity be v.
We know that momentum (p) = Mass × velocity
Therefore,
Initial momentum of object = mu
And Final momentum of the object = mv
Therefore, change in momentum = mv – mu

$$\Rightarrow \text{Rate of change of momentum} = \frac{mv - mv}{t}$$

Now, from the Newton's 2nd Law of Motion, we have:

$$\text{Force} \propto \text{Rate of change of momentum}$$

$$\Rightarrow \quad F \propto \frac{mv - mu}{t} \propto \frac{m(v-u)}{t} \qquad ....(i)$$

But we know that $\frac{(v-u)}{t} = a(\text{Acceleration})$

Using above relation in equation (i), we get:

$$F \propto ma$$

Or $\quad F = kma \qquad ....(ii)$

Where k is the proportionality constant
Now, 1 unit force is defined as the force applied on an object of mass 1kg to

produce the acceleration of $1m/s^2$.
Thus, 1 unit of force = k ×1kg ×1m/s2
⟹ k = 1

By putting the value of k=1 in equation (ii), we get:
F = ma
i.e., Force = Mass × Acceleration

The SI unit of Force

SI unit of force is Newton (N).

Since Force = Mass x Acceleration

The unit of mass = kg and The unit of acceleration = m/s^2
If force, mass and acceleration is taken as 1 unit.

Therefore,

1 Newton (N) = 1kg x $1m/s^2$
Thus, Newton (N) = kg m/s^2
Thus, one unit of force is defined as the amount that produces an acceleration of 1 m/s^2 in an object of mass 1 kg.

Applications of Newton's 2nd Law of Motion

- A fielder pulls his hand backward; while catching a cricket ball coming with a great speed. Actually, while catching a cricket ball the momentum of ball is reduced to zero. If the ball is stopped suddenly, its momentum will be reduced to zero instantly causing the instant rate of change in momentum due to which ball will exert great force on the hands of player due to which the player's hand may get injured. Therefore, by pulling the hand backward a fielder gives more time to the change of momentum to become zero. This prevents the hands of fielder from getting hurt.

- For athletes of long and high jump, sand bed or cushioned bed is provided at the place of landing. This is because when an athlete falls on the ground after performing a high or long jump, the momentum of his body is reduced to zero. If the momentum of an athlete will be reduced to zero instantly, it will result in the production of a large force which may hurt the player. Whereas, by providing a cushioned bed, the momentum of player's body is reduced to zero in a delayed period due to which less force acts on his body hence, preventing the athlete from getting hurt.

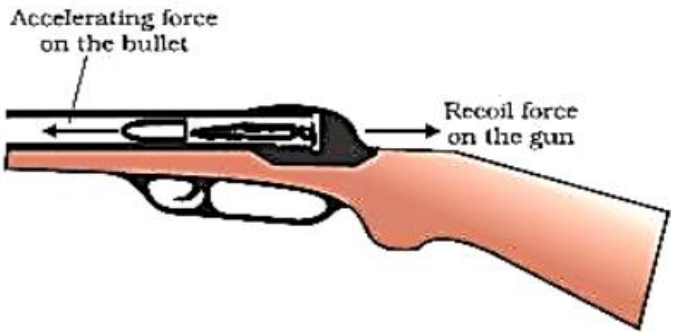
- Seat belts in a car are provided to prevent the passenger from getting thrown in the direction of motion. In case of sudden braking or any accident, passengers may get thrown in the direction of motion of vehicle and may get fatal injuries. Whereas, the stretchable seat belts prevent the passenger's body to fall suddenly and thus increase the time of the rate of momentum to be become zero. This will reduce the effective force hence preventing the passenger from getting any fatal injury.

Newton's Third Law of Motion

Newton's Third Law of Motion states that there is always reaction for every action in opposite direction and of equal magnitude, i.e., action and reaction forces are equal and opposite.

Applications of Newton's Third Law of Motion:

- Recoil of gun: When bullet is fired from a gun, it moves ahead. By the Newton's 3rd law of motion, the bullet apply same force on gun in backward direction. Due to this force, gun moves back giving a jerk to the shoulder of the gunman. This is called recoil of gun. Here, gun moves back only by small amount due to its heavy mass.



- During walking, a person pushes the ground in backward direction and in the reaction the ground also pushes the person with equal magnitude of force but in opposite direction. This enables him to move in forward direction against the push.
- Swimming in water: Man pushes water back by applying force. By Newton's 3 Law, water applies equal and opposite force on swimmer. Due to this force man moves ahead.
- Propulsion of a boat in forward direction – Sailor pushes water with oar in backward direction; resulting water pushing the oar in forward direction. Consequently, the boat is pushed in forward direction.

Conservation of Momentum

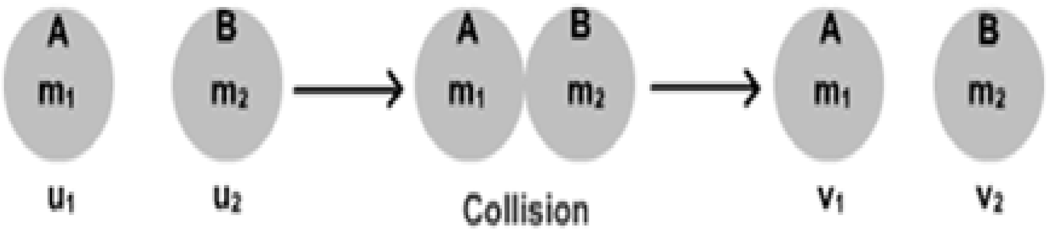
If t or more objects apply force on each other with no external force, their final momentum remains same as initial momentum.

Total momentum before collision = Total momentum after collision

Mathematical Formulation of Conservation of Momentum:

Suppose, two objects A and B each of mass m_1 and mass m_2 are moving initially with velocities u_1 and u_2, strike each other after time t and start moving with velocities v_1 and v_2 respectively.

We know that, Momentum = Mass x Velocity



Therefore,

Initial momentum of object A = m_1u_1

Initial momentum of object B = m_2u_2

Final momentum of object A = m_1v_1

Final momentum of object B = m_2v_2

Now, Rate of change of momentum = Change in momentum/ time taken

Therefore,

$$F_{AB} = \frac{(m_1v_1 - m_1u_1)}{t} = \frac{m_1(v_1 - u_1)}{t} \quad ....(i)$$

Also,Rate of change of momentum in B during collision,

$$F_{BA} = \frac{(m_2v_2 - m_2u_2)}{t} = \frac{m_2(v_2 - u_2)}{t} \quad ....(ii)$$

But from Newton's third law of motion, we have:

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

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

$$\Rightarrow \quad m_1v_1 - m_1u_1 = -m_2v_2 + m_2u_2$$

$$\Rightarrow \quad m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

Thus, Total initial momentum = Total final momentum

Applications of Conservation of Momentum:

- Propelling of rocket: The chemicals inside the rocket burn and produce the high velocity blast of hot gases. These gases get ejected downwards with a great velocity. To conserve the total momentum of gases, the rocket moves up with a large velocity.

- Flight of jet planes: In jet planes, a large volume of gases produced by combustion of fuel is allowed to escape through a jet in backward direction. Due to the high velocity, the backward moving gases have a large momentum. In order to conserve the momentum, the plane get a push in forward direction and moves with the great speed.

Facts about Conservation Laws

- They are considered as 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 – law of conservation of energy, the law of conservation of angular momentum, the law of conservation of charge.