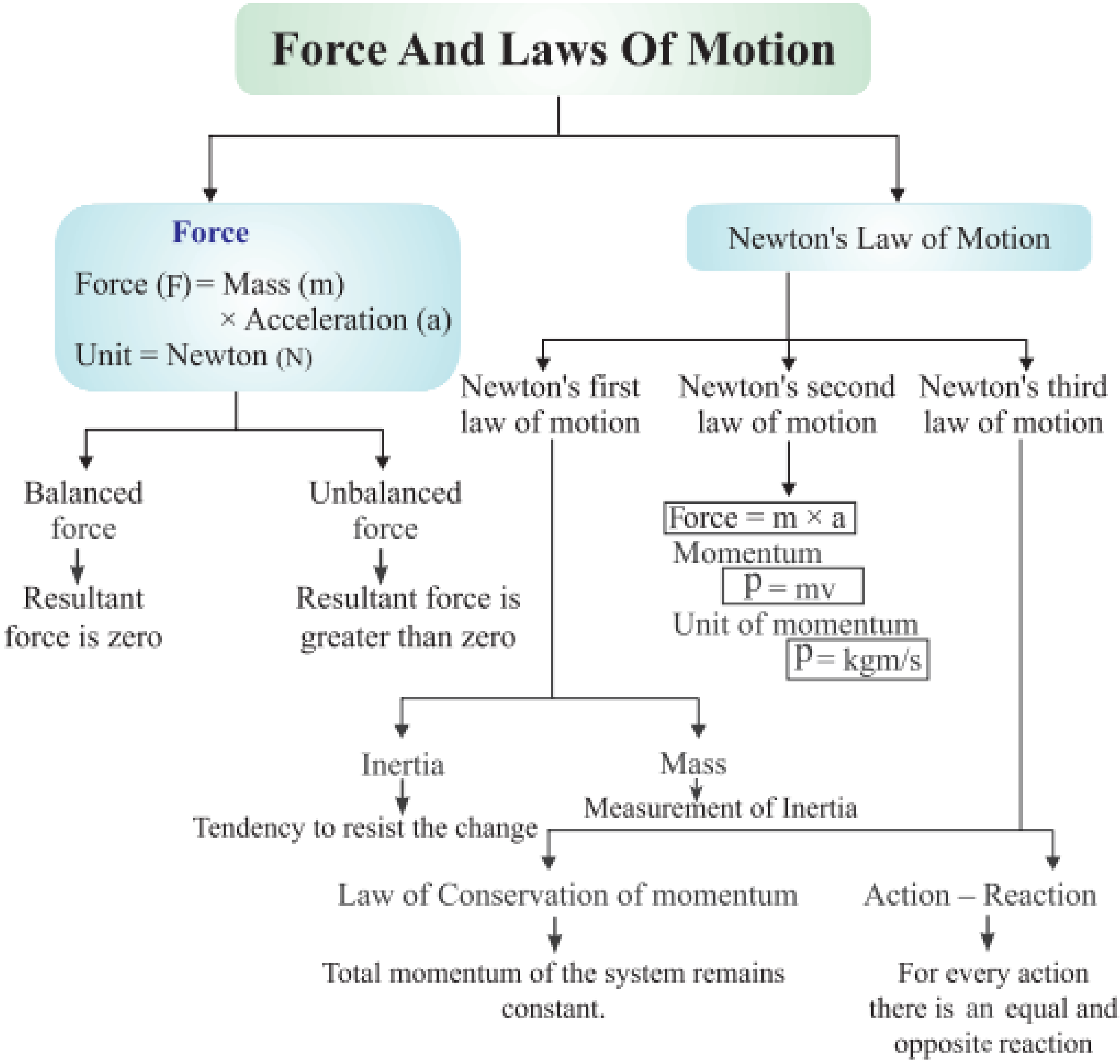
Chapter 9

Force and Laws of Motion

CONCEPT MAPPING



Force :

- It is the force that enables us to do any work.
- For doing work we pull or push the object.
- Therefore, *pull or push* is called **force**.

Example:

- ✓ to open a door, either we push or pull it.
- ✓ A drawer is pulled to open and pushed to close.
- ✓

Effect of Force

i) Force can **move** a stationary body or object.

For example,

- a football can be set to move by kicking it, i.e., by applying a force.

ii) Force can **stop** a moving body.
For example,
- by applying brakes, a running cycle or a running vehicle can be stopped.

iii) Force can **change the direction** of a moving object.
For example,
- by applying force, i.e., by moving handle, the direction of a running bicycle can be changed.
- by moving steering, the direction of a running vehicle is changed.

iv) Force can **change the speed** of a moving body.
By ***accelerating***, the speed of a running vehicle can be increased or
by ***applying brakes*** the speed of a running vehicle can be decreased.

v) Force can ***change the shape and size*** of an object.

vi) *For example*,
By **hammering**, a block of metal can be turned into a thin sheet.
By **hammering**, a stone can be broken into pieces.

Type of Forces

(A) Balanced forces

(B) Unbalanced forces

(A) Balanced Forces

- ✓ If the resultant of applied forces is equal to zero, these are called balanced forces.
  Example,
  In a tug of war if both the team apply the *same magnitude of forces in opposite directions*, rope does not move in either side.
  This happens because of *balanced forces* in which *resultant of applied forces become zero.*
- ✓ 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 forces are applied from both sides over a balloon, the size and shape of balloon is changed**.**

(B) Unbalanced Forces

If the *resultant* of applied forces are greater than zero, the forces are called *unbalanced forces*.

Unbalanced forces can do the following :

* Move a stationary object

* Increase the speed of a moving object
* Decrease the speed of a moving object
* Stop a moving object
* Change the shape and size of an object

Newton's Laws of Motion :

Newton's First Law of Motion (Law of Inertia):

Any object remains in the state of rest or in uniform motion along a straight line, until it is compelled to change the state by applying external force.

Explanation :

- ✓ If any object is in the state of rest, then it will remain in rest until a external force is applied to change its state.
- ✓ Similarly, an object will remain in uniform motion in a straight line until any external force is applied over it to change its state.
- ✓ This means all objects resist a change in their state.
- ✓ The state of any object can be changed by applying external forces only.

Newton's First Law of Motion in Everyday Life *:*

a) A person standing in a bus falls backward when bus starts moving suddenly. This happens because the person and bus both are in rest while bus is not moving, but as the bus starts moving, the legs of the person start moving along with bus but rest portion of his body has the tendency to remain in rest. Because of this, the person falls backward; if he is not alert.

b) A *person standing in a moving bus falls forward* if *driver applies brakes suddenly*.

This happens because when bus is moving, the person standing in it is also in motion along with bus.

But when driver applies brakes the speed of bus decreases suddenly or bus comes in the state of rest suddenly.

In this condition the legs of the person which are in contact with the bus come in rest, while the rest part of his/her body has the tendency to remain in motion.

Because of this person falls forward if he / she is not alert.

c) Before hanging the wet clothes over laundry line, usually many jerks are given to the clothes to get them dried quickly.

Because of jerks, droplets of water from the pores of the cloth falls on the ground and reduced amount of water in clothes dries them quickly.

This happens because when suddenly clothes are moved by giving jerks, the water droplets in it have the tendency to remain in rest and they are separated from clothes and fall on the ground.

d) When the pile of coin on the carom-board is hit by a striker, only the coin at the bottom moves away leaving rest of the pile of coin at same place.

This happens because when the pile is struck with a striker, the coin at the bottom comes in motion, while rest of the coin in the pile has the tendency to remain in the rest and they vertically falls on the carom-board and remain at same place.

Mass and Inertia

- The property of an object because of which it resists a change in its state is called **inertia**.
- Inertia of an object is measured by its mass.
- Inertia is directly proportional to the mass.
- This means inertia increases with increase in mass and decreases with decrease in mass.
- A heavy object will have more inertia than the lighter one.

- In other words, the *natural tendency of an object* that *resists the change in state of uniform motion or rest* of the object is called *inertia*.
- Since a heavy object has more inertia, thus it is *difficult to push or pull a heavy box over the ground than the lighter one*.
- Similarly, a greater opposing force is needed to stop a heavy body than a light body in the same time, if they are moving with the same speed.

Momentum

Momentum is the *quantity of motion* an object has.

The product of velocity and mass is called the momentum. Momentum is denoted by ‘p’

Therefore, Momentum of the object = Mass x Velocity

Or,

$p=m\times v$ v

Where, p = momentum, m = mass of the object and v = velocity of the object.

Relation Between Momentum and Inertia

Inertia describes an object’s resistance to *change* in state- motion or rest (or lack of motion)

i.e, it is **property of the object by virtue of its mass**

Momentum describes how much motion the object has **by virtue of its mass and velocity .**

Momentum and Mass and Velocity

• Since momentum is the product of mass and velocity (/> = m x v) of an object. This means momentum is directly proportional to mass and velocity.

Momentum increases with increase of either mass or velocity.

of an object.

This means if a lighter and a heavier object is moving with same velocity, then heavier object will have more momentum than the lighter one.

If a small object is moving with great velocity, it has tremendous momentum. And because of momentum, it can harm an object more severely.

For example, a small bullet having a little mass even kills a person when it is fired from a gun.

Usually, road accidents prove more fatal because of high speed than in slower speed. This happens because vehicles running with high speed have greater momentum compared to a vehicle running with slower speed.

Momentum of an object which is in the state of rest

Let an object with mass 'w' is in the rest.

Since, object is in rest, therefore, its velocity, v=0

Now, we know that

Momentum = mass x velocity

Or p = m x 0 = 0

Thus, the momentum of an object in the rest i.e., non-moving, is equal to zero.

Unit of momentum :

SI unit of mass=kg

SI unit of velocity =meter per second i.e.,m/s

We know that Momentum(p) = m x v

Therefore, p = kg x m/s

Or p = kg m/s

Therefore, SI unit of momentum= kg m/s

Numerical Problems Based on Momentum

Type I. Calculation of Momentum

Example 1. What will he the momentum of a stone having mass of 10 kg when it is thrown with a velocity of 2 m/s?

Solution:

Mass (m)=10 kg

Velocity (v)=2 m/s

Momentum (p)=?

We know that, Momentum (p)=Mass(m) x Velocity (v)

Therefore, p=10 kg x 2 m/s = 20 kg m/s

Thus, the momentum of the stone=**20 kg m/s.** *Ans.*

Example 2. The mass of a goods lorry is 4000 kg and the mass of goods loaded on it is 20000 kg. If the lorry is moving with a velocity of 2 m/s, what will be its momentum?

Solution :
Given, Velocity (v) = 2 m/s
Mass of lorry= 4000kg, Mass of goods on the lorry = 20000 kg
Therefore,Total mass (m) on thelorry = 4000 kg + 20000 kg = 24000 kg
Momentum (p) = ?
We know that, Momentum (p) = Mass (m) x Velocity (v)
Therefore, p= 24000 kg x 2 m/s
Or p= 48000 kg m/s
Thus, the momentum of the lorry = **48000 kg m/s.** *Ans.*

Example 3. A car having mass of 1000 kg is moving with a velocity of 0.5 m/s. What will be its momentum ?
Solution :
Given, Velocity of the car (v) = 0.5 m/s
Mass of the car (m) = 1000 kg
Momentum (p) = ?
We know that, Momentum (p)= Mass (m) x Velocity (v)
Therefore, p = 1000 kg x 0.5 m/s = 500 kg m/s
Thus, momentum of the car = 500 kg m/s. *Ans.*

Newton's Second Law of Motion (definition of Force)

Rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.

Mathematical expression

Let Mass of an object = m kg

Initial velocity of the object = u m/s

Final velocity of the object = v m/s

Initial momentum, p_1 = mu. Final momentum, p_2 = mv
Change in momentum = Final momentum - Initial momentum
= mv - mu
- m(v - u)

$$\therefore Rate\ of\ change\ of\ Momentum = \frac{Change\ in\ Momentum}{Time\ taken}$$

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

According to Second law, this rate of change is momentum is directly proportional to force.

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

We know that, $\frac{(v-u)}{t} = a$ (From First equation of motion)

So, $F = kma$

Where k is a constant. Its value = 1.

F = 1 x m x a = ma

SI unit of force = **kgm/s^2 or Newton**

Definition of 1 Newton.

When an acceleration of 1 m/s^2 is observed in a body of mass 1 kg, then the force applied on the body is said to be 1 Newton.

Proof of Newton's First Law of Motion from Second Law

First law states that if external force F = 0, then a moving body keeps moving with the same velocity, or a body at rest continues to be at rest.

So, F = 0

As per Second Law of Motion;

$$i.e. \quad F \propto \frac{m(v-u)}{t}$$

$$i.e\ F = k\frac{m(v-u)}{t}$$

$$i.e.\ F = \frac{m(v-u)}{t} \quad (as\ k = 1)$$

(a) A body is moving with initial velocity u, then

$$0 = \frac{m(v-u)}{t} \quad \Longrightarrow v - u = 0$$

So, v=u

Thus, final velocity is also same.

(b) A body is at rest i.e., u = 0.

Therefore, from above u = v = 0

So, the body will continue to be at rest.

Third Law of Motion

To every action there is an equal and opposite reaction.

Note: *Action and reaction act on two different objects*.

Applications :
(i) Walking is enabled by Third law.
(ii) A boat moves back when we deboard it.
(iii) A gun recoils.
(iv) Rowing of a boat.

Law of Conservation of Momentum

When two (or more) bodies act upon one another, their total momentum remains constant (or conserved) provided no external forces are acting.

Initial momentum before collision = Final momentum after collision

Let 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 for time t and start moving with velocities v_1 and v_2 respectively.