NEWTON'S LAWS OF MOTION

Force : Force is defined as an external influence which changes or tends to change the state of rest, speed or direction of motion of an object. It is a vector quantity and its SI unit is newton (N).

When a force applied on an object, it can do the following things :

(i) It can change the state of rest of a stationary object.

(ii) It can change the speed of a moving object, i.e., it can accelerate or retard a moving object.

(iii) It can change the direction of motion of an object.

(iv) It can change the shape of an object.

Galileo's law of Intertia : This law states that when no force is exerted on a body, it stays at rest or it moves in a straight line-with constant speed.

Inertia : *Inertia* of an object is a property by virtue of which is opposes any change in its position of rest or of uniform motion along a straight line. It is an inherent property of all natural objects.

(A) Inertia of rest : It is the property of matter due to which it opposes any change in its state of rest. For example,

(a) when a blanket is given a sudden jerk, the dust particle, fall off.

(b) passengers standing in a bus fall backwards when the bus suddenly starts moving.

(c) The fruits fall down when branches of the fruit tree are shaken.

(B) Inertia of motion : It is the property of matter due to which it opposes any change in its state of uniform motion along a straight line. For example,

(a) A ball thrown upwards in a moving train comes back to the thrower.

(b) An athlete runs for some distance before taking a long jump.

(c) A passenger standing in a running bus falls forward when the bus comes to a sudden stop.

(C) Inertia of direction : It is the property of matter due to which it opposes any change in its direction. For example,

(a) when a wheel rotates at high speed, the mud sticking to it flies off tangentially.

(b) when a running car suddenly takes a turn, the passengers experience a jerk in the outward direction.

(c) when a stone is tied at the end of a string being whirled in a horizontal circle and the string breaks, the stone tends to fly off tangentially along a straight line.

Newton's first law of motion (or law of inertia) :

(a) Every body continues its state of uniform motion or of rest until an external force is applied over it.

(b) Newton's first law gives the qualitative definition of force according to which "force is that external cause which tends to change or actually change the state of motion of the body."

(c) Newton's first law is called "Law of Inertia" by Galelio.

(d) Inertia $\propto$ mass.

Momentum : The momentum of an object is equal to the product of its mass and its velocity, i.e.,

momentum = mass × velocity

$$\vec{P} = m\vec{v}$$

It is a vector quantity. Its SI unit is kg ms^{-1}.

Newton's second law of motion :

(a) According to this law "the rate of change of momentum is directly proportional to the applied force. The change in momentum takes place in the direction of applied force.

(b) Newton's second law gives the quantitative definition of force, i.e.,

$$\vec{F} \propto \frac{d\vec{p}}{dt}$$

$$\text{or } \vec{F} \propto \frac{d}{dt}(m\vec{v})$$

$$\text{or } \vec{F} \propto m\frac{d\vec{v}}{dt} \text{ (taking '}m\text{' as constant)}$$

$$\text{or } \vec{F} \propto m\vec{a}$$

$$\text{or } \vec{F} = m\vec{a} \text{ (taking constant of proportionality as unit)}$$

Hence Force = mass × acceleration.

Newton (N) : The SI unit of force is newton (N) one newton is expressed as 1 N and is defined as the force which can produce an acceleration of 1 ms^{-2} in a body of mass 1 kg. Hence,

$$1\ N = 1\ kg\ ms^{-2}$$

Also $1\ N = 10^5$ dyne,

where dyne is the unit of force in CGS system.

(c) Out of Newton's three laws of motion, the most fundamental one is second law, because first and third laws can be derived from it.

(d) 1 kg. wt. = g newton.

Kilogram weight (kg. wt.) is gravitational unit of force in SI system.

One kilogram weight of force is that force with which an object of mass 1 kg is attracted towards the centre of the earth.

Also, 1 kg wt. = 9.8 N (at a place where g = 9.8 ms^{-2})

Newton's third law of motion :

(a) According to this law, every action has equal and opposite reaction. Action and reaction act on different bodies and they are simultaneous.

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

(b) Newton's third law contradicts theory of relativity, because it states that force signals can travel with infinite speed while theory of relativity states that nothing can be travel with a velocity greater than velocity of light.

Basic Force in Nature

(i) Gravitational forces
(ii) Nuclear forces—the strong and weak forces
(iii) Elastic forces
(iv) Electric and magnetic forces—electromagnetic forces

Law of conservation of linear momentum : This law states that, if the resultant external force acting on a system of particles is zero, the total linear momentum of the system is conserved or remain constant, i.e.,

$$\vec{p} = \text{constant}$$

Impulse : The total effect of a force is known as impulse. It is easily measured by the change in momentum produced in a body. Hence,

$$\begin{aligned} \text{Impulse} &= \vec{F} \times \Delta t \\ &= \Delta \vec{p} \\ &= \text{change in momentum} \\ &= m\,(\vec{v} - \vec{u}) \end{aligned}$$

It is a vector quantity and its SI unit is Ns.

Friction : The force which opposes the motion of an object over another body in contact with it, is called as the force of friction, or simply friction.

(i) **Static friction :** It is the force of friction which exactly balances the applied force during the stationary state of the object.

(ii) **Limiting friction :** It is the maximum value of static friction when an object just starts sliding over the surface of another object.

(iii) **Dynamic or Kinetic friction :** It is the force of friction which comes into play when the two objects in contact are in relative motion.

(iv) **Sliding friction :** When an object slides over a surface, the friction between them is called as sliding friction.

(v) **Rolling Friction :** When an object rolls over a surface, the friction between them is called as rolling friction. It should be noted that rolling friction is always less than sliding friction.

Laws of friction

(i) Friction acts in a direction opposite to the direction of motion of the objects.

(ii) Friction depends upon the nature of the two surfaces in contact.

(iii) Friction is independent of the area of contact of the two surfaces.

(iv) Rolling friction is less than sliding friction.

(v) Force of friction (F) is directly proportional to the normal (R), i.e.,

$$F \propto R$$

or $F = \mu R$, where μ is a constant of proportionality and is called as the coefficient of friction.

Angle of friction (θ) : It is the angle which the resultant of limiting frictional force makes with the normal reaction.

Also, $\tan \theta = \mu_s$

where μ_s = coefficient of static friction.
