Laws of Motion

1. Force

Force may be defined as an external agent/cause (a push or a pull) which changes or tends to change the state of rest or of uniform motion or the direction of motion of a body. The dimensions of force are $[MLT^{-2}]$ and SI unit is newton.

2. Inertia

The term inertia means resistance of any physical object. It is defined as the inherent property of a material body by virtue of which it remains in its state of rest or of uniform motion in a straight line.

3. Law of Inertia

Galileo first asserted that objects move with constant speed when no external forces act on them. Galileo experimented with single inclined plane. He observed that

(*i*) When an object moves down on the inclined plane, its speed increases.

(*ii*) When an object is moved up on the inclined plane, its speed decreases, i.e. retards.

(*iii*) When an object is moving on a horizontal plane, there should be no acceleration nor retardation, i.e. constant speed.

4. Various Types of Inertia

(*i*) **Inertia of Rest** It is defined as the tendency of a body to remain in its position of rest.

(*ii*) **Inertia of Motion** It is defined as the tendency of a body to remain in its state of uniform motion in a straight line.

(*iii*) **Inertia of Direction** It is defined as the inability of a body to change its direction of motion by itself.

5. Newton's Laws of Motion

Sir Isaac Newton (1642-1727) made a systematic study of motion and extended the views of Galileo. He gave three laws of motion which are called **Newton's laws of motion.**

(*i*) **Newton's First Law of Motion** This law states that every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by some external force to change that state.

(*ii*) **Newton's Second Law of Motion** This law states that the rate of change of linear momentum of a body is directly proportional to the external force applied on the body and the change takes place in the direction of the applied force.

So, force, $\mathbf{F} = m\mathbf{a}$

In scalar form, this equation can be written as

$$F = ma \qquad [\text{where, } m = \text{constant}]$$

The force is a vector quantity and its SI unit is newton.

In CGS system, absolute unit of force is dyne.

Relation between newton and dyne,

$$1\text{N} = 10^5 \text{ dyne.}$$

Momentum Momentum of a body is the quantity of motion possessed by the body. It is defined to be the product of its mass m and velocity $\mathbf{v}$ and is denoted by $\mathbf{p}$. Momentum, $\mathbf{p} = m\mathbf{v}$

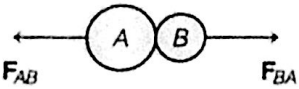
Impulse The measure of the action of a large force acting for a short time to produce a finite change in momentum is called an impulse. In other words, impulse is defined as the product of the average force and the time interval for which the force acts on the body. It is denoted by I.

Thus, impulse = average force × time

(iii) **Newton's Third Law of Motion** Newton's third law states that for every action, there is always an equal and opposite reaction. In simple terms, *the third law can be stated as follows.*

Force in nature always occur in pairs. Force on body A by body B is equal and opposite to the force on the body B by A.

As shown in figure, if $\mathbf{F}_{BA}$ is the force exerted by body A on B and $\mathbf{F}_{AB}$ is the force exerted by B on A, then according to Newton's third law,



Forces acting on bodies A and B

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

Force on A by B = – Force on B by A

6. Conservation of Momentum

According to this principle,

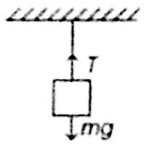
"In the absence of an external force, the total momentum of a system remains constant or conserved and does not change with time".

If $\Sigma \mathbf{F}_{ext} = 0$ then momentum, $\mathbf{p}$ = constant.

This equation shows that the linear momentum of the system remains conserved.

7. Tension

When a body of mass m is fastened with the string then the weight of the body acts downwards while a force acts just opposite to the downward force for balancing it is called tension.



$$T = mg$$

where, g = acceleration due to gravity,

T = tension in the string.

8. Friction

Whenever a body moves or tends to move over the surface of another body, a force comes into play which acts parallel to the surface of contact and opposes the relative motion.

This opposing force is called friction $f_r \propto N, f_r = \mu N$

where, N = normal reaction

μ = coefficient of friction

9. Types of Friction

There are mainly two types of friction such as

(i) **Static Friction** Force of friction which comes into play between two bodies before one body actually starts moving over the other is called static friction and it is denoted by f_s.

Limiting Friction Maximum value of static friction which comes into play when a body just starts moving over the surface of another body is called limiting friction. Thus, $f_s \leq f_{s\,(max)}$

Note *The value of limiting static friction $f_{s\,(max)}$ between two given surfaces is directly proportional to the normal reaction (R) between the two surfaces.*

i.e. $f_{s\,(max)} \propto R \Rightarrow f_{s\,(max)} = \mu_s R \Rightarrow \mu_s = \dfrac{f_{s\,(max)}}{R}$

The proportionality constant μ_s is called coefficient of static friction.

(ii) **Kinetic Friction** Kinetic friction or dynamic friction is the opposing force that comes into play when one body is actually moving over the surface of another body. Thus, kinetic friction opposes the **relative motion.** The value of kinetic friction f_k is directly proportional to the normal reaction R between the two surfaces.

i.e. $f_k \propto R$ or $f_k = \mu_k R$

$$\Rightarrow \quad \mu_k = \frac{f_k}{R}$$

The proportionality constant μ_k is called coefficient of kinetic friction.

10. Centripetal Force

Centripetal force, $F_c = \dfrac{mv^2}{r}$ where, m is the mass of the body. This force is directed towards the centre,

But $\dfrac{v^2}{r}$ is centripetal acceleration or radial acceleration.

$\therefore$ Centripetal force, $F_c = mr\omega^2$ $\quad [\because v = \omega r]$