

Force and laws of motion

Force

- Force is an external effort in the form of pushing, pulling, stretching, compressing etc., which
 - may move a body at rest
 - stop a moving body
 - change the speed of a body
 - change the direction of a moving body
 - changes the size and shape of a body

Balanced and unbalanced forces

- **Balanced forces:** if the resultant of all the forces acting on a body is zero

balanced forces does not change the state of motion

Example: a wooden block placed on a table. In this case weight mg of wooden block is balanced by normal reaction by the table

- **Unbalanced forces:** if the resultant of all the forces is non zero
unbalanced forces change the state of motion

Newton's laws of motion

- ▶ First law of motion which defines inertia and force
- ▶ Second law of motion gives quantitative relation between force and effect (acceleration and change in momentum) produced by force.
- ▶ Third law of motion gives the nature of force that equal and opposite forces always exist between pair of objects keeping the harmony in nature

First law of motion or Law of inertia

- ▶ It states that, a body continues to be in a state of rest or in a state of uniform motion along a straight line, unless some external unbalanced force is applied on the body to change that state.
- ▶ From this law, we may define force as external effort in the form of push or pull which
 - a) Actually moves or tries to move a body at rest,
 - b) Actually stops or tries to stop a moving body,
 - c) Actually changes or tries to change the direction of the motion of the body

Inertia

- ▶ Inertia of a body is the inability of the body to change by itself its state of rest or state of uniform motion along a straight line
- ▶ Mass of a body is a measure of inertia of the body. Larger the mass, greater is inertia. Example: it is easier to push an empty box than to push a box full of books.
- ▶ Inertia is of three type:
 - i. Inertia of rest
 - ii. Inertia of motion
 - iii. Inertia of direction

Types of Inertia

- Inertia of rest: Inability of a body to change by itself, its state of rest.

Examples:

when a bus or train starts suddenly, the person sitting inside tends to fall backwards

When we shake vigorously a branch of tree, the leaves and fruits fall down.

- Inertia of motion: Inability of a body to change by itself, its state of motion.

Examples:

when a bus or train starts suddenly, the person sitting inside tends to fall backwards

- Inertia of direction: Inability of a body to change by itself, its direction of motion.

Examples:

when a bus or train takes a sharp turn suddenly, the person sitting inside tends to fall in opposite direction

Linear Momentum

- ▶ Linear momentum is the amount of motion contained in a moving body
- ▶ It is defined as product of mass and velocity of the body.
- ▶ $P=mv$ where p = momentum, m = mass of body and v = velocity of the body
- ▶ If $v=0$ then $p=0$ means an object at rest possesses no linear momentum.
- ▶ Linear momentum is a vector quantity, its direction is same as the direction of velocity
- ▶ SI unit of linear momentum is $kgms^{-1}$

Second law of motion

- It states that, the rate of change of linear momentum of a body is directly proportional to the external force applied on the body, and this change takes always in the direction of the applied force.

$$\frac{\text{change in momentum}}{\text{time}} \propto \text{force applied}$$

Suppose m=mass of body, u= initial velocity of the body along a straight line,

F= external force applied on body, t= time for which force is applied,

v= final velocity of the body along same straight line, after t seconds

Change in linear momentum of the body= $p_2 - p_1 = mv - mu = m(v - u)$

Rate of change in momentum= $\frac{m(v-u)}{t} = ma$

$$ma \propto f \text{ or } f \propto ma \text{ or } f = kma$$

If we define f=1, when m=1 and a=1 then k=1 and $f = ma$

SI unit of force= 1 newton(N) and $1N = 1 \text{ kgm/s}^{-2}$

Application of second law of motion

- ▶ Catching a cricket ball: to catch a fast ball, a player pulls his hands backwards to prevent injury to his hands.
- ▶ High jump: the athletes are made to fall either on a cushioned bed or on a sand bed
- ▶ Use of seat belt in cars: to prevent the injuries to the passengers in case of an accident or in case of sudden application of brakes.

Third law of motion

- ▶ It states that to every action, there is equal and opposite reaction i.e., the forces of action and reaction are always equal and opposite.
- ▶ These forces act on different objects and never cancel each other.
- ▶ Each force produces its own effect.
- ▶ Examples
 1. Walking
 2. Swimming
 3. Recoiling of gun
 4. Man and boat
 5. The flying of rockets and jet planes

Law of conservation of linear momentum

- ▶ When two or more bodies interact with each another, the vector sum of their linear momenta remains constant(i.e. conserved), and is not affected due to their mutual action and reaction. The only condition is that no external unbalanced force should be acting on the system of bodies.
- ▶ i.e. if system is isolated or no unbalanced force is acting on it, then total linear momentum of system remains constant or conserved

Proof:

- suppose two balls A and B are moving in the same direction along straight line

Let m_a = mass of ball A m_b = mass of ball B

u_a = velocity of ball A u_b = velocity of ball B, $u_a > u_b$

The two balls collide with each other, let this collision last for t seconds, during collision suppose F_{AB} = force exerted by A on B, and F_{BA} = force exerted by B on A

v_a = velocity of A after collision v_b = velocity of B after collision

According to second law of motion,

$$F_{AB} = \frac{\text{change in momentum of B}}{\text{time}} = \frac{m_b (v_b - u_b)}{t}, \quad F_{BA} = \frac{\text{change in momentum of A}}{\text{time}} = \frac{m_a (v_a - u_a)}{t}$$

According to third law of motion, $F_{BA} = -F_{AB}$

$$\frac{m_b (v_b - u_b)}{t} = - \frac{m_a (v_a - u_a)}{t} \quad \text{or } m_b (v_b - u_b) = -m_a (v_a - u_a)$$

$$\text{or } m_b v_b + m_a v_a = m_b u_a + m_a u_a = \text{constant}$$

Application of conservation of linear momentum

- ▶ Flight of planes and rockets
- ▶ Recoiling of gun

