LECTURE 04

FORCE

Force is a kind of impact, external or internal which tends to change or in real sense it changes the inertia of any object.

All forces in nature are classified into four as gravitational forces, electromagnetic forces, weak nuclear forces and strong nuclear forces.

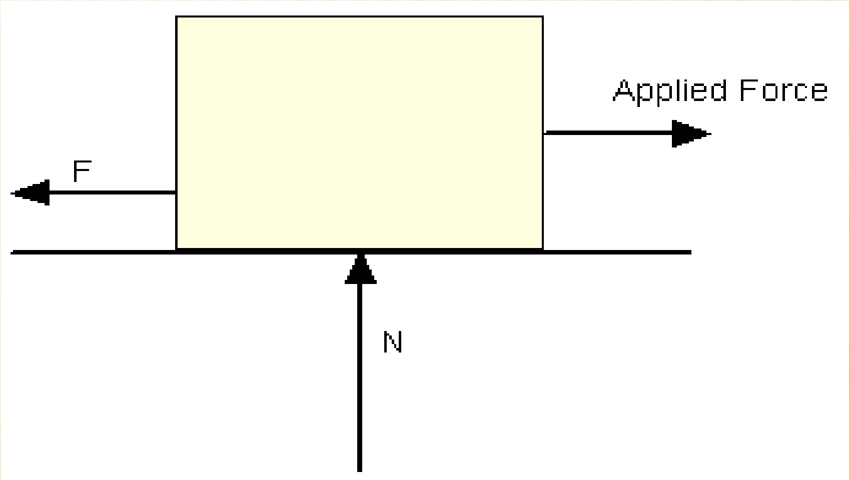
A force is a push or pull acting upon an object as a result of its interaction with another object

TYPES OF FORCES

- Frictional Force
- Gravitational Force
- Tension Force
- Electrical Force
- Normal Force
- Magnetic Force
- Air Resistance Force
- Spring Force

FRICTION/FRICTIONAL FORCE

When surfaces of two bodies are in contact whether they are at rest or in relative motion with respect to one another, they developed a force at plane of their contact which opposes their relative motion. The force which produced at the plane of contact between surfaces due to the relative motion of their surface called frictional force.



Frictional Force depends on the following factors:

- Nature of the surface
- Degree of their smoothness
- Presence of foreign materials (Air, oil, water etc.)
- Temperature.

Laws of Friction

- The maximum force of friction between any pair of surfaces follows two empirical laws.
- These are (1) the maximum force of friction is approximately independent of the area of contact over wide limits. (2) It is proportional to the normal force.

Frictional force can be expressed as

$F_f = \mu N$

Where,

F_f = frictional force

μ = coefficient of friction

N = normal force

TYPES OF FRICTIONAL FORCE

Kinetic friction:

The frictional forces acting between surfaces in relative motion are called forces of kinetic friction.

The ratio of the magnitude of the maximum force of kinetic friction to the magnitude of the normal force is called the **coefficient of kinetic friction.**

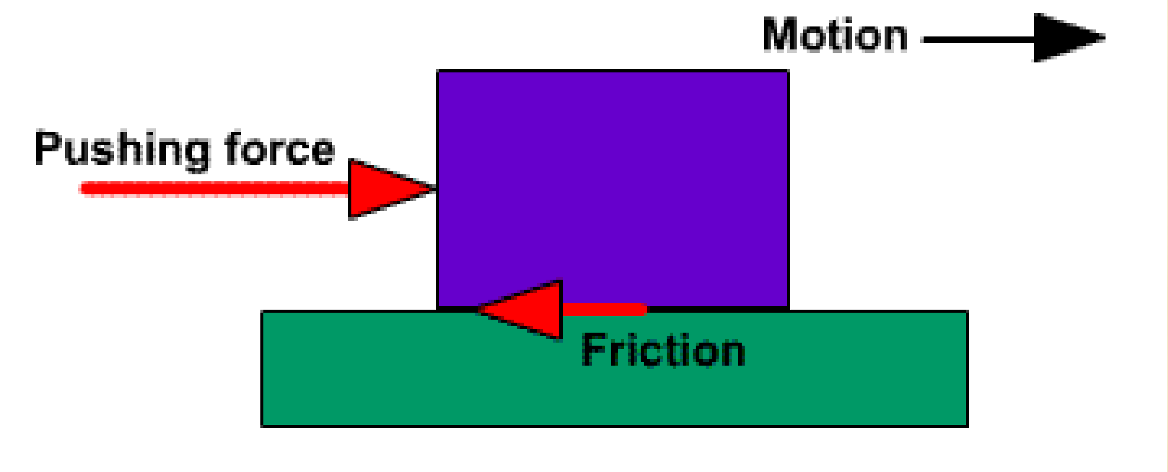
If f_k represents the magnitude of the force of kinetic friction

$f_k = \mu_k N$

where μ_k is the coefficient of kinetic friction.

Kinetic friction:

- If force **F** is greater than friction $\mathbf{F_r}$ (written as $\mathbf{F > F_r}$), then the object will slide or move. The friction is considered kinetic friction, which means moving friction.



Pushing force is greater than friction force

Static Friction

- The frictional forces acting between surfaces at rest with respect to each other are called forces of static friction.

The ratio of the magnitude of the maximum force of static friction to the magnitude of the normal force is called the **coefficient of static friction.**

If f_s represents the magnitude of the force of static friction, we can write ,

$$f_s = \mu_s N$$

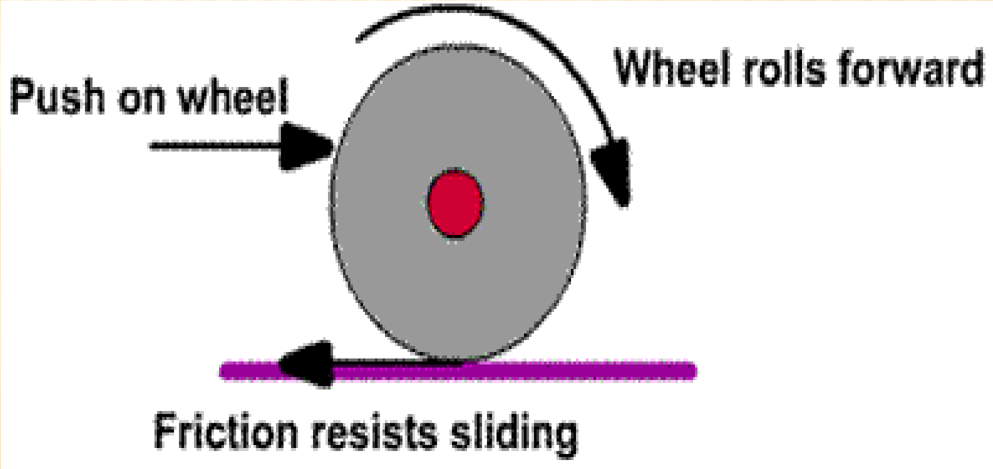
where μ_s is the coefficient of static friction and N is the magnitude of normal force.

Static Friction

If the pushing force F is less than the resistive force of friction F_r (written as $F < F_r$), there is no motion and the objects remain static with respect to each other. In this case, the friction is considered static friction, which means it is not moving.

Rolling Friction

The force resisting the motion of a rolling body on a surface is known as Rolling friction or Rolling resistance. This type of friction is experienced by a wheel or a ball rolling on the ground. The primary cause of this friction is that the energy of deformation is greater than the energy of recovery. There is an adhesive force between the two surfaces which needs to be overcome constantly.



EXAMPLES OF ROLLING FRICTION

- Heavy duty trucks get greater gas mileage when tread begins to wear on the tires because there is less rolling friction, allowing the truck to move more quickly with less resistance.
- Roller skates have greater rolling friction than Rollerblades because there is more surface-to-wheel contact on roller skates.

Fluid Friction

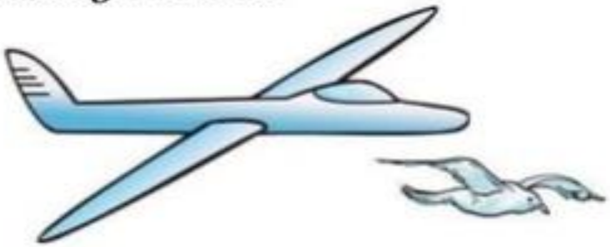
Fluid friction occurs between fluid layers that are moving relative to each other. This internal resistance to flow is named viscosity. In everyday terms, the viscosity of a fluid is described as its “thickness”.

All real fluids offer some resistance to shearing and therefore are viscous.

EXAMPLE

FLUID FRICTION

- *Fluid friction is the force of friction exerted by liquids and gases on objects moving through them.*
- *Fluid friction depends upon :-*
  - The speed of the object.
  - Shape of the object.
  - The nature of the fluid.



- Birds flying in air have streamlined body to reduce fluid friction.
- Fishes living in water have streamlined body to reduce fluid friction.

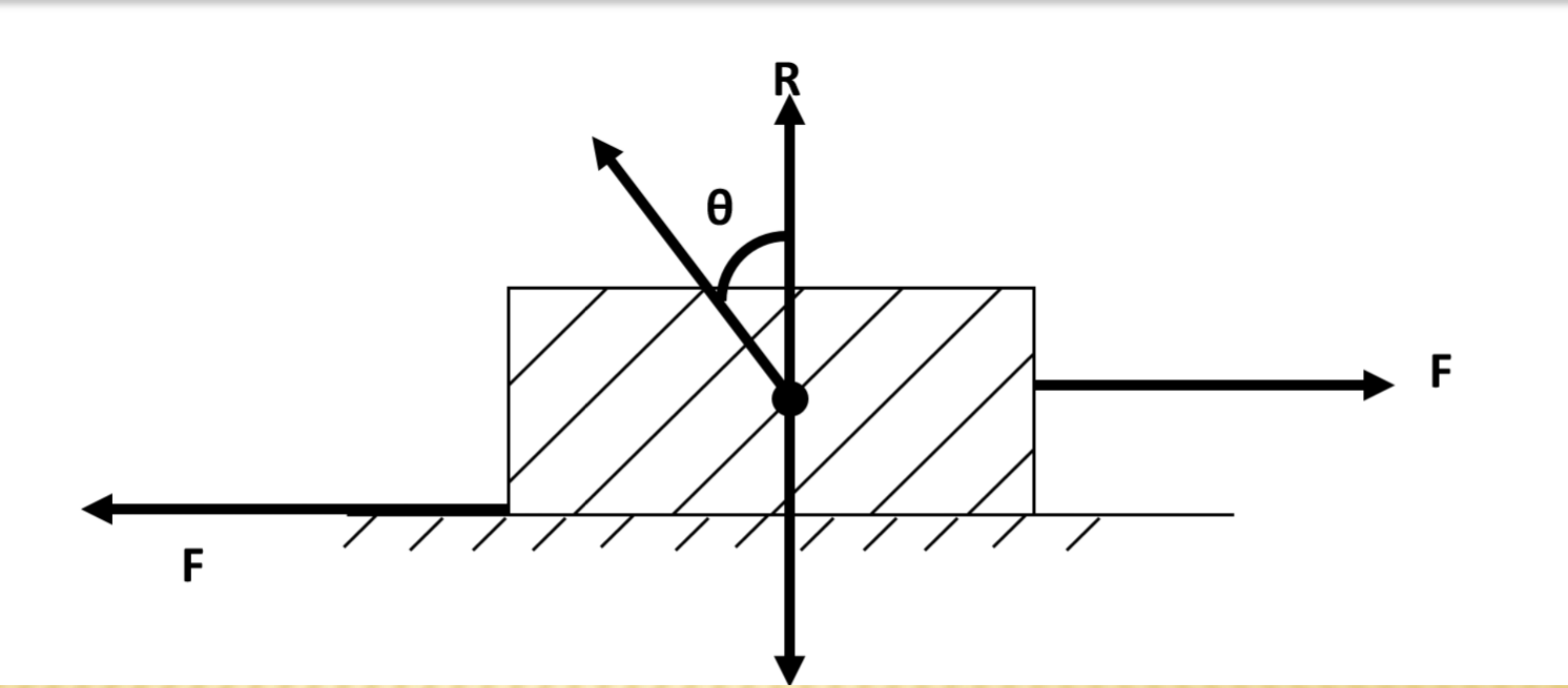
Advantages or Positive effects of friction:

Disadvantages or negative effects of friction:

Angle of friction:

The resultant of the limiting static friction and normal reaction force is called the resultant reaction. The angle between this resultant reaction and normal reaction is called the angle of friction. In figure, the resultant of the limiting static force (F_l) and normal reaction (R) is . Now, according to definition, the angle θ between and R is the angle of friction.

Angle of friction



DETERMINATION OF Θ$_F$:

Determination of θ$_f$: From the fig-2, we have, $F_l = R_r \sin\theta_f$ ....(1) and $R = R_r \cos\theta_f$ ....(2)

Dividing eq. (1) by eq. (2), we obtain,

$$\frac{R_r \sin\theta_f}{R_r \cos\theta_f} = \frac{F_l}{R} \Rightarrow \tan\theta_f = \frac{F_l}{R} \Rightarrow \theta_f = \tan^{-1}\left(\frac{F_l}{R}\right) \Rightarrow \theta_f = \tan^{-1}\mu_s \text{ ......(3) [Since, } \mu_s = \frac{F_l}{R}\text{]}$$

That is, the tangent of the angle of friction is equal to the coefficient of static friction.

Equation (3) represents the relation between the coefficient of static friction and angle of friction.

MOMENTUM

Linear Momentum:

The momentum of a body is defined as the product of its mass and its velocity. It is denoted by the symbol 'p'. It is a vector quantity. Its SI unit is kg.m/s. Mathematically, momentum=mass X velocity or, p=mv.

MOMENTUM

Angular Momentum

The moment of the linear momentum about a point or an axis is known as the angular momentum. It is defined as the vector product of the linear momentum & relative position vector.

ANGULAR MOMENTUM:

Angular momentum

For a particle:

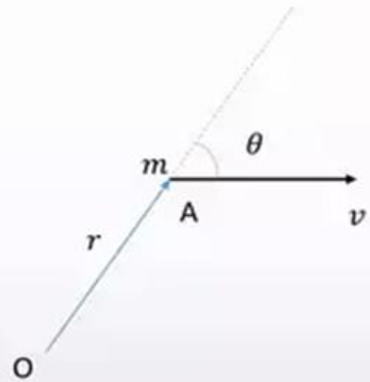
Angular momentum **about origin (O)** is given as:

$$\boxed{\vec{L} = \vec{r} \times \vec{p}} = \vec{r} \times (m\vec{v})$$

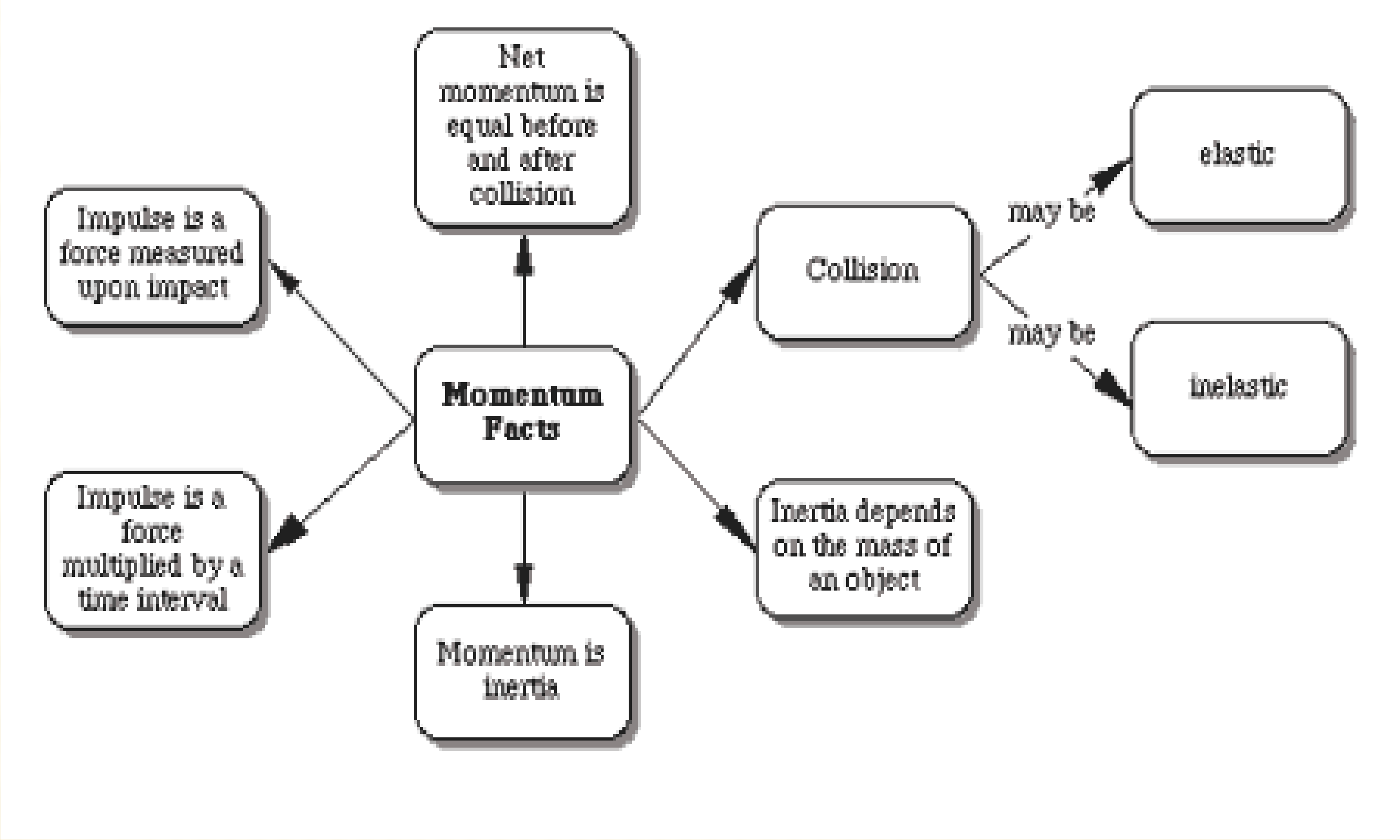
Here $\vec{r}$ is the position vector of the particle; $\vec{v}$ is the velocity vector

$$\Rightarrow \vec{L} = mvr\sin\theta = mv(OA)\sin\theta$$
$$= mvr_{\perp}$$

where $r_{\perp}$ is the perpendicular distance of velocity vector from O.



MOMENTUM


Net momentum is equal before and after collision
Impulse is a force measured upon impact
Momentum Facts
Collision
may be
elastic
may be
inelastic
Impulse is a force multiplied by a time interval
Momentum is inertia
Inertia depends on the mass of an object

- ***Principle of conservation of momentum:*** If no external forces act on a system of colliding objects, the total momentum of the objects in a given direction before collision is equal to the total momentum in the same direction after collision.
- ***Explanation:*** Let two particles of mass m1 and m2 move in the same direction in straight line with velocity u1 and u2 respectively as shown in fig-2. Here, u1 > u2. At one time the first particle hits the second particle from behind and then the two particles continue moving in the same direction and along the same line with velocities v1 and v2 respectively.

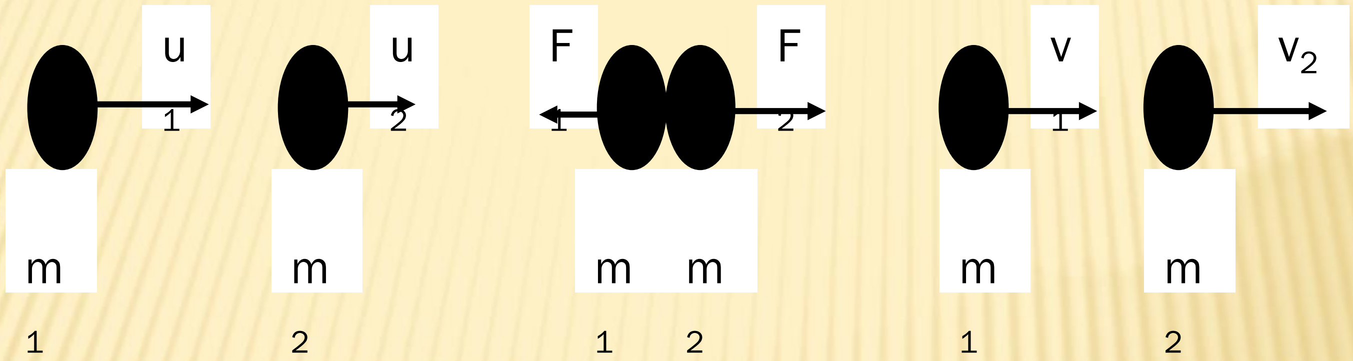


Fig-2 (a): Before collision Fig-2 (b): At the time of collision Fig-2 (c): After collision

Let the time of action and reaction due to collision be t, thus the total initial (before collision) momentum of the two particles= $m_1u_1+m_2u_2$ and the total final (after collision) momentum of the two particles= $m_1v_1+m_2v_2$.

According to the principle of conservation of momentum, it is to be proved that,

$m_1u_1+m_2u_2 = m_1v_1+m_2v_2$.

Proof: The rate of change of momentum of the first particle = $\frac{m_1v_1 - m_1u_1}{t}$ = reaction force of the 2^{nd} particle on the first particle $=F_1$.

The rate of change of momentum of the second particle = $\frac{m_2v_2 - m_2u_2}{t}$ = reaction force of the 1^{st} particle on the 2^{nd} particle $=F_2$.

From Newton's 3rd law, $F_2 = - F_1 \Rightarrow \dfrac{m_2v_2 - m_2u_2}{t} = - \dfrac{m_1v_1 - m_1u_1}{t}$

$$\Rightarrow m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \ldots\ldots\ldots\ldots = Constant \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

That is sum of the initial momentum of the two particles = sum of the final momentum of the particles.

i.e., $\sum mv = constant$. So, no change of total momentum takes place due to the action and reaction forces between two particles. In other words, the amount of momentum lost by one particle is exactly gained by the second particle i.e., momentum remain same before and after the collision. Hence, the conservation principle is proved.

If initially the 2nd body remains at rest, equation (1) becomes:

$$\Rightarrow m_1u_1 = m_1v_1 + m_2v_2 [\because u_2 = 0]$$

If two bodies maintain same velocity after collision, equation (1) gives:

$$\Rightarrow m_1u_1 = v(m_1 + m_2) [\because v_1 = v_2 = v]$$

Examples of principle of conservation of momentum:

1) Recoil of a gun   2) Jump from a boat.

PROBLEMS

- An inelastic collision occurs in one dimension, in which a 10 kg block traveling at 5 m/s collides with a 5 kg block traveling at 3 m/s in the same direction, and they stick together. What are the velocities of the blocks immediately after the collision? (Answer: 4.33 m/s)

- An 82-kg male and a 48-kg female pair figure skating team are gliding across the ice at 7.4 m/s, preparing for a throw jump maneuver. The male skater tosses the female skater forward with a speed of 8.6 m/s. Determine the speed of the male skater immediately after the throw. (Answer: 6.7 m/s)