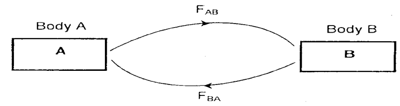
Conservation of Linear Momentum



The linear momentum which is the product of mass and velocity also remains constant if the total force acting on it is zero. Consider two particles A and B. We can call the group of these two particles as System of Particles. The force exerted by A on B and exerted by B on A are called Internal Forces. Force applied on A or B by any external particle is called External Forces.

Principle of Conservation of Momentum: "If the net external forces on a system of particles are zero, the linear momentum of the system remains constant."

The internal forces cannot change the linear momentum of the system. If the momentum of one particle is increased, that some other particle must decrease in order to keep the total momentum remains constant.

Principle of Conservation of Linear Momentum and Newton's Laws of Motion

Let us consider the interaction between two bodies A and B. of masses 'm_A and m_B' kept on smooth horizontal table, negligible friction. Suppose A is made to move with velocity 'u_A' and B is made to move with 'u_B' in the direction AB. Suppose, $u_A > u_B$. Linear Momentum of A = $m_A u_A$ and Linear momentum of B = $m_B u_B$.

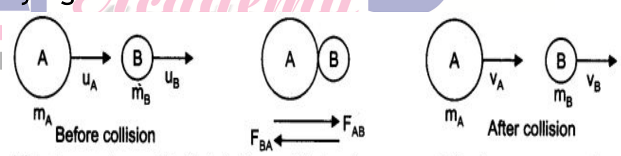
Total momentum of system = $m_A u_A + m_B u_B$ = P2

As $u_A > u_B$, A will collide with B and remain in contact for time "t". The velocities after collision of A will be 'v_A' and velocity of B will be 'v_B'.

During collision, A will push B rightwards and B will push A leftwards. By Newton's Third Law of Motion, magnitude of force on B by A is F_{AB} and force on A by B is $-F_{AB}$.

These forces are internal forces. Applying Newton's Second Law on 'A':

$a1 = -F_{AB} / m_A$ OR



$(v_A - u_A) / t = -F_{AB} / m_A$

$m_A v_A - m_A u_A = -F_{AB} \times t$ (1)

Applying Newton's Second Law on 'B' :

$a2 = F_{AB} / m_B$ OR $(v_B - u_B) / t = F_{AB} / m_B$

$m_B v_B - m_B u_B = F_{AB} \times t$ (2)

Adding equation 1 and 2:

$m_A v_A - m_A u_A + m_B v_B - m_B u_B = 0$ OR

$m_A v_A + m_B v_B = m_A u_A + m_B u_B$ OR

P2 = P1, where P2 is the linear momentum of system after collision.

Thus the linear momentum of the system remained constant.

Impact Force: The impact force is a force of very high magnitude acting for a short period of time. A high velocity collision is an example of an impact force. Usually when a collision occurs at low velocity, it dissipates a lot of energy through vibrations and deformation. But when the collision occurs at a very high speed, there is not much time for these vibrations or deformation to occur. So under a high impact force, materials break rather than deform. As you can see in a highway accident. So an impact force causes more damage than smaller force acting for a longer duration

When a hammer strikes a nail, the high velocity impact force tends to drive in the nail since there is no time for friction to act. Note that here the motion starts before the friction takes effect. To reduce the impulse of an impact force, we will have to extend the time of action of force.

Think and answer

1. Why do you bend your knees as you jump from a height?
2. Why does a boxer move away from a punch?
3. Why does a fielder pull back his hands while catching the ball?
4. Why do automobiles have a collapsible frame (crash zone)?

Impulse: It is termed as the total impact of force. This is equal to the change in momentum of the body. In other words, impulse is defined as the product of force and a small time in which the force acts.

SI unit of Impulse if N s (Newton Second)

Newton's second law of motion and equations of motion

Newton's second law applied for a constant force acting on a body of invariable mass is F = ma. Here, acceleration can be obtained from various kinematics equations, i.e

$$a = \frac{v - u}{t} \quad \text{(from definition of acceleration)}$$

$$a = \frac{2(S - ut)}{t^2} \quad \left(\text{from } S = ut + \frac{1}{2}at^2\right)$$

$$a = \frac{2(vt - S)}{t^2} \quad \left(\text{from } S = vt - \frac{1}{2}at^2\right)$$

$$a = \frac{v^2 - u^2}{2S} \quad (\text{from } 2aS = v^2 - u^2)$$

Now, we can substitute these values of 'a' in the second law to obtain various expressions for force:

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

$$F = \frac{2m(S - ut)}{t^2}$$

$$F = \frac{2m(vt - S)}{t^2}$$

$$F = \frac{m(v^2 - u^2)}{2S}$$

Exercise

Q1. A body having mass 250 kg starting from rest, uniformly accelerates to cover a distance of 50 m in 5 s Find the net force acting on the body.

Q2. A bus of mass 5000 kg is moving with a uniform speed when it is brought to rest by applying brakes. Before coming to rest, the bus covers a distance of 100 m in 10s. Calculate the average retarding force exerted by the brakes. (Assume that the braking force was uniform)

Q3. Accelerating uniformly on a scooter from an initial velocity of 35 km/hr, Rahul attains a velocity of 50 km/hr while covering a distance of 30 m. Calculate the average force exerted by the scooter's engine if Rahul's mass is 50 kg and the scooter's mass is 150 kg.

Q4. A car is moving with a uniform speed. It is brought to rest by applying an average retarding force of 5000 N. Before coming to rest, the car covers a distance of 150 m in 10 s, Calculate the mass of the car (Assume that the braking force was uniform)

Q5. The velocity of the bus of mass 6000 kg changes from 36 km/hr to 54 km/hr in 15 sec. Calculate the magnitude of the force exerted.

Q6. A constant retarding force of 200 N is applied to a body of mass 50 kg moving with a uniform velocity of 30 km/hr How much time will it take to stop the body?

Q7. The driver of a train moving with a velocity of 60 km/hr sees another train standing on the same track and applies the brakes. The train comes to rest in 20 s, just in time, to avoid the collision. What was the average retarding force of the train if the mass of the train is 15 metric tonnes?

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