Laws of Motion

Force - It is a push or a pull which changes or tends to change the shape, size, position & direction of an object.

Inertia

The inability of a body to change its state of rest or motion by itself is called inertia

Newton's 1st law of motion

"A body continues to be in its state of rest or motion unless an external force is applied to change its state."

Types of inertia

(I) **Inertia of rest**

(a) When a bus starts suddenly, the passengers fall forward.

Reason: When the bus is at rest, the whole body of the passenger is at rest. But when the bus starts suddenly, the lower part of the body of the passenger comes into motion while the upper part remains at rest due to inertia. Hence the passenger fall forward.

(b) The dust particles from a matt fall off when it is beaten with a stick

Reason: Due to beating the matt comes into motion while the dust particles remain at rest due to iner

(c) When we shake the branch of a tree, the fruit fall down.

Reason : Due to shaking, the branch comes into motion while the fruit remains at rest due to inertia & hence fell down.

(II) Inertia of motion

(a) When a bus stops suddenly, the passengers fall forward.

Reason : When the bus is in motion, the whole body of the passenger is also in motion. When the bus stops suddenly, the lower body of the passenger comes to rest while the upper body continues to be in motion due to inertia & hence it falls forward.

(b) An athelete runs a certain distance before taking a long jump.

Reason : Velocity acquired by running is added to the velocity of the athelete at the time of jump. & so he can jump over a longer distance.

(III) Inertia of direction

(a) When a stone tied to one end of a string is whirled & the string suddenly breaks, the stone flies off along the tangent to the circle.

Reason : The pull in the string forces the stone to move in a circle, but as soon as the string breaks, the pull vanishes. The stone in a bid to move along the straight line flies off tangentially.

(b) When a car rounds a curve suddenly, the person sitting inside is thrown outwards.

Reason: Because the person tries to maintain his direction of motion due to directional inertia while the car turns.

(c) Mud guards are used over the wheels to protect the clothes of the driver of the bike.

Reason: The rotating wheels of any vehicle throws out mud tangentially due to directional inertia so mud guards are used.

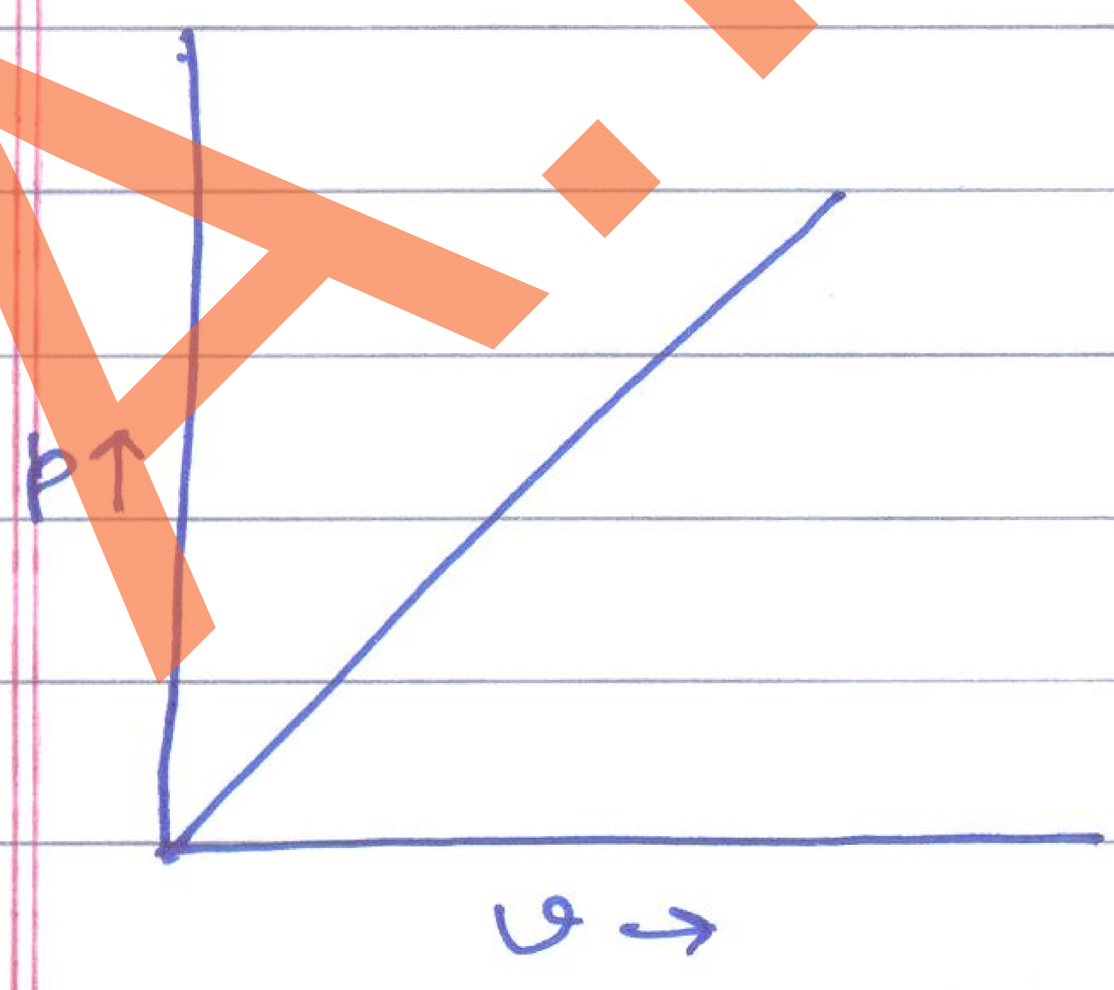
<u>Linear momentum</u> (p)

It is the quantity of motion contained in a body & is equal to the product of mass & velocity of the body

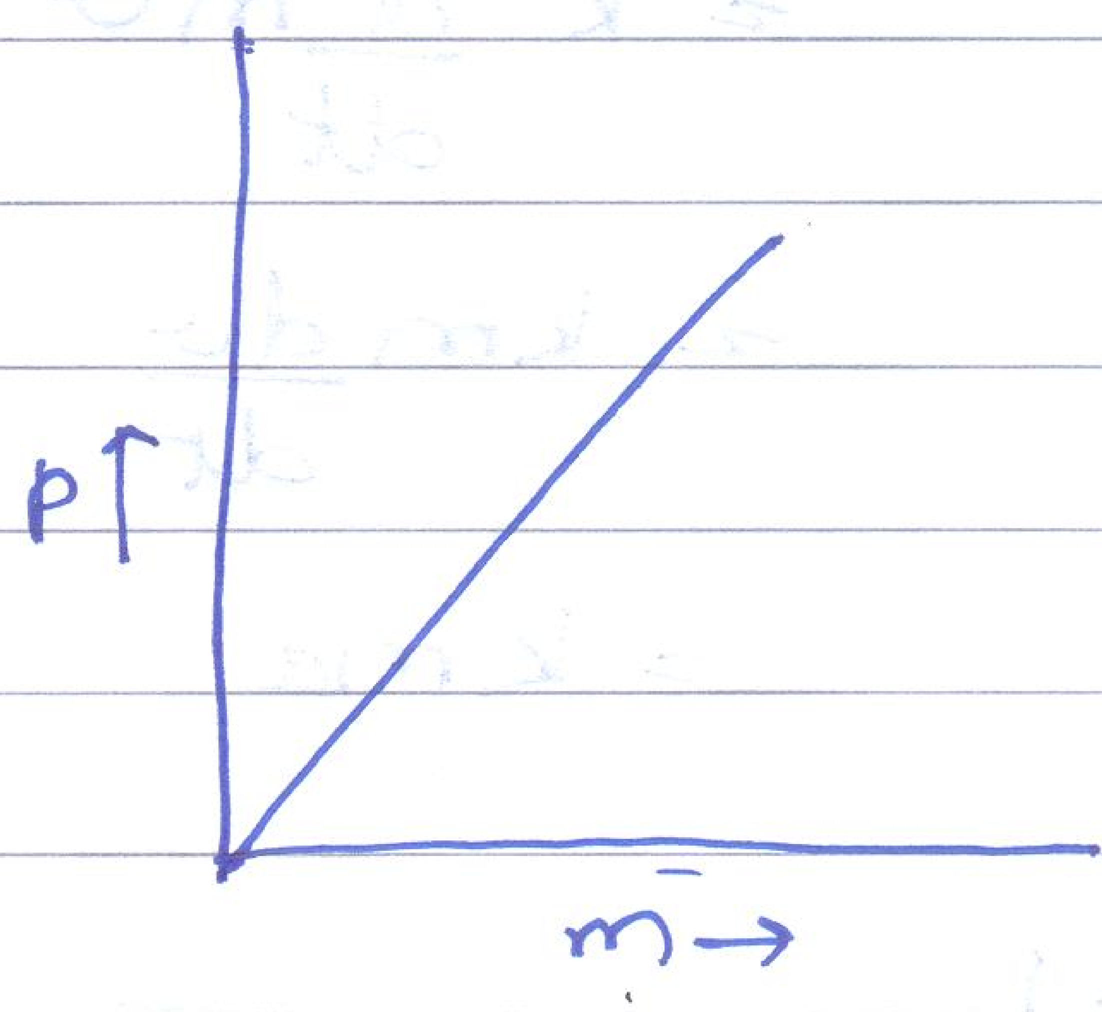
$$\vec{p} = m\vec{v}$$

S.I. unit - $kg\,ms^{-1}$

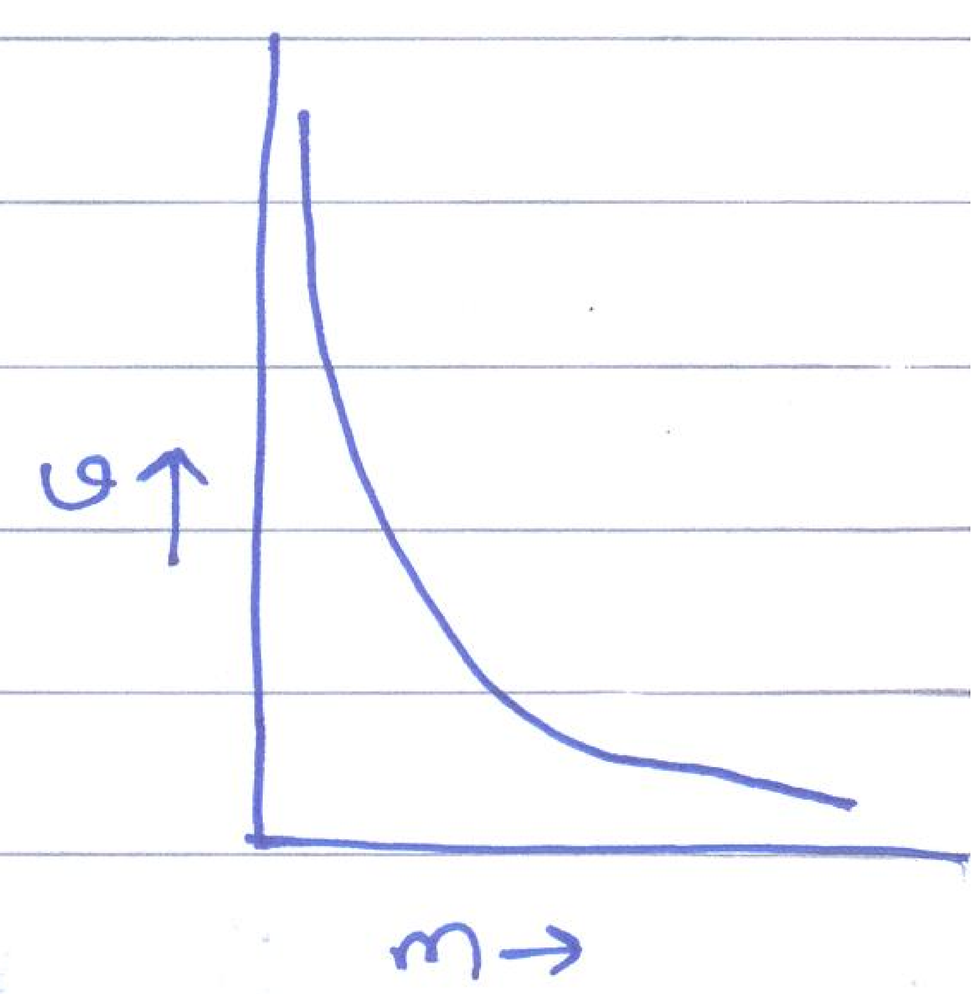
D.F. - $[MLT^{-1}]$



m - const.



v - const.



p - const.

Newton's 2nd law of motion

"The rate of change of momentum of a body is directly proportional to the force applied & the change takes place in the direction of applied force."

Consider a body of mass 'm' moving with a velocity $\vec{v}$.
So, momentum of the body is

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

Let an external force $\vec{F}$ is applied on the body for a short time 't'.

Acc. to Newton's 2nd law

$$F \propto \frac{dp}{dt}$$

$$F = k\frac{dp}{dt}$$

$$= k\frac{d\,mv}{dt}$$

$$= km\frac{dv}{dt}$$

$$= kma$$

if $k = 1$

$$\boxed{\vec{F} = m\vec{a}}$$

Dimensional formula - MLT^{-2}

Units of force

(a) Absolute units

S.I. → N (newton) , $1N = 1kg \times 1ms^{-2}$

c.g.s → dyne , $1\ dyne = 1g \times 1cms^{-2}$

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

(b) Gravitational units

S.I. → kg.wt or kg.f , $1kgf = 1kg \times 9.8ms^{-2} = 9.8N$

c.g.s → g.wt or gf , $1gf = 1g \times 980\ cms^{-2} = 980\ dyne$

Impulse ($\vec{I}$)

It is a measure of total effect of force & is equal to the product of average force & the time for which the force acts on the body.

$$\boxed{\vec{I} = F_{av} \times t}$$

D.F - $[MLT^{-1}]$

unit - $kgms^{-1}$ (SI) , $g\ cms^{-1}$ (c.g.s)
(Ns) (dyne-sec)

Relation betn $\vec{I}$ & $\vec{P}$

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

$$\vec{F}.dt = d\vec{p}$$

Integrating both sides

$$\int_0^t \vec{F}.dt = \int_{P_1}^{P_2} d\vec{p}$$

If $\vec{F}_{av}$ is the constant force during the time, then

$$\vec{F}_{av}\,[t]_0^t = [p]_{p_1}^{p_2}$$

$$\vec{F}_{av} \times t = \vec{p}_2 - \vec{p}_1$$

$$\boxed{\vec{I} = \vec{F}_{av} \times t = \vec{p}_2 - \vec{p}_1}$$

* Vector quantity
* Impulse of a variable force is equal to area enclosed in F – t graph.

Applications of impulse

1. A cricket player lowers his hand while catching a cricket ball.

Reason: By doing so, the player increases the time for the momentum to be reduced to zero. Due to this less force acts on the hands of the player.

2. An athlete is advised to come to stop slowly after finishing a fast race.

Reason: Time of stop increases & hence force experienced by athlete decreases.

3. Vehicles are provided with shockers.

Reason: Shockers increases the time of impact so that less force is experienced by the rider.

4. Bogies of a train are provided with buffers.

Reason: Buffers increases the time of impact so force during jerks decreases & so chances of damage decreases.

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Newton's 3rd law of motion

"To every action, there is equal & opposite reaction. Action & reaction act on different bodies."

Examples :

(a) Walking

- A person presses the ground in the backward direction (action) by his feet.
- The ground pushes the person in the forward direction (reaction) with an equal force.
- The component of reaction in the horizontal direction makes the person move forward.

(b) Swimming

- A swimmer pushes the water backwards, in turn, the water pushes the swimmer with the same force.

(c) Driving a nail into a wooden block without holding the block is difficult.

Reason: When the wooden block is not resting against a support, the block & nail, both move forward on being hit with a hammer as no reaction takes place since there is no fixed rigid support to generate reaction.

(d) Rebounding of a rubber ball

When the ball is struck against the floor, it exerts a force on the ~~wall~~ floor. The ball rebounds with an equal force exerted by the floor on the ball.

Apparent weight of a man in a lift

Suppose a person of mass 'm' is standing on a weighing machine placed in a lift.

Actual weight of the person = mg

This weight acts on the weighing machine which offers a reaction 'R' (given by reading of weighing machine)

(a) **When the lift is at rest**

$$a = 0$$

Net force on the person, $f = 0$

So, $R - mg = 0$

$$\boxed{R = mg}$$

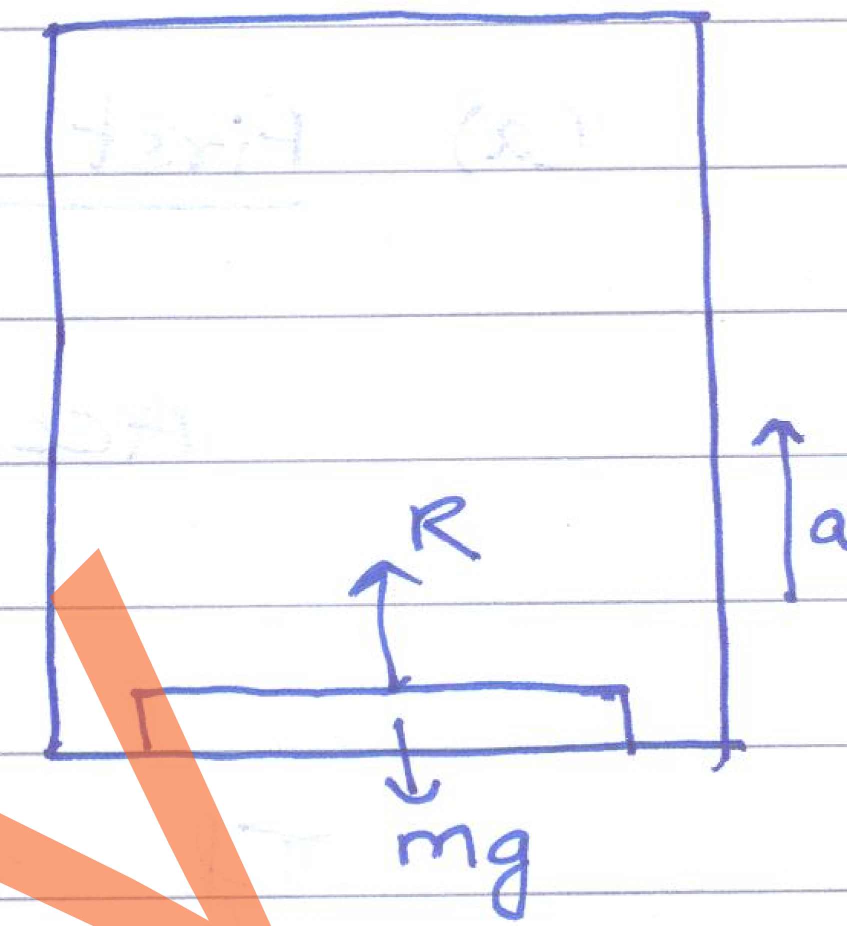
apparent weight = actual weight

(b) **When the lift is moving uniformly in upward or downward direction**

$$a = 0$$
$$f = 0$$
$$R - mg = 0$$
$$\boxed{R = mg}$$

apparent weight = actual weight

(c) When the lift is accelerating upwards with acc. 'a'



Net upward force, $f = ma$
on the person

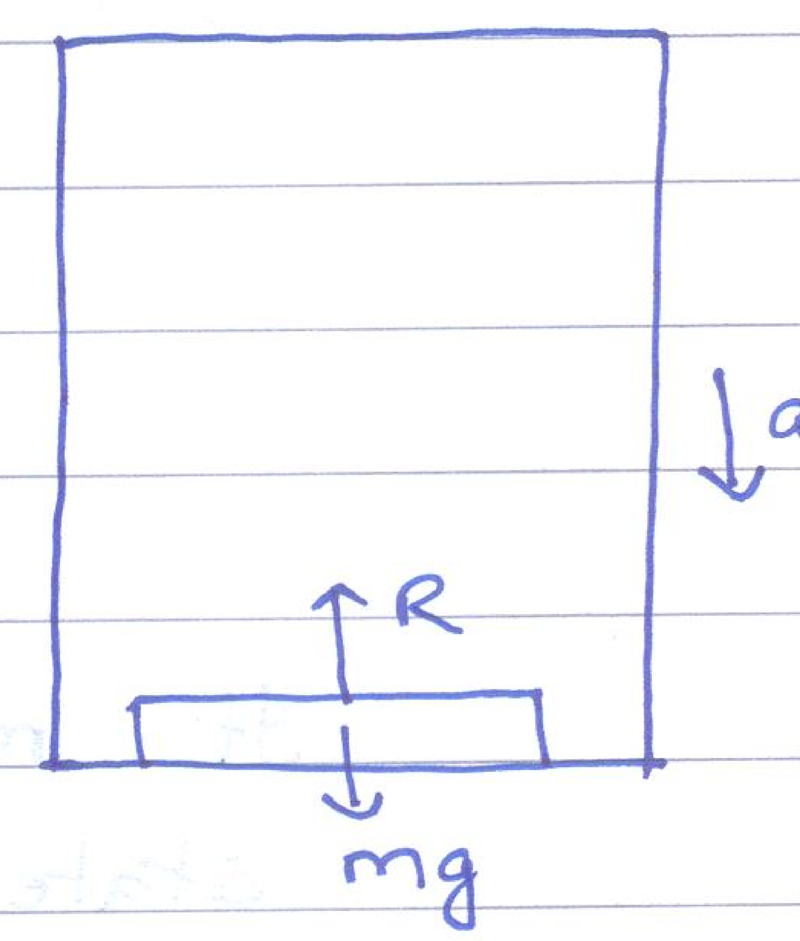
$\therefore R - mg = f$

$R = ma + mg$

$$\boxed{R = m(g+a)}$$

apparent weight > actual weight

(d) When the lift is accelerating downwards with acc 'a'



Net downward force, $f = ma$
on the person

$\therefore mg - R = ma$

$R = mg - ma$

$$\boxed{R = m(g-a)}$$

apparent weight < actual weight

(e) During free fall under gravity $(a = g)$

$$\boxed{R = m(g-g) = 0}$$

apparent weight = 0
Body becomes weightless.

(f) When downward acceleration is greater than g $(a > g)$

$$\boxed{R = m(g-a) = -ve}$$

apparent weight = −ve

Person will rise from the floor & stick to ceiling of lift.

Second law is the real law

(a) **First law is contained in second law**

Acc. to Newton's 2^{nd} law

$$F = ma$$

If no external force is acting on the body

$$F = 0$$

$$ma = 0$$

$m \neq 0$ so $a = 0$

$$\frac{v-u}{t} = 0$$

$$v - u = 0$$

$$\boxed{v = u}$$

It means that the body will remain in its state of rest ($u=0, v=0$) or uniform motion ($u=v$) when no external force is acting on it & this is first law.

(b) **Third law is contained in second law**

Consider an isolated system of 2 bodies A & B which exert force on each other.

Let p_1 – momentum of body A

p_2 – " " " B

F_{AB} – force exerted by A on B

F_{BA} – " " " B " A

Force applied by A on B will result in its change in momentum so,

$$F_{AB} = \frac{dp_2}{dt}$$

Similarly, $F_{BA} = \frac{dp_1}{dt}$

$$F_{AB} + F_{BA} = \frac{dp_2}{dt} + \frac{dp_1}{dt}$$

$$= \frac{d}{dt}(p_1 + p_2)$$

As no external force acts on the system so the momentum remains constant so

$$\frac{d}{dt}(p_1 + p_2) = 0$$

$$\therefore \boxed{F_{AB} = -F_{BA}}$$

It means action is equal & opposite to reaction & this is the third law.

Law of conservation of linear momentum

If no external force acts on a system, the total linear momentum of the system is conserved & is not affected due to mutual action & reaction of the bodies.

Consider an isolated system consisting of 2 bodies A & B. Let the 2 bodies collide for a small time 'Δt' & separate.

Let $\vec{p}_A$ - initial momentum of A before collision
$\vec{p}_B$ - ~~final~~ " " B " "
$\vec{p}_A'$ - final " " A after "
$\vec{p}_B'$ - " " " B " "

$\vec{F}_{AB}$ - force exerted by A on B
$\vec{F}_{BA}$ - " " " B on A

Acc. to Newton's 2nd law

$$\vec{F}_{AB} \times \Delta t = \text{change in linear momentum of B}$$
$$= \vec{p}_B' - \vec{p}_B$$

& $$\vec{F}_{BA} \times \Delta t = \text{change in linear momentum of A}$$
$$= \vec{p}_A' - \vec{p}_A$$

Acc. to Newton's 3rd law

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

$$\vec{p}_B' - \vec{p}_B = -(\vec{p}_A' - \vec{p}_A)$$

$$\boxed{\vec{p}_A' + \vec{p}_B' = \vec{p}_A + \vec{p}_B}$$

Total final linear momentum = Total initial linear momentum

Practical applications

① Recoiling of gun

Let m_1 - mass of the bullet
m_2 - " " " gun
v_1 - velocity " " bullet
v_2 - " " " gun

Before firing,
initial momentum of bullet = 0
" " " gun = 0

Total initial momentum = 0

After firing
final momentum of bullet = $m_1 v_1$
" " " gun = $m_2 v_2$

Total final momentum = $m_1 v_1 + m_2 v_2$

Acc. to law of conservation of linear momentum
Total initial momentum = Total final momentum

$$0 = m_1 v_1 + m_2 v_2$$

$$v_2 = -\frac{m_1 v_1}{m_2}$$

Negative sign shows direction of v_2 is opposite to the direction of v_1 i.e. gun recoils.

(2) Explosion of bomb

- When a bomb falls vertically downwards, its horizontal velocity is zero
- When bomb explodes, its pieces are scattered horizonta[lly] in directions so that vector sum of momenta of these pieces becomes zero acc. to law of conservation of linear momentum.

(3) When a man jumps out of a boat to shore, the boat is pushed slightly away from shore.

Reason: Momentum of boat = −(momentum of man) [explain yoursel[f]