CLASS IX

FORCE & LAWS OF MOTION

Force is defined as push or pull applied on a body which can change the state of rest or motion or direction of motion of body.

EFFECTS of FORCE

① To set a stationary body into motion.

② To stop the moving bodies.

③ To change speed or direction of a moving body.

④ To change shape and size of the bodies.

* Force is a vector quantity.
* SI unit of force is Newton (N).

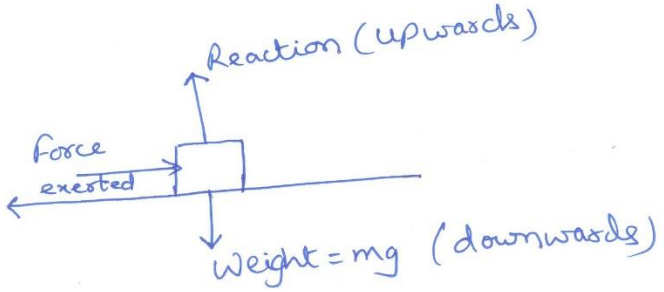
BALANCED FORCE

When resultant of forces acting simultaneously on an object is zero.

eg: In tug of war, when both teams exert same force from both sides.

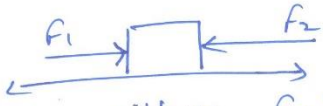
Balanced force cannot bring any change in motion or direction except change in shape and size is possible.

eg: Frictional force which always act in opposite direction to that of motion and opposes motion.



UNBALANCED FORCE -

when resultant of a number of forces acting simultaneously on an object is non-zero.



either, $F_1 > F_2$ or $F_2 > F_1$

Unbalanced forces can change the state of rest, state of uniform motion, direction of body.

NEWTON'S FIRST LAW OF MOTION

A body continues to remain in state of rest or of uniform motion until or unless an external unbalanced force acts on it.

INERTIA - property of a body to oppose any change in its state of rest.

I^st Law is also called as LAW OF INERTIA.

* Mass is a measure of inertia of the body.

eg: Greater mass of a body means more is the inertia possessed by it.

INERTIA

- Inertia of Rest
  - ↓
  - Tendency of a body to resist change in its state of rest.
- Inertia of Motion
  - ↓
  - Tendency of a body to resist any change in its state of motion
- Inertia of direction
  - ↓
  - Tendency of a body to resist any change in its ~~state~~ direction of motion

Give Reasons why -

① It is dangerous to kick a heavy stone like a football.

② when a vehicle suddenly starts moving, the passengers fall backwards.

③ Ripe fruits fall down from tree if trunk is vigorously shaken.

④ A vertical pile of carrom coins is struck by a striker on board, only lower most coin slides off the pile due to force exerted by the striker.

⑤ when a moving bus stops suddenly, the passengers fall forward

⑥ Oil or water tank vehicles always have empty space in the tank.

⑦ It is dangerous to jump out of a moving bus and person is likely to fall down.

⑧ when a moving vehicle takes a steep turn, the passengers tends to fall outwards.

(9) The player in a discuss throw game whirls the ball along a circular path and then releases it.

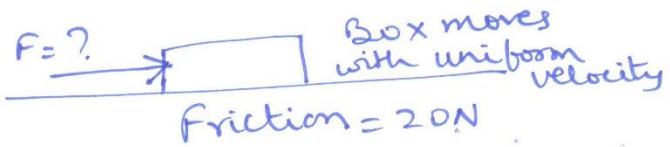
(10) Before taking a long jump, a boy runs a certain distance.

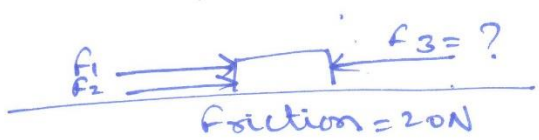
(11) While getting down off a moving bus, we must run in the same direction.

Questions -

(1) How does inertia depends on mass of the body?

(2) If force in the cases given below is balanced, find magnitude and direction of each force -

(a) 

(b) 

$F_1 = 20N$
$F_2 = 30N$

(3) Why does a rolling foot ball come to rest after sometime?

LINEAR MOMENTUM -

↳ The product of mass and velocity

$$p = m \times v$$

* More the mass of moving body, more is force possessed by it.
* more the velocity of moving body more is force possessed by it.

* Momentum is a vector quantity.
* SI unit of momentum =

$$\vec{p} = 1 \text{ kg m/s}$$

$$\text{or} = 1 \text{ Ns}$$

Momentum always changes the direction of applied force.

NEWTON'S SECOND LAW OF MOTION

The force applied on a body is directly proportional to rate of change of momentum applied.

DERIVATION of SECOND LAW

According to the law,

$$\text{Force} \propto \frac{\text{change in momentum}}{\text{time taken}}$$

Proof - Initial momentum of body $= P_i = mu$

Final momentum of body $= P_f = mv$

where, u = initial velocity, v = final velocity

m = mass of body.

$$\text{Change in momentum} = P_f - P_i$$
$$= mv - mu$$
$$= m(v-u)$$

Sub $\Rightarrow$

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

We Know, $v = u + at$ [From Ist eqn. of motion]

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

$$F \propto m \times a$$

$$F = \boxed{K}\, m \times a$$

↳ Constant of Proportionality

But $K = 1$, hence

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

SI unit of force is Newton,

$$1\,N = 1\,Kg \times 1\,m/s^2$$
$$= 1\,Kg\,m/s^2$$

NOTE - IInd law is Considered as Universal law since all the laws can be derived from these.

If a body is stationary or moves with constant uniform velocity then, acc. is zero.

$$F = m \times a$$
$$F = m \times 0$$
$$F = 0$$

Thus, no force is exerted on body. which means that a body will remain in state of rest or in uniform motion unless ~~and~~ any external unbalanced force acts on it [Ist Law].

Special Case -

1. When large amount of force is exerted its momentum changes at a faster pace.
2. Force applied for short duration,

$$F \times t = \text{Impulse}$$

Impulse = change in momentum

SI unit $\Rightarrow$ 1 Ns or Kg m/s

Give Reason – (5)

① A cricket player while taking a catch always moves his hands backwards.

② One gets seriously hurt while jumping from roof of a building, but does not get hurt, if he jumps on sand or foam.

③ Seat belts and shockers are provided in cars to reduce impact of large momentum change on passengers and vehicles respectively.

* Slope of v-t graph is positive if ~~slope~~ acc. is positive
* slope is negative for retarded motion
* During retarded motion, force always acts in opposite direction.

NUMERICALS -

(1) Both mass and velocity are doubled. What is ratio between its initial and final momentum?

(2) For how much time should a force of 400N be exerted on a body of mass 8kg to increase its velocity from 150m/s to 300m/s.

(3) The Force of attraction between two bodies is 20N. Calculate the force between them when mass of each body as well as distance between them are halved.

(4) A cricket ball of mass 70g moving with a velocity of 0.5 m/s is stopped by a player in 0.5 sec. What is the force applied by the player to stop the ball?

(5) A car travelling at velocity 54km/h stops in 6 sec after brakes are applied. How much force do the brakes apply to the car if its mass along with its driver is 800Kg?

⑥ A force of 5N produces an acc. of $8\ m/s^2$ on a mass m_1, and an acc. of $24\ m/s^2$ on a mass m_2. What acc. would the same force provide if both masses are tied together?

⑦ A car of mass 800kg, moving at 54km/h is brought to rest over a distance of 15m. Find the retarding force developed by the brakes of the car.

⑧ A car of mass 1000kg develops a force of 500N over a distance of 49m. If initially car is at rest. Find

(i) Final velocity

(ii) Time for which it accelerates.

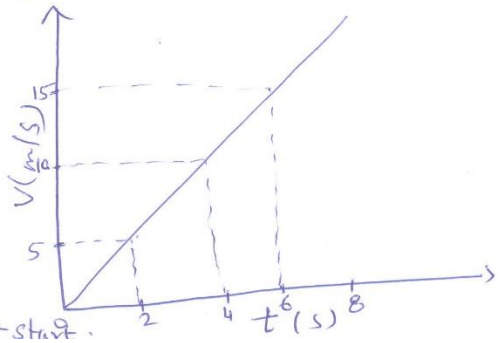
⑨ The motion of a body of mass 5kg is shown in the figure.

Find

ⓐ its acceleration

ⓑ the force acting on the body

ⓒ change in momentum of body 2sec after the start.



Numericals for Practice

(1) A ball at rest, is hit by a stick, such that the force acts on the ball for 0.08 sec. If the ball is of mass 100g and covers a distance of 80m in 1.6 sec, find the magnitude of force.

→ Distance = 80 m

Uniform velocity = $\frac{\text{Dis}}{\text{Time}} = \frac{80\text{m}}{1.6\text{ sec}} = 50\text{m/s}$

∴ Final velocity after the force stops acting on it = 50 m/s

Initial velocity of ball = 0

Time for which the force acts = 0.08 sec

$$V = u + at$$

$$50\text{ m/s} = 0 + a \times 0.08\text{ sec}$$

$$a = \frac{50}{0.08} = 625\text{ m/s}^2$$

Force acting on ball, $F = m \cdot a$

$$= \frac{1000}{1000} \times 625$$

$$= 62.5\text{ N}$$

② A cyclist along with the machine weighs 160 kg. while driving at 72 km/h he stops his machine over a distance of 8 m. Find the ~~resisting~~ retarding force of the brakes.

$$u = 72 \text{ km/h}$$
$$= 72 \times \frac{5}{18} = 20 \text{ m/s}$$

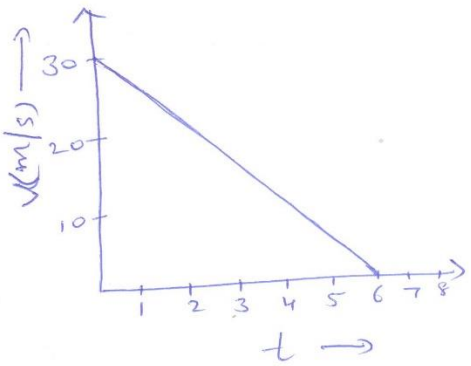
$$v = 0 \text{ m/s}$$
$$s = 8 \text{ m}$$

$$v^2 - u^2 = 2as$$
$$0^2 - (20)^2 = 2 \times a \times 8$$
$$-400 = 16a$$
$$a = -\frac{400}{16} = -25 \text{ m/s}^2$$

Retardation $= 25 \text{ m/s}^2$

Retarding force = Mass × Retardation
$= 160 \times 25$
$= 4000 \text{ N}$

③ The velocity – Time graph of a ball moving on the surface of a floor is shown in the figure. Find the force acting on the ball if its mass is 50g.



→ Mass of ball = 50g
= 0.05kg

Acceleration = slope of velocity - time graph

$$= \frac{V_{(at\ t=6s)} - V_{(at\ t=0s)}}{6}$$

$$= \frac{0 - 30}{6} = -5\ m/s^2$$

Thus, ball is retarded and force acts in opposite direction to that of the motion.
The ball experiences retarding force.
From Newton's Second law,

$$F = ma$$
$$= 0.05\ kg \times (-5\ m/s^2)$$
$$= -0.25\ N$$

NEWTON'S THIRD LAW OF MOTION

Every action has an equal and opposite reaction.

eg: (1) when we walk, we push the ground backwards with our foot. This is action force exerted by us on ground. And ground exerts an opposite reaction force on us and pushes us forward.

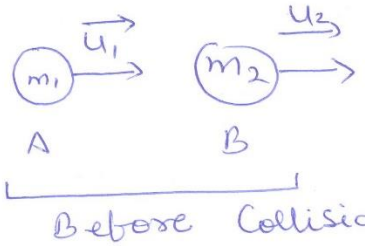
(2) A Swimmer pushes water backwards while the reaction force of water pushes the swimmer forward.

(3) Recoil of gun occurs due to reaction force of bullet exerted on gun. The gun exerts action force on the bullet to fire it.

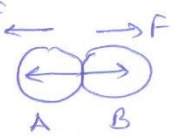
(4) when rocket is propelled, huge quantities of gases are expelled out in downward direction. Reaction force exerted by these gases on the rocket in opposite direction pushes it upwards in Space.

LAW OF CONSERVATION OF MOMENTUM

It states that total momentum of a system of particles remains constant.



Before Collision



During Collision

After Collision

Initial momentum of m_1 = $P_1 = m_1 u_1$

" " of $m_2 = P_2 = m_2 u_2$

Total initial momentum = $P_1 + P_2$

$= m_1 u_1 + m_2 u_2$

On Collision, both balls exert equal and opposite force on each other and further more ~~them~~ with velocities v_1 and v_2 after collision.

After Collision,

Final momentum of $m_1 = P_1' = m_1 v_1$

Final momentum of $m_2 = P_2' = m_2 v_2$

Total final momentum $= P_1' + P_2'$

$= m_1 v_1 + m_2 v_2$

Total initial momentum = Total final momentum

$P_1 + P_2 = P_1' + P_2'$

$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

When 2 bodies collide they exert equal and opposite forces on each other

Acc. to Newton's IIIrd Law,

Force on m_2 due to $m_1 = F_{12} =$ $\frac{\text{change in mom of } m_2}{\text{Time of collision}}$

$$F_{12} = \frac{m_2 v_2 - m_2 u_2}{t}$$

Similarly, Force on m_1 due to $m_2 =$ $\frac{\text{change in mom of } m_1}{\text{Time of collision}}$

$$f_{21} = \frac{m_1 v_1 - m_1 u_1}{t}$$

From, IIIrd Law,

$$F_{12} = -F_{21}$$

$$\frac{m_2v_2 - m_2u_2}{t} = \frac{m_1v_1 - m_1u_1}{t}$$

$$m_2v_2 - m_2u_2 = m_1v_1 - m_1u_1$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Total initial momentum = Total final momentum

eg: Recoil of gun,

When no bullet is fired, both gun and bullet are at rest.

Before firing, total momentum = 0

Once, bullet is fired it moves forward with velocity 'v'. The gun recoils with velocity 'V' in opposite direction

If mass of gun = M

mass of bullet = m

Total final momentum = $mv + (-MV)$

$= 0$

[$\because$ Initial momentum = 0]

Recoil velocity, $\boxed{V = \frac{mv}{M}}$

v & V are in opposite direction.

$\therefore M \gg m$, the recoil velocity of gun is very small compared to velocity of bullet.

NUMERICALS -

(1) $mass_1 = 2kg$, $m_2 = 5kg$

$u_1 = 10 m/s$, $u_2 = 0 m/s$ (at rest)

$v_1 = 1 m/s$, $v_2 = ?$

Acc. to Law of conservation of momentum,

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$v_2 = \frac{m_1 u_1 + m_2 u_2 - m_1 v_1}{m_2}$$

$$= \frac{2(10) + 5(0) - 2(1)}{5}$$

$$= \frac{20 - 2}{5} = \frac{18}{5} = 3.6 m/s$$

= velocity of second body after collision.

(2) $m_1 = 20g = 0.02 kg$
(mass of bullet)

Mass of pistol, $m_2 = 2kg$

Initial velocity $\Rightarrow$ $u_1 = u_2 = 0$ (as both bullet & pistol are at rest)

Final velocity $\Rightarrow$ $v_1 = 150 m/s$

$v_2 = ?$

Recoil velocity, $V_2 = -\frac{m_1 v_1}{m_2}$

$= -\frac{0.02 \times 150}{2}$

$= -1.5$ m/s

(3) A bullet of mass 20g moves with velocity 200 m/s and gets embedded in a wooden plank of mass 980 g. With what velocity does the plank move?

→ Mass of bullet, $m_1 = 20g = 0.02$ Kg

Mass of plank, $m_2 = 980g = 0.98$ Kg

Initial velocity, $u_1 = 200$ m/s

$u_2 = 0$ (as plank is stationary)

Final velocity are same since both Plank & bullet move in combination

Velocity of combined mass,

$V = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$

$= \frac{(0.02 \times 200) + (0.98 \times 0)}{0.02 + 0.98}$

$= 4$ m/s

QUESTIONS

① Two identical bullets are fired one by a light rifle and another by a heavy rifle with same force. Which rifle will hurt shoulder more and why?

Ans - The one with less weight will have more acceleration and hence, it will recoil more and hence, will hurt the shoulder of shooter more.

② A truck of mass M is moved under a force F. If the truck is then loaded with an object equal to mass of truck, and driving force is halved, then how does the acceleration change?

→ Initial force = F, mass of truck = M

Total mass = 2M

Force, $F = F/2$

Initial acc. $a_1 = F/M$

Final acc. $a_2 = \frac{F/2}{2M} = \frac{F}{4M} = \frac{1}{4} a_1$

acc. becomes one fourth of its initial value.

(3) what is the momentum of a car of mass 700kg parked on roadside?

(4) How much force is required to produce an acceleration of $2.5 m/s^2$ in a body of 4kg?

(5) Glasswares are wrapped in newspapers and straw when transported. Why?

(6) A revolver of mass 500g, fires a bullet of mass 10g with a speed of 100 m/s. Find:

(i) Momentum of the bullet

(ii) Initial momentum of revolver and bullet as a system.

(iii) Recoil velocity of the revolver.

(7) when we jump out of boat, it moves backwards. Why?