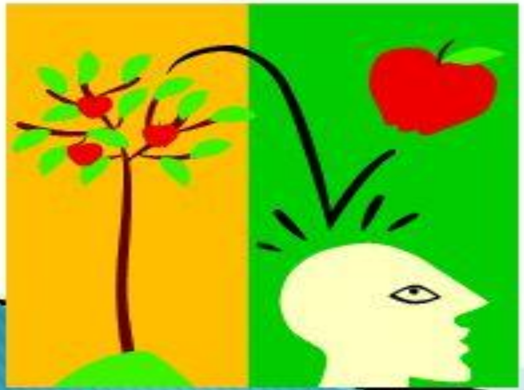
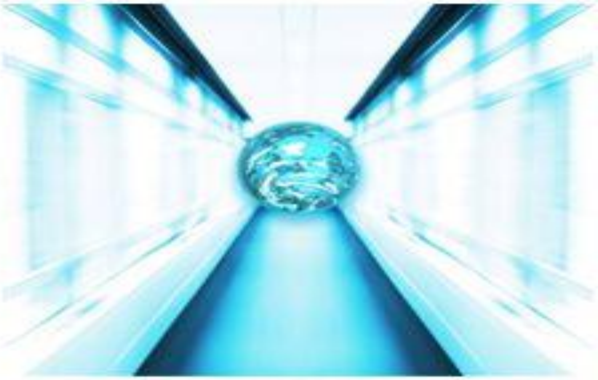



Forces and the Laws of Motion





Topics in the Chapter :-

- Introduction
- Effect of Force
- Balanced Force
- Unbalanced Force
- Laws of Motion
- Newton's Laws of motion
  - → First law of Motion
- Mass and Inertia
- Momentum
  - → Momentum and Mass
  - → Numerical based on momentum
- Second Law of Motion
  - → Proof of Newton's First law of motion from Second Law
- Third law of Motion
  - → Law of conservation of Momentum

Force :-

- It is the force that enables us to do any work. To do anything, either we pull or push the object.
- **Therefore, pull or push is called force.**

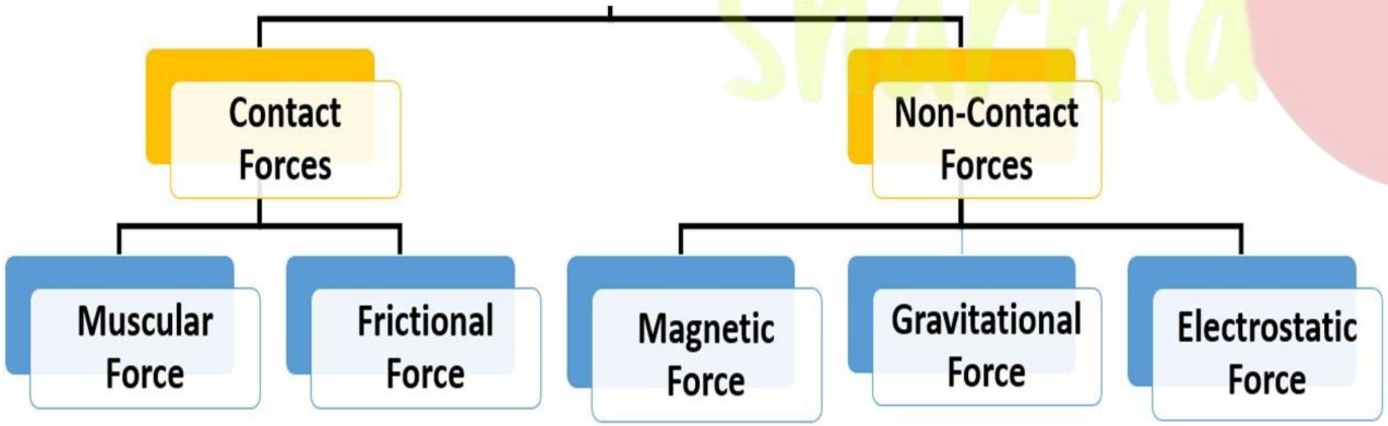
Example:- to open a door, either we push or pull it. A drawer is pulled to open and pushed to close.

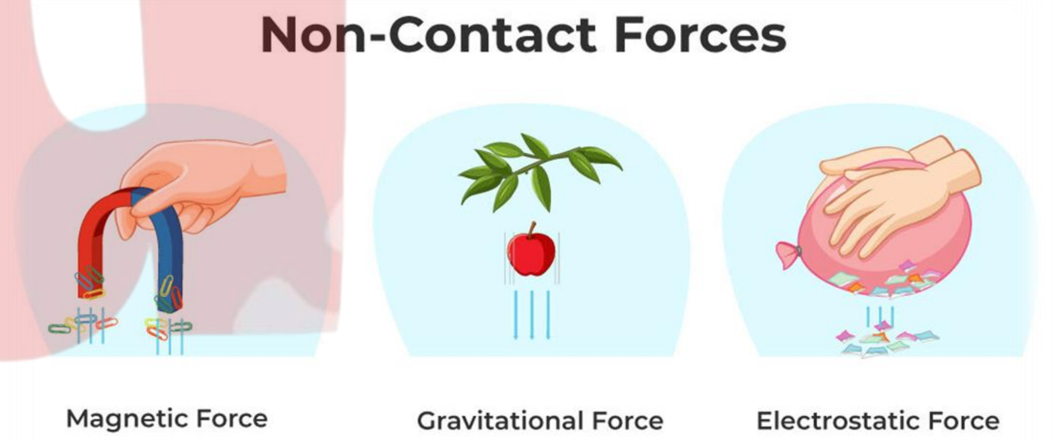
Unit of force:-

- S.I. unit of forces ;- **newton** denoted by "N"
- CGS unit of force :- **dyne**

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

Types of Forces





Effect of forces

- Force can move a stationary object.

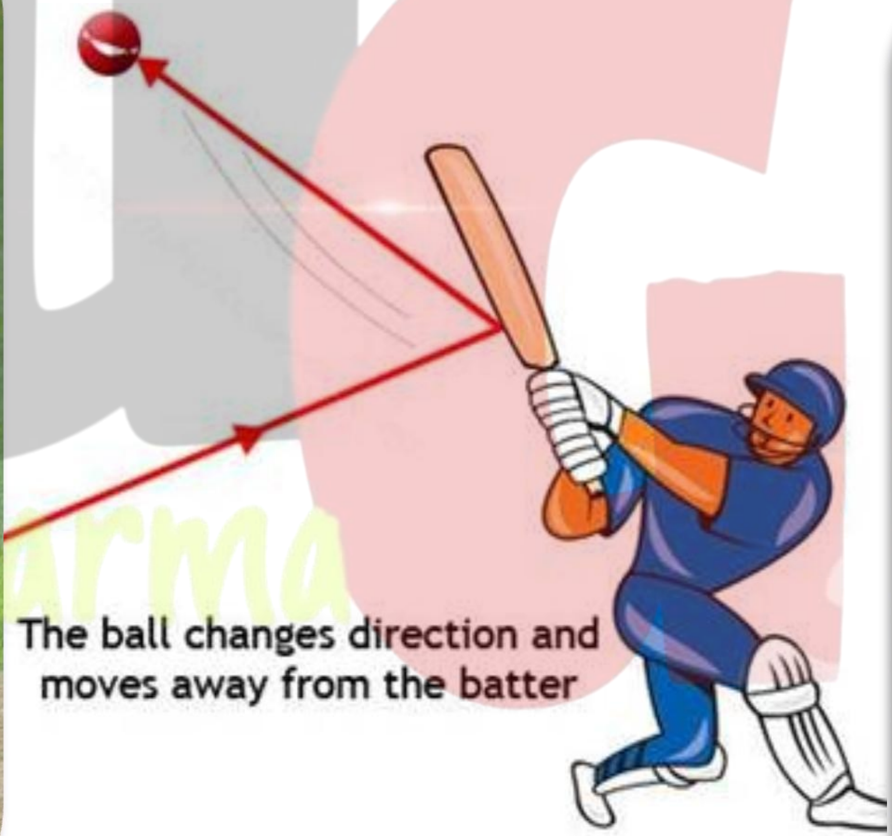
For example: a football can be set to move by kicking it i.e. by applying a force.

- Force can stop a moving body.

For example, by applying brakes, a running cycle or a running vehicle can be stopped.

- Force can change the direction of a moving object.

For example: by applying force on cricket ball by bat its direction changes



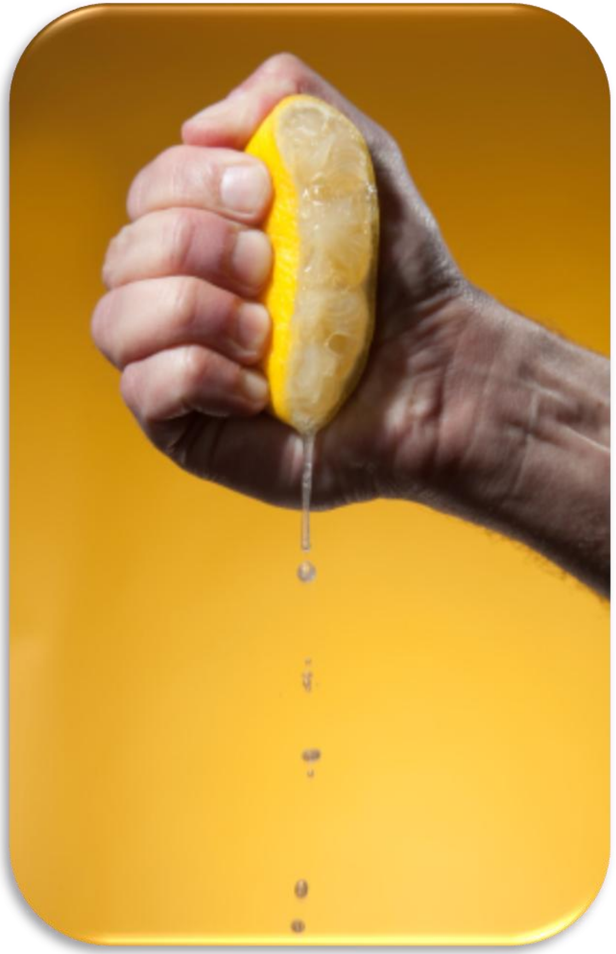
- Force can change the speed of a moving body.

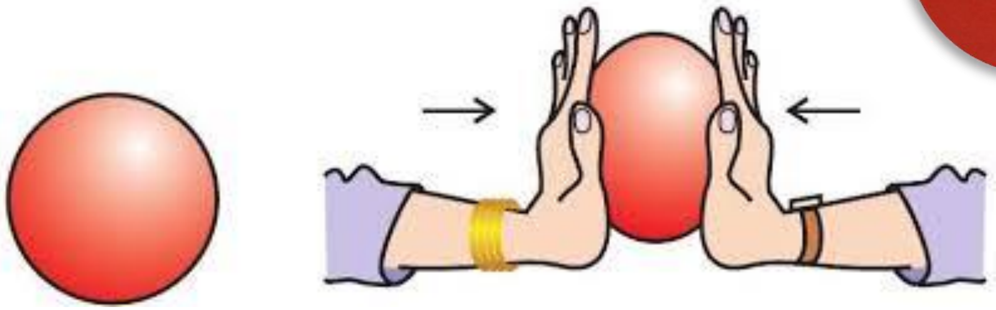
By accelerating, the speed of a running vehicle can be increased or by applying brakes the speed of a running vehicle can be decreased.

- Force can change the shape and size of an object.

For example: by hammering, a block of metal can be turned into a thin sheet.

By hammering, a stone can be broken into pieces.



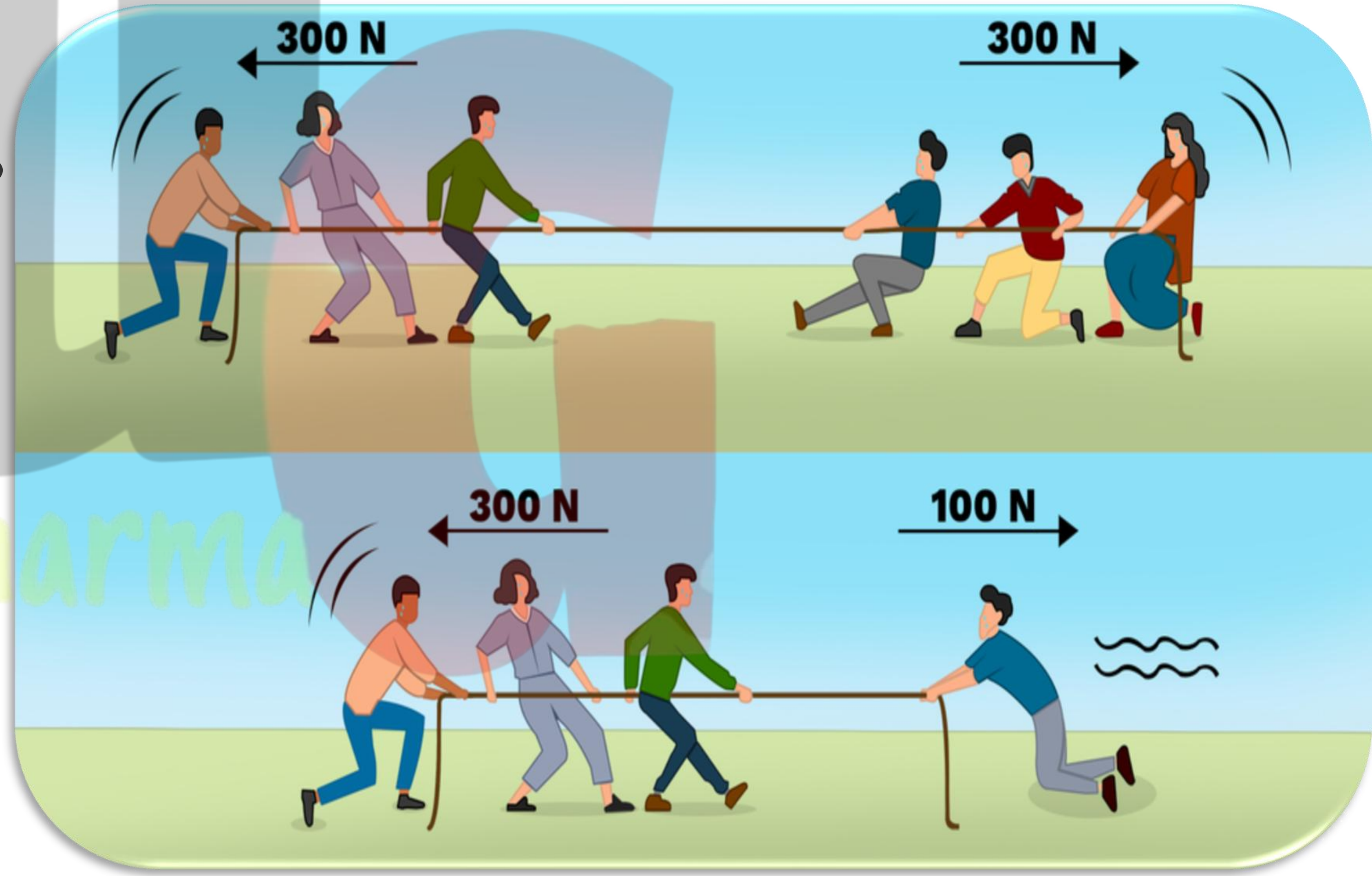


Types of forces

Forces are mainly of two types:-

(i) Balanced forces

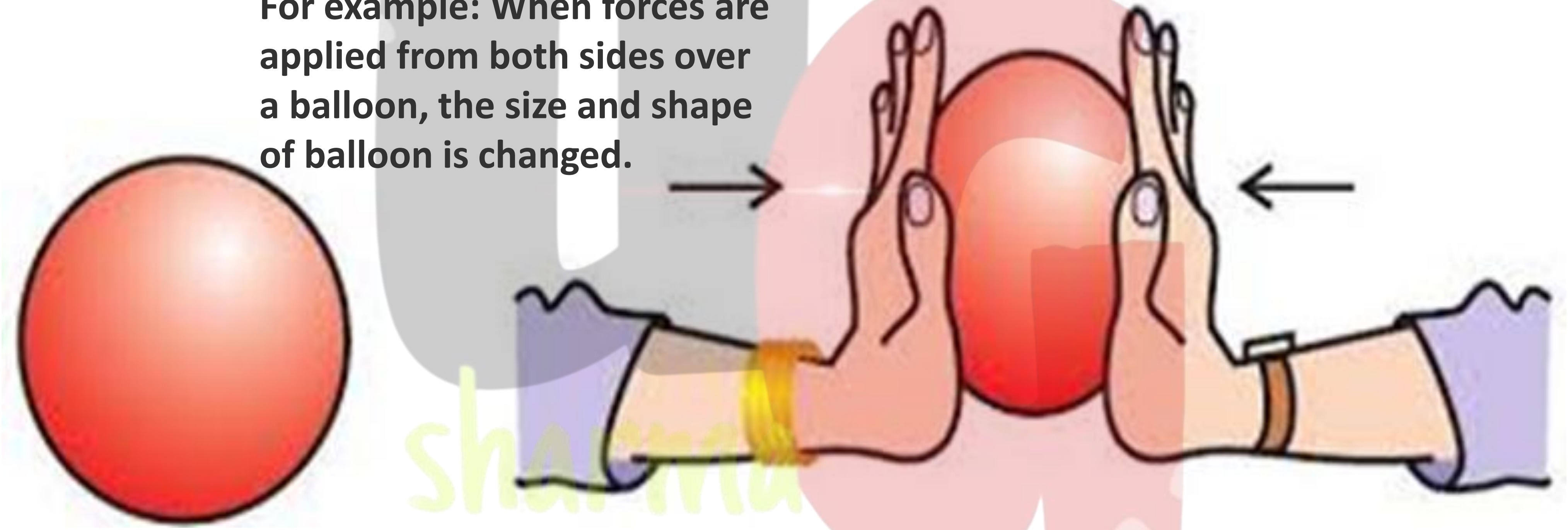
(ii) Unbalanced forces



01. Balanced Forces

- If the resultant of applied forces is equal to zero, it is called balanced forces.

For example: When forces are applied from both sides over a balloon, the size and shape of balloon is changed.



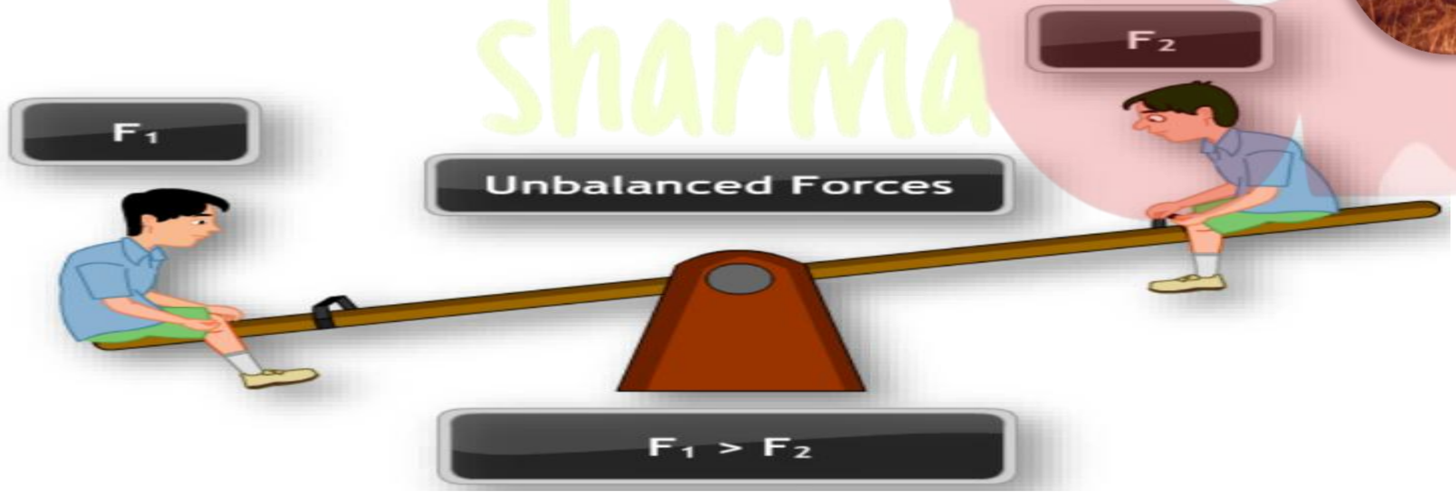
- Balanced forces do not cause any change of state of an object.
- However, balanced forces can change shape of an object.

02. Unbalanced Forces

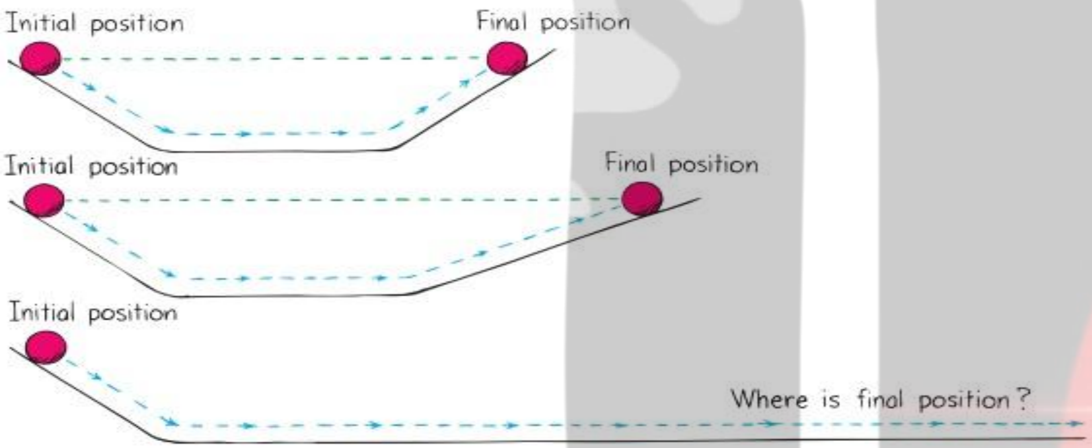
➢ If the resultant of applied forces are greater than zero, the forces are called unbalanced forces.

- Unbalanced forces can do the following:

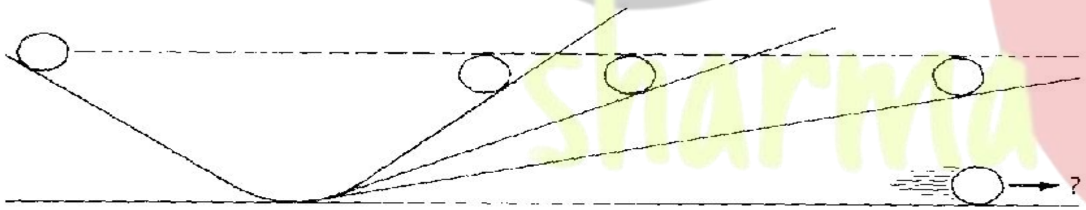
→ Move a stationary object
→ Increase the speed of a moving object
→ Decrease the speed of a moving object
→ Stop a moving object
→ Change the shape and size of an object



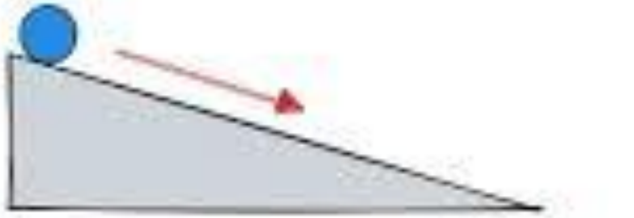
LAWS OF MOTION



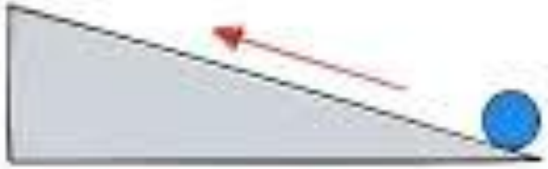
GALILEO'S EXPERIMENT



An illustration of Galileo's experiment. A ball would roll farther, the smoother the surface. In an ideal case of no friction, the ball would continue (slide) indefinitely, since there would be no force to alter its motion.



Downward slope - objects moving down a smooth inclined plane accelerates



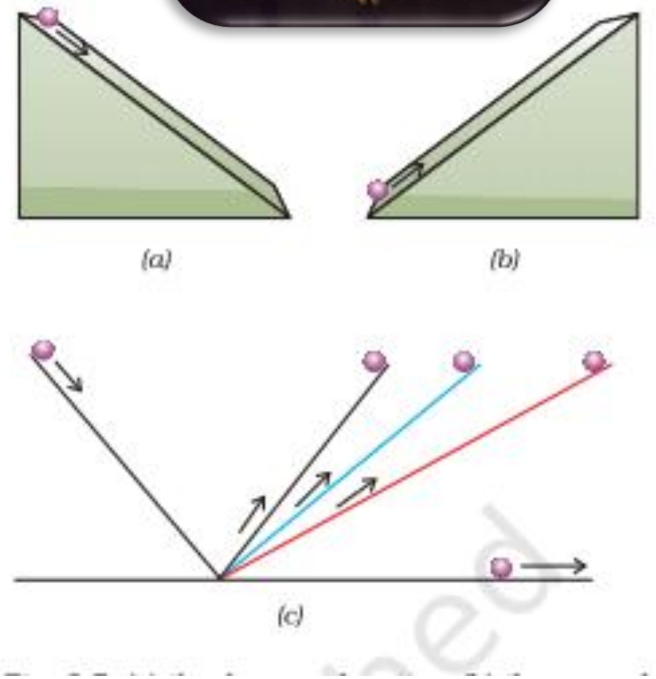
Upward slope - objects moving up a smooth inclined plane decelerates

Objects moving on a frictionless horizontal plane neither accelerates nor decelerates

- **Galileo Galilei:**

Galileo first of all said that object move with a constant speed when no forces act on them.

- ➢ This means if an object is moving on a frictionless path and no other force is acting upon it, the object would be moving forever.



What do you mean by friction force?

Ans:- It is a resistive force which oppose motion.

Newton's laws of motions

Newton studied the ideas of Galileo and gave the three laws of motion. These laws are known as Newton's laws of motion.

Newton's First law of motion

The first law of motion state that "Any object remains in the state of rest or in uniform motion along a straight line, until it is compelled to change the state by applying external force".

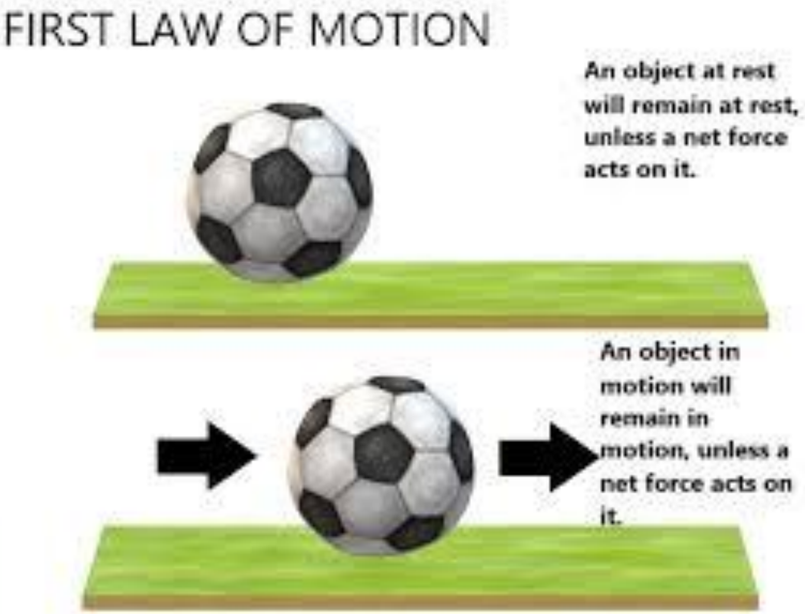
or

" An object resist to change its state of rest or uniform motion"

This is also known as "**law of inertia**"

Explanation: If any object is in the state of rest, then it will remain in rest until a external force is applied to change its state. Similarly, an object will remain in motion until any external force is applied over it to change its state.

This means all objects resist to in changing their state. The state of any object can be changed by applying external forces only.



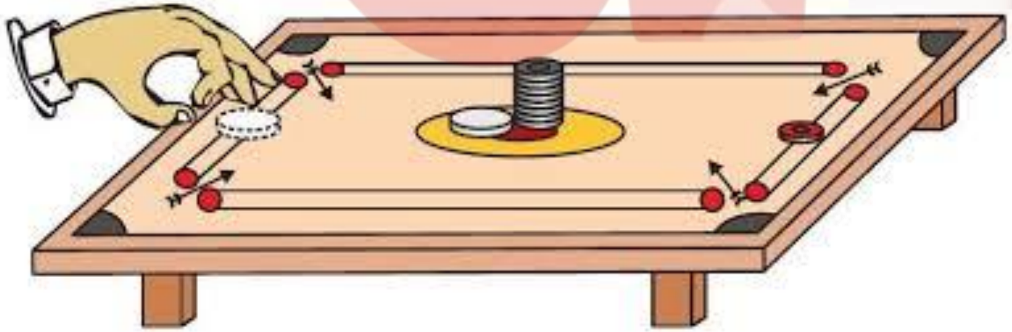
Newton's First Law of Motion in Everyday Life

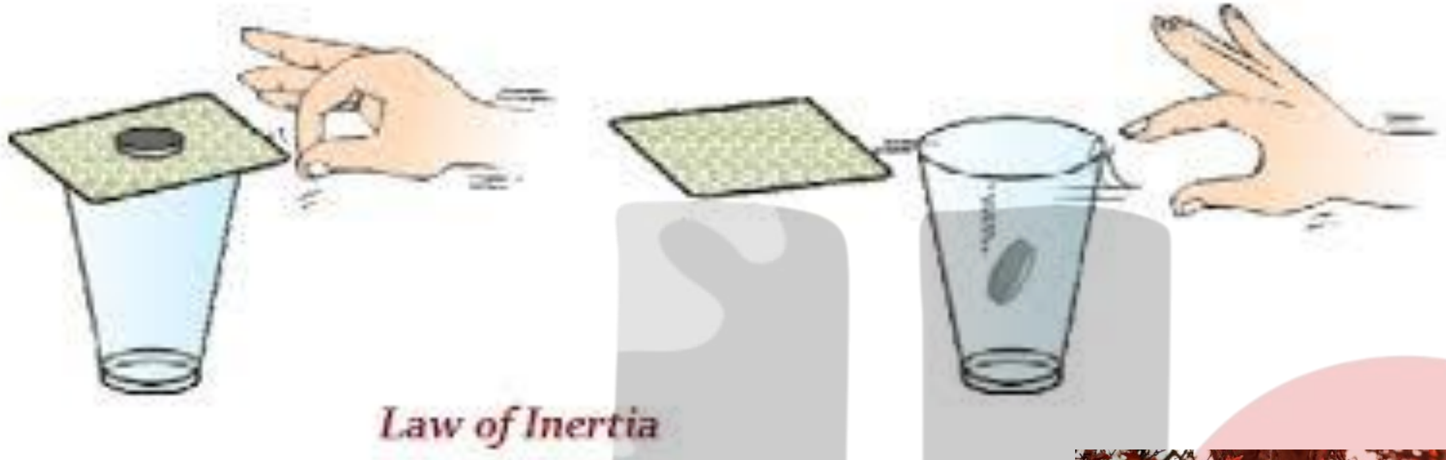
(i) A person standing in a bus falls backward when bus starts moving suddenly.

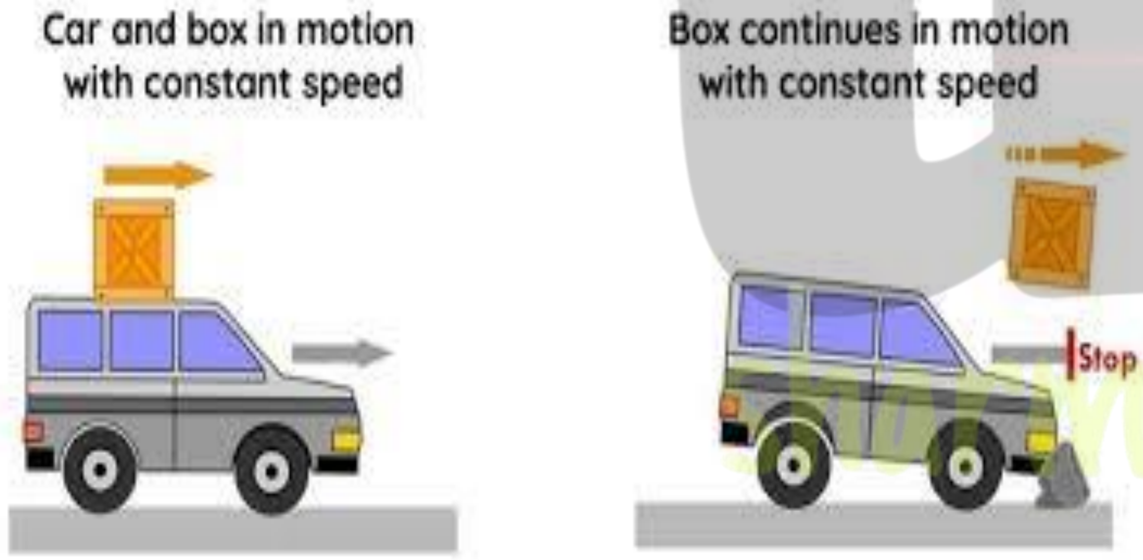
(ii) A person standing in a moving bus falls forward if driver applies brakes suddenly.

(iii) Before hanging the wet clothes over laundry line, usually many jerks are given to the clothes to get them dried quickly. Because of jerks, droplets of water from the pores of the cloth falls on the ground and reduced amount of water in clothes dries them quickly.

(iv) When the pile of coin on the carom-board is hit by a striker, coin only at the bottom moves away leaving rest of the pile of coin at same place.




Law of Inertia


Car and box in motion with constant speed
Box continues in motion with constant speed
Stop

Inertia and Mass

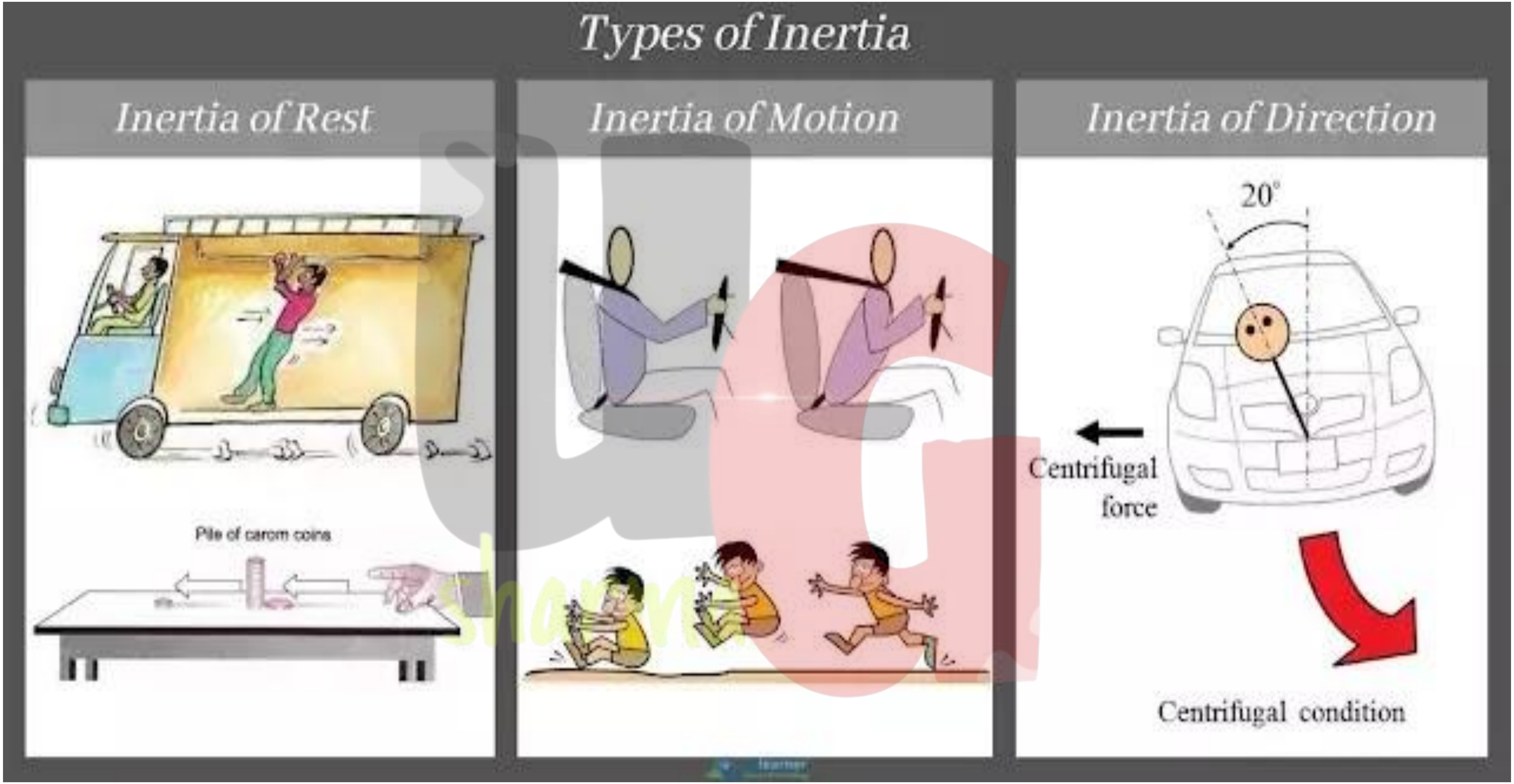
Inertia-The property of matter that causes it to resist changes to its state of rest or uniform straight-line motion is known as inertia.
Inertia can be categorized into three types:

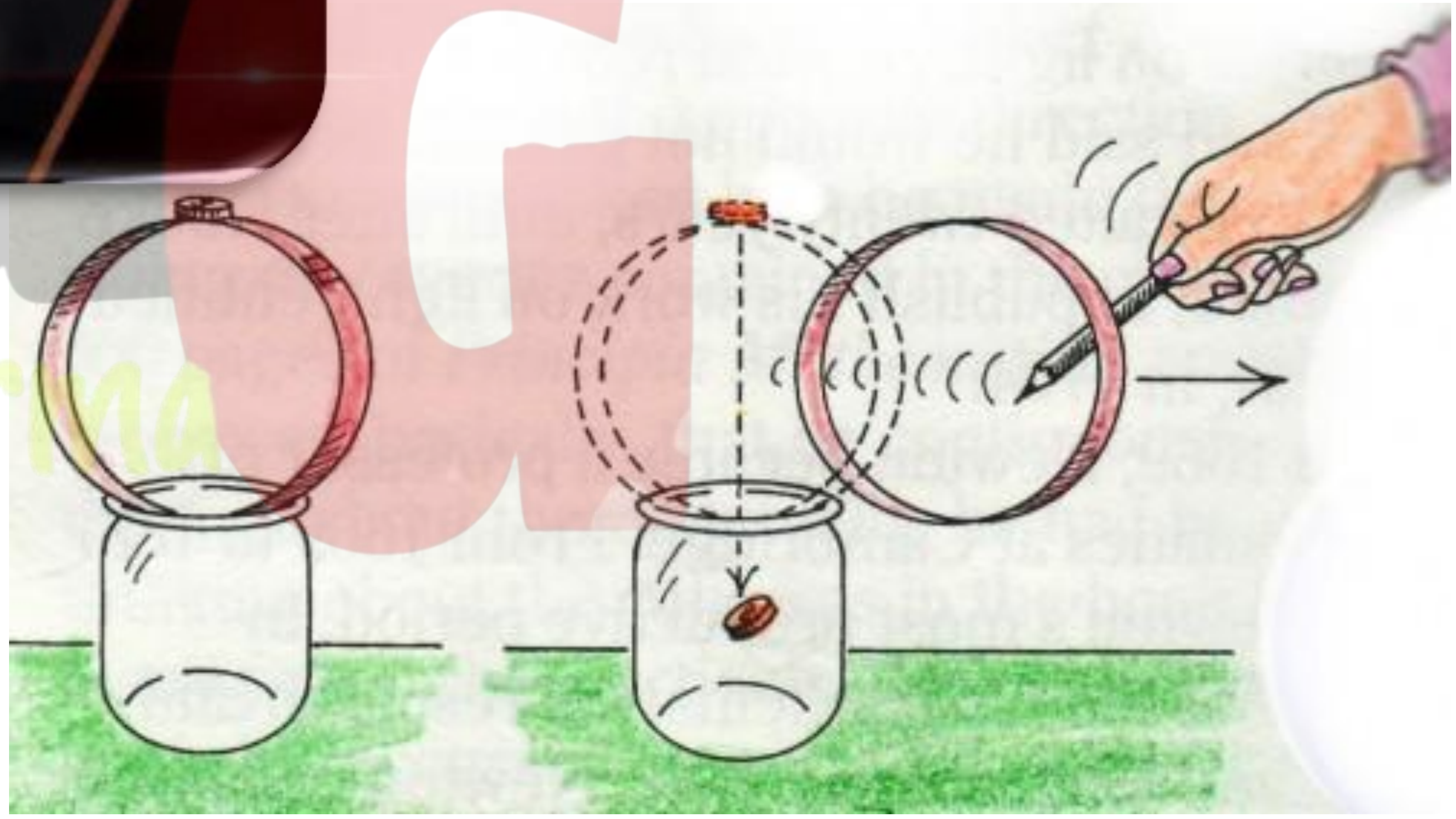
- Inertia of Rest
- Inertia of Motion
- Inertia of Direction

Inertia is directly proportional to mass.

Mass-Mass is a measure of the quantity of matter in an object or substance. Mass is calculated in grams (g) or kilograms (kg).

- Mass is a quantitative measure of Inertia ,more the mass ,more will be the inertia and vice-versa.


Types of Inertia
Inertia of Rest
Inertia of Motion
Inertia of Direction
Pile of carom coins
20°
Centrifugal
force
Centrifugal condition



1. Which of the following has more inertia: (a) a rubber ball and a stone of the same size? (b) a bicycle and a train? (c) a five rupees coin and a one-rupee coin?

2. In the following example, try to identify the number of times the velocity of the ball changes: “A football player kicks a football to another player of his team who kicks the football towards the goal. The goalkeeper of the opposite team collects the football and kicks it towards a player of his own team”. Also identify the agent supplying the force in each case.

3. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.

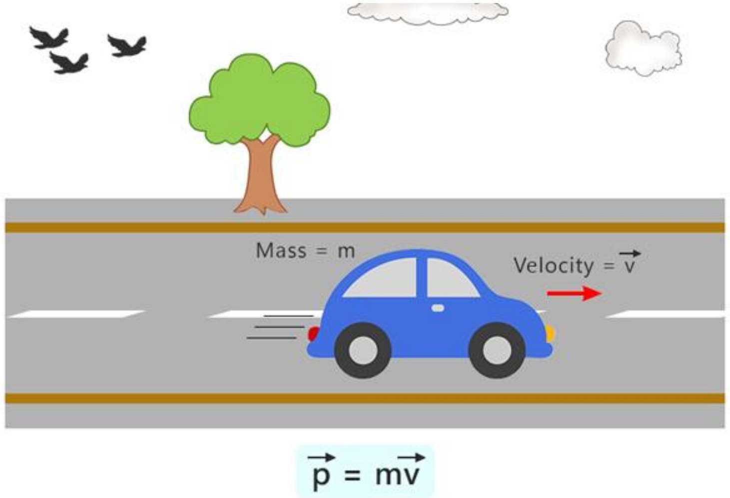
4. Why do you fall in the forward direction when a moving bus brakes to a stop and fall backwards when it accelerates from rest?

Momentum

- Momentum is the power of motion of an object.
- Introduced by Newton.
- *The product of mass and velocity is called momentum. It is denoted by P*

i.e. Momentum = mass x velocity

Or, P = m x v



SI unit :-

P = m x v

kg x m/s or Kgms $^{-1}$

So, SI unit of momentum is "kilogram metre per second".

- Momentum is directly proportional to mass and velocity.
- It is a vector quantity (directions same as velocity).
- Momentum of a body in rest (i.e. non moving body) is zero.

$$P = m \times v$$
$$= m \times 0 \qquad (v = 0)$$
$$P = 0$$

Q.n.1 Calculate the momentum of a 10 kg stone thrown at 2 m/s

Q.n.2 Find the momentum of a 25 g bullet fired at 100 m/s.

Q.n.3.A vehicle has a velocity of 5 m/s and a momentum of 5000 kg m/s. What is its mass?

Q.n.4 A flying brick has a momentum of 50 kg m/s and a mass of 10 kg. Calculate its velocity.

Q.n.5 The mass of a goods lorry is 4000 kg and the mass of goods loaded on it is 20000 kg. If the lorry is moving with a velocity of 2 m/s, what will be its momentum?

Newton's second laws Of motion

The Newton's second law of motion state that " the rate of change of momentum of an object is directly proportional to the applied unbalanced force in the direction of force "

OR

"the rate of change of momentum of a body is directly proportional to the external force applied on the body in the direction of force"

i.e.

$$Force \propto \frac{\textbf{Change in momentum}}{\textbf{Time Take}}$$

Mathematical Representation :-

Suppose an object of mass 'm' is moving along a straight line with an initial velocity 'u'. It is uniformly accelerated to velocity 'v' in time 't' and application of a constant force 'F' throughout the time 't'.

Therefore,

Initial momentum, $P_i = mu$

Final momentum, $P_f = mv$

∴ Change in momentum = Final momentum – Initial momentum

= mv – mu

= m(v – u)

$$\therefore \text{Rate of change of momentum} = \frac{\text{Change in momentum}}{\text{Time taken}}$$

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

According to 2nd law of motion :-

$$Applied\ Force \propto \frac{\text{Change in momentum}}{\text{Time Take}}$$

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

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

{where k = proportional constant}

$$F = kma$$

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

If k = 1, then

$$F = ma$$

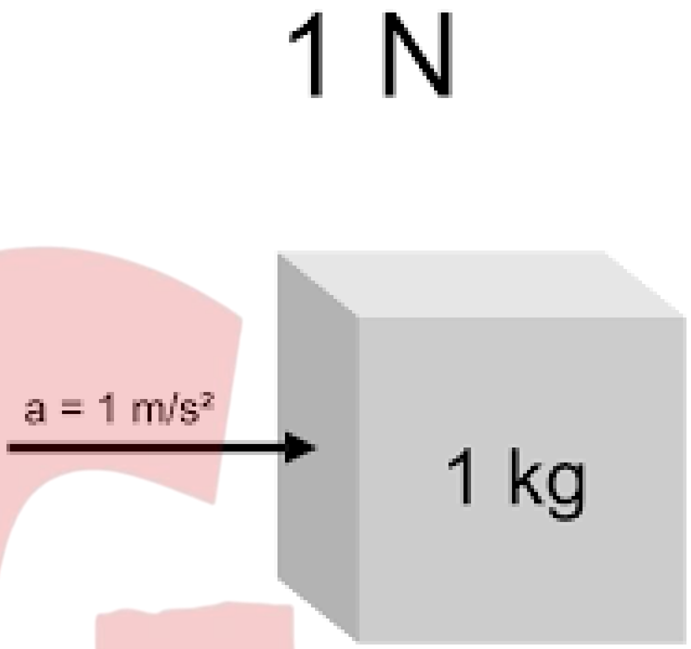
Unit :-

$F = Kgm/s^2$ or $Kgms^{-2}$

S.I unit of force is "newton" denoted by N.

Define 1 N ?

$$1\ \text{N} = 1\ \text{kg}\frac{\text{m}}{\text{s}^2}$$



$$F = ma$$

$$1\text{N} = 1\text{Kg} \times 1\text{ms}^{-2}$$

One newton force is defined as When an acceleration of 1 m/s^2 is seen in a body of mass 1 kg, then the force applied on the body is said to be 1 Newton.

Proof of Newton's First Law of Motion from Second Law :-

First law states that if external force F = 0, then a moving body keeps moving with the same velocity, or a body at rest continues to be at rest.

$\therefore F = 0$

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

(i) A body is moving with initial velocity u then,

$\Rightarrow \frac{m(v-u)}{t} = 0$

$\Rightarrow v - u = 0$

$\therefore v = u$

Thus, final velocity is also same.

(ii) A body is at rest i.e., u = 0

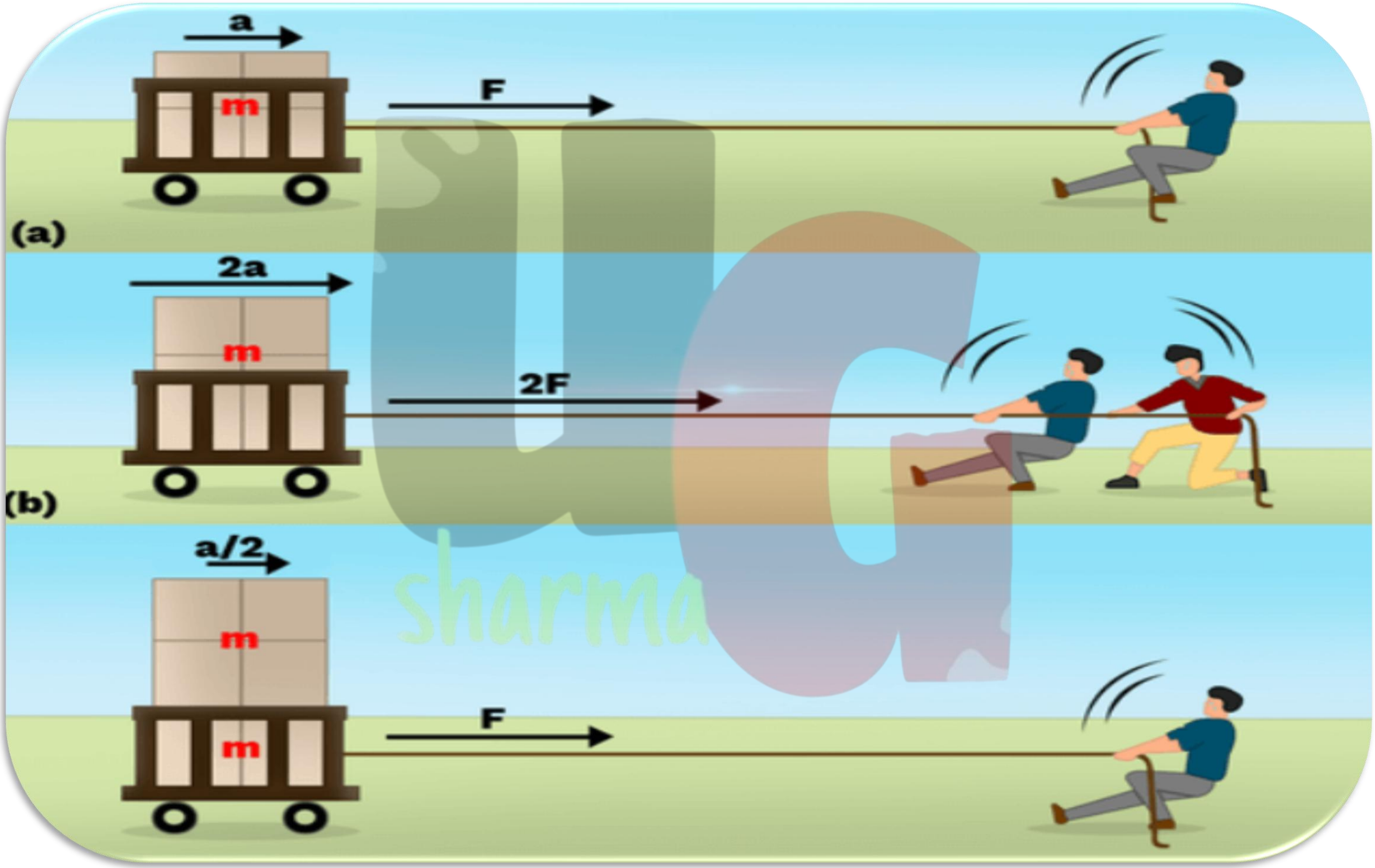
Therefore, from above u = v = 0

So, the body will continue to be at rest

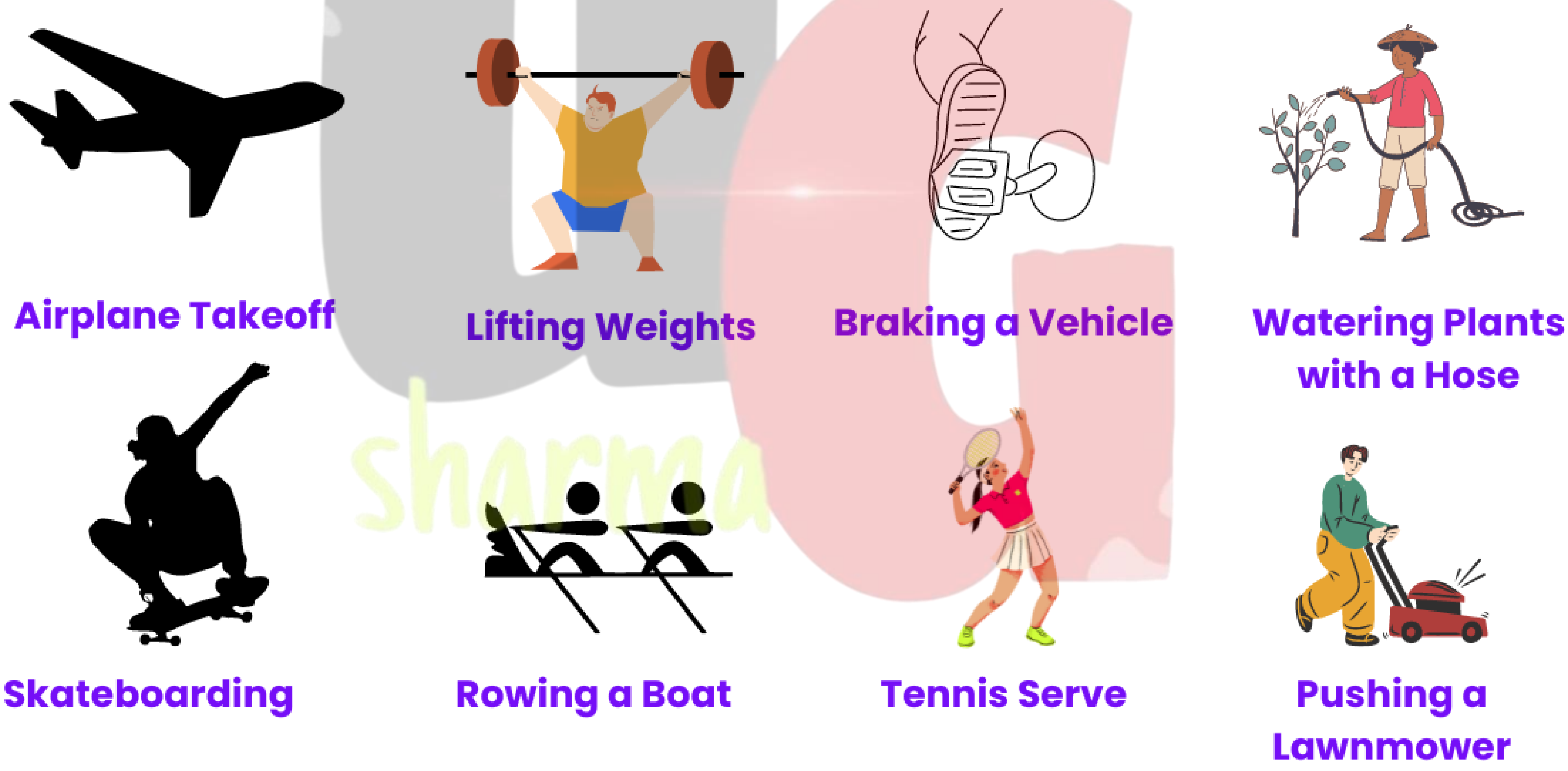
Application of 2^{nd} law of motion :-

01. While catching a fast moving cricket ball, a fielder in the ground gradually pulls his hands backwards with the moving ball.

02. In a high jump athletic event, the athletes are made to fall either on a cushioned bed or on a sand bed.


a
m
F
(a)
2a
m
2F
(b)
a/2
m
m
F

NEWTON'S SECOND LAW OF MOTION EXAMPLES IN REAL LIFE



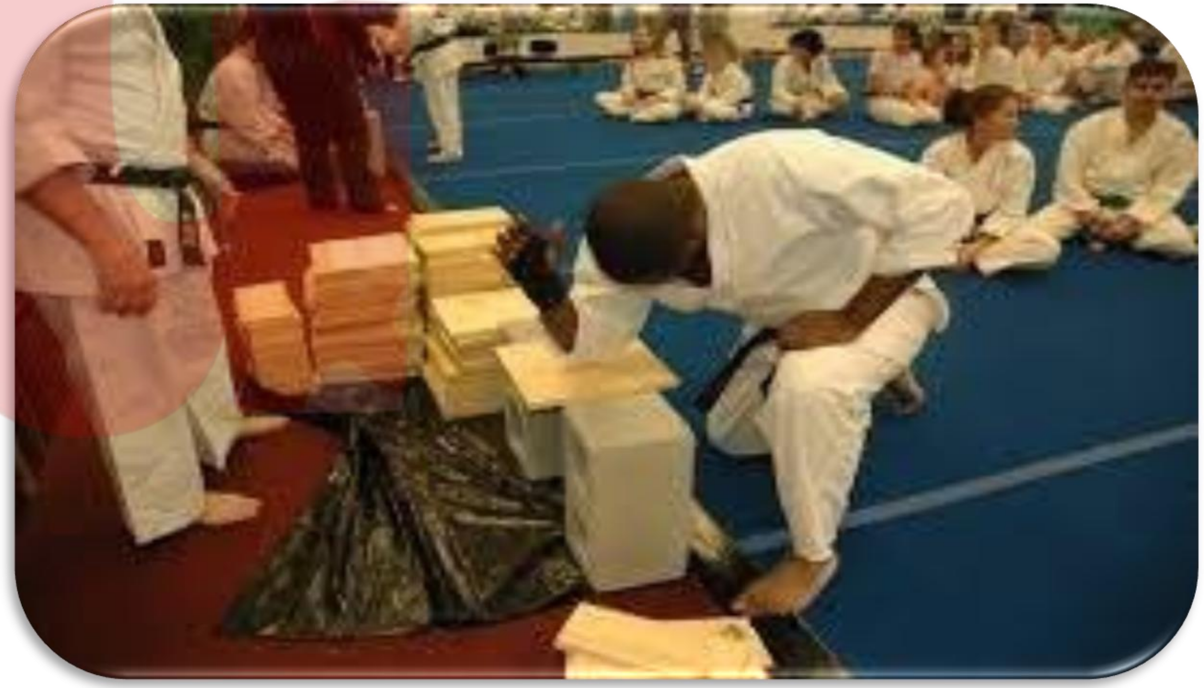
Application of Newton's 2^{nd} law :-

The fielder increases the time during which the high velocity of the moving ball decreases to zero. Thus, the acceleration of the ball is decreased and therefore the impact of catching the fast moving ball is also reduced. If the ball is stopped suddenly then its high velocity decreases to zero in a very short interval of time. Thus, the rate of change of momentum of the ball will be large. Therefore, a large force would have to be applied for holding the catch that may hurt the palm of the fielder.

Fig. 8.8: *A fielder pulls his hands gradually with the moving ball while holding a catch.*

In a high jump athletic event, the athletes are made to fall either on a cushioned bed or on a sand bed. This is to increase the time of the athlete's fall to stop after making the jump. This decreases the rate of change of momentum and hence the force.

How a karate player breaks a slab of ice with a single blow.



Example 8.1 A constant force acts on an object of mass 5 kg for a duration of 2 s. It increases the object's velocity from 3 m s–1 to 7 m s-1. Find the magnitude of the applied force. Now, if the force was applied for a duration of 5 s, what would be the final velocity of the object?

Example 8.2 Which would require a greater force –– accelerating a 2 kg mass at 5 m s–2 or a 4 kg mass at 2 m s-2 ?

Example 8.3 A motorcar is moving with a velocity of 108 km/h and it takes 4 s to stop after the brakes are applied. Calculate the force exerted by the brakes on the motorcar if its mass along with the passengers is 1000 kg.

Example 8.4 A force of 5 N gives a mass m_1, an acceleration of 10 m s^{-2} and a mass m_2, an acceleration of 20 m s^{-2}. What acceleration would it give if both the masses were tied together?

Example 8.5 The velocity-time graph of a ball of mass 20 g moving along a straight line on a long table is given in Fig. 8.9.

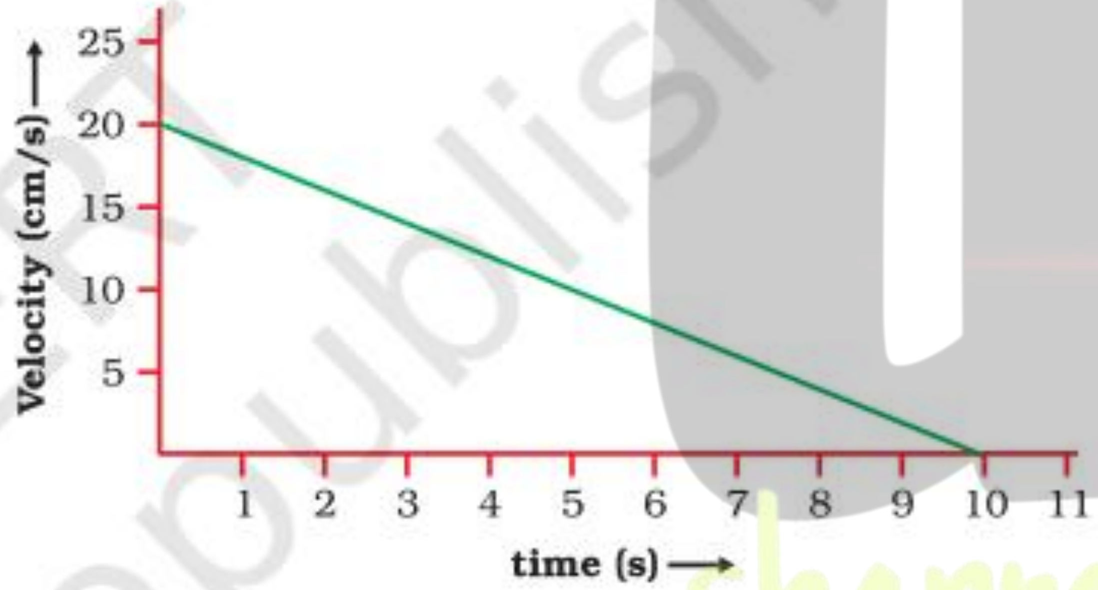


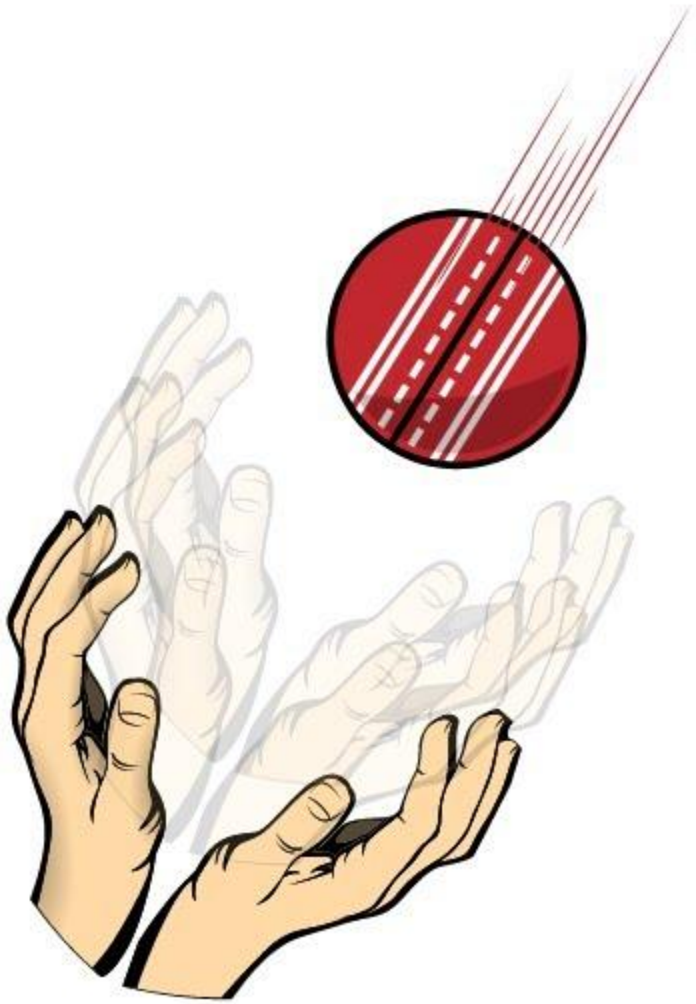
Fig. 8.9

How much force does the table exert on the ball to bring it to rest?

Impulse

- Is defined as the product of a force, F acting on an object of mass, m for time ,t
  - Impulse = Force x Time
  - Impulse = Ft
- Also can be define as the change of momentum
  - Impulse= mv – mu
- Impulse ,Ft = mv – mu
- Unit $kgms^{-1}$ or Ns
- Is a vector quantity

Impulse of Force and Impulsive Force



Newton's third laws Of motion

- The third law of motion states that "when one object exerts a force on another object, the second object instantaneously exerts a force back on the first".
- These two forces (known as action & reaction) are always equal in magnitude but opposite in direction.
  So, 3rd law of motion can also be defined as :-
- It state that " *To every action there is an equal and opposite reaction*".

$$F_A = -F_R$$

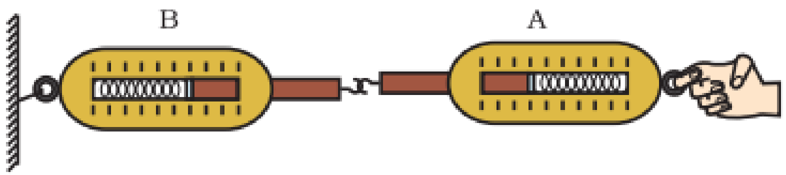
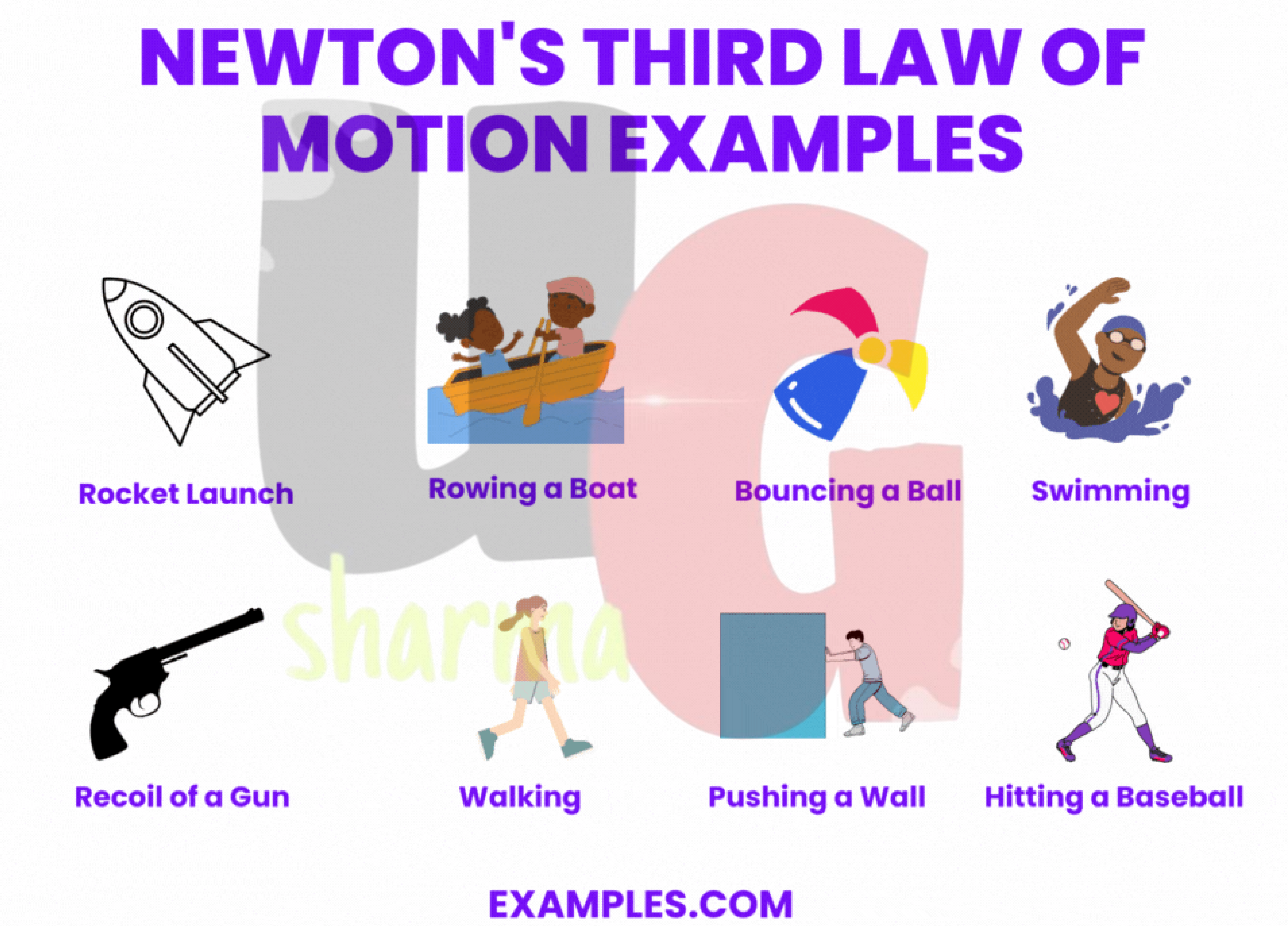
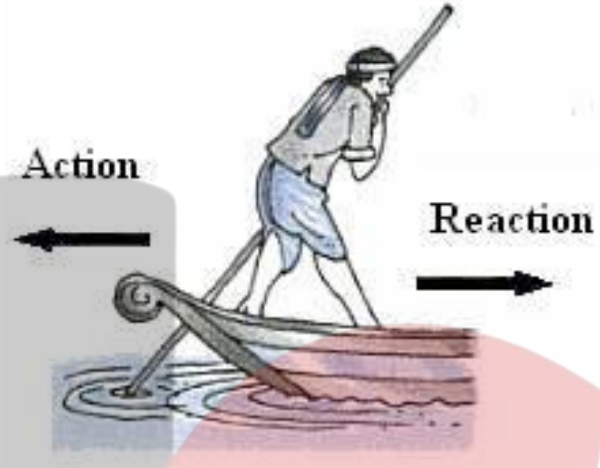
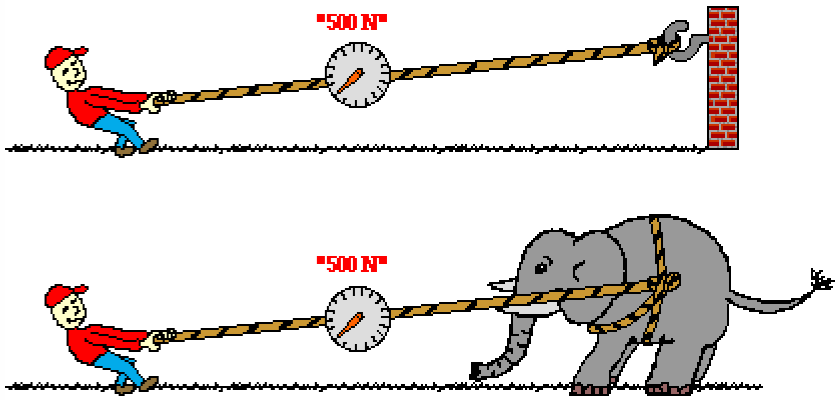


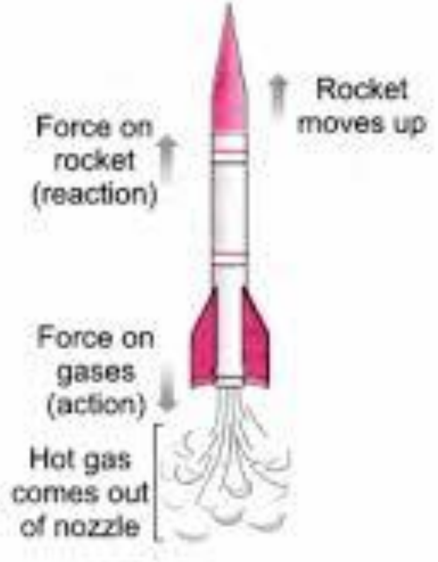
Fig. 8.10: Action and reaction forces are equal and opposite.

- These forces act on different objects simultaneously and never on the same object.
- These forces may not produce acceleration of same magnitude each forces acts on different object that may have different mass.


NEWTON'S THIRD LAW OF MOTION EXAMPLES
Rocket Launch
Rowing a Boat
Bouncing a Ball
Swimming
Recoil of a Gun
Walking
Pushing a Wall
Hitting a Baseball
EXAMPLES.COM

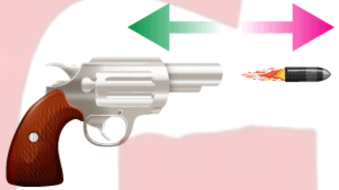






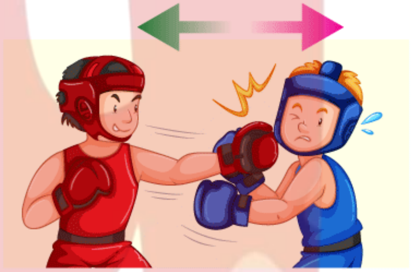
For every action, there is equal and opposite reaction

Action
Accelarating force of the bullet



Reaction
Recoil force on the gun

Action
Fist Exert Force on Jaw



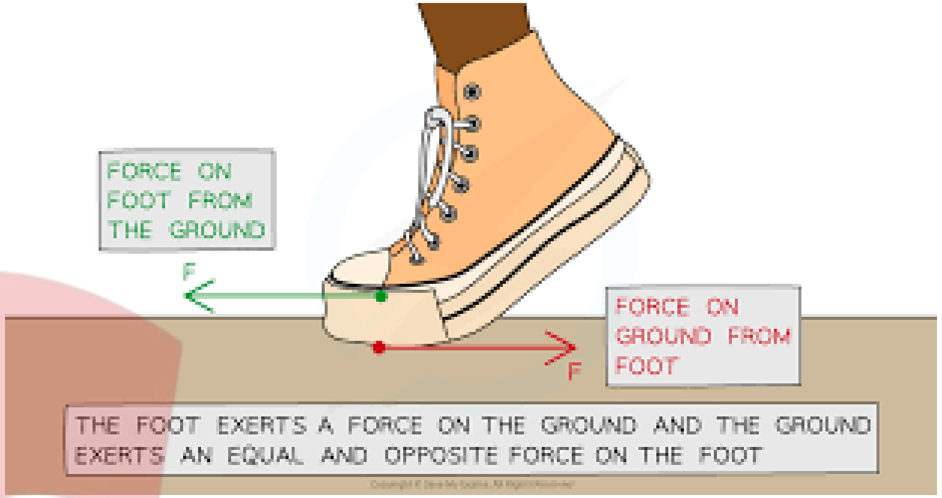
Reaction
Jaw Exert Force on Fist

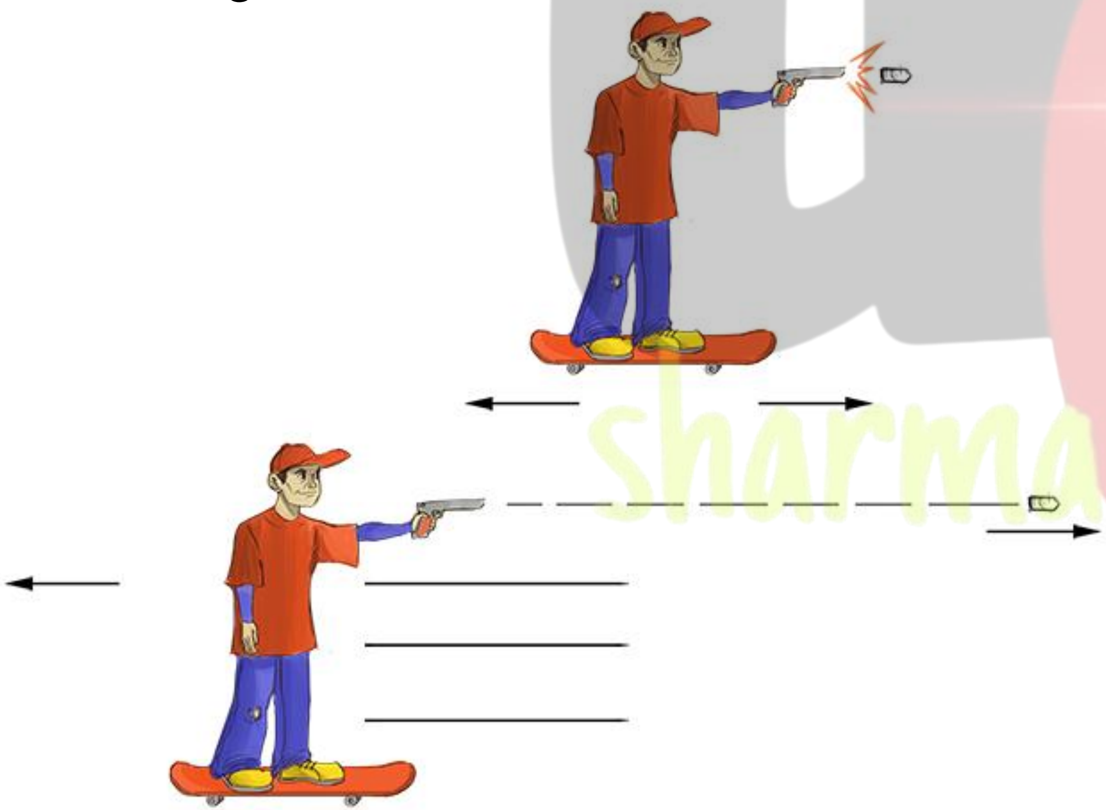
Action
Boy's feet exert force on boat

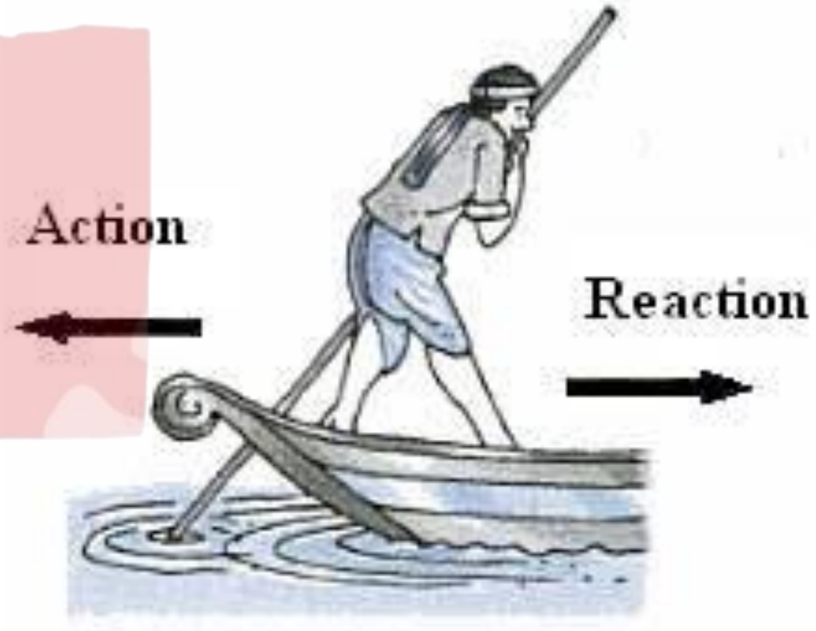
Reaction
Boat exerts force on feet

Applications of 3rd law :-

(i) Walking is enabled by 3rd law.
(ii) A boat moves back when we deboard it.
(iii) A gun recoils.
(iv) Rowing of a boat.







Conservation of momentum

The law states that the total momentum of an isolated system remains constant if no external forces act on it.

i.e. the momentum can neither be create nor be destroyed.

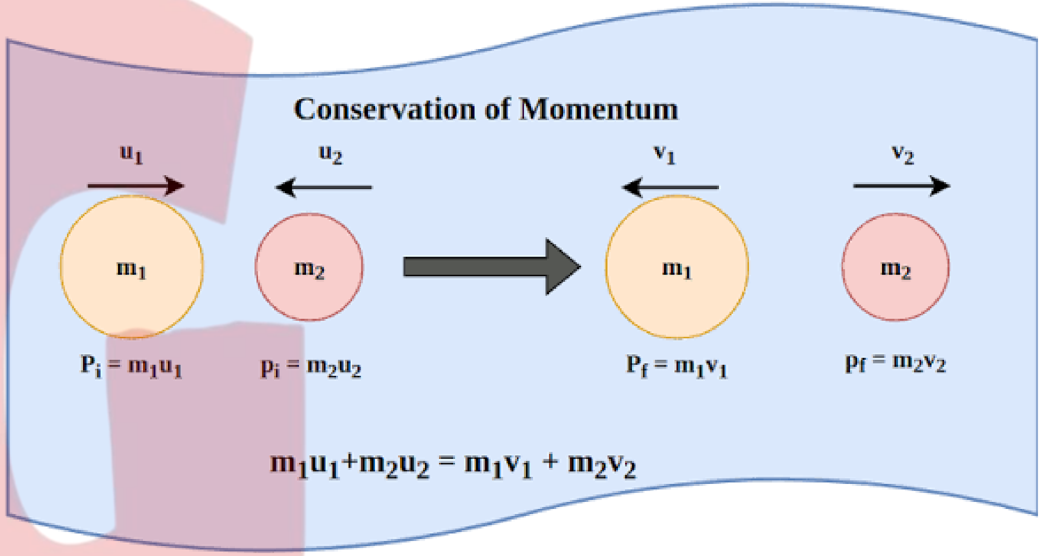
<u>Mathematical expression for a collision</u>

Consider two objects with masses m_1 and m_2, and initial velocities u_1 and u_2 respectively.

- After a collision, their velocities become v_1 and v_2.
- The law of conservation of momentum can be expressed as:

$m_1u_1+m_2u_2=m_1v_1+m_2v_2$

- This formula states that the total momentum before the collision equals the total momentum after the collision.

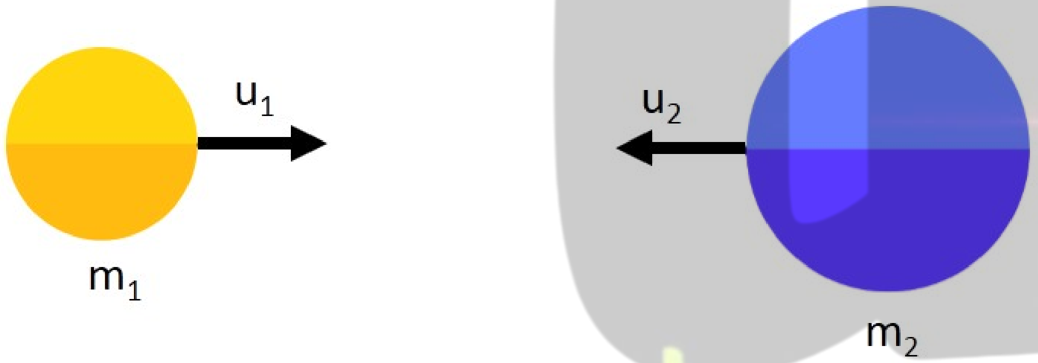


Conservation of Momentum Derivation

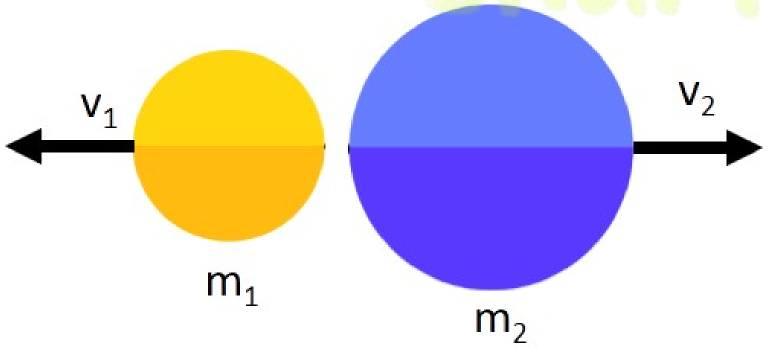
Suppose there are 2 objects A and B

Both objects collide with each other

Before Collision



After Collision



Calculating the forces on both objects

Force on Object 1

Mass = m_1

Acceleration = a_1

Now,

Force = Mass × Acceleration

$$F_{BA} = \text{Mass} \times \frac{(Final\ Velocity - Initial\ Velocity)}{t}$$

$$= m_1 \frac{(v_1 - u_1)}{t}$$

Force on Object 2

Mass = m_2

Acceleration = a_2

Now,

Force = Mass × Acceleration

$$F_{AB} = \text{Mass} \times \frac{(Final\ Velocity - Initial\ Velocity)}{t}$$

$$= m_2 \frac{(v_2 - u_2)}{t}$$

From Newton's Third Law,

When one object exerts a force on other object,

the other object also exerts an equal & opposite force on the first object

Force exerted by Object A = Force exerted by Object B

$$F_{BA} = - F_{AB}$$

$$m_1 \frac{(v_1 - u_1)}{t} = -m_2 \frac{(v_2 - u_2)}{t}$$

Cancelling t

$$m_1 (v_1 - u_1) = -m_2 (v_2 - u_2)$$

$$m_1v_1 - m_1u_1 = -m_2v_2 + m_2u_2$$

$$m_1v_1 + m_2v_2 = m_2u_2 + m_1u_1$$

$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

∴ Final Momentum of 2 objects = Original Momentum of 2 objects

Thus, momentum is conserved

A bullet of mass 20 g is fired horizontally with a velocity of 150 m/s from a pistol of mass 2 kg. Find the recoil velocity of the pistol.

Exercises

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on
2. When a carpet is beaten with a stick, dust comes out of it, Explain.
3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?
4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because
   (a) the batsman did not hit the ball hard enough.
   (b) velocity is proportional to the force exerted on the ball.
   (c) there is a force on the ball opposing the motion.
   (d) there is no unbalanced force on the ball, so the ball would want to come to rest.

5. A truck starts from rest and rolls down a hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 tonnes (*Hint*: 1 tonne = 1000 kg.)
6. A stone of 1 kg is thrown with a velocity of 20 m s^{-1} across the frozen surface of a lake and comes to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice?
7. A 8000 kg engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate:
   (a) the net accelerating force and
   (b) the acceleration of the train.
8. An automobile vehicle has a mass of 1500 kg. What must be the force between the vehicle and road if the vehicle is to be stopped with a negative acceleration of 1.7 m s^{-2} ?

9. What is the momentum of an object of mass *m*, moving with a velocity *v*?

(a) $(mv)^2$ (b) mv^2 (c) $\frac{1}{2} mv^2$ (d) mv

10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?

11. According to the third law of motion when we push on an object, the object pushes back on us with an equal and opposite force. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.

12. A hockey ball of mass 200 g travelling at 10 m s^{-1} is struck by a hockey stick so as to return it along its original path with a velocity at 5 m s^{-1}. Calculate the magnitude of change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.

13. A bullet of mass 10 g travelling horizontally with a velocity of 150 m s^{-1} strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also calculate the magnitude of the force exerted by the wooden block on the bullet.

14. An object of mass 1 kg travelling in a straight line with a velocity of 10 m s^{-1} collides with, and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact and just after the impact. Also, calculate the velocity of the combined object.

15. An object of mass 100 kg is accelerated uniformly from a velocity of 5 m s^{-1} to 8 m s^{-1} in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

17. How much momentum will a dumb-bell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be 10 m s^{-2}.

UG

sharma