Force and Laws of Motion

Force – A push, pull or hit is known as force.

Effects of force :-

- It can change the magnitude of velocity
- It can change the direction of the motion
- It can change the shape and size of an object

Balanced force – When sum of forces acting on an object is zero.

- Such forces do not change the state of rest or of motion of an object.

Unbalanced force – When sum of forces acting on an object is not zero.

- Such forces cause motion in the direction of greater force.

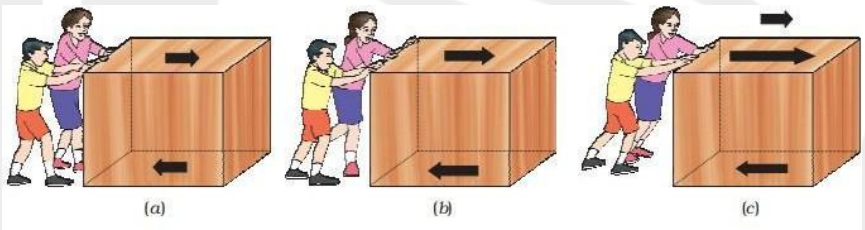
Aristotle's Fallacy – Rest is the natural state of an object. (Aristotle missed the concept of friction.)

Friction:- Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

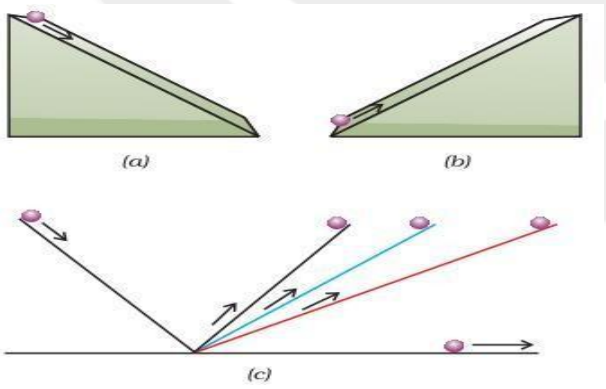
Types of Friction –

Kinetic friction – applied between the surfaces of two moving objects.

Static friction – self adjusting opposing force between the surfaces of two stationary objects.



Inertia - The natural tendency of objects to resist a change in their state of rest or of uniform motion is called inertia. The **mass** of an object is a measure of its inertia.



In this experiment Galileo gradually decreased the inclination till it become horizontal and then observed that the ball tries to reach the same height and keep on moving if the surface is frictionless.

Based on Galileo idea Newtonm gave 3 fundamental laws that govern the motion.

Newton's 1st Law :-

An object continues to be in a state of rest or of uniform motion along a straight line unless acted upon by an unbalanced force.

Examples-

a. While travelling in a motor car

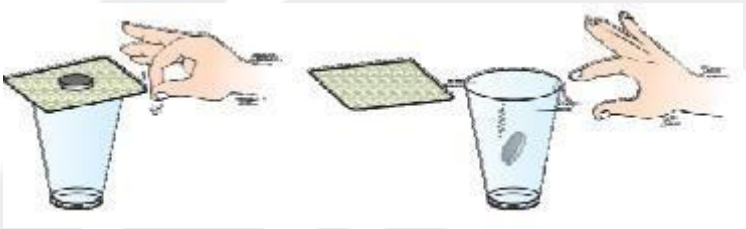
- when driver suddenly applies brake – we fall forward

- when driver suddenly accelerate or move from rest – we fall backward

- on a sharp turn – we are thrown to one side.

b. Only the carom coin at the bottom of a pile is removed when a fast moving carom coin (or striker) hits it.

c. When the card is flicked with the finger the coin placed over it falls in the tumble



Momentum :- The momentum, p of an object is defined as the product of its mass, m and velocity, v. That is,

p = mv

Momentum has both direction and magnitude. Its direction is the same as that of velocity, v. The SI unit of momentum is kilogram-metre per second (kg m s-1).

- The impact produced by an object depends upon their mass and velocity.

Example-

* Table tennis ball and cricket ball – more impact of cricket ball due to its mass

* Bullet fired from gun and a football kicked by player – more impact of bullet due to its velocity

Newton's 2nd Law :-

The rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of the force.

$$\text{The change in momentum} \propto p_2 - p_1$$
$$\propto mv - mu$$
$$\propto m \times (v - u).$$

$$\text{The rate of change of momentum} \propto \frac{m \times (v-u)}{t}$$

Or, the applied force,

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

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

Here a [= (v – u)/t] is the acceleration, and

the unit of force is so chosen that the value of the constant, k becomes one.

So the equation becomes,

F= ma

The unit of force is kg m s-2 or newton, which has the symbol N.

- The 2nd Law of motion gives us a method to measure the force acting on an object as a product of its mass and acceleration.

Application :-

- while catching a fast moving cricket ball, a fielder in the ground gradually pulls his hands backwards with the moving ball to reduce the impact by increasing the time duration.
- In a high jump athletic event, the athletes are made to fall either on a cushioned bed or on a sand bed to reduce the impact by increasing the time duration.
- A karate player breaks a slab of ice with a single blow by decreasing the time duration to have large impact.

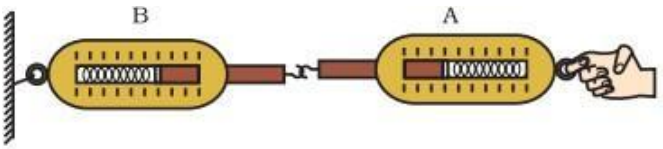
Newton's Thirds Law:-

To every action, there is an equal and opposite reaction and they act on two different bodies.

Examples:-

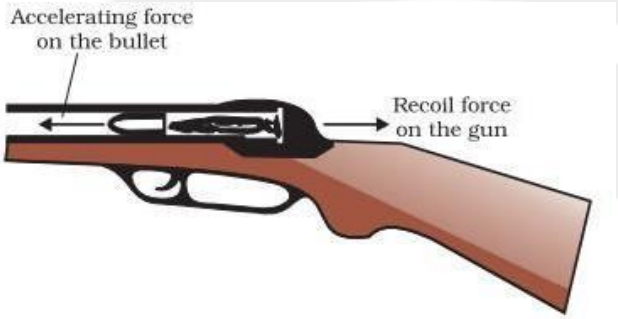
- While walking you push the road below backwards. The road exerts an equal and opposite reaction force on your feet to make you move forward.

- Two spring balance connected together



Action and reaction forces are equal and opposite.

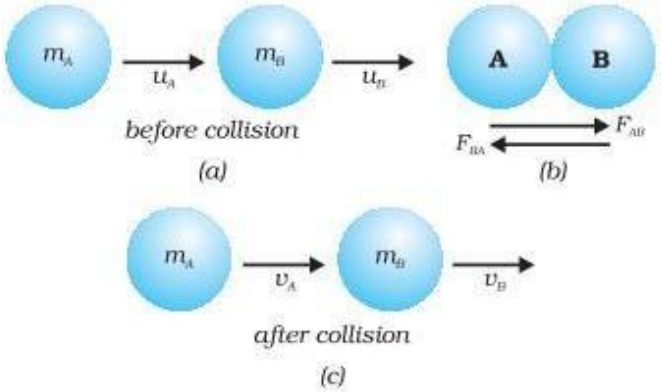
- Bullet fired from gun



A forward force on the bullet and recoil of the gun.

It is important to note that even though the action and reaction forces are always equal in magnitude, these forces may not produce accelerations of equal magnitudes. This is because each force acts on a different object that may have a different mass.

Conservation of Momentum :-



Conservation of momentum in collision of two balls.

Change in momentum of A is: $m_1(v_1 - u_1)$

Change in momentum of B is: $m_2(v_2 - u_2)$

According to third law of motion,

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

$F_{BA} = m_2 \times a_2 = \frac{m_2(v_2 - u_2)}{t}$

$F_{AB} = m_1 \times a_1 = \frac{m_1(v_1 - u_1)}{t}$

Here, a_1 & a_2 are the acceleration of A and B.

Therefore,

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

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

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

So, initial momentum = final momentum

We observe that the total momentum of the two balls remains unchanged or conserved provided no other external force acts. This is known as law of conservation of momentum.
