- Unbalanced force acting on an object brings it in motion.
- An object moves with a uniform velocity when the forces (pushing force and frictional force) acting on the object are balanced and there is no net external force on it. If an unbalanced force is applied on the object, there will be a change either in its speed or in the direction of its motion. Thus, to accelerate the motion of an object, an unbalanced force is required. And the change in its speed (or in the direction of motion) would continue as long as this unbalanced force is applied. However, if this force is removed completely, the object would continue to move with the velocity it has acquired till then.
- Galileo deduced that objects move with a constant speed when no force acts on them.
- Newton studied Galileo's ideas on force and motion and presented three fundamental laws that govern the motion of objects. These three laws are known as
- Newton's laws of motion.
- The first law of motion is stated as: An object remains in a state of rest or of uniform motion in a straight line unless compelled to change that state by an applied force.
- The natural tendency of objects to resist a change in their state of rest or of uniform motion is called **inertia**.
- All objects resist a change in their ***state of motion***. In a qualitative way, the tendency of undisturbed objects to stay at rest or to keep moving with the same velocity is called **inertia.** This is why, the first law of motion is also known as **the law of inertia.**
- We tend to remain at rest with respect to the seat until the drives applies a braking force to stop the motorcar. With the application of brakes, the car slows down but our body tends to continue in the same state of motion because of its inertia. A sudden application of brakes may thus cause injury to us by impact or collision with the panels in front. Safety belts are worn to prevent such accidents. Safety belts exert a force on our body to make the forward motion slower.
- When we are standing in a bus and the bus begins to move suddenly, we tend to fall backwards. This is because the sudden start of the bus brings motion to the bus as well as to our feet in contact with the floor of the bus. But the rest of our body opposes this motion because of its inertia.
- When a motorcar makes a sharp turn at a high speed, we tend to get thrown to one side. We tend to continue in our straight-line motion. When an unbalanced force is applied by the engine to change the direction of motion of the motorcar, we slip to one side of the seat due to the inertia of our body.
- If a body is at rest it tends to remain at rest; if it is moving it tends to keep moving. This property of an object is called its inertia.
- Heavier or more massive objects offer larger inertia. Quantitatively, the inertia of an object is measured by its mass.
- Relation inertia and mass as follows: Inertia is the natural tendency of an object to resist a change in its state of motion or of rest. The mass of an object is a measure of its inertia.

- Impact produced by the objects depends on their mass and velocity.
- If an object is to be accelerated, a greater force is required to give a greater velocity. In other words, there appears to exist some quantity of importance that combines the object's mass and its velocity. One such property called momentum was introduced by Newton
- 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}). Since the application of an unbalanced force brings a change in the velocity of the object, it is therefore clear that a force also produces a change of momentum.
- The change of momentum of the body not only determined by the magnitude of the force but also by the time during which the force is exerted.
- The force necessary to change the momentum of an object depends on the time rate at which the momentum is changed.
- The **second law of motion** states that the rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.
- 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 by the application of a constant force, F throughout the time, t.
- The initial and final momentum of the object will be, $p_1 = mu$ and $p_2 = mv$ respectively.

The change in momentum $\propto p_2 - p_1$

$$\propto mv - mu$$

$$\propto m \times (v - u).$$

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

Or, the applied force, F $\propto \frac{m \times (v - u)}{t}$

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

$$= kma$$

Here a [= $(v - u)/t$] is the acceleration, which is the rate of change of velocity. The quantity, k is a constant of proportionality.

The SI units of mass and acceleration are kg and m s^{-2} respectively. The unit of force is so chosen that the value of the constant, k becomes one.

For this, one unit of force is defined as the amount that produces an acceleration of 1 m s^{-2} in an object of 1 kg mass. That is,

1 unit of force = $k \times (1\text{ kg}) \times (1\text{ m s}^{-2})$.

Thus, the value of k becomes 1.

$F = ma$

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

- The second law of motion gives us a method to measure the force acting on an object as a product of its mass and acceleration.
- While catching a fast moving cricket ball, a fielder in the ground gradually pulls his hands backwards with the moving ball. In doing so, 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.
- 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.
- The first law of motion can be mathematically stated from the mathematical expression for the second law of motion. Eq. (9.4) is

  $F = ma$

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

  $Ft = mv - mu$
- That is, when $F = 0$, $v = u$ for whatever time, t is taken. This means that the object will continue moving with uniform velocity, u throughout the time, t.
- If u is zero then v will also be zero. That is, the object will remain at rest.
- 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 are always equal in magnitude but opposite in direction.
- These forces act on different objects and never on the same object. The two opposing forces are also known as action and reaction forces.
- 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 :** In an isolated system, the total momentum remains conserved.
- Suppose two objects (two balls A and B, say) of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B, respectively And there are no other external unbalanced forces acting on them. Let $u_A > u_B$ and the two balls collide with each other.

  During collision which lasts for a time t, the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A.

  Suppose v_A and v_B are the velocities of the two balls A and B after the collision, respectively The momenta (plural of momentum) of ball A before and after the collision are m_Au_A and m_Av_A, respectively.

The momenta (plural of momentum) of ball B before and after the collision are $m_B u_B$ and $m_B v_B$, respectively.

The rate of change of momentum of ball A during the collision will be $m_A \times \frac{v_A - u_A}{t}$

Similarly, the rate of change of momentum of ball B during the collision will be $m_B \times \frac{v_B - u_B}{t}$

According to the third law of motion, the force F_{AB} exerted by ball A on ball B (action) and the force F_{BA} exerted by the ball B on ball A (reaction) must be equal and opposite to each other. Therefore,

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

- $m_B \times \frac{v_B - u_B}{t} = -m_A \times \frac{v_A - u_A}{t}$

  Or, $m_A u_A + m_B u_B = m_A v_A + m_B v_B$
- Since $(m_A u_A + m_B u_B)$ is the total momentum of the two balls A and B before the collision and $(m_A v_A + m_B v_B)$ is their total momentum after the collision, the total momentum of the two balls remains unchanged or conserved provided nonother external force acts.
- m