Force and Laws of motion

Force

An agent that change or try to change the state of an object is called force.
A force may be :

i. Push
ii. ii. Pull
iii. iii. Gravitational force
iv. Frictional force

The force applied on a body can bring about the following changes:

- It can change the state of rest of a body or change its position
- It can change the speed of the body
- It can change the direction of motion of a body .
- Force can change the shape and size of an object

Resultant Force

The resultant force is that single force which when acting on a body produces the same effect as that produced by a number of forces.
For example, several people can jointly move a boulder but a strong person can move the same boulder all by himself. That is, the force applied by the strong man produces the same effect as that produced by the net force applied by all. The force applied by the strong man is the resultant force.

Forces are of two types:
• Balanced Force
• Unbalanced Force

Balanced Force

Forces which do not cause any change in state of rest or of uniform motion along a straight line are called balanced forces. The resultant of balanced forces is always equal to zero (because the forces are equal and opposite)

Unbalanced Forces

The forces acting on a body produce any change in state of rest or motion, then the forces are said to be unbalanced Force.
Unbalanced force acting on an object changes its speed or direction. The resultant of unbalanced forces is always greater than zero.

Galileo's Observation and Origin of Newtonian Mechanics

Aristotle and other medieval thinkers believed that the natural state of bodies is the state of rest. Galileo opposed this concept. Galileo observed that, when a ball was made to roll down an inclined plane, its speed increased.
An Object Moving
Down an Inclined Plane with Increasing Speed Similarly, when it was made to roll up the inclined plane, its speed decreased.
An Object Moving Upward with Decreasing Speed; He then tried rolling it on a horizantal plane. Galileo repeated this experiment by making the surface very smooth. He observed that the ball continued to move for a longer time. Galileo suggested that the speed of the ball moving on a horizontal plane would remain constant in the absence of an external force or force of friction
Galileo suggested that the natural tendency of all bodies is to oppose a change in their state of rest or motion.

Inertia

All objects have a tendency to continue in their state of rest or of uniform motion until an external force acts on it.
Or
Tendency of an object to resist any change in its state of rest or of uniform motion is called inertia. Or
Inertia can be defined as the property of matter by virtue of which it opposes any change in its state of rest or of uniform motion along a straight line.

Inertia is classified as

- Inertia of rest
- Inertia of motion
- Inertia of direction

Examples of Inertia of Rest

- A passenger standing in a bus leans backwards when the bus starts all of a sudden
- Fruits fall down when the branches of a tree are shaken
- Dust particles on a carpet falls when we beat the carpet with a stick.

  Examples of Inertia of Motion A passenger standing in a moving bus leans forward when the bus stops all of a sudden A man carelessly alighting from a moving train leans forward

Example of Inertia of Direction

- The water particles sticking to the cycle tyre are found to fly off tangentially

- Whenever a driver is negotiating a curve, the passengers experience force acting away from the centre of the curve Inertia of a body depends upon its mass. That is, massive objects possess more inertia than lighter ones.

Newton's First Law of Motion

A body continues to be in a state of rest or of uniform motion along a straight line unless an external force acts upon it.
This means that every object has a tendency to resist any change in its state of rest or motion. This tendency is inertia. This law is also known as law of inertia. Newton's first law of motion gives a qualitative definition of force.

Momentum

The momentum of an object is defined as the product of its mass and its velocity. Momentum is a vector quantity and its direction will be same as that of velocity.
It is represented by:
$p = mv$
where, m is the mass of the object, v is its velocity. SI unit of momentum is kg m/s.

Newton's Second Law of Motion

Newton's second law of motion states that rate of change of momentum is directly proportional to applied force and takes place in the same direction as the applied force .
Explanation
Consider a body of mass m, having an initial velocity u.

Let the body be acted upon by some force F for time t, such that its final velocity is v.
Initial momentum = m u
Final momentum = m v

Change in momentum in time t = m(v - u)

Change in momentum in unit time= $m\frac{(v-u)}{t}$

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

Change in momentum in unit time = ma

According to Newton's second law

Rate of change of momentum $F \propto m.a$

F = Km.a (K is the constant of proportionality)

If a body has unit mass and unit acceleration, such that force possessed by it is also one unit then 1 = K 11 or K = 1

F = ma

Or,

Force = mass acceleration

Unit of Force

F = ma We know that SI unit of mass is kg and acceleration is m/s^2.

SI unit of force is kgm/s^2.

But $1kgm/s^2$ is defined as 1 Newton in honour of Sir Issac Newton. $1\ N = 1\ kgm/s^2$

One Newton force is that force which produces an acceleration of 1 m/s2 on an object of mass 1 kg.

Impulse

Mathematical representation of Newton's second law of motion is

$$F = \frac{mv - mu}{t}$$

or

When the time of application of force is short then Ft is defined as impulse. Impulse is large force acting for a short duration. SI unit of impulse = N s or kg m/s.

Example for an impulsive force

When we kick a football, the kick lasts only for a fraction of a second. The force, which we apply on a football, is an example for impulsive force

Applications of Newton's Second Law of Motion

In a cricket match a fielder moves his arms back while trying to catch a cricket ball because if he tries to stop the fast moving ball suddenly then the speed decreases to zero in a very short time. Therefore the retardation of the ball will be very large. As a result the fielder has to apply a larger force to stop the ball. Thus, if he tries to stop a fast moving cricket ball the fielder may get hurt as the ball exerts a great pressure on the hands but if he tries to stop it gradually by moving his arms back then the velocity decreases gradually in a longer interval of time and hence retardation decreases. Thus the force exerted by ball on the hand decreases and the fielder does not get hurt.

Newton's Third Law of Motion

"To every action there is an equal and opposite reaction".

Some of the situations in daily life to illustrate Newton's third law of motion

- When we walk on the ground, then our foot pushes the ground backward (action force) and the ground in turn exerts a force on the foot (reaction force) pushing the foot forward
- When a man jumps from a diving board he pushes the board (action force) and the board in turn pushes the man forward in the opposite direction (reaction force)
- The birds, while flying, push the air downwards with the help of their wings (action force) and the air in turn exerts a force on the bird in the upward
- direction (reaction force)
- A swimmer pushes the water in the backward direction (action force) and the water exerts a force on the swimmer (reaction force) which pushes him forward

Law of Conservation of Momentum

If a group of bodies are exerting force on each other, i.e., interacting with each other, their total momentum remains conserved before and after the interaction provided there is no external force acting on them.

Suppose two objects (two balls A and B, say) of masses mA and mB are travelling in the same direction along a straight line at different velocities uA and uB, respectively. And there are no other external unbalanced forces acting on them. Let uA > uB 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 vA and vB are the velocities of the two balls A and B after the collision, respectively

The rate of change of its momentum (or F_{AB}, action) during the collision will be

$$F_{AB}=m_A \frac{(v_A-u_A)}{t}$$

Similarly, the rate of change of momentum of ball B (= F_{BA} or reaction) during the collision will be

$$F_{BA}=m_B \frac{(v_B-u_B)}{t}$$

According to the third law of motion,

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

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

$m_AV_A-mu_A=-m_BV_B + m_Bu_B$

$m_Au_A + m_Bu_B = m_BV_B + m_AV_A$

Since ($m_Au_A + m_Bu_B$) is the total momentum of the two balls A and B before the collision and ($m_Av_A + m_Bv_B$) .

i.e., Total momentum before collision is equal to the total momentum after collision, which is nothing but law of conservation of momentum.

Applications of Law of Conservation of Momentum, Newton's Third Law of Motion

Recoil of a Gun When a bullet is fired from a gun, the gases produced in the barrel exerts a tremendous force on the bullet (action force). As a result, the bullet moves forward with a great velocity called the muzzle velocity. The bullet at the same time exerts an equal force on the gun in the opposite direction (reaction force). Due to this the gun moves backwards. This backward motion of the gun is called the recoil of the gun. The velocity with which the gun moves backwards is called the recoil velocity.