Newton's Laws of Motion

Sir Isaac Newton gave the three laws of motion in the 17th century. These laws are widely used in the field of classical mechanics. They are valid almost everywhere. The laws are briefly stated below.

- ***Newton's 1st law*** states that a body continues to be in a state of rest or of uniform motion along a straight line, unless it is acted upon by an external force to change the state.
- ***Newton's 2nd law*** states that the rate of change of linear momentum of a body is directly proportional to the external force applied on the body and this change always takes place in the direction of force applied.
- ***Newton's 3rd law*** states that for every action there is an equal and opposite reaction. i.e. the forces of action and reaction are always equal and opposite.

Explanation of the Newton first law:

Newton first law defines the force:

According to the Newton first law of motion a body continues to be in a state of rest or of uniform motion along a straight line, unless it is acted upon by an external force to change the state. This means that force applied on a body alone can change its state of rest or state of uniform motion along a straight line. Hence we define the force as an external effort in the form of push or pull which moves or tries to move at rest; stops or tries to stop a body in motion; changes or tries to change the direction of motion of a body. Hence newton first law of motion defines force.

Newton first law defines the inertia:

According to the Newton first law of motion a body continues to be in a state of rest or of uniform motion along a straight line, unless it is acted upon by an external force to change the state. This means that a body on its own cannot change its state of rest or state of uniform motion along a straight line.

The inability of a body to change the state of rest or state of uniform motion along a straight line is called inertia of the body. Hence the newton first law defines the inertia and is rightly called law of inertia.

Inertia of body is measured by mass of the body. Heavier the body, greater is the force required to change its state and hence greater is its inertia.

There are 3 types of inertia:

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

Inertia of rest:
It is the inability of a body to change by itself its state of rest. This means a body at rest remains at rest at cannot start moving on its own.
Inertia of motion:
It is the inability of a body to change by itself its state of uniform motion. That is a body in uniform motion can neither accelerate nor retard on its own and come to rest.
Inertia of rest:
It is the inability of a body to change by itself its state of direction of motion. That is a body continues to move along the same straight line unless compelled by some external force to change it.

Explanation of the Newton second law:

Newton's 2nd law states that the rate of change of linear momentum of a body is directly proportional to the external force applied on the body and this change always takes place in the direction of force applied.

It means that when a bigger force is applied on a body, its linear momentum changes faster and vice-versa. The momentum will change in the direction of the applied force.

Suppose, m = mass of body
v = velocity of the body
Therefore, The linear momentum of the body is

$$\mathbf{p = mv} \qquad \text{..................} \ (1)$$

Let, **F**= external force applied on the body
dp= a small change in the linear momentum in time ***dt***
Therefore,
The rate of change of linear momentum of the body is ***dp/dt***

According to the newton law:

$$dp/dt \propto F$$

or $$F \propto dp/dt$$

or $$F = k\ dp/dt \qquad \text{..................} \ (2)$$

where k is the constant of proportionality

Using …… (1),

$$F = k\ d(mv)/dt$$

$$F = k\ m\ dv/dt$$

But we know that **a=dv/dt** represents acceleration of body

$$F = k\ m\ a \qquad \text{..................} \ (3)$$

The value of constant to proportionality **k** depends on the units adopted for measuring the force. Both in S.I and in C.G.S systems, the unit of force is selected in such a manner that **k=1**.

Now put the value of k in …… (3), we get

$$\mathbf{F = m\ a} \qquad \text{……………………} \ (4)$$

The direction of F is same as the direction of a. Therefore, equation (4) represents equation of motion of the body.
The magnitude of force can be calculated by multiplying mass of the body and the acceleration produced in it. Hence, second law of motion gives us the measure of force.

Explanation of the Newton third law:

Newton's 3rd law states that for every action there is an equal and opposite reaction. i.e. the forces of action and reaction are always equal and opposite.

Here the term action means the force exerted by one body on the other, while the term reaction means the force exerted by the second body on the first.

If $\mathbf{F_{AB}}$ is the force exerted on the *body A by body B* and $\mathbf{F_{BA}}$ is the force exerted on the *body B by body A*, then according to the Newton third law of motion.

$$\mathbf{F_{AB} = -F_{BA}} \qquad \text{…………………} \ (5)$$

To prove this law, consider an isolated system consisting of two bodies A and B moving along a straight line.

Let them collide so that mutually act and react on each other. Due to this there velocities change and hence linear momentum will also change.

Let $\mathbf{\Delta p_1}$ and $\mathbf{\Delta p_2}$ be the change in linear momentum of the body A and B respectively. According to the law of conservation of linear momentum, the net change in the momentum of the system is zero. i.e.

$$\mathbf{\Delta p_1 + \Delta p_2 = 0} \qquad \text{……………………}(6)$$

$$\text{(or)} \quad \mathbf{\Delta p_1 = -\Delta p_2}$$

Dividing both sides Δt and taking the limit as Δt->0, we get

$$\underset{\Delta t \to 0}{\text{Limit}} \left(\frac{\Delta \vec{p}_2}{\Delta t} \right) = - \underset{\Delta t \to 0}{\text{Limit}} \left(\frac{\Delta \vec{p}_1}{\Delta t} \right)$$

$$\frac{d\vec{p}_2}{dt} = - \frac{d\vec{p}_1}{dt} \qquad \text{…} \qquad \text{…………………}(7)$$

Rate of change of linear momentum of B = -Rate of change of linear momentum of A

(or) Force on B = -Force on B

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

Hence the force of action and reaction are equal and opposite, which proves newton 3rd law of motion.

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<u>Examples of Newton first law:</u>

Brakes applied by a Bus Driver Abruptly:

While travelling on a bus, when the bus driver abruptly applies the breaks, we tend to feel a momentary pull in the forward direction. The reason behind this jerk felt by the passengers sitting inside the bus is the law of inertia. Due to the inertia of motion, our body continues to maintain a state of motion even after the bus stops, thereby pushing us in the forward direction.

<u>Examples of Newton second law:</u>

Pushing a Car and a Truck:

Newton’s second law of motion can be observed by comparing the acceleration produced in a car and a truck after applying an equal magnitude of force to both. It is easy to notice that after pushing a car and a truck with the same intensity, the car accelerates more than the truck. This is because the mass of the car is less than the mass of the truck.

<u>Examples of Newton third law:</u>

Pushing the Wall:

When a person sitting on a chair pushes the wall with his feet, the chair moves backward. The motion of the chair can not exist without the existence of a force. Therefore, the force responsible to move the chair is the reaction force. The reaction force is always exerted in the direction opposite to the direction of the action force. Hence, the chair moves in a backward direction.