Laws of motion

V Vijaykiran
M.Sc., B.Ed., NET
SIGMA Physics Resource Centre
http://www.sigmaprc.in

Laws of motion

Newtons first law of motion

Every body continues to be in a state of rest or of uniform motion in a straight line unless exerted upon by an external force.

Analysis

- First law gives qualitative introduction of force.
- The property of a body by which it tends to continue its state (of rest or of uniform motion in a straight line) is called inertia.
- Inertia may be classified as inertia of rest and inertia of motion
- Equilibrium is a state characterized by the net force acting on the body being zero. A body in equilibrium continues to remain at rest or move with uniform velocity in a straight line
- Mass is the measure of inertia.
- SI unit of mass is kilogram (kg)

Linear momentum (p)

Linear momentum is defined as the product of mass of a body and its velocity.

$$\bar{p} = m\bar{v}$$

- linear momentum is a vector quantity
- SI unit of linear momentum is kg ms^{-1}
- It is also informally called 'quantity of motion' in a body
- Change in linear momentum of a body may be due to
  - (a) Change in its mass
  - (b) Change in magnitude of velocity
  - (c) Change in its direction of velocity

Newton's second law :

Rate of change of linear momentum of a body is directly proportional to the net external force acting on it and takes place in the direction of the applied force.

$$\boldsymbol{F}_{\text{net}} = k\frac{d\boldsymbol{p}}{dt}$$

Analysis

- Newton's 2nd law gives the quantitative introduction of force
- Force is the cause of change in the state of any body
- Force is a vector quantity
- SI unit of force is newton (N)

Laws of motion

Derivation of $\boldsymbol{F} = m\boldsymbol{a}$

Considering a body of mass m subjected to a net force $\boldsymbol{F}$. From Newton's second law of motion we get

$$\boldsymbol{F}_{\text{net}} = k\frac{d\boldsymbol{p}}{dt}$$

Using the relation $\boldsymbol{p} = m\boldsymbol{v}$,

$$\boldsymbol{F}_{\text{net}} = k\frac{d(m\boldsymbol{v})}{dt}$$

When mass of the body remains constant during its motion

$$\boldsymbol{F}_{\text{net}} = k\,m\frac{d\boldsymbol{v}}{dt}$$

Using the relation $\boldsymbol{a} = d\boldsymbol{v}/dt$

$$\boldsymbol{F}_{\text{net}} = k\,m\boldsymbol{a}$$

The value of k is set equal to 1 in defining 1 newton as the amount of force required to cause an acceleration of $1 ms^{-2}$ in a body of mass 1 kg. Therefore

$$\boxed{\boldsymbol{F}_{\text{net}} = m\boldsymbol{a}}$$

Impulse (J)

Impulse is defined as the product of force and the small interval of time for which the force acts on a body.

$$\boldsymbol{J} = \boldsymbol{F}\ \mathrm{d}t$$

$$\boldsymbol{F} = \frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}$$

$$\boldsymbol{J} = \frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}\mathrm{d}t$$

$$\boldsymbol{J} = \mathrm{d}\boldsymbol{p}$$

$$\boldsymbol{J} = \boldsymbol{p}_{\mathrm{f}} - \boldsymbol{p}_{\mathrm{i}}$$

Impulse is equal to change in momentum of the body.

SI unit of impulse is Ns or kgms^{-1}

Law of conservation of linear momentum

When the net external force acting on a system is zero then the total linear momentum of the system remains constant.

$$\boldsymbol{F} = \frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}$$

If $\boldsymbol{F}$ is zero then

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = 0$$

$$\mathrm{d}\boldsymbol{p} = 0$$

$$\boldsymbol{p} = \text{constant}$$

$$\boldsymbol{p}_{\text{final}} = \boldsymbol{p}_{\text{initial}}$$