Laws of Motion

Newton's law of motion

Newton's first law of motion:

Everybody in the universe will remain in the state of rest or of uniform motion in a straight line unless no external force act on it. It gives the definition of force as

"Force is that external agent which changes or tends to change the state of rest or of uniform motion in a straight line."

Inertia is the tendency of a body to remain in its own state unless external force act on it. It is divided as

a) Inertia of rest

b) Inertia of motion

c) Inertia of direction

Hence, Newton's first law of motion is also called **law of inertia**.

Momentum (P): Quantity of motion contained by body. It is equal to the product of mass and velocity.

$\therefore$ Momentum (P) = mv

It is a vector quantity.

Newton's second law of motion:

Rate of change in momentum of a body is directly proportional to the force act on body and displacement takes place in the direction of force.

$\therefore$ Force $(F)=\frac{dp}{dt}=\frac{d(mv)}{dt}=\mathrm{m}\frac{\mathrm{d}v}{\mathrm{dt}}+v\frac{\mathrm{dm}}{\mathrm{dt}}$

- If m is constant i.e. for a body $\frac{\mathrm{dm}}{\mathrm{dt}}=0$

  So, F = ma

- If *v* is constant then $\frac{\mathrm{dm}}{\mathrm{dt}}=0$

  So, $\mathrm{F}=v\frac{\mathrm{dm}}{\mathrm{dt}}$

Newton's third law of motion:

For every action, there is an equal and opposite reaction.

Action and reaction act on two different bodies so they never cancel each other.

Impulse

The net effect of force acting on a body is measured by a quantity called impulse.

$\therefore$ Impulse (I) = $\int_{t_1}^{t_2} F\cdot dt=\int_{P_1}^{P_2}\frac{dp}{dt}\cdot dt=P_2-P_1$

Hence, Impulse (I) = Change in momentum

Free body diagram

While solving the problems relating the Newton's law of motion, free body diagram is used. During free body diagram, only the body of our consideration is taken and all the forces acting on it are drawn. The net force acting on body give the acceleration so

F_R = ma

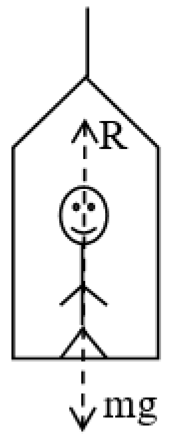
Motion in a lift

When a person of mass `m' is standing on the floor of lift at rest then R = mg is called wt. of person.

For uniform motion of lift a = 0 so

Net force = R -mg = ma

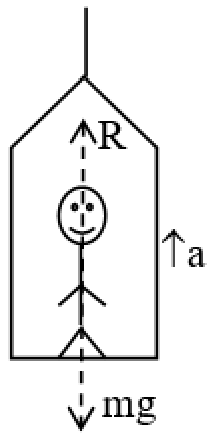
$\Rightarrow$$\mathrm{R}$ = mg



- When lift is accelerating upward
  When lift is accelerating upwards with an acceleration `a' then

  R -mg = ma

  $\Rightarrow$ R = mg + ma

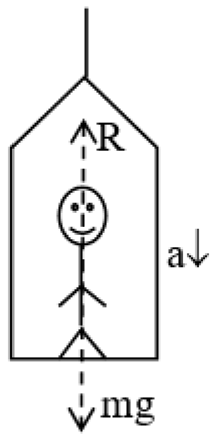
  

  Reaction of floor measure the apparent wt. of body which increases.

- When lift is accelerating downwards
  When lift is accelerating downwards with an acceleration `a' then

  mg -R = ma

  or, R = mg -ma

  Reaction of floor decreases. Hence apparent weight of person decreases.

Principle of conservation of linear momentum

When no external force act on the system of colliding bodies then the total linear momentum of system remain constant (conserved).

$$\therefore \mathrm{F} = \frac{dp}{dt}$$

If $\mathrm{F} = 0$ then $\frac{dp}{dt} = 0$

$\Rightarrow$$\mathrm{P}$ = constant

$\Rightarrow$$\mathrm{mv}$ = constant

If two bodies of mass `$m_1$' and `m_2' moving with `$u_1$' and `u_2' collide then their velocities changes to `$v_1$' and `v_2' respectively then

$m_1 u_1 + m_2 u_2 = m_1 V_1 + m_2 V_2$

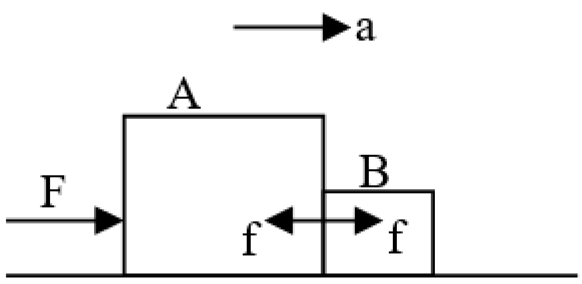
When two bodies move together after collision then

$$V = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$$

Contact force

When two blocks of mass m_1 and m_2 are kept in contact of each other and a force F is applied on A then,

Acceleration $(a) = \frac{F}{m_1 + m_2}$



f be the contact force between two blocks then

For Mass m_1,

$F - f = m_1 a$

$\Rightarrow f = F - m_1 a$

$\therefore f = F - F \cdot \frac{m_1}{m_1 + m_2} = F\left(\frac{m_2}{m_1 + m_2}\right)$

Rocket propulsion

The propulsion of rocket is based on the principle of conservation of linear momentum or Newton's third law of motion.

A rocket of initial mass M_0 eject combust fuel at the rate of $\frac{dm}{dt}$ at any instant at which M be the mass of rocket. The velocity of ejected gas relative to rocket is v then

- Force on rocket due to ejection of gas in absence of gravity is
  $F = \frac{dm}{dt} \cdot v$
- Acceleration on rocket due to this force is
  $a = \frac{F}{M} = \frac{dm}{dt} \cdot \frac{v}{M}$
- Net force on rocket due to gravity
  $F = \frac{dm}{dt} v - Mg$
- Acceleration on rocket in gravity is
  $a = \frac{F}{M} = \frac{dm}{dt} \cdot \frac{v}{M} - g$

Tension inside acceleration train

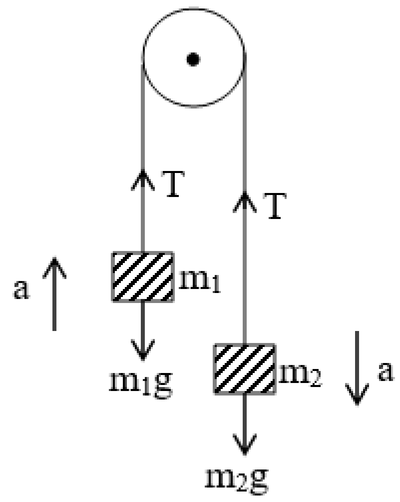
When a train is accelerating with `a' in horizontal direction and a body is suspended from ceiling of train then resultant acceleration is

$a_R = \sqrt{g^2 + a^2}$

Tension on rope (T) $= m a_R = m\sqrt{g^2 + a^2}$

Single pulley system

When two blocks of mass m_1 and m_2 are connected by a string and passes over smooth pulley then m_1 move up & m_2 down if $m_2 > m_1$ then



For m_1

$$\mathrm{T - m_1 g = m_1 a \ldots\ldots\ldots (1)}$$

For m_2

$$\mathrm{m_2 g - T = m_2 a \ldots\ldots\ldots (2)}$$

Adding (1) and (2),

$$\mathrm{a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g = \frac{difference\ in\ mass}{sum\ of\ mass} \times g}$$

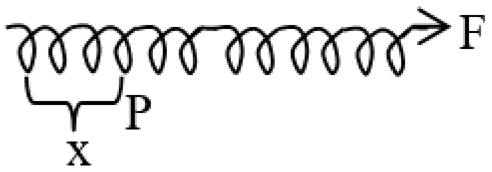
For tension on string,

$$\mathrm{T = \frac{2m_1m_2}{m_1 + m_2} g = \frac{2 \times\ product\ of\ mass}{sum\ of\ mass} \times g}$$

Pulling a rope on floor

When a rope of mass M and length l is pulled by a force F on floor then

$$a = \frac{F}{M}$$



P is a point at x from free end then

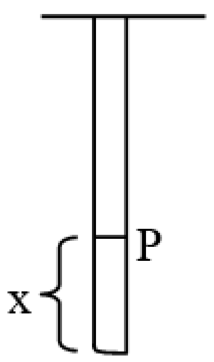
$$\mathrm{T} = \left(\frac{\mathrm{M}}{l}\mathrm{x}\right)\mathrm{a} = \frac{\mathrm{M}}{l}\mathrm{X} \cdot \frac{\mathrm{F}}{\mathrm{M}} = \frac{\mathrm{x}}{l}\mathrm{F}$$

When distance of point is taken from end where pulled then

$$\mathrm{T} = \frac{\mathrm{M}}{l}(l - \mathrm{x})\mathrm{a} = \left(1 - \frac{\mathrm{x}}{l}\right)\mathrm{F}$$

Tension on chain due to its own weight

When a uniform chain of mass M & length l is suspended then tension at any point at a distance x fromfree end will be



$$\mathrm{T} = \frac{\mathrm{M}}{l} \cdot \mathrm{xg} = \left(\frac{\mathrm{x}}{l}\right)\mathrm{Mg}$$

If x is the distance of point from fixed end then

Tension (T) $= \frac{\mathrm{M}}{l}(l-\mathrm{x})\mathrm{g} = \left(1-\frac{\mathrm{x}}{l}\right)\mathrm{Mg}$