Law of Motion

1. **Newton's first law of motion:** Every body continues to be in the state of rest or of uniform motion unless it is compelled by an external unbalanced force to change that state.
2. The first law of motion gives the concepts of force and inertia.
3. Inertia is the inability of a body to change its state of rest or of uniform motion along a straight line in the absence of any external force
4. **Inertia is of three types**

   i) Inertia of rest

   ii) Inertia of motion and

   iii) Inertia of direction
5. **Inertia of rest**: The inability of a body to change its state of rest by itself is called inertia of rest.

   Eg: When a bus at rest starts suddenly passengers fall back.
6. **Inertia of motion**: The inability of a body to change its uniform motion by itself is called as inertia of motion. Eg: When a bus in uniform motion suddenly stops, the passengers fall forward.
7. **Inertia of direction**: The inability of a body to change its direction of motion by itself is called inertia of direction. Eg: When a bus takes a turn passengers will be pulled outwards.
8. **Force:** Force is that which changes or tries to change the state of rest or of uniform motion of a body along a straight line.
9. **Momentum:** Momentum is the product of mass and velocity ($\vec{P} = m\vec{v}$). SI unit is kg ms^{-1}. It is a vector quantity.
10. **Newton's second law of motion:** The rate of change of momentum of a body is directly proportional to the impressed force and it takes place in the direction of force.
11. Newton's second law gives the quantitative definition of force and defines the unit force.
12. $F = \frac{dp}{dt} = \frac{d(mv)}{dt}$ OR $F = m\left(\frac{dv}{dt}\right) + v\left(\frac{dm}{dt}\right)$

   (a) If m = constant , $F = m\frac{dv}{dt}$ = ma

(b) If v = constant , $F = v\frac{dm}{dt}$ (For a variable mass system)

13. A unit force: A unit force is one which when acting on unit mass produces unit acceleration in its direction. Unit of force : newton

Gravitational unit of force :1kgwt= 9.8 Newton

14. Rocket Propulsion

Velocity of a rocket at any instant of time is given by $v = u_0 + v_r \log_e \frac{m_0}{m}$

m_0 = mass of the rocket at t = 0

v_0 = velocity of the rocket at t = 0

m = mass of the rocket at any instant of time

v = velocity of the rocket at any instant of time

v_r = velocity of the exhaust gases relative to the rocket

a) If the rocjet is to moveup with constant speed over comming its weight then

Thrust on the rocket = $\left(\frac{dm}{dt}\right)u$ = Mg

b) If the rocket moves up with constant acceleration 'a'. then

Thrust on the rocket = $\left(\frac{dm}{dt}\right)u$ = Mg + Ma

15. A liquid of density d flowing through a pipe of length l and cross section A with a velocity V strikes a vertical wall normally

a) If the liquid comes to rest after striking the wall then $F = Av^2d$

b) If the liquid moves back with same velocity then $F = 2Av^2d$

c) Power P = $P = Av^3d$

d) If the rate of water ejected is n times the initial rate then, force become n^2 times and power becomes n^3 times.

c) If water reflects with a velocity v^1 then, $F = Avd\left(v + v'\right)$

e) Pressure exerted on the wall $p = \frac{F}{A}$

b) In the above case if water strikes the surface at angle θ with the normal and reflects with the same speed, force exerted on the wall is $2Av^2dCos\theta$.

16. If a machine gun fires 'n' bullets each of mass m with a velocity u in a time t , then the force required to hold the gun is $F = \frac{mnu}{t}$

17. If a plate of mass M is suspended in air by firing the bullets on to it

a) If bullets comes to rest after striking the plate then $\frac{mnu}{T} = Mg$

b) If the bullets gets reflected back with the same Velocity perpendicular to the plate, then

$2\frac{mnu}{T} = Mg$

18. A body of density d_B moves down in a liquid of density d_l then the acceleration of the body is given by $a = \left(\frac{d_B - d_l}{d_B}\right)g$

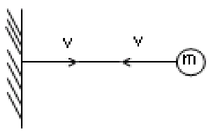
19. Linear Momentum

a) If the initial velocity of a body is $\bar{u}$ and final velocity is $\bar{v}$ then the change in momentum is given by $\overline{\Delta P} = m\left(\bar{v} - \bar{u}\right)$

$\left|\overline{\Delta P}\right| = m\sqrt{u^2 + v^2 - 2uv\cos\theta}$ Where θ is the angle between $\bar{u}$ and $\bar{v}$.

If v = u, $\left|\overline{\Delta P}\right| = 2mu\sin\left(\frac{\theta}{2}\right)$

b) If a ball of mass m strikes a wall normally and bounces back with same velocity, then the change in momentum is

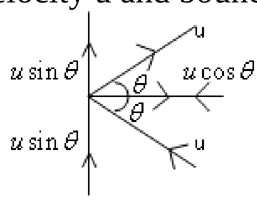


$\Delta\overline{P} = mv(i) - mv(-i)$

$\Delta\overline{P} = 2mvi$

The magnitude of the change in momentum is $\Delta P = 2mu$

c) If a ball of mass m strikes a wall at angle of incidence θ with a velocity u and bounces back with same velocity at the same angle



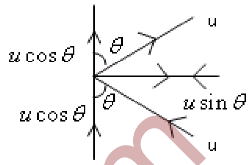
i) Along the wall, $\overline{\Delta P} = mu\sin\theta(j) - (mu\sin\theta)j = 0$

ii) Perpendicular to the wall,

$\overline{\Delta P} = mu\cos\theta(i) - mu\cos\theta(-i) \ = (2mu\cos\theta)i$

The magnitude of the change in momentum is $\left|\overline{\Delta P}\right| = +2mu\cos\theta$

d) If a ball of mass m strikes a wall at an angle θ with the wall with a velocity u and bounces back with same velocity at the same angle then



i) Along the wall , $\Delta\overline{P} = mu\cos\theta(j) - mu\cos\theta(i) = 0$

ii) Perpendicular to the wall,

$\Delta\overline{P} = mu\sin\theta(i) - mu\sin\theta(-i) \ = (2mu\sin\theta)j$

The magnitude of the change in momentum is $\left|\Delta\overline{P}\right| = 2mu\sin\theta$

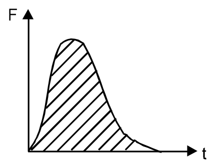
iii) A body of mass 'm' is released from a height 'h', the momentum of the body on reaching the ground is $m\sqrt{2gh}$

20. Impulse

i. Very large force acting for a short interval of time is called impulsive force. Eg: Blow of a hammer on the head of a nail.

ii. The impulse of a force is defined as the product of the average force and the time interval for which it acts.

Impulse J = $F_{AV}\,\Delta t = m\vec{v} - m\vec{u}$



iii. Impulse due to a variable force is given by the area under F–t graph.

iv. If a force F_1 acts on a body at rest for a time t_1 and after that another force F_2 brings it to rest again in a time t_2, then $F_1t_1 = F_2t_2$.

v. While catching a fast moving cricket ball the hands are lowered, there by increasing the time of catch which thus decreases the force on hands.

vi. A person jumping on to sand experiences less force than a person jumping on to a hard floor, because sand stops the person in more time.

21. The gravitational force that acts on a body is called its weight (W = mg). It is a vector always pointing in a vertically downward direction.

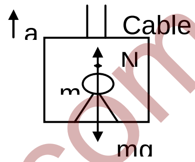
22. A bird is in a wire cage hanging from a spring balance when the bird starts flying in the cage, the reading of the balance decreases.

23. In the above case, if the bird is in a closed cage or air - tight cage and it hovers in the cage, the reading of the spring balance does not change.

24. In the above case for a closed cage if the bird accelerates upward reading of the balance is $R = W_{bird} + ma$, where m is the mass of the bird and a, its acceleration.

25. Apparent weight of a person in a lift

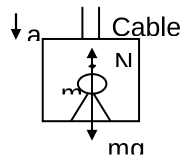
Consider a person of mass m in a stationary lift whose weight is W = mg



a) If the lift moves up with an acceleration 'a' apparent wt

$$W' = mg + ma \Rightarrow W' = W\left(1 + \frac{a}{g}\right)$$

b) If the lift moves down with an acceleration 'a'



$W' = mg - ma$ OR $W' = W\left(1 - \frac{a}{g}\right)$

c) If the lift is freely falling under gravity

i.e. If a = g, then $w' = 0$

d) If the lift is moving up or down with uniform velocity, i.e. if a = 0 then

$$W' = W = mg$$

26. Newton's third law: For every action there is an equal and opposite reaction.

27. Newton's first and third laws are only special cases of second law.

28. Limitations of Newton's law of motion

a) It is applicable only for speeds V << C (C = speed of light)

b) It is not applicable in the domain of atoms, molecules, and sub atomic particles.

c) It is not applicable when there is a very strong gravitational field.

d) The Newton III law is not applicable, when particles interact with each other by means of a force field.

e) Newton's laws are not applicable for very small accelerations. ($a < 10^{-10}\ ms^{-2}$)