SHORT NOTES: CLASS 11

CHAPTER 4: LAWS OF MOTION(PART-1)

1. **Force:** Force is an external effort in the form of push or pull which…
   (i) produces or tries to produce motion in a body at rest
   (ii) Stops or tries to stop a moving body.
   (iii) Changes or tries to change the direction of motion of the body.
2. **Frictional force**: Frictional force is defined as an opposing force that comes into play when one body moves or even tries to move over the surface of another body. The force of friction arises due to the irregularities between the surfaces at contact. Thus, the force of friction develops at the surfaces of contact of two bodies and opposes their relative motion.
3. **Aristotle's fallacy**: External force is required to keep the body in motion.

- ***Flaw:*** If there exist no friction, there would be no need of external force, F. But frictional force, f is always present in the natural world. He failed to realize that external force is required to counter the frictional force exactly, so that the two forces (F & f) sum to a zero net external force.

4. **The law of Inertia:** *by Galileo Galilei*

- **The state of rest and state of uniform linear motion (constant velocity) are equivalent.**
- **Inertia:** The tendency of a body to oppose any change in its state of rest or of uniform motion is called inertia of the body.

  If the net external force is zero, a body at rest remains at rest and a body in motion continuously moves with uniform velocity. This property is called inertia. Inertia means **resistance to change.**

  Types of Inertia:

(i) ***Inertia of rest:*** The tendency of a body to oppose any change in its state of rest.
Ex: when a bus starts suddenly in a forward direction, the bus's passengers fall backward.

(ii) ***Inertia of motion:*** The tendency of a body to oppose any change in its state of uniform motion.
Ex: the passengers fall forward when a fast-moving bus stops suddenly.

(iii) ***Inertia of direction:*** The tendency of a body to oppose any change in its direction of motion.
Ex: when a fast-moving bus negotiates a curve on the road, passengers fall toward the center of the curved road.

- **Inertia and mass:** It's more difficult to move a heavier object as compared to a lighter object. Therefore, heavier or more massive objects offer large inertia.

⇨ The inertia of a body is measured by its mass.

⇨ Inertia is the natural tendency of an object to resist any change in its state of rest or of motion.

⇨ The mass of the object is a measure of its inertia.

5. **Newton's first law of motion:** Everybody continuous in its state of rest or of uniform motion in a straight line unless compelled by some external unbalanced force to change that state. If the net external force on a body is zero, its acceleration is zero.

Newton's first law is also known as the law of inertia.

6. **Momentum:** The quantity of motion possessed by a moving body is known as momentum of the body. It is a vector quantity.
   Mathematically, momentum of a body is equal to the product of mass and velocity of the body.

Momentum= Mass x velocity

$$\vec{P} = m.\vec{v}$$

Unit is kgm/s; Dimensional formula: $[MLT^{-1}]$.

7. **Newton's second law of motion:** The rate of change of momentum of an object is directly proportional to the force acting on the object and the change in the momentum takes place always in the direction of applied force on the object.
   i.e., **F α dp/dt** where, **dp** is the change in momentum and **dt** is the time taken for this change.

- The greater the change in momentum in a given time, the greater is the force that needs to be applied.
- Shorter time for change needs greater applied force.

Mathematical formulation:

Consider an object of mass, **m** moving with initial velocity, $\vec{v}$. let a force, **F** acts on the body and its velocity changes to **v + Δv** after time, Δ**t**.

Initial momentum of the body, **p= m.v**

Change in momentum of the body, $\Delta\vec{p} = m.\Delta v$

Time taken for this change in momentum = Δt

As, $\vec{F} \propto \Delta\vec{p}/\Delta t$

⇨ **F = k Δp/Δt** (where, k is a constant of proportionality)

⇨ **F =k dp/dt** (taking the limit Δt → 0, the term Δp/Δt becomes dp/dt)

⇨ **F =k d(mv)/dt** ⇨ **F = km dv/dt** ⇨ **F = kma**

⇨ **F = ma** (for k=1)

Force acting on an object is directly proportional to its mass and acceleration.

Unit of force – Newton, N or kgm/s^2

1 N = 1 kgm/s^2

Dimension of force: $[MLT^{-2}]$

- **1 Newton:** 1 Newton is that much force that produces an acceleration of 1 m/s^2 in a body of mass 1 kg.
- **Application:** A cricket player lowers his hand while catching the ball. Because, in doing so, the fielder increases the time during which the high velocity of the moving ball decreases to zero. Thus, acceleration of the ball is decreased and therefore, impact of catching the fast-moving ball is also reduced.

- **Some important points about the second law:**
  (i) **F=0 => a=0** : consistent with the first law.
  (ii) It is a vector law: **$F_x = dp_x/dt = ma_x$, $F_y = dp_y/dt = ma_y$, $F_z = dp_z/dt = ma_z$**

8. Impulse: It is a measure of total effect of the force. A large force acting for a short time to produce a finite change in momentum is called Impulsive force.
Impulse = force x time = change in momentum.
For Example, A ball hits a wall and bounces back.
Applications:
(i) A cricket player lowers his hands to catch the ball.
(ii) Vehicles are provided with shockers.
(iii) Boogies of trains are provided with buffers.

9. Newton's third law of motion: Action and Reaction Forces.
"To every action, there is an equal and opposite reaction".
The third law of motion states that when one object exerts a force on another object, the second object instantaneously exerts an equal and opposite force back on the first.
Note:
a) Action and Reaction forces are always equal in magnitude but opposite in direction.
b) They act on two separate bodies.
c) As they act on two different bodies, therefore they don't cancel each other. i.e., they are not balanced forces.
d) Though action and reaction forces are equal in magnitude, they may not produce equal acceleration. This is because they act on bodies of different masses.

Examples:
a) An object resting on a table.
b) A ball rebounds after striking against a floor.
c) Walking of a person- we push the ground in the backward direction. Ground pushes us forward.
d) Swimming: The swimmer pushes water backward. The reaction offered by the water to the swimmer pushes him forward.
e) When a bullet is fired from a gun, the gun recoils i.e., it moves backward.
f) Motion of the rockets and jet airplanes.

The third law is contained in the first law:

$$\overrightarrow{F_{AB}} = -\overrightarrow{F_{BA}} \qquad \overrightarrow{F_{AB}} + \overrightarrow{F_{BA}} = 0$$

Net external force = 0

The third law is contained in the second law: consider two objects A and B moving in the same straight line and colliding. Let $\Delta\vec{P_1}$ and $\Delta\vec{P_2}$ be the change in momenta of A and B after collision.

$$\Delta\overrightarrow{P_1} + \Delta\overrightarrow{P_2} = 0$$ **(law of conservation of momentum)**

$$\Delta\overrightarrow{P_1} = -\Delta\overrightarrow{P_2}$$

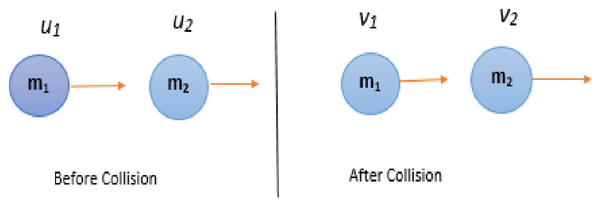
$$\lim_{\Delta t\to 0}\left(\frac{\Delta\overrightarrow{P_2}}{\Delta t}\right) = \lim_{\Delta t\to 0}\left(\frac{\Delta\overrightarrow{P_1}}{\Delta t}\right)$$

$$\frac{d\overrightarrow{P_2}}{dt} = -\frac{d\overrightarrow{P_1}}{dt}$$

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

10.Law of conservation of momentum: According to this law, the total momentum of the system remains constant if no external force acts on the system.

i.e., P= constant if F_{ext}=0.



Consider two objects of masses m_1 and m_2 moving in the same direction in the same straight line with velocities u_1 and u_2.

Let $u_1 > u_2$. After some time, the two balls collide.

Let F_{12} => force exerted on object 2 due to 1.

And F_{21} => force exerted on object 1 due to 2.

Suppose v_1 and v_2 are the velocities of the object after collision.

Momentum of object 1 before collision = m_1u_1

momentum of object 2 before collision = m_2u_2

momentum of object 1 after collision = m_1v_1

momentum of object 2 after collision = m_2v_2

$F_{12} = m_2 (v_2 - u_2)/t$; $F_{21}= m_1(v_1 - u_1)/t$

According to third law of motion:

$F_{12} = - F_{21}$

⇨ $m_2 (v_2 - u_2)/t = - m_1(v_1 - u_1)/t$

⇨ $m_2v_2 - m_2u_2 = - m_1v_1 + m_1u_1$

⇨ $m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$

⇨ Total momentum after collision = Total momentum before collision

Type 1: Bullet and Gun:

a) The total initial momentum of the bullet and the gun is zero as they are at rest.

b) The total final momentum of the gun-bullet system must be zero. Therefore, the velocity of the gun and bullet must be in the opposite direction.

Final Momentum = Initial Momentum

$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

⇨ $m_1v_1 + m_2v_2 = 0$ ⇨ $m_1v_1 = - m_2v_2$ ⇨ $v_1 = - m_2v_2/ m_1$

None of the quantities in the above equation is negative. Therefore, a negative sign implies that the velocity of the gun is in the direction opposite to the bullet.

Type 2: The colliding bodies joined and get entangled after collision.

Final Momentum = Initial Momentum

$$(m_1 + m_2) v = m_1u_1 + m_2u_2$$

Type 3: Two colliding bodies interact and then separate:

Final Momentum = Initial Momentum

$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

As, $p = m_1v_1 + m_2v_2 + m_3v_3 +$ _____________________ $+ m_nv_n$

$= MV_{CM}$

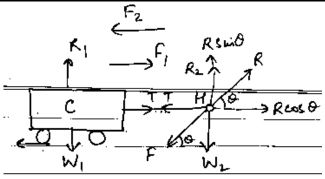
⇨ **$F = dp/dt = MdV_{CM}/ dt = Ma_{CM}$**

In case of an isolated system, F =0

⇨ **dp/dt = 0**

⇨ **p = Constant**

11.Horse and cart problem:



The horse pushes the ground backward by a force F, the Ground exerts a force, N on the horse and the cart will move if NCosθ > f

F_1 = force on the cart by the horse.

F_2 = force on the horse by the cart.

Acceleration of the cart = $\frac{F_1 - f}{M_C}$

Acceleration of the horse = $\frac{N\cos\theta - F_2}{M_h}$

NCosθ and f : Self-adjustable

adjust so that : $\frac{T-f}{M_C} = \frac{N\cos\theta - T}{M_h}$

12.The Apparent weight of a man in a lift/elevator:

(i) Elevator at rest: v = 0 and a = 0 :N = mg : Apparent weight = Actual weight

(ii) Elevator is moving uniformly in an upward/downward direction: N = mg: v = constant and a = 0: Apparent weight = Actual weight

(iii) Elevator is accelerating upwards:

a) v = variable and a < g: N – mg = ma => N = m (g + a) **:** Apparent weight > Actual weight

b) v = variable and a = g: N – mg = mg => N = 2 mg : Apparent weight = 2 Actual Weight

(iv) Elevator is accelerating downwards:

a) v = variable and a < g: mg - N = ma => N = m (g - a) : Apparent weight < Actual weight

b) v = variable and a = g: mg – N = mg => N = 0 : Apparent weight = 0 : Weightlessness

c) v = variable and a > g: N = m(g – a) => N = -ve : Apparent weight = -ve : person will rise from the floor and stick to the ceiling.

13.Connected motion:

$m_1 > m_2$

$m_1g – T = m_1a$……………..(1)

$T – m_2g = m_2a$……………..(2)

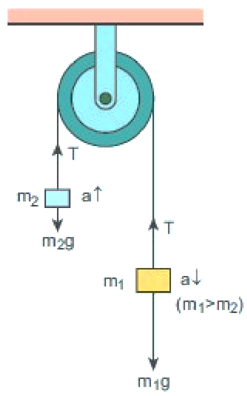
1) + (2) gives

$(m_1 – m_2)g = (m_1 + m_2)a$

➩ a = $\frac{(m_1 - m_2)g}{m_1 + m_2}$

Clearly, a < g

1) ÷ (2) gives



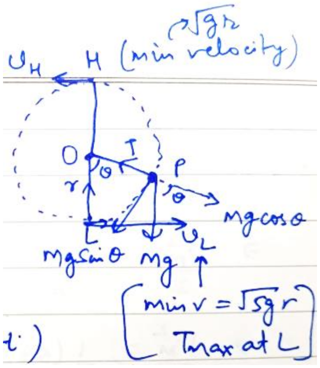
$$\frac{m_1 g - T}{T - m_2 g} = \frac{m_1 a}{m_2 a} = \frac{m_1}{m_2}$$

$$m_1 m_2 g - T m_2 = T m_1 - m_1 m_2 g$$

$$T(m_1 + m_2) = 2 m_1 m_2 g$$

$$T = \frac{2 m_1 m_2 g}{m_1 + m_2}$$

14. Dynamics of Non-uniform circular motion: Under the action of torque, it requires angular acceleration, therefore, angular velocity and angular momentum will change, and hence, velocity, momentum, and kinetic energy will change.



$\alpha = \frac{d\omega}{dt}, \tau = I\alpha$

At H:

Motion of a body, tied to one end of the string, whirled in a (vertical circle)

$$T - mg\cos\theta = \frac{mv^2}{r}$$

⇨ $T = \frac{mv^2}{r} + mg\cos\theta$

T: minimum, $\cos\theta = -1$(minimum)

⇨ $\Theta = 180^o$ (Highest Point)

If $T_{min} < 0$

⇨ String will slack and body will fall from H.

Therefore, $T_{min} \geq 0$

$T_{min} = \left(\frac{mv_H^2}{r} - mg\right) \geq 0$

⇨ $\frac{mv_H^2}{r} \geq mg$ ⇨ $v_H \geq \sqrt{gr}$

At L: Total mechanical energy at L = Total mechanical energy at H

$$\frac{1}{2}mv_L^2 = \frac{1}{2}mv_H^2 + mg(2r)$$

⇨ $\frac{1}{2}v_L^2 = \frac{1}{2}v_H^2 + g(2r)$ ⇨ $v_L^2 \geq 5gr$

⇨ $\frac{1}{2}v_L^2 \geq \frac{1}{2}(gr) + 2gr$ ⇨ $v_L \geq \sqrt{5gr}$

T: max, $\cos\theta = +1(max)$

⇨ $\theta = 0^0(lowest\ point)$ ⇨ $T_L \geq 6mg$

⇨ $T_{max} = \frac{mv_L^2}{r} + mg$

⇨ $T_{max} \geq 5mg + mg(= 6mg)$

At M: Total mechanical energy at M = Total mechanical energy at L

$$= \frac{1}{2}mv_M^2 + mgr = \frac{1}{2}mv_L^2$$

⇨ $\frac{1}{2}v_M^2 = \frac{1}{2}v_L^2 - gr$ ⇨ $v_M \geq \sqrt{3gr}$

⇨ $\frac{1}{2}v_M^2 \geq \frac{1}{2}(5gr) - gr$

$\theta = 90^0$

⇨ $T_M = \frac{mv_M^2}{r} + mg\cos 90^0$

⇨ $T_M \geq 3mg$

⇨ $T_M = \frac{mv_M^2}{r} \geq 3mg$