CHAPTER-4: LAWS OF MOTION

Part–1 : Newton's Laws & Friction

1. Newton's First Law

With no forces acting on it, the ball keeps moving at the same speed in the same direction, or will remain be in rest.

Law of Inertia

A body continues in its state of rest or uniform motion unless acted upon by an external unbalanced force.

2. Momentum

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

SI Unit

kg m s^{-1}

3. Newton's Second Law

$$Fnet = ma$$

For constant mass

$$\vec{F} = m\vec{a}$$

Force related with linear momentum as:

$$\vec{F} = \frac{d\vec{P}}{dt}$$

4. SI Unit of Force

Newton

$$1N = 1kgms^{-2}$$

5. Impulse

$$\vec{J} = \vec{F}\Delta t = \Delta\vec{P}$$

6. Newton's Third Law

Force of person on box and force of box on person are equal in magnitude, opposite in direction, and act on different objects

Contact example

Pushing a box, Colliding balls, Box on table

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

7. Weight

$$W = mg$$

Where

- M = Mass
- g= 9.8 m/s^2

8. Normal Reaction

For horizontal surface

$$N = mg$$

9. Static Friction

$$f_s \leq \mu_s N$$

Maximum Static Friction

$$f_{s,\max} = \mu_s N$$

10. Kinetic Friction

$$f_k = \mu_k N$$

11. Coefficient of Friction

$$\mu = \frac{f}{N}$$

12. Angle of Friction

$$\tan\phi = \mu$$

13. Angle of Repose

$$\tan\theta = \mu$$

14. Motion on Smooth Horizontal Surface

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

15. Motion with Friction

$$a = \frac{F - f}{m}$$

Part–2 : Inclined Plane • Pulley • Elevator • Circular Motion Applications

1. Motion on a Smooth Inclined Plane

Inclined Plane Acceleration

2. Components of Weight

Parallel to Plane

$$w = mgsin\theta$$

Perpendicular to Plane

$$w = mgcos\theta$$

3. Normal Reaction

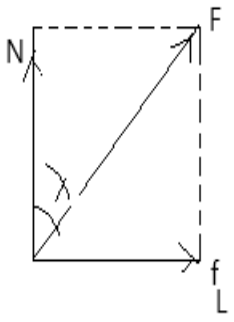
Smooth Plane

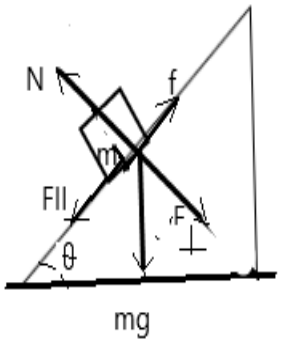
$$N = mg\cos\theta$$

4. Friction on Inclined Plane

Limiting Friction

$$f = \mu N$$





$$f_L = \mu_s N = \mu N$$

Therefore

$$f = \mu mg\cos\theta$$

Angle of Friction (λ)

$$\lambda = tan^{-1}\mu$$

Angle of Repose (α)

$$\alpha = tan^{-1}\mu$$

Driving Force (Down the Plane),

$$F = mg\sin\theta$$

Note:

1. **If $\theta < \alpha$, *the block is stationary*.**
2. **If $\theta = \alpha$, *the block is about to slide***
3. **If $\theta > \alpha, F > f_L$, *the block slides down with acceleration*.**
   And, the acceleration is,

$$a = \frac{F - f_L}{m} = g(\sin\theta - \mu\cos\theta)$$

5. Acceleration with Friction

Moving Down the Plane

$$a = g(\sin\theta - \mu\cos\theta)$$

Moving Up the Plane

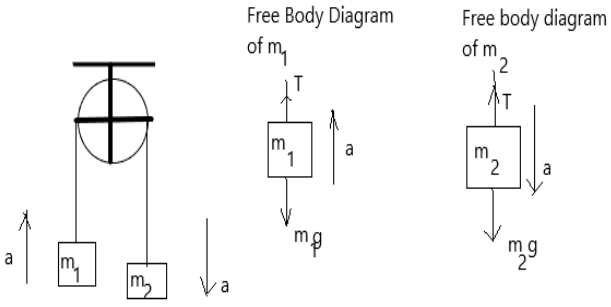
$$a = g(\sin\theta + \mu\cos\theta)$$

6. Connected Bodies

For two masses
(Ideal Pulley)

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

7. Tension in String



For Mass m_1

$$T = m_1(a + g)$$

For Mass m_2

$$T = m_2(g - a)$$

8. Elevator

Moving Upward

Normal Reaction

$$N = m(g + a)$$

Moving Downward

$$N = m(g - a)$$

Free Fall

$$N = 0$$

9. Apparent Weight

$$\text{Apparent Weight} = N$$

10. Banking of Roads

Ideal Banking

$$\tan\theta = \frac{v^2}{rg}$$

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11. Circular Motion

Centripetal Force

$$F = \frac{mv^2}{r}$$

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12. Centripetal Acceleration

$$a = \frac{v^2}{r}$$

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13. Uniform Circular Motion

Angular Velocity

$$\omega = \frac{v}{r}$$

In Vector Form,

$$\vec{v} = \vec{\omega} \times \vec{r}$$

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14. Linear Velocity

$$v = r\omega$$

Exam Tips

- **Impulse = Change in Momentum**
- **Static Friction is always greater than Kinetic Friction.**
- Make Free Body Diagram (FBD) of a body first and then write equations of forces acting on it.
- Resolve weight of a mass placed on inclined plane in two components_ Horizontal and Vertical
- Check first in Elevator Problems
  - Upward Acceleration
  - Downward Acceleration
  - Free Fall
