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QUICK REVISION FORMULA SHEET

for

GATE -AE ENGINEERING MECHANICS



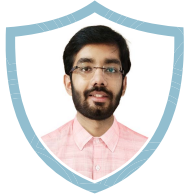
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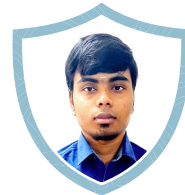
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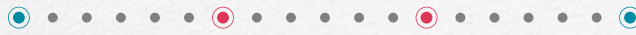
Sastra Univ - Tanjore

Vagicharla Dinesh

Lovely Professional Univ - Punjab

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Fathima J

MIT - Chennai

Mohan Kumar H

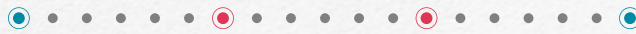
MVJCE - Bangalore

Arathy Anilkumar Nair

Amrita Univ - Coimbatore

Sadsivuni Tarun

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HAL DT ENGINEER 2021

DRDO & ADA Scientist B

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Amrita Univ - Coimbatore

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IIST - Trivendrum

Dheeraj Sappa

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MIT - Chennai

Goutham

KCG College - Chennai

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Mohit Kudal

RTU - Kota

Niladhari Pahari

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Nitesh Singh

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KIIT - Bhubaneswar

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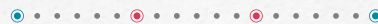
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S Komesh

Sathyabama University - Chennai

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Ankur Vats

School Of Aeronautics - Neemrana

Engineering Mechanics

Chapter 1: STATICS (REST)

Newton 1st law (NFL)

\vec{a} = Acceleration vector

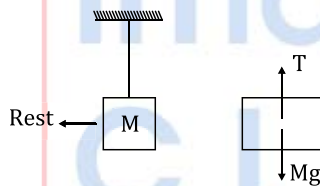
For a Particle:

$\sum \vec{F} = 0$, then $\vec{a} = 0 \rightarrow$ Rest; Uniform velocity

For a Rigid Body:

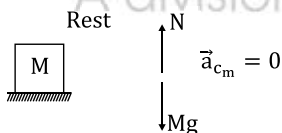
$\sum \vec{F}_{\text{ext}} = 0$ then $\vec{a}_{\text{cm}} = 0$

Case 1:

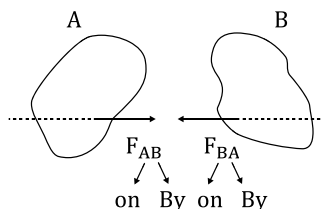


$\vec{a}_{\text{cm}} = 0$; $\sum \vec{F}_{\text{ext}} = 0$; $T - mg = 0$, $T = mg$

Case 2:

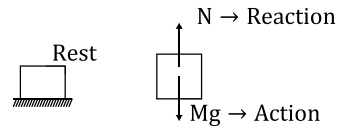


Newton's Third Law (NTL):



$$\vec{F}_{AB} = -\vec{F}_{BA}$$

Case:



Equilibrium:

Rest or uniform linear velocity

i.e. $\sum \vec{F} = 0$

For Particle $\sum \vec{F} = 0$

For a rigid body $\sum \vec{F} = 0 \Rightarrow \sum \vec{F}_x = 0, \sum F_y = 0$

$\sum \vec{F}_z = 0$

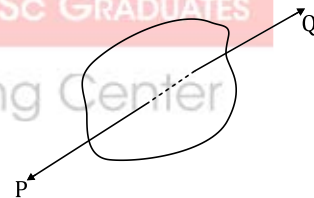
$\sum M = 0$ (about any point or line in plane)

System of Equilibrium:

1. **Two force system**

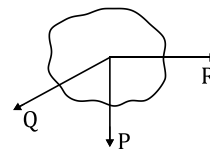
$$\vec{P} + \vec{Q} = 0, \vec{P} = -\vec{Q}$$

$$\vec{M} = 0 \rightarrow \text{Collinear}$$



2. **Three Force System**

For equilibrium three forces must be coplanar and con-current.

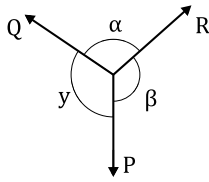


$$\vec{P} + \vec{Q} + \vec{R} = 0$$

$$\sum \vec{M} = 0 \text{ (Concurrent)}$$

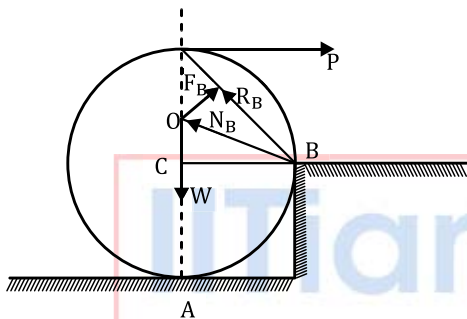
Lami's Theorem:

For a three-force system



$$\frac{P}{\sin \alpha} = \frac{Q}{\sin \beta} = \frac{R}{\sin \gamma}$$

Important concepts:



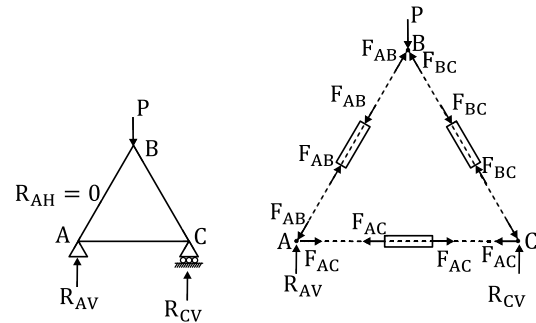
- As roller is about to move out of curb, normal reaction at A becomes zero, as it loses its contact at point A and cylinder or roller will be under equilibrium at verge of motion.
- Here comes a contact force (Resultant of normal reaction and friction at B (i.e., R_B))
- So, only three forces are P, W, R_B which maintain equilibrium, so these must be coplanar and concurrent.
- If the horizontal force 'P' is applied at centre, no friction will be there i.e., reaction force at B will act as normal reaction.

For P to be minimum its line of action should be \perp^r to R_B

Chapter 2: PLANE TRUSS

Numbers of members = m

Number of Joints = J



J = No. of Joints (Whether it is binary or ternary joint)

For perfect truss: $m = 2j - 3$ (DOF = 0)

$m < 2j - 3$ Unstable truss (DOF > 0)

$m > 2j - 3$ Redundant, stable and (DOF < 0) indeterminate truss

Method of Joint:

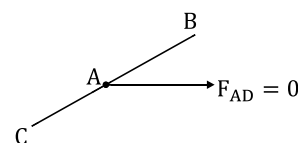
Equilibrium of joint is considered in method of joint to find loading in the member.

Procedure:

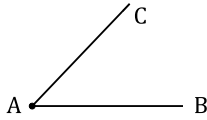
- Find support reactions if required
- Consider equilibrium of joint where only two members are meeting and use $\sum f_x = 0, \sum f_y = 0$.

Note:

- At a joint if 3 members are meeting and 2 members are collinear the forces in 3rd member = 0



2. If at a joint two members are meeting and they are non-collinear then forces in both members will be zero.



$$F_{AB} = F_{AC} = 0$$

Method of Section:

Equilibrium of a section of truss is considered.

Procedure:

1. Find reactions at support if required
2. Cut the member under consideration by section 1 ... 1 and consider the equilibrium of either LHS or RHS of section 1 ... 1 and use $\sum f_x = 0, \sum f_y = 0, \sum M = 0$ to find unknowns.

Note: Don't cut more than 3 members.

Chapter 3: Principle of Virtual Work (POVW)

$$WD(\text{Work done}) = \vec{F} \cdot \vec{d}_s$$

\vec{d}_s = Displacement vector of a point where \vec{F} is acting.

Principle of virtual work states that if the system is in equilibrium then sum of virtual work by all the forces = 0

$$\text{Virtual work} = F \cdot ds$$

F = Actual force

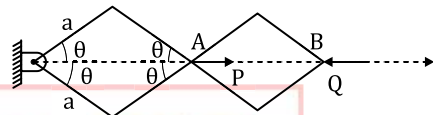
ds = virtual displacement.

Procedure:

1. Take any fixed point as problem as origin. fix coordinate axes and find coordinates of all joint where forces are acting.
2. Find virtual displacements.
3. Use POVW to find unknowns

Note: In POVW, we don't consider reaction at supports, because their work done is zero.

Example:



Find P: Q = ?

Solution:

$$x_A = 2a \cos \theta, \partial x_A = -2a \sin \theta \partial \theta$$

$$x_B = +4a \cos \theta, \partial x_B = -4a \sin \theta \partial \theta$$

$$(VW)_P + (VW)_Q = 0 \text{ for equilibrium}$$

$$P \cdot \partial x_A - Q \partial x_B = 0$$

$$P[-2a \sin \theta] \partial \theta - Q[-4a \sin \theta \partial \theta] = 0$$

$$-2P + 4Q = 0$$

$$\frac{P}{Q} = 2$$

Chapter 4: TRANSLATORY MOTION

Kinematics:

For a particle with $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

$$\vec{V} = \frac{d\vec{r}}{dt} \quad \vec{a} = \frac{d\vec{V}}{dt}$$

Acceleration (\vec{a}):

• **Uniform**

$$v = u + at$$

$$S = ut + \frac{1}{2}at^2$$

$$V^2 = u^2 + 2as$$

• **Non-uniform**

$$a = \frac{dV}{dt}$$

$$a = V \cdot \frac{dV}{ds}$$

Newton's Second Law (NSL):

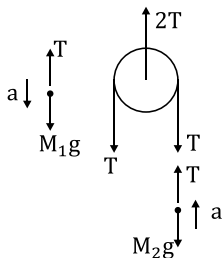
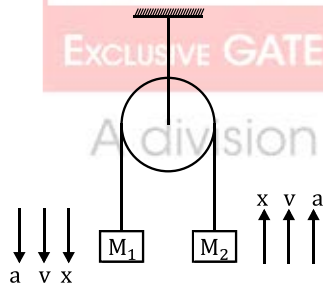
For a particle:

$$\sum \vec{F}_{\text{ext}} \neq 0 \text{ then } \vec{a} \neq 0$$

$$\vec{a} = \frac{\sum \vec{F}_{\text{ext}}}{m} \text{ NSL}$$

Dynamics:

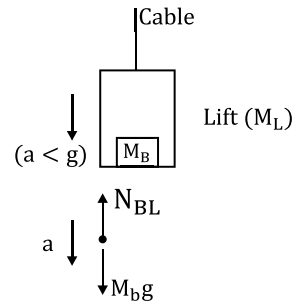
Case A:



$$a = \left(\frac{m_1 - m_2}{m_1 + m_2} \right) g \quad \begin{cases} m_1g - T = m_1a \rightarrow \textcircled{1} \\ T - m_2g = m_2a \rightarrow \textcircled{2} \end{cases}$$

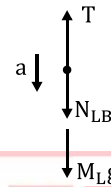
$$T = \left(\frac{2m_1m_2}{m_1 + m_2} \right) g$$

Case B :



$$M_B g - N_{BL} = M_B a \text{ NSL}$$

For Lift



$$\vec{N}_{BL} = -\vec{N}_{LB}$$

$$M_L g + N_{LB} - T = M_L a \text{ NSL}$$

Chapter 5: CIRCULAR MOTION

Curvilinear Motion

$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$$

$$\vec{V} = \frac{d\vec{r}}{dt} = \frac{dx}{dt}\hat{i} + \frac{dy}{dt}\hat{j} + \frac{dz}{dt}\hat{k}$$

$$\vec{V} = V_x\hat{i} + V_y\hat{j} + V_z\hat{k}$$

$$\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$$

Projectile Motion:

$$\text{Total time (T)} = \frac{2U \sin \theta}{g}$$

$$\text{Max height (H}_{\text{max}}) = \frac{U^2 \sin^2 \theta}{g}$$

$$\text{Horizontal Range (R)} = U_x \cdot T$$

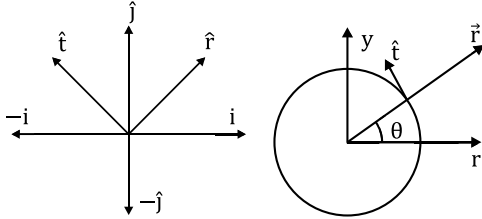
$$R = \frac{U^2 \sin 2\theta}{g} \quad R_{\text{max}} \text{ at } \theta = 45^\circ$$

Equation of Trajectory:

$$y = x \tan \theta - \frac{gx^2}{2U^2 \cos^2 \theta}$$

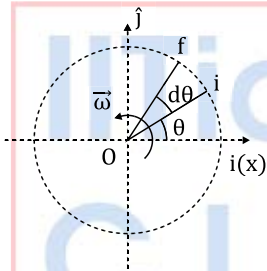
or $y = x \tan \theta \left(1 - \frac{x}{R}\right)$

Circular Motion:



$$\vec{r} = \cos \theta \hat{i} + \sin \theta \hat{j}$$

$$\hat{t} = \sin \theta (-\hat{i}) + \cos \theta \hat{j}$$



Angular velocity

$$\omega = \frac{d\theta}{dt} \rightarrow (\text{rad/sec})$$

Angular acceleration

$$\alpha = \frac{d\omega}{dt} \rightarrow \text{rad/sec}^2$$

Direction of ' ω ' and ' α ' \rightarrow Right hand thumb rule.

Angular acceleration:

- **Uniform**

$$\omega = \omega_0 + \alpha t$$

$$d\theta = \omega_0 t + \frac{1}{2} \alpha t^2$$

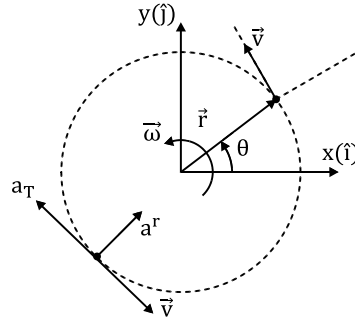
$$\omega^2 = \omega_0^2 + 2\alpha(d\theta)$$

- **Non-uniform**

$$\alpha = \frac{d\omega}{dt}$$

$$\alpha = \omega \frac{d\omega}{d\theta}$$

Vector Analysis of Circular Motion:



$$\vec{r} = |r| \cdot \hat{r}$$

$$\vec{r} = r[\cos \theta \hat{i} + \sin \theta \hat{j}]$$

$$\vec{V} = \frac{d\vec{r}}{dt} = r[-\sin \theta \hat{i} + \cos \theta \hat{j}] \frac{d\theta}{dt}$$

$$\vec{V} = r\omega(\hat{t})$$

$$\vec{a} = \frac{d\vec{V}}{dt} = r \left(\omega \left(-\cos \theta \frac{d\theta}{dt} \hat{i} - \sin \theta \frac{d\theta}{dt} \hat{j} \right) + \cos \theta \hat{j} \right) \frac{d\omega}{dt}$$

$$\vec{a} = r\omega^2(-\cos \theta \hat{i} + (-\sin \theta) \hat{j})$$

$$+ r\alpha(-\sin \theta \hat{i} + \cos \theta \hat{j})$$

$$\vec{a} = r\omega^2(-\hat{r}) + r\alpha(\hat{t})$$

$$\vec{a} = \vec{a}_r + \vec{a}_T$$

\vec{a}_r = radial/centripetal acceleration

\vec{a}_T = tangential acceleration

$$a_r = r\omega^2 = \frac{V^2}{r}$$

For uniform circular motion

$$V = r \cdot \omega = \text{constant}$$

$$\omega = \text{constant}$$

$$\alpha = 0, \quad \vec{a}_T = 0$$

$$\vec{a} = \vec{a}_r$$

Chapter 6: FRICTION

Dry Friction/Coulomb Friction:

• **Static friction**

Rest + Verge of motion

$$0 < f_s < (f_s)_{max}$$

$$(f_s)_{max} = \mu_s N$$

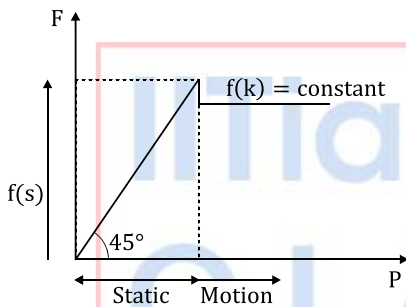
μ_s = Coefficient of static friction

N = Normal reaction

If applied force i.e:

$$P < (f_s)_{max}$$

then $(f_s) = P$



Note:

$$(f_s)_{max} > F_k$$

$$\mu_s > \mu_k$$

$$\text{Then } f_s = \mu_k N$$

$$f_s = F_k$$

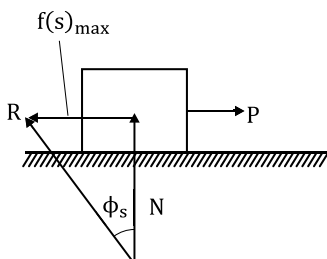
• **Kinetic friction**

Motion

$$F_K = \mu_k N \text{ constant}$$

Angle of Static Friction (ϕ_s):

Angle made by normal reaction with contact force.

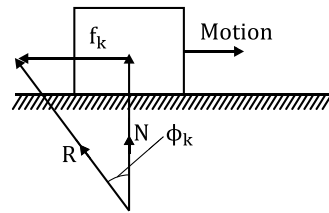


$$\tan \phi_s = \frac{(f_s)_{max}}{N}$$

$$\tan \phi_s = \frac{\mu_s N}{N} = \mu_s$$

Angle of Kinetic Friction (ϕ_k):

During motion of body, the angle made by contact force with normal reaction is called as ϕ_k .



$$\tan(\phi_k) = \frac{f_k}{N} = \frac{\mu_k N}{N} = \mu_k$$

Note:

If μ_s and μ_k not given separately

1. $\mu_s = \mu_k = \mu$
2. $0 \leq f_s \leq (f_s)_{max} = \mu N = f_k$
3. $\tan \phi = \mu$ (ϕ = angle of friction)

Chapter 7: WORK & ENERGY

Linear Momentum (\vec{P}):

$$\vec{P} = m \cdot \vec{V}_{cm}$$

$$\frac{d\vec{P}}{dt} = m \cdot \frac{d\vec{V}_{cm}}{dt} \Rightarrow \frac{d\vec{P}}{dt} = \vec{m} \cdot \vec{a}_{cm} = \sum \vec{F}_{ext}$$

$$\sum \vec{F}_{ext} = \frac{d\vec{P}}{dt}$$

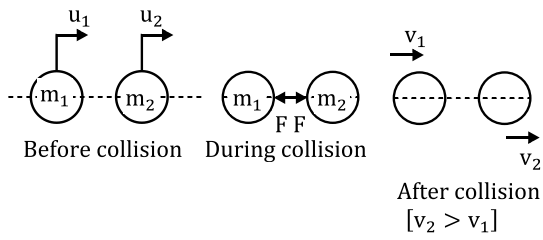
Conservation of Linear Momentum \vec{P} :

$$\vec{P} = \text{Constant}$$

$$d\vec{P} = 0$$

Only when $\sum \vec{F}_{ext} = 0$

$$P_x = \text{constant}; P_y = \text{Constant}$$



$P_x = \text{constant}$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Collision:

1. Perfectly elastic collision $e = 1$ ($m_1 + m_2$) system

$$(k\varepsilon)_{\text{initial of system}} = (k\varepsilon)_{\text{Final of system}}$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2 \rightarrow \textcircled{1}$$

$$\left[\frac{1}{2} m_1 u_1 + \frac{1}{2} m_2 u_2 = \frac{1}{2} m_1 v_1 + \frac{1}{2} m_2 v_2 \right] \rightarrow \textcircled{2}$$

From $\textcircled{1}$ & $\textcircled{2}$

$$(u_1 - u_2 = v_2 - v_1)$$

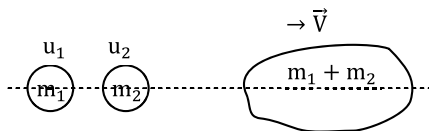
$u_1 - u_2 = \text{Velocity of approach}$

$v_2 - v_1 = \text{Velocity of separation}$

$$\left(e = \frac{v_2 - v_1}{u_1 - u_2} \right)$$

$e = \text{coefficient of restitution}$

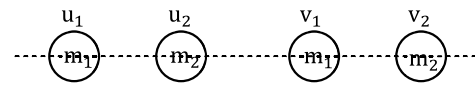
2. Perfectly Inelastic (Plastic) collision ($e = 0$)



$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$$

$$(k\varepsilon)_{\text{loss}} = (k\varepsilon)_{\text{initial}} - (k\varepsilon)_{\text{final}}$$

3. Partially Elastic Collision: ($0 < e < 1$)

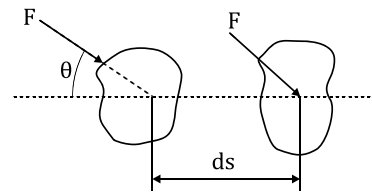


No complete region in size \Rightarrow Same energy loss due to deformation.

$$k\varepsilon \neq \text{conserved}$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Work done:



$$WD = \vec{F} \cdot \vec{ds} = F ds \cos \theta$$

$$(WD)_{\text{spring}} = \int F s dx = -\frac{1}{2} kx^2$$

Work Energy Theorem:

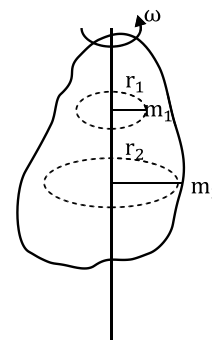
Work done by all the forces acting on a particle = change in kinetic energy

$$W_{\text{net}} = (k\varepsilon)_{\text{final}} - (k\varepsilon)_{\text{initial}}$$

If $(\text{work done})_{\text{non conservative}} = 0$

Then mechanical energy = constant

Rotation of Rigid Bodies:



Mass moment of inertia

$$I = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \dots$$

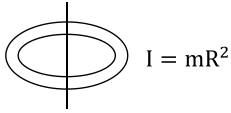
$$I = \sum m_i r_i^2$$

Let $\sum M_i = m = \text{Total mass}$

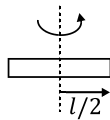
$$I = mk^2$$

k = radius of gyration

Ring/Hollow Cylinder:



Rod:

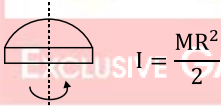


$$I_{cm} = \frac{mL^2}{12}$$

Solid Sphere

$$I = \frac{2}{5} mR^2$$

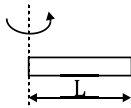
Disc/Hollow Cylinder



Hollow sphere

$$I = \frac{2}{3} mR^2$$

Rod about end



$$J = \frac{mL^2}{3}$$

Dynamics of Rigid Body Rotation:

If $\sum \vec{T}_{net} = 0$ then $\vec{\alpha} = 0$

If $\sum \vec{T} \neq 0$ then $\vec{\alpha} \neq 0$

$$\boxed{\sum \vec{T}_{net} = I \cdot \vec{\alpha}}$$

$$\sum \vec{T}_{cm} = I_{cm} \cdot \alpha$$

$$\sum \vec{T}_{Axis} = I_{Axis} \cdot \alpha$$

Angular Momentum (\vec{L}) (Moment of linear momentum)

$$\vec{L} = \vec{r} \times \vec{P}$$

$$\boxed{\sum \vec{T} = \frac{dL}{dt}}$$

Conservation of Angular Momentum:

$\vec{L} = \text{Constant}$, $dL = 0$, when $\sum \vec{T} = 0$

Eg: $I_1 \omega_1 = I_2 \omega_2$

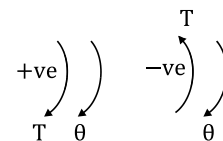
Rotational Kinetic Energy

$$K_E = \sum \frac{1}{2} m_i V_i^2 = \sum \frac{1}{2} m_i r_i^2 \omega_i^2$$

$$\boxed{K_E = \frac{1}{2} I \cdot \omega^2}$$

Work done:

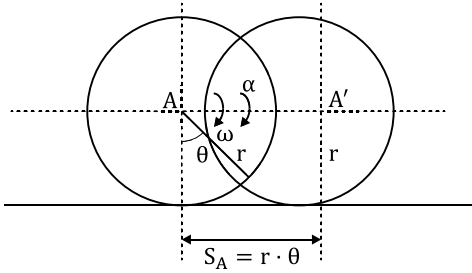
$$(W_D)_T = T \cdot d\theta$$



$$\text{Power (P)} = T \cdot \frac{d\theta}{dt} = T \cdot \omega$$

$$= \frac{2\pi NT}{60} \quad (N \rightarrow \text{rpm})$$

General Motion = Rotation + Translation



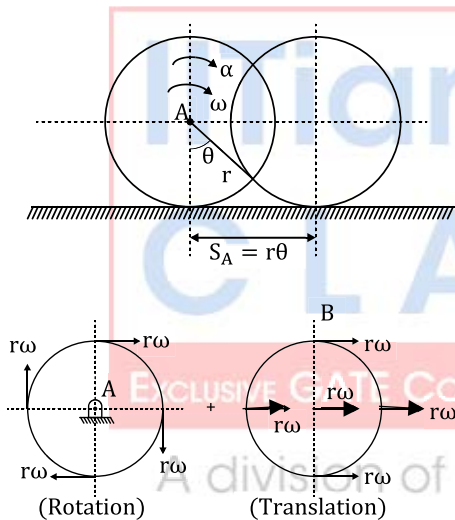
Conditions:

If $S_A = r\theta \rightarrow$ Pure rolling ($V = r\omega$ $a = r\alpha$)

If $S_A > r\theta \rightarrow$ Skidding

If $S_A < r\theta \rightarrow$ Slipping

Velocity Analysis:



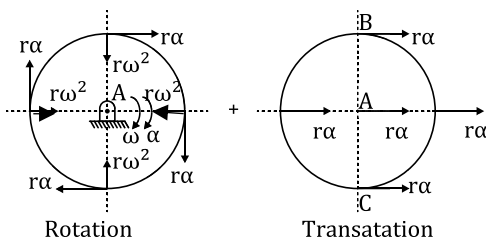
$$\vec{V}_T = \vec{V}_{\text{Translation}} + \vec{V}_{\text{rotation}}$$

$$\vec{V}_A = r\omega\hat{i} + 0 = r\omega$$

$$\vec{V}_B = r\omega\hat{i} + r\omega\hat{i} = 2r\omega\hat{i}$$

$$V_C = r\omega\hat{i} - r\omega\hat{i} = 0 \text{ (Pure rolling)}$$

Acceleration Analysis:



$$\vec{a}_T = \vec{a}_{\text{Trass}} + \vec{a}_{\text{Rot}}$$

$$a_B = r\alpha\hat{i} + r\alpha\hat{i} - r\omega^2\hat{j} = 2r\alpha\hat{i} - r\omega^2\hat{j}$$

$$a_C = r\alpha\hat{i} - r\alpha\hat{i} + r^2\alpha\hat{j}$$

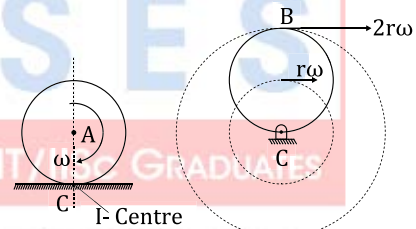
$$\vec{a}_C \neq 0$$

Note:

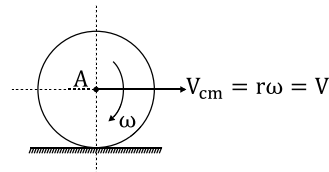
1. In pure rolling static friction will be there on the roller, because contact point has zero velocity.
2. Energy of a roller rolling on rough surface remains conserved because the work done by static friction = 0.

I-Centre (Instantaneous Centre)

Point about which a body is in general motion can be assumed in pure rotation to find velocity only.



Kinetic Energy in Rolling:



Body is rolling due to applied torque (T)

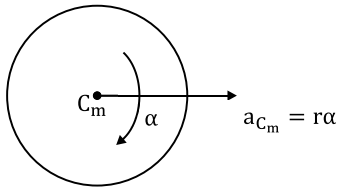
$$(K\epsilon)_{\text{Rolling}} = \frac{1}{2} mV^2 + \frac{1}{2} I_A \omega^2$$

$$= \frac{1}{2} mr^2 \omega^2 + \frac{1}{2} I_A \omega^2$$

$$= \frac{\omega^2}{2} [I_A + mr^2]$$

$$(K\epsilon)_{\text{rolling}} = \frac{1}{2} I_C \cdot \omega^2$$

Dynamics:



$$\sum F_{net} = m a_{cm} \text{ (NSL)}$$

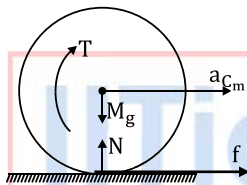
$$\sum F_{net} = m \cdot r \alpha \rightarrow \textcircled{1}$$

$$\sum T_{C_m} = I_{C_m} \times \alpha$$

$$\sum T_{Axis} = I_{Axis} \times \alpha$$

Friction in Rolling:

Case 1:



Body is rolling due to applied torque (T)

$$N = mg \rightarrow N = F$$

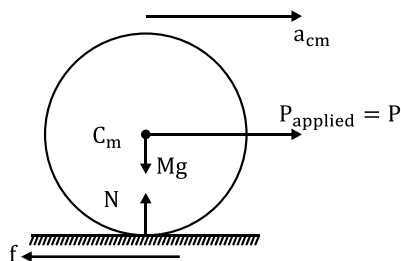
$$F = m a_{cm} \rightarrow \text{NSL}$$

$$F = m r \alpha \quad (T_{app} = T)$$

$$\sum T_{C_m} = I_{C_m}$$

$$(T_{app} - F(r)) = I_{C_m} \alpha$$

Case 2:



In this case friction will roll the body

$$P_{app} - f(r) = m \cdot a_{cm}$$

$$a_{cm} = r \alpha$$

$$F(r) = I_{C_m} \alpha$$

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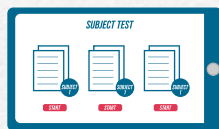
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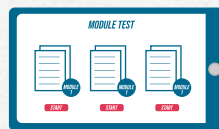
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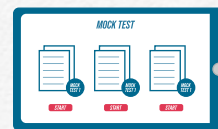
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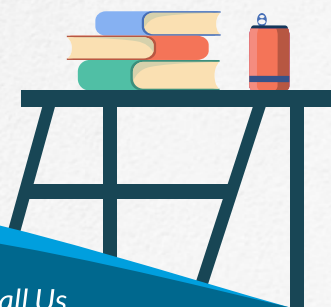
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