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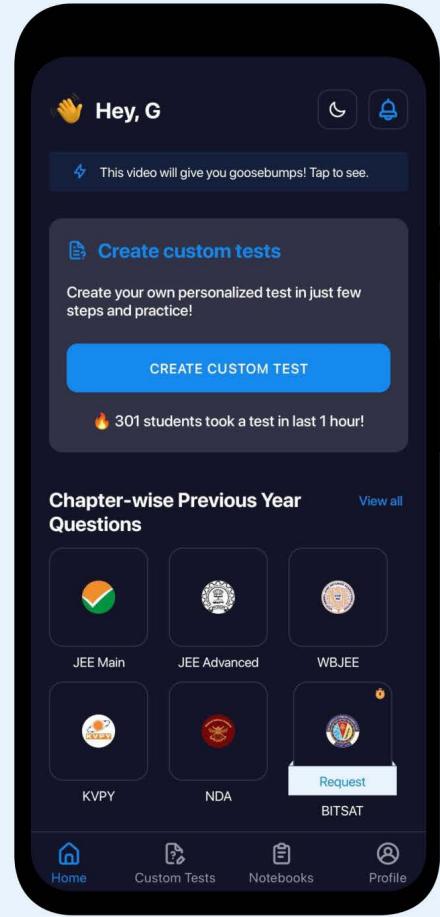


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## CIRCULAR MOTION

Motion along a circular path : when a body is moving along a circular path with constant speed called uniform circular motion, when speed is not constant, motion is said to be non-uniform circular motion.

$$\vec{F}_c = \frac{mv^2}{r}(-\hat{r}) ; \hat{r} = \text{unit vector along radially outward}$$

A force required to keep of body on circular path always acts in radially inward direction called centripetal force whose magnitude is  $\frac{mv^2}{r}$ .

For non-uniform circular motion

$$\vec{F} = \vec{F}_c(-\hat{r}) + \vec{F}_t(\hat{n})$$

$\hat{n}$  = unit vector along direction of motion or velocity

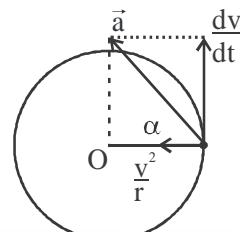
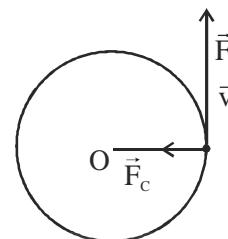
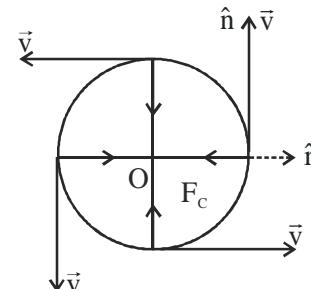
$$\vec{F}_c = \frac{mv^2}{r} \text{ and } \vec{F}_t = m \cdot \frac{dv}{dt}$$

$$\vec{a} = \text{Resultant or net acceleration} = \vec{a}_c(-\hat{r}) + \vec{a}_t(\hat{n})$$

$$= \frac{v^2}{r}(-\hat{r}) + \frac{dv}{dt}(\hat{n})$$

$$|a| = \sqrt{\left(\frac{v^2}{r}\right)^2 + \left(\frac{dv}{dt}\right)^2}$$

$$\alpha = \tan^{-1}\left(\frac{dv/dt}{v^2/r}\right)$$



Angle of banking: Angle by which an outer edge of circular track is raised to provide the necessary centripetal force through the horizontal component of normal reaction.

$$\text{angle of banking } \theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

Motion of vehicle on a horizontal circular track:

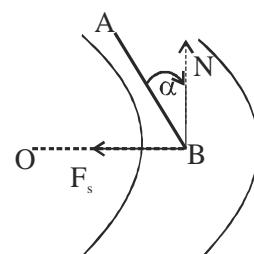
$\frac{mv^2}{r}$  is being provided by force of static friction i.e.,  $F_s = u_s N$  and  $N = mg \Rightarrow v^2 = u_s rg$  or  $v = \sqrt{u_s rg}$

Condition for no skidding on circular track

$$F_s \geq \frac{mv^2}{r} \text{ or } u_s mg \geq \frac{mv^2}{r} \text{ or } v \leq \sqrt{u_s rg}$$

Angle of bending of a cyclist on a rough horizontal circular track to move on is given

$$\tan \theta = \frac{v^2}{rg} \Rightarrow \theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$



$F_s$  provides necessary centripetal force  $\frac{mv^2}{r}$  and  $N = mg$ . For safe turn there is a rotational equilibrium hence

no torque about A (Centre of gravity of cycle and cyclist).

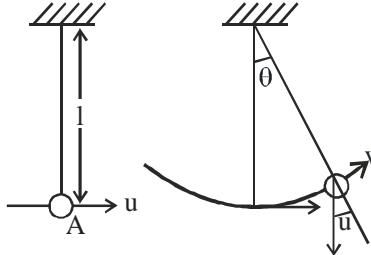
### Vertical Circular Motion

$u$  is the velocity imparted at the bottom of the vertical circle. At P, equation of motion

$$T - mg \cos \theta = \frac{mv^2}{r} \quad \dots(i)$$

and from mechanical energy conservation principle,

$$\frac{1}{2}mu^2 = mgl(1 - \cos \theta) \Rightarrow v^2 = u^2 - 2gl(1 - \cos \theta) \quad \dots(ii)$$



$$\text{from (i) and (ii)} \quad T = mg \cos \theta + \frac{m}{l} [u^2 - 2gl(1 - \cos \theta)]$$

$$= \frac{m}{l} [u^2 - 2gl + 3gl \cos \theta] \quad \dots(iii)$$

from (ii) and (iii) we have velocity and tension at any point on the vertical circular path

For just to complete the vertical circle

$$u = \sqrt{5gl} = \text{velocity}$$

At A,  $v_A = \sqrt{5gl}$ ;  $T_A = 6mg$  = tension in string when block is at A

At B,  $V_B = \sqrt{3gl}$ ;  $T_B = 3 mg$

At C,  $V_C = \sqrt{gl}$ ;  $T_C = mg$

For no toppling of the automobile on horizontal circular track

$$F_s.h \leq mg a \quad ;$$

$$\frac{mv^2}{r}.h \leq mg a$$

$h$  is the height of centre of gravity of automobile from surface of road.

$$v \leq \sqrt{\frac{arg}{h}}$$

While toppling wheels nearer to centre of track loose the contact.

