NAME

SUBJECT STD. BATCH

ROLL NO.

DATE

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# Circular motion

## Synopsis

1) $\omega = 2\pi/T = 2\pi n = \frac{d\theta}{dt}$

2) $v = \frac{d\vec{r}}{dt} = r\omega$

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

4) $a_{cp} = r\omega^2 = \frac{v^2}{r} = v\omega$

5) $a_t = r\alpha$

6) $a = \sqrt{a_{cp}^2 + a_t^2}$

7) $F_{cp} = mr\omega^2 = \frac{mv^2}{r} = mv\omega = F_{cf}$

8) for a curved path

$V_{max} = \sqrt{\mu r g}$

9) for a banked path

$v = \sqrt{rg\left(\frac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta}\right)}$ ... (with friction)

$v = \sqrt{rg\tan\theta}$ ... (without friction)

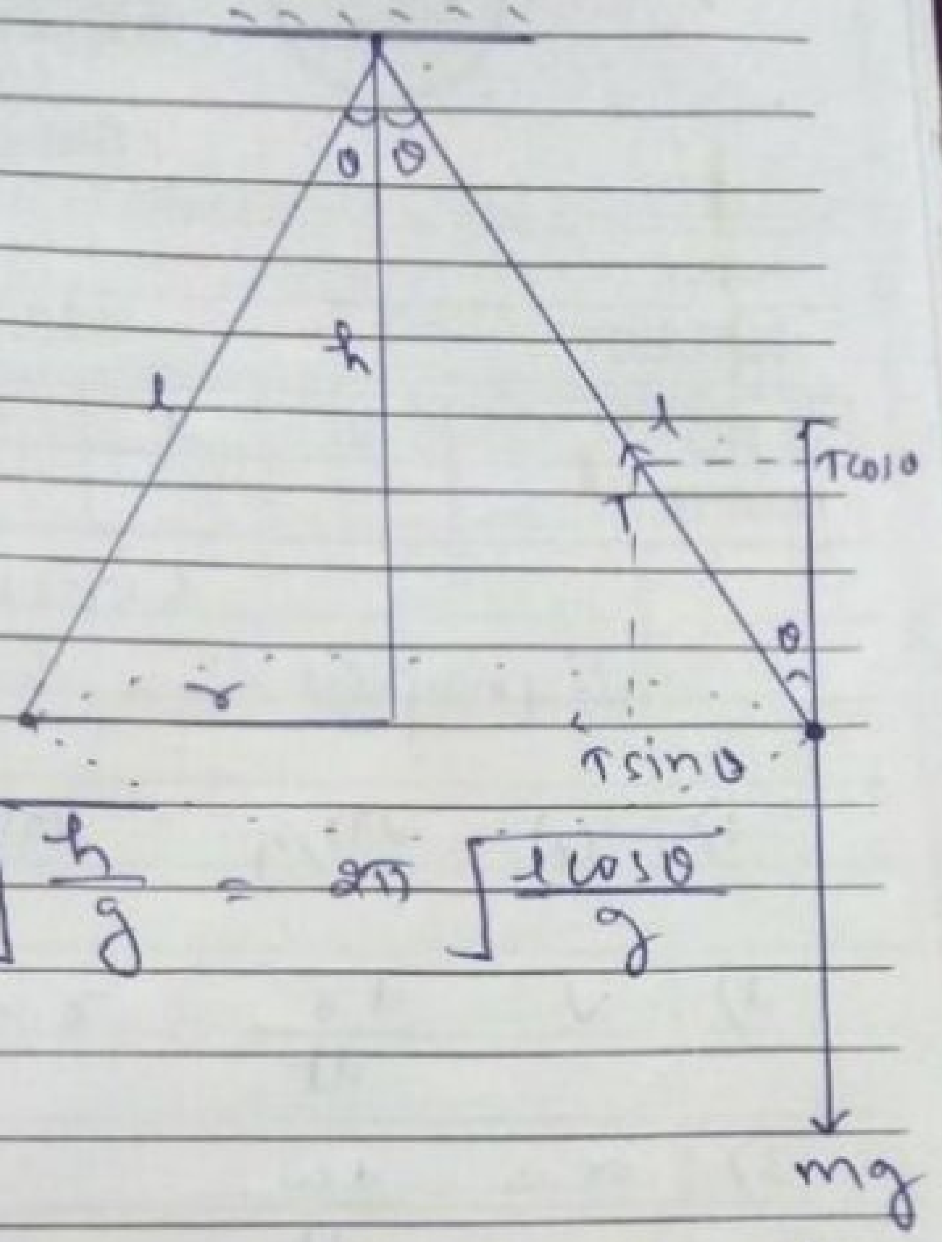
Conical pendulum

$T\cos\theta = mg$

$T\sin\theta = \frac{mv^2}{r}$

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

$v = \sqrt{rg\tan\theta}$




$T' = 2\pi\sqrt{\frac{r}{g\tan\theta}} = 2\pi\sqrt{\frac{h}{g}} = 2\pi\sqrt{\frac{l\cos\theta}{g}}$

Q) There are two pendulums of the same length one is simple and other is conical. whose time periord is more?

for simple pendulum,

$T_s = 2\pi\sqrt{l/g}$

for conical pendulum,

$T_c = 2\pi\sqrt{\frac{l\cos\theta}{g}}$

$\because \quad l > l\cos\theta$

$\therefore \boxed{T_s > T_c}$

Hence simple pendulum has more time period.

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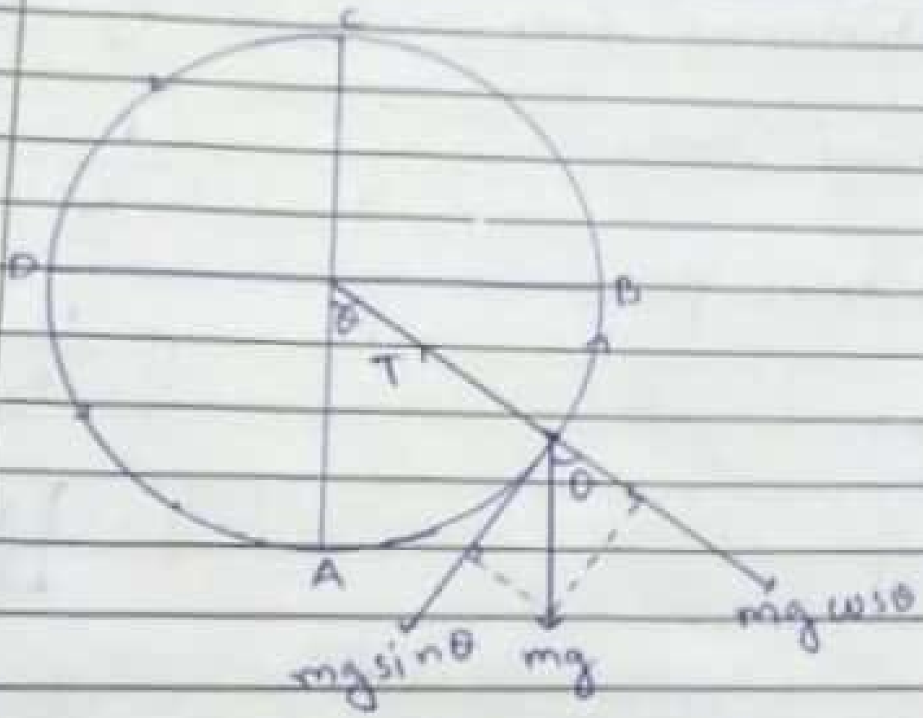
11) Vertical circular motion




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

| At bottom position i.e. at point A | At top position i.e. at point 'c' | At horizontal position i.e. at pt B | At any position i.e. at point 'P' |
|---|---|---|---|
| $T_A = \frac{mv_A^2}{r} + mg$ | $T_C = \frac{mv_C^2}{r} - mg$ | $T_B = \frac{mv_B^2}{r}$ | $T_P = \frac{mv_P^2}{r}$ |
| $v_A = \sqrt{5rg}$ | $v_C = \sqrt{rg}$ | $v_B = \sqrt{3rg}$ | $v_P = \sqrt{rg(3+2\cos\theta)}$ |
| $KE = \frac{5}{2}mrg$ | $KE = \frac{1}{2}mrg$ | $KE = \frac{3}{2}mrg$ | $KE = \frac{1}{2}mrg(3+2\cos\theta)$ |
| $PE = 0$ | $PE = 2mrg$ | $PE = mrg$ | $PE = mrg(1-\cos\theta)$ |
| $TE = \frac{5}{2}mrg$ | $TE = \frac{5}{2}mrg$ | $TE = \frac{5}{2}mrg$ | $TE = \frac{5}{2}mrg$ |

→ A vehicle of mass 'm' moving with linear speed 'v'. If it's speed is double then new centrifugal force becomes 4 time but centripetal force remains the same because-

depends depends

$F_{cp} = \frac{mv^2}{r} = F_{cf}$

depends
- → Gravitational force
- → frictional force
- → Electrostatic force
- → Tension

As $F \propto v^2$

$\therefore \frac{F_1}{F_2} = \left(\frac{v_1}{v_2}\right)^2$

$\therefore \frac{F_1}{F_2} = \left(\frac{v}{2v}\right)^2$

$\therefore \frac{F_1}{F_2} = 1/4$

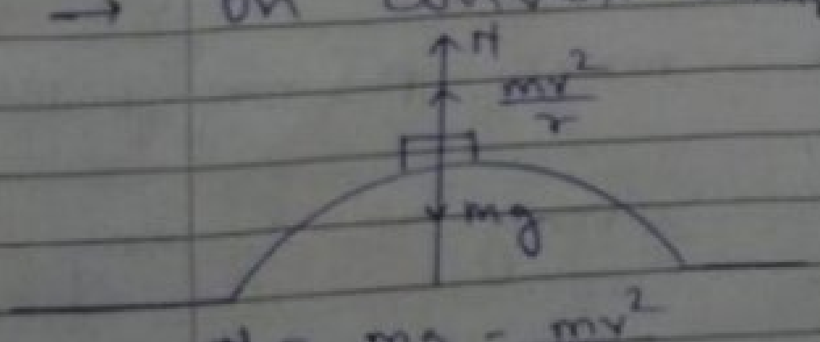
$\therefore \boxed{F_2 = 4F_1}$

→ Tendency of overturn = Centrifugal force $= \frac{mv^2}{r}$

i.e. Tendency of overturn OR centrifugal force $\propto v^2$

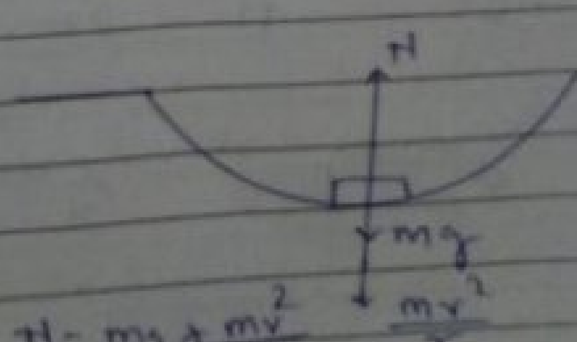
→ On overturn of a vehicle, inner wheels of vehicle leave the ground first. While normal reaction on outer wheel will be more.

→ On convex bridge




$N = mg - \frac{mv^2}{r}$

On concave bridge




$N = mg + \frac{mv^2}{r}$

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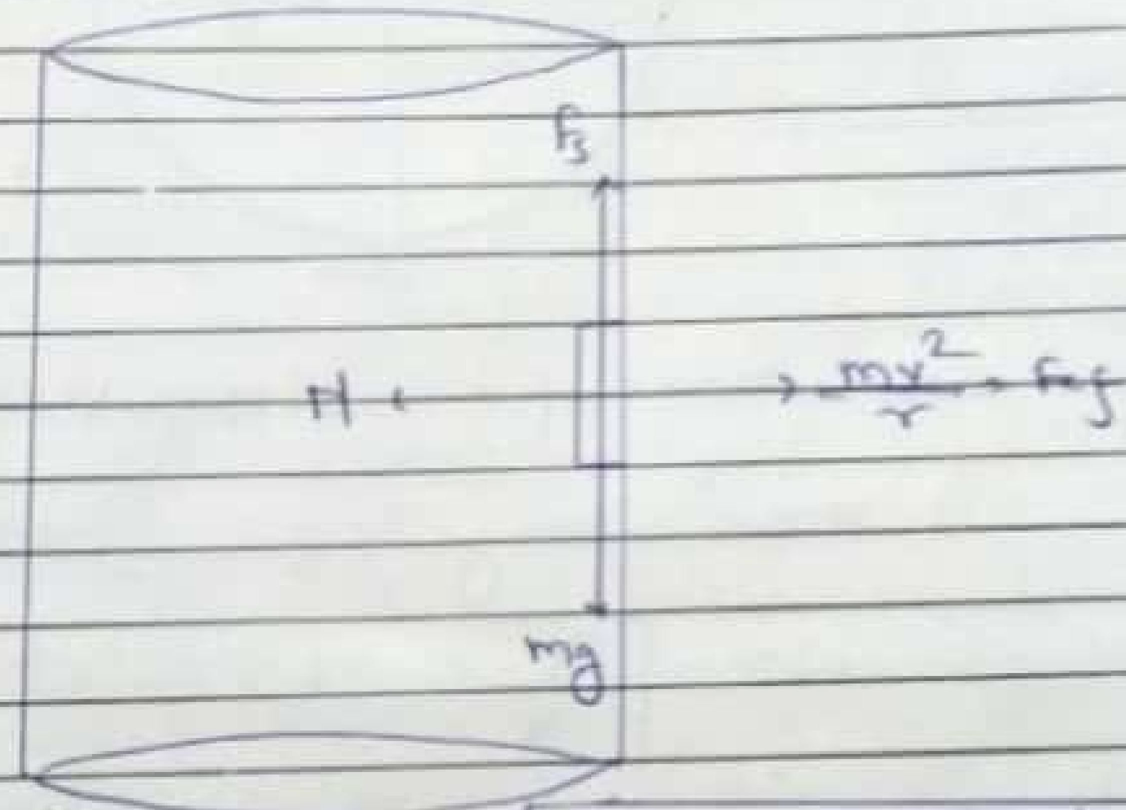
→ Death well




In equilibrium.

$$f_s = mg \text{ - - - - - } (1)$$

$$N = \frac{mv^2}{r} \text{ - - - - } (11)$$

By definition.

$$f_s = \mu_s N$$

$$mg = \mu_s \left(\frac{mv^2}{r}\right)$$

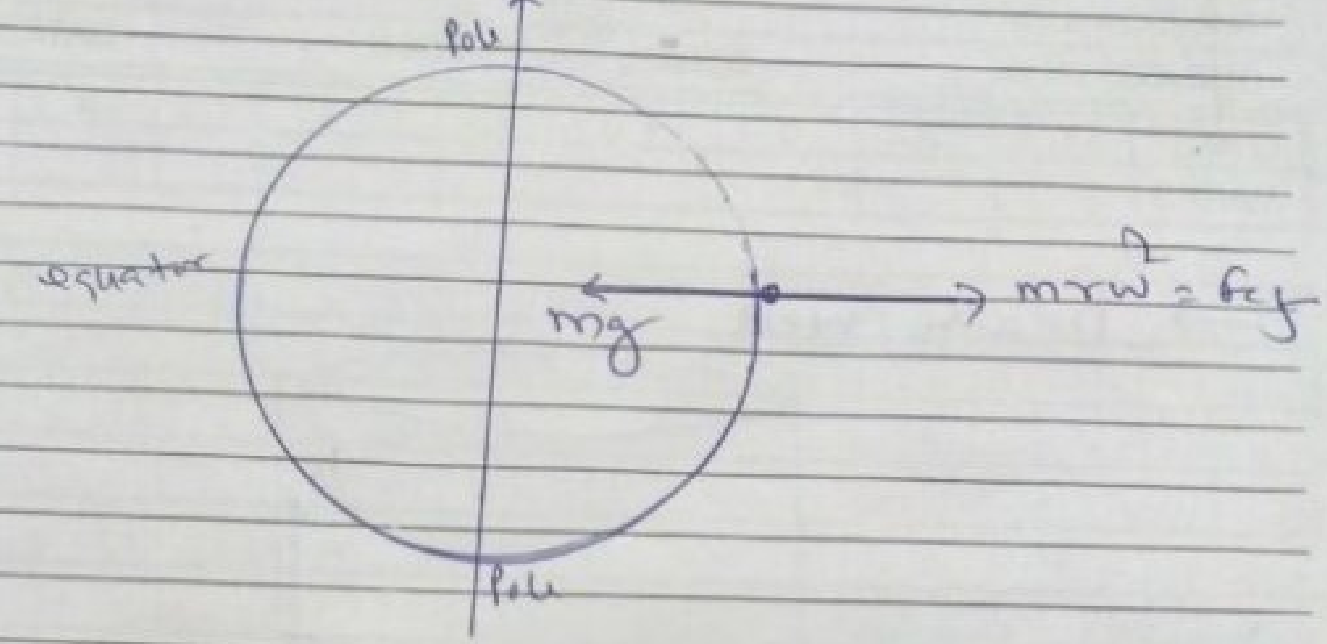
$$\boxed{v = \sqrt{\frac{rg}{\mu_s}}}$$

$$r\omega = \sqrt{\frac{rg}{\mu_s}}$$

$$\boxed{\omega = \sqrt{\frac{g}{r\mu_s}}}$$

Here v and ω are minimum linear speed and angular speed with which motor-cyclist can revolve.

→ With what angular speed Earth should rotate so that a person on equator experiences weightlessness ?




condition for weightlessness,

$\because mr\omega^2 = mg$

$\therefore \omega = \sqrt{\dfrac{g}{r}}$

$\because g = 10\ m/s^2$ and $r = 6.4 \times 10^6 m$ i.e. radius of Earth

$\therefore \omega = \sqrt{\dfrac{10}{6.4 \times 10^6}}$

$= \sqrt{\dfrac{100}{64} \times 10^{-6}}$

$= \dfrac{10}{8} \times 10^{-3}$

$= 1.25 \times 10^{-3}$ rad/sec

i.e. If Earth will rotate with angular speed more than $1.25 \times 10^{-3}$ rad/sec then bodies will fly off from equator

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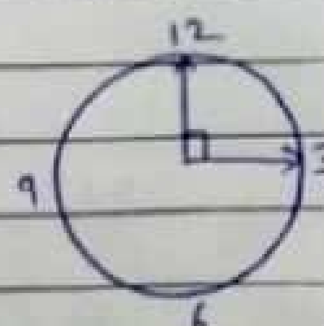
→ A body of mass 'm' moving on horizontal circular path with constant linear speed 'v'. As body is performing UCM, it speed is constant but direction is changing continuously it's velocity and displacement changes

formulas for change in displacement and velocity are..

$$\boxed{\begin{aligned}\Delta s &= 2r\sin\left(\theta/2\right)\\ \Delta v &= 2v\sin\left(\theta/2\right)\end{aligned}}$$

Q→ What is change in velocity in 15 sec of a second hand of a clock having length 1 cm.




$\because$ $\Delta v = 2v\sin\left(\theta/2\right)$

Since $\theta = 90$

$\therefore \Delta v = 2v\sin 45°$

$= \sqrt{2}v$

$= \sqrt{2}(r\omega)$

$= \sqrt{2}\times 1\times \frac{2\pi}{T}$

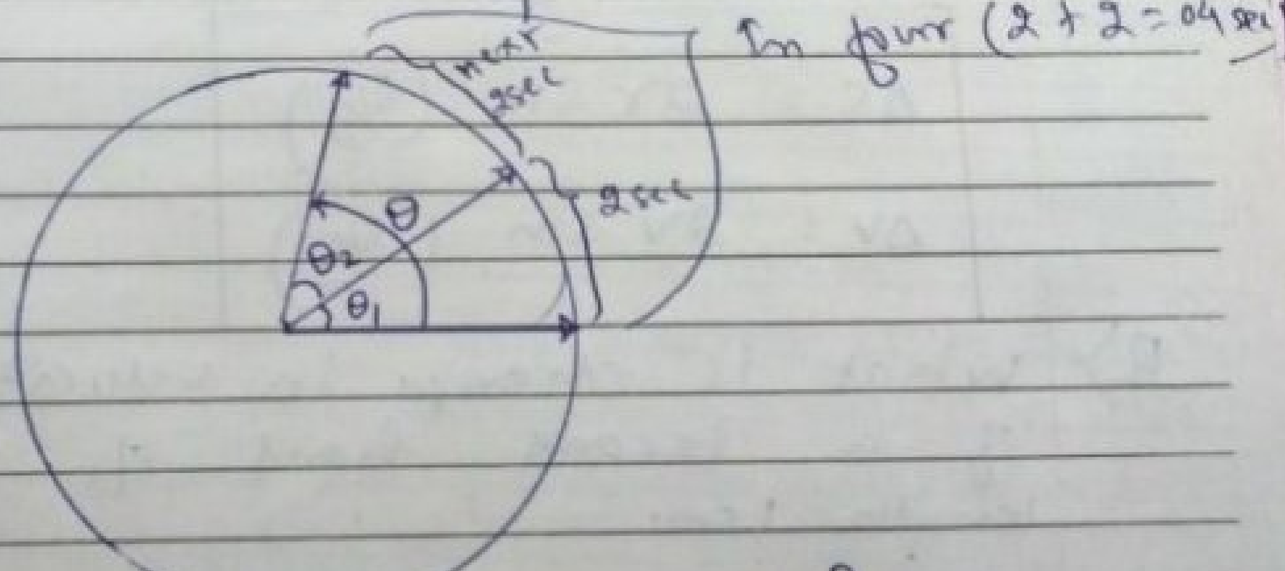
$= \sqrt{2}\times\frac{2\pi}{60}$

$\boxed{\Delta v = \sqrt{2}\pi \text{ cm/sec}}$

Note- for second hand time period is 60 sec. for minute hand 60×60 sec and for hour hand time period is 12×60×60 sec.

| → | for linear motion | for circular motion OR Rotational motion |
|---|---|---|
| (i) | $v = u + at$ | (i) $\omega = \omega_0 + \alpha t$ |
| (ii) | $S = ut + \frac{1}{2}at^2$ | (ii) $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ |
| (iii) | $v^2 = u^2 + 2as$ | (iii) $\omega^2 = \omega_0^2 + 2\alpha\theta$ |

Q.) A particle performing non uniform circular motion, starts it's motion from rest. If it describe angle $\theta_1$ in 2 second and $\theta_2$ in next 2 second then ratio of $\frac{\theta_2}{\theta_1} = ?$




we have

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

since $\omega_0 = 0$

$\therefore \theta = \frac{1}{2}\alpha t^2$

$\therefore \theta_1 = \frac{1}{2}\alpha(2)^2$

$\boxed{\theta_1 = 2\alpha}$

$\because \theta = \frac{1}{2}\alpha(4)^2$

$\boxed{\theta = 8\alpha}$

$\because \theta_2 = \theta - \theta_1$

$= 8\alpha - 2\alpha$

$\boxed{\theta_2 = 6\alpha}$

$\therefore \boxed{\frac{\theta_2}{\theta_1} = \frac{6\alpha}{2\alpha} = \frac{3}{1}}$

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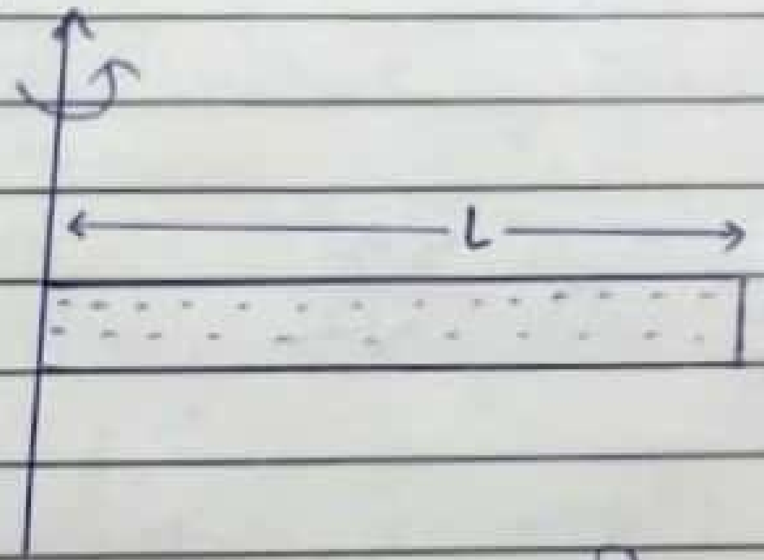
Q) A cylindrical vessel contains liquid of mass 'm' rotating about an axis of rotation which is passing through one of the end. If L be the length of rod then centrifugal force acting on other end if it is rotating with angular speed ω?



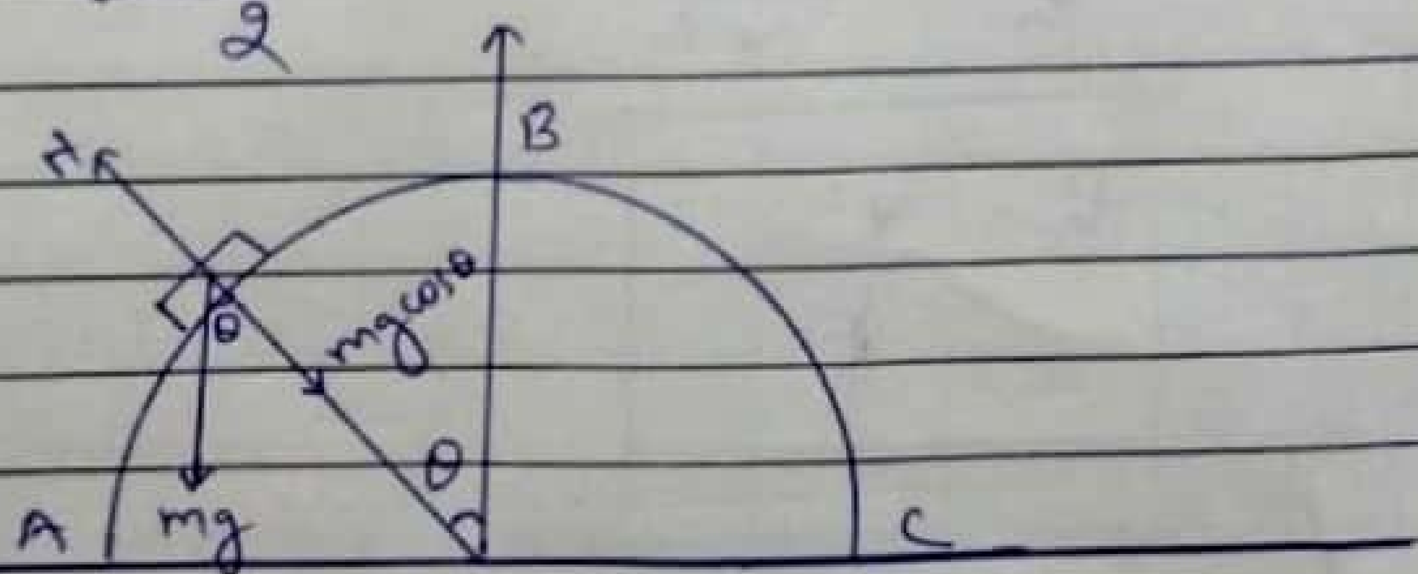

Note :- As there is uniform mass distribution, centre of mass of the is considered.

$$F_{cf} = mr\omega^2$$

$$= m\left(\frac{L}{2}\right)\omega^2$$

$$= \frac{mL\omega^2}{2}$$

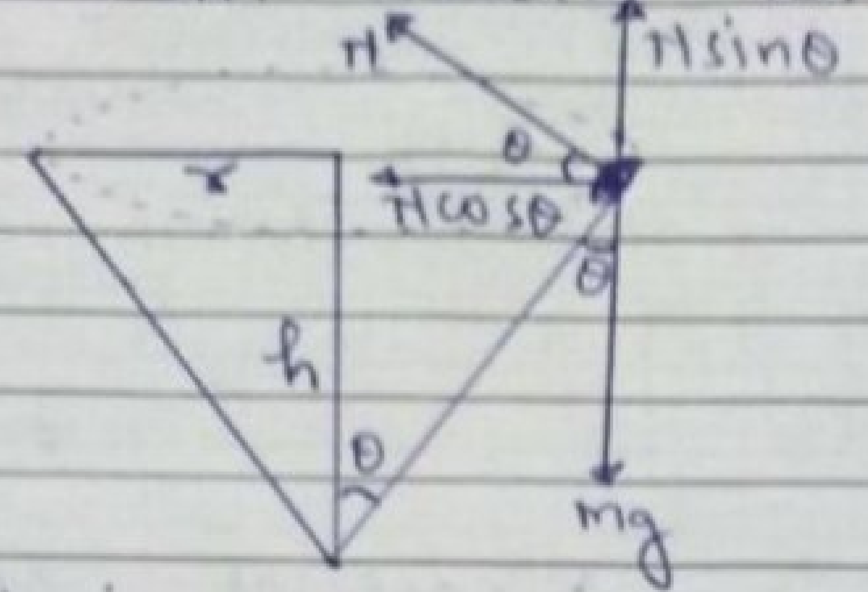
→




$\because$ $N = mg\cos\theta$

Hence as vehicle is moving from A to B normal reaction on it increases and decreases from B to C.

→ In conical funnel, at what height a coin can revolve without slipping?




In equilibrium,

$$N\sin\theta = mg \quad \text{.....} (1)$$

As $N\cos\theta$ is acting towards the centre, it provides centripetal force

$$N\cos\theta = \frac{mv^2}{r} \quad \text{.....} (11)$$

$$\therefore \frac{N\sin\theta}{N\cos\theta} = \frac{mg}{\frac{mv^2}{r}} = \frac{rg}{v^2}$$

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

Since $\tan\theta = \frac{r}{h}$

$$\therefore \frac{r}{h} = \frac{rg}{v^2}$$

$$\therefore \boxed{h = \frac{v^2}{g}}$$

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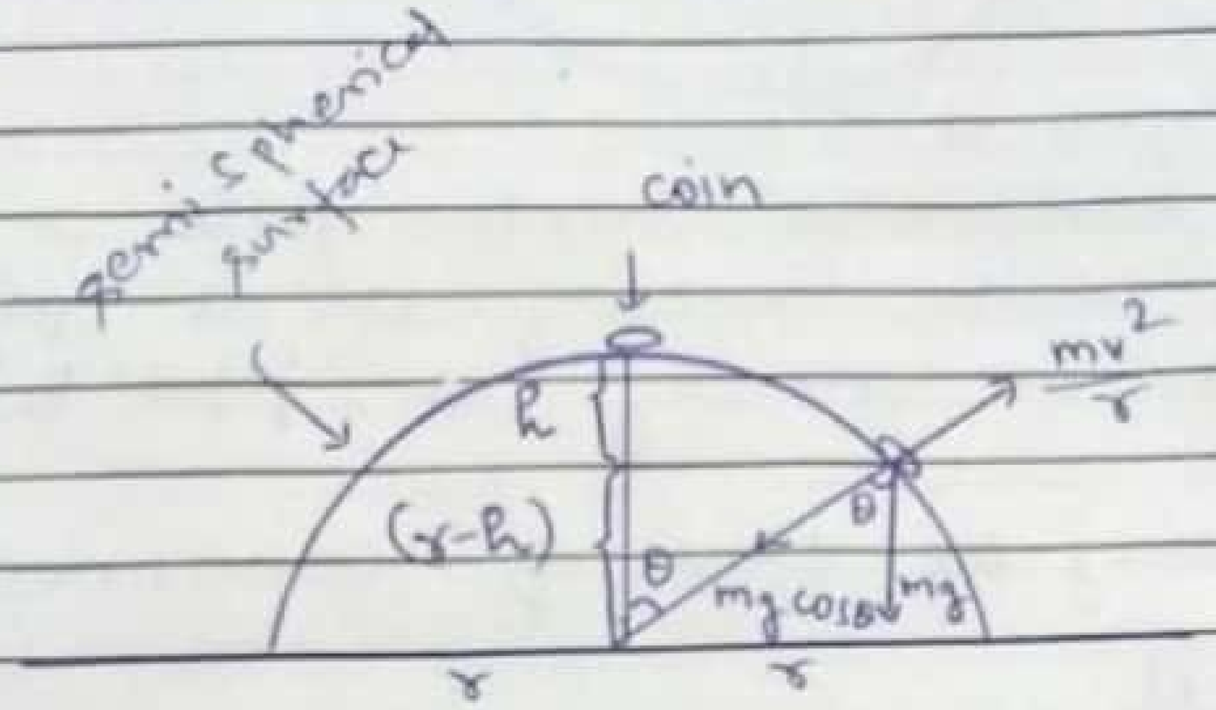
Q)




At what height from top coin will thrown off?

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

$\therefore v^2 = rg\cos\theta \; \ldots\ldots (1)$

$\because v^2 = u^2 + 2gs$

Here $u = 0\ m/s,\ s = h$

$\therefore \boxed{v^2 = 2gh} \; \ldots\ldots (11)$

from eqns (1) and (11)

$\therefore 2gh = rg\cos\theta$

$\therefore 2h = r\left(\frac{r-h}{r}\right)$

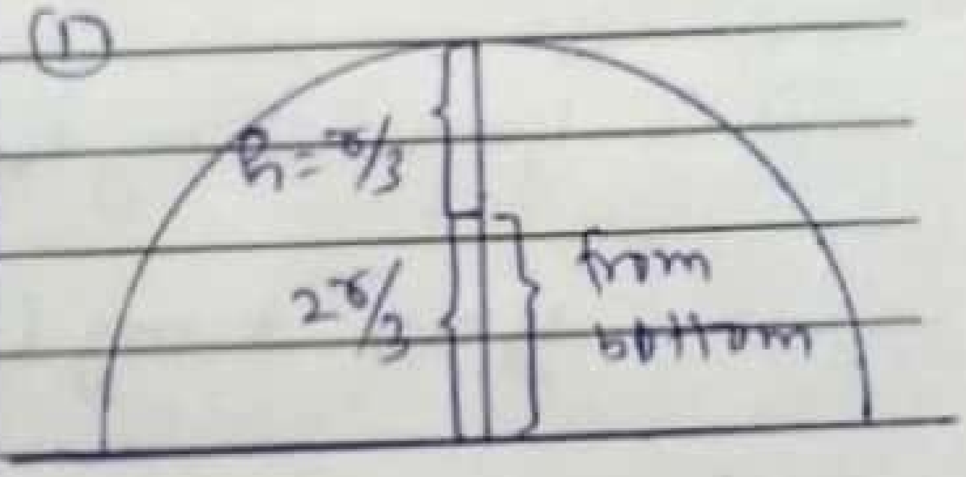
$\therefore 2h = r - h$

$\therefore 3h = r$

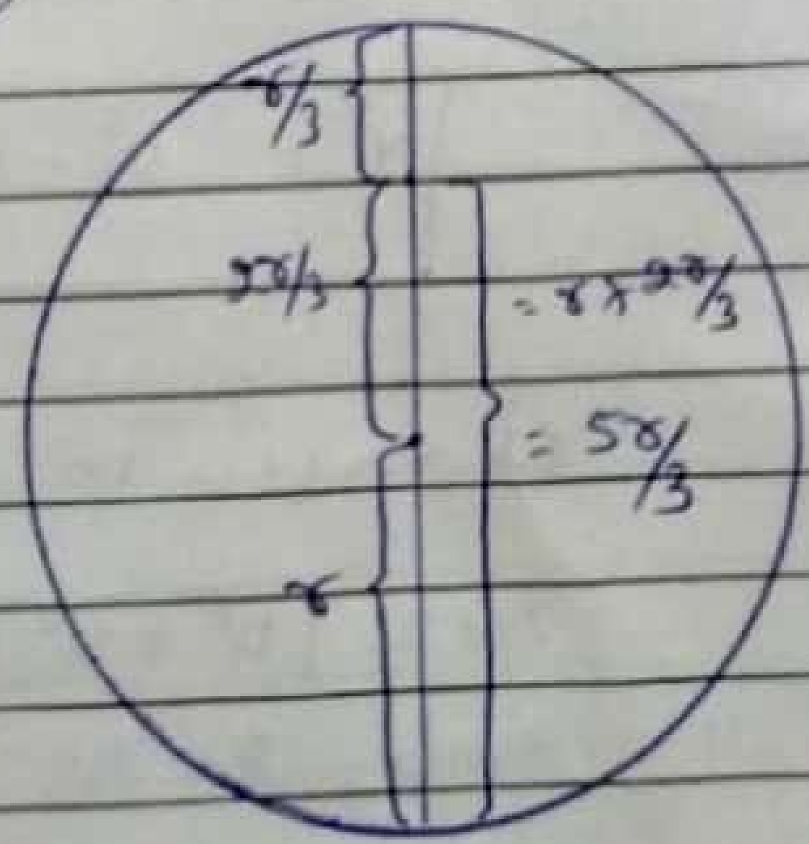
$\therefore \boxed{h = r/3}$

Note

(1)




(11)

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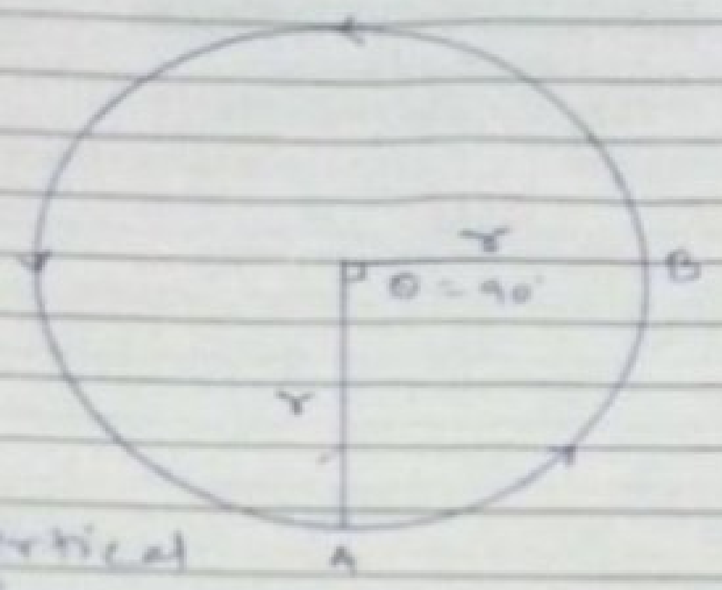


vertical

In ~~horizontal~~ circular path a particle is moving with velocity u at point A. find change in velocity at point B?

According to law of conservation of energy.

$\therefore (T.E)_A = (T.E)_B$

$\therefore (K.E)_A + (P.E)_A = (K.E)_B + (P.E)_B$

$\therefore \frac{1}{2} m v_A^2 + m g h_A = \frac{1}{2} m v_B^2 + m g h_B$

$\therefore \frac{1}{2} m u^2 + m g (0) = \frac{1}{2} m v^2 + m g (r)$

$\therefore \frac{1}{2} m u^2 = \frac{1}{2} m v^2 + m r g$

$\therefore u^2 = v^2 + 2 r g$

$\therefore \boxed{v^2 = u^2 - 2 r g}$

Change in velocity is given by

$\Delta v = \sqrt{u^2 + v^2 + 2 u v \cos\theta}$

since $\theta = 90$ and $\cos 90 = 0$

$\Delta v = \sqrt{u^2 + v^2}$

$= \sqrt{u^2 + (u^2 - 2rg)}$

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$$\therefore \Delta v = \sqrt{2u^2 - 2rg}$$

$$\therefore \boxed{\Delta v = \sqrt{2(u^2 - rg)}}$$