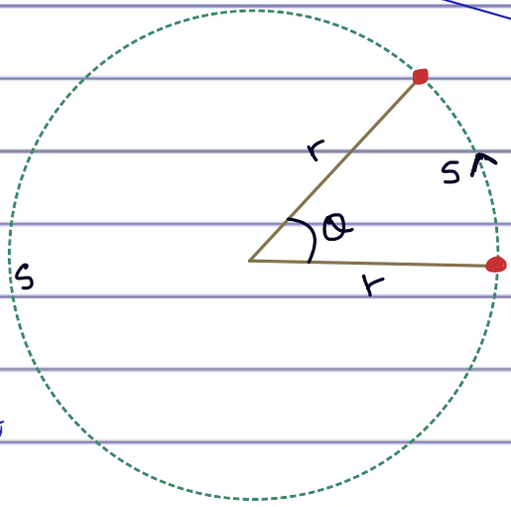
Topic: ⇒ Circular motion:

Date:

# Displacment:

⇒ Linear Displacment

* The length of the curved track formed when an object is moving in circle about a point.




⇒ Angular Displacment

It is an angle suspended by an object moving in a circle about a point.

(measured in radians)

If an object move from one point toanother in circular path

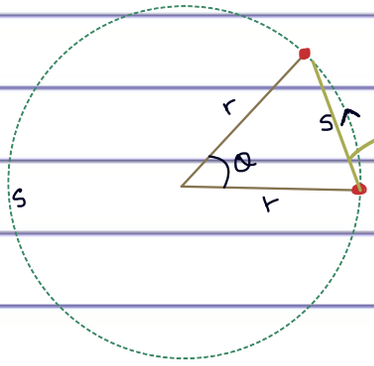
Object is moving in 2 ways

Linear Displacment (s)

Angular Displacment (θ)

Sawal yeh hai k isay Displacment kion kehtay hain.

Ans: Kion k circle mayn move kartay hua yeh sab sa chota raasta hai.




yeh circular motion nahi hai.

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## How S and θ are Related.

$S \propto \theta$

$S = r\theta$ → AS circular Measure.

$\theta = \frac{S}{r}$ → linear Displacement; r → radius.

Angular Displacement

Angle has no unit its just ratio
Radians only tell us mode of calculation

**Convertion Factor**

$180^\circ \longrightarrow \pi$ Rad

$60^\circ \longrightarrow x$ Rad

$C = \frac{\theta}{360} \times 2\pi r$ $\quad S = r\theta$

$C = \frac{\theta}{180} \times \pi r$

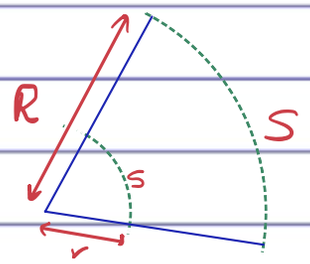
Converter.

## Define Radian.

$S = r \quad (\theta = 1\text{rad})$

It is angular Displacment when linear displament is equal to the radius of the track

* when particle moves in circle about a point.

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# Velocity

Topic: _____ Date: _____

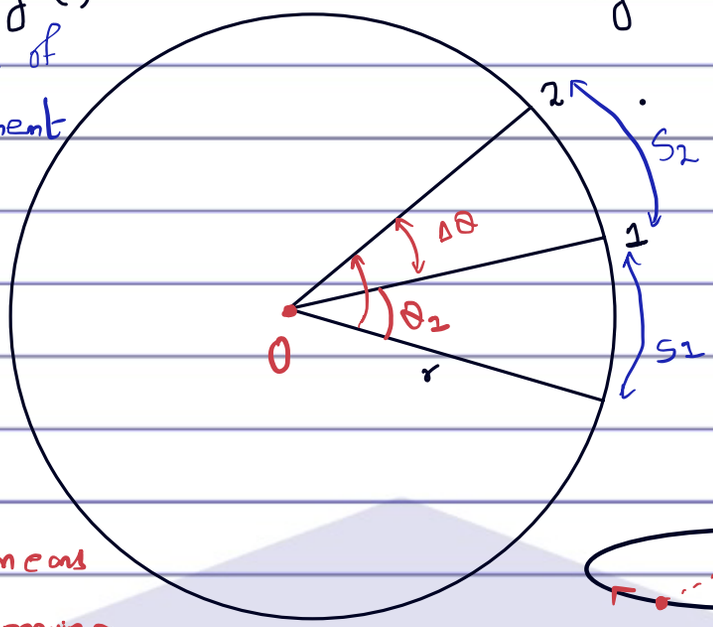
## Linear Velocity (v)

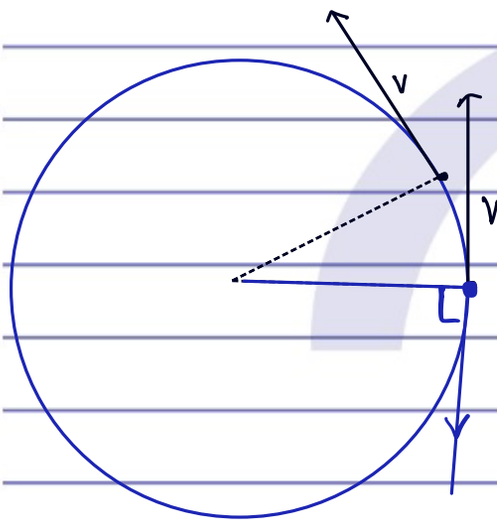
Rate of change of linear Displacment about a point.

m/s

$$V = \frac{\Delta s}{\Delta t} \quad m/s$$

This statement about a point means an object is moving in circles. (O)



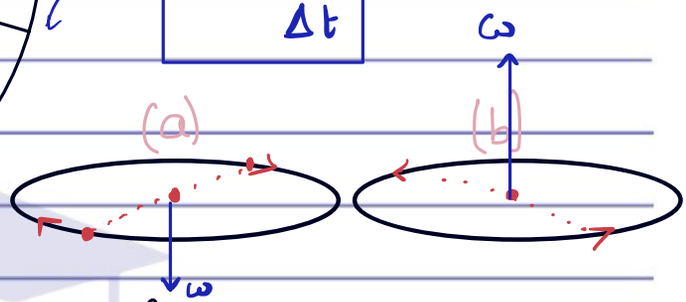




## Angular Velocity. ($\omega$)

↳ Omega.

The rate of change of angular displacment about a point rad/s

$$\omega = \frac{\Delta\theta}{\Delta t}$$




Right hand grip rule

(a) Curl fingers in clockwise direction (Thumb will point downwards)

(b) Curl your fingers in anticlockwise direction (Thumb will point upwards)

$$\omega = \frac{\Delta\theta}{\Delta T} \rightarrow 2\pi$$

## Omega K Formulay ☺

$\Delta\theta = 2\pi$ rad $(360^\circ)$

$\Delta t = T$

If I take complete rotation $\Delta\theta$ will be $2\pi$ rad and $\Delta t$ is called complete time period.

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

(T: Time Period)

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freq = RPS

$f \times 60 = N$

$f = \frac{N}{60}$

We know $f = \frac{1}{T}$ f = frequency

hence $\omega = 2\pi f$

$N(rpm)$ rev. per min

frequency: rps (Revolutions per second)

$N = f \times 60 \rightsquigarrow \frac{N}{60} = f$

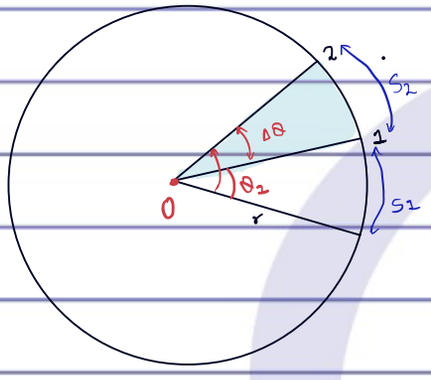
$\omega = \frac{2\pi}{T} \Rightarrow 2\pi \times \frac{1}{T} = f$

$\omega = 2\pi f$

$\omega = \frac{2\pi N}{60}$

$\omega = 2\pi f$

As $s = r\theta$




$\Delta s = r \Delta\theta$

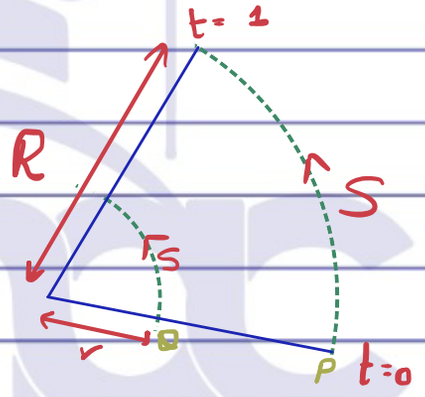
dividing by $\Delta t$

$\frac{\Delta s}{\Delta t} = r \frac{\Delta\theta}{\Delta t}$

$v = r\omega$

$v \propto \omega$ (If $r$ = const)

$v \propto r$ (If $\omega$ = const)




In the same time interval more displacment is covered by P then by Q as $\omega$ is same

So $v_p > v_q$

* Example of channel (slap)
* Example of Bat (Cricket)

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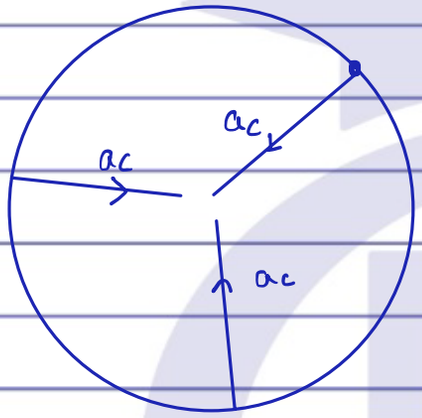
## Centripetal Acceleration :

The rate of change of linear velocity about a point due to change in direction of motion.

$$a_c = \frac{\Delta v}{\Delta t} \longrightarrow a_c = v\omega$$

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

$a = r\omega^2$ or $a = v\left(\frac{v}{r}\right) \Rightarrow a_c = \frac{v^2}{r}$




The direction of centripetal acceleration is towards the centre.

## ⇒ Centripetal Force :

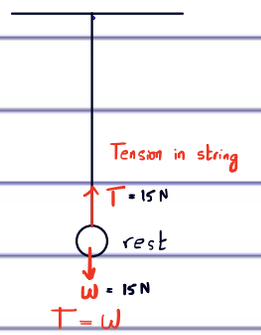
A Resultant Force that tends to rotate an object in a circular path about a point.

$$F_{net} = ma$$

$$F_c = ma$$

$F_c = mr\omega$ $\quad F_c = mr\omega^2$ $\quad F_c = \frac{mv^2}{r}$

### Example




The extra tension is acting as centripetal force

$T - W = F_c$

$15 - 10 = 5N$

$F_c = 5N$

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Stone example: Centrifugal force wants stone to go outwards and centripetal force wants it to stay in.

* Centripetal force is the name given to any force that causes an object to rotate in a circle about a point

## Circular Motion

When a body is moving in a circular path, a force exerts on that body that keeps it moving on that path. If that force disappears, the circular motion of the body will cease to exist and the body will follow a motion in a straight line.

### Centripetal Force

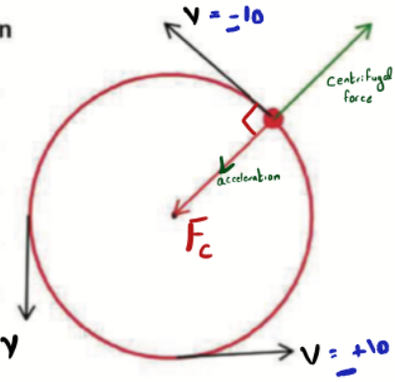
The resultant force that causes an object to move in a circle about a point. It is any force that causes circular motion.

| Case # | Centripetal force |
|---|---|
| 1. Stone and string | Tention in String |
| 2. Car making a turn | Frichon force |
| 3. Planetary motion | Gravitational force. |
| 4. Electrons around the nucleus | Electrostatic force |
| 5. Water in a rotating bucket | Reaction force. |

### Direction of centripetal force, velocity and centripetal acceleration

Centripetal force } Towards the
Centripetal acceleration } centre.

Velocity : Always perpendicular to force

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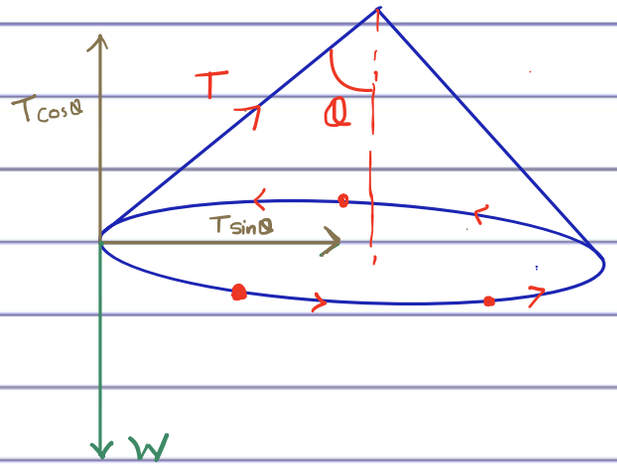
## ⇒ Stone in Horizontal circle.




In this case

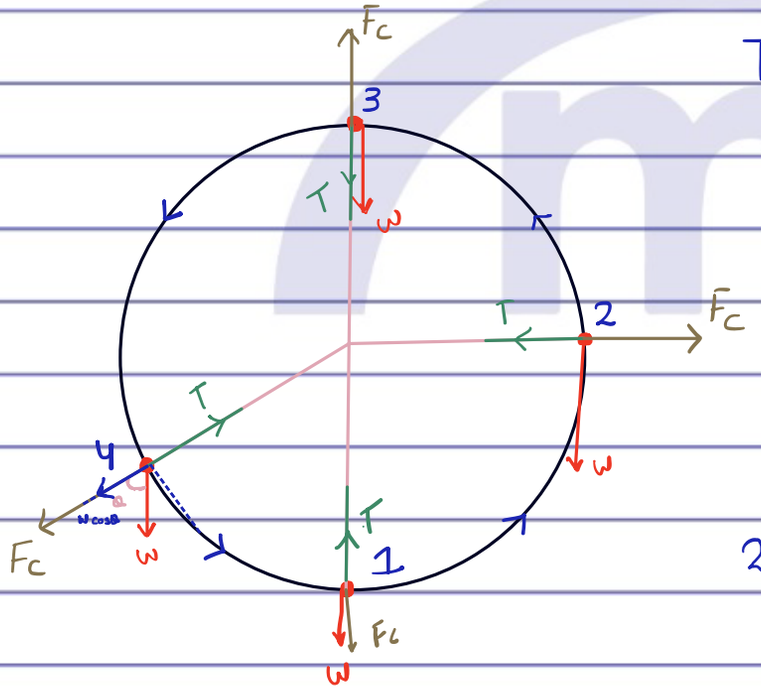
$T\sin\theta = F_c$

e.g $T\sin\theta = mr\omega^2$

$T\cos\theta = W$ (stone is not moving up or down)

$T\cos\theta = mg$

## ⇒ Stone Moving in Vertical circle:




The stone is moving at a constant angular velocity in a Fixed circle.

$F_c$ is constant.

1. $W + F_c = T$

$F_c = T - W$

2. $T = F_c$ Weight is countered by momentum of motion (inertia)

3. $W + T = F_c$

$T = F_c - W$

If $F_c$ is smaller then W, the stone will drop.

4. $W\cos\theta + F_c = T$

$F_c = T - W\cos\theta$

Note: If $F_c = W$ there will be no tention in the string as stone crosses vertical position.

* If $F_c > W$, the tension will also act

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to help Balance Fc

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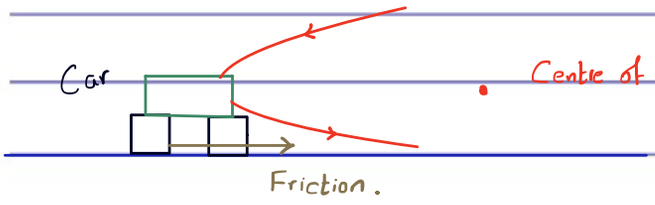
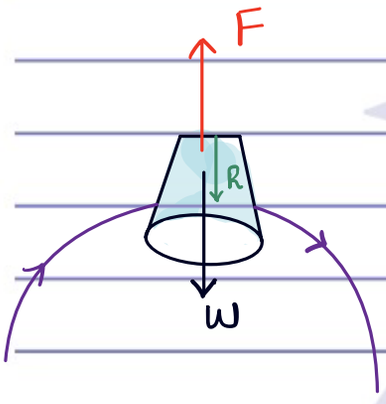



Frictional force acts as a centrepetal Force.




W = Weight of water

R = Contact force from bucket on water.

F = Centrifugal force.

$F_c = W + R.$

For minimum angular velocity to keep water in bucket $R = 0$, centrifugal force must be enough to counter weight of object

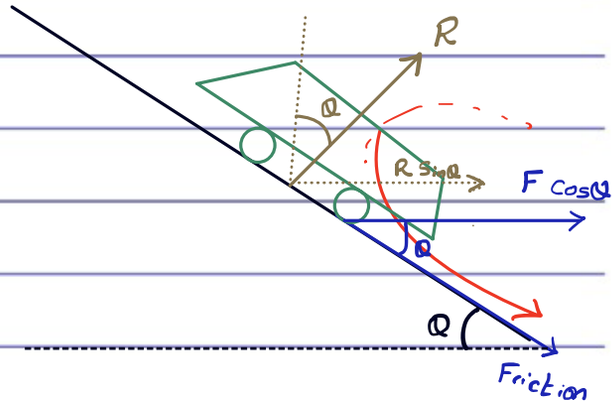
$F_c = W + 0$

$F_c = mg$

$mr\omega^2 = mg$

$r\omega^2 = g$

$$\omega^2 = \frac{g}{r}$$




$R\sin\theta$ and $F\cos\theta$ both act as centripetal force

$F_c = R\sin\theta + F\cos\theta$

Rove Paper

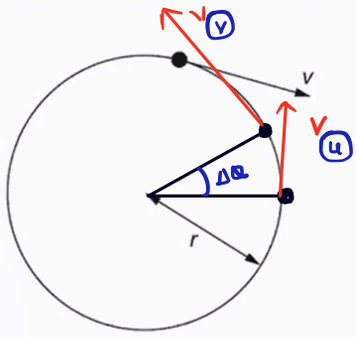
Hw: Review the Lecture
→ Postpapers try.

Book Parh lena.
& Sandhya. bhejay ge

→ University of Brunel.

Topic: _____ Date: _____

1 **(a)** A body is travelling in a circular orbit of radius $r$ with constant speed $v$ as shown in Fig. 1.1.



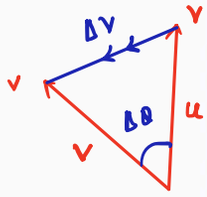




**Fig. 1.1**

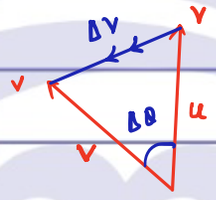
Use a vector diagram to show that the acceleration $a$ of the body is given by

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

towards the centre of the circle.

/4

For a small change of $\Delta\theta$ a sector can be approximated as a triangle so using formula for sector




$$s = r\theta$$

$$\frac{\Delta v}{t} = v\,\frac{\Delta\theta}{t}$$

$$a_c = v\omega$$

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

Hence $a = v\left(\frac{v}{r}\right) \Rightarrow a = \frac{v^2}{r}$

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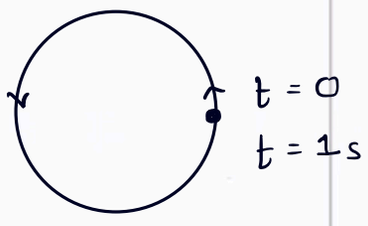
**(b)** The drum of a spin drier has a rate of rotation of 4.0 revolutions per second. An object in the drum has a mass of 0.20 kg and rotates in a vertical circle of radius 0.16 m.

*For Examiner's Use*

**(i)** Calculate the magnitude of the acceleration of the object.



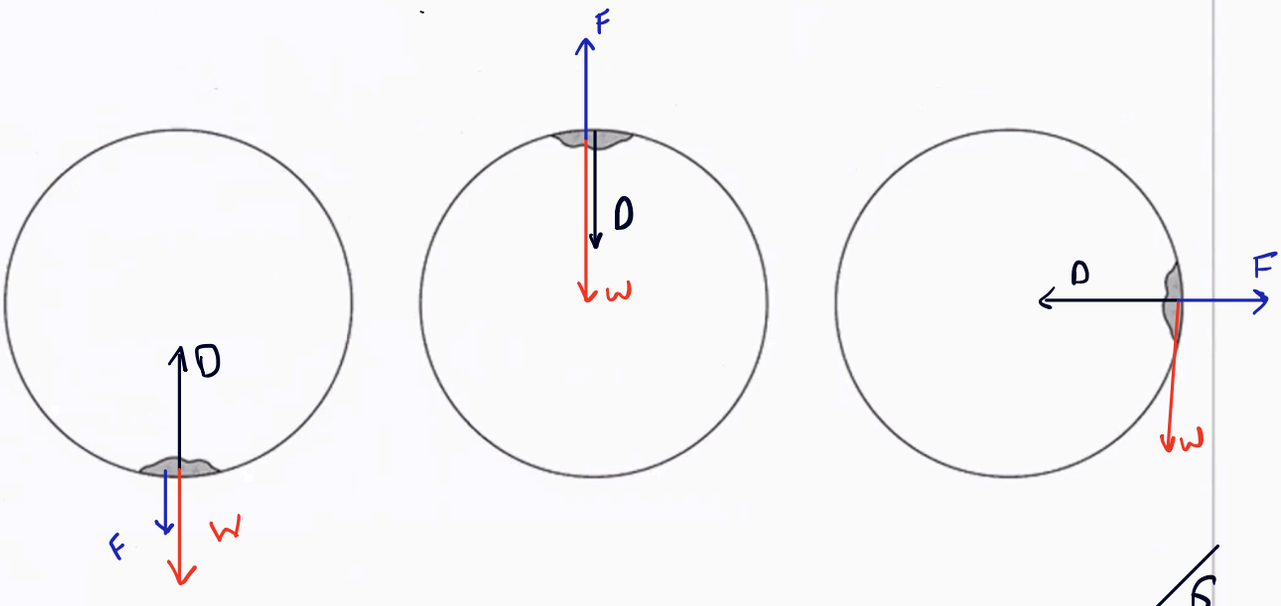

acceleration = ..... $m s^{-2}$ [2]

**(ii)** Calculate the magnitude of the resultant force on the object.

$F_c = m a_c$

resultant force = ..... N [1]

**(iii)** For each of the three positions shown in Fig. 1.2 draw arrows to represent the weight *W* of the object and the force *D* that the drum exerts on the object. Indicate how these two forces always add to produce the resultant force of constant magnitude calculated in **(ii)**.




6

$W + F = D$ $F = D + W$ $F = D$

$F = D - W$

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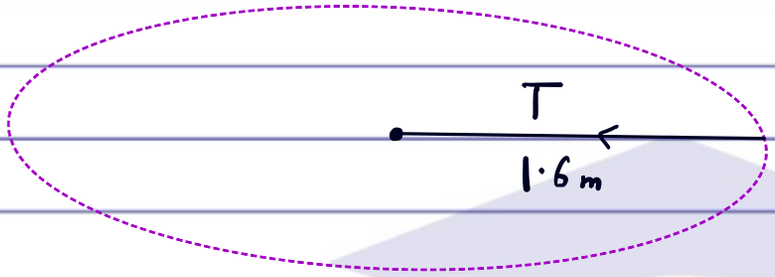
Topic: _____ Date: _____

Ex 1 An elastic string of length 1.2m attaches a mass of 0.2kg to perform horizontal circular motion as shown below. Two strings stretches and its final length becomes 1.6m. If spring constant of spring is $50Nm^{-1}$ calculate the linear velocity of the mass.




$v = ??$

- Tention (T) in the string (Directed towards the centre) provides Centripetal force for circular motion to occur.

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Topic: _____ Date: _____

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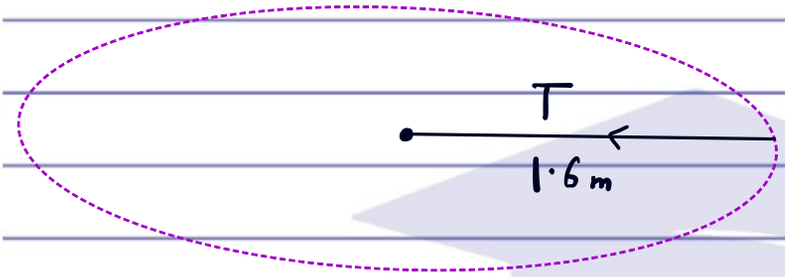


v = ??

• Tention (T) in the string (Directed towards the centre) provides centripetal force for circular motion to occur.

$F = Ice$

$F = F_c$

Solution

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

$$(50)(1.6-1.2) = \frac{0.2v^2}{1.6}$$

$$v = 13 \text{ m/s}$$

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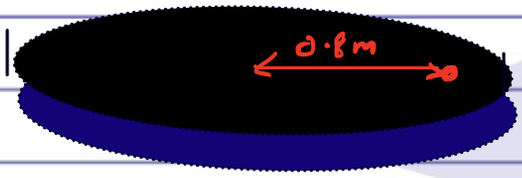
Ex 2 The diagram below shows a mass positioned on a turn table. The frictional force which prevents the mass from sliding amount to 0.9W (W = weight of the mass) If the mass performs Horizontal motion whose radius is 0.8 m. Calculate the max # of revolution which a mass can complete in 1 min?

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Topic: _____ Date: _____

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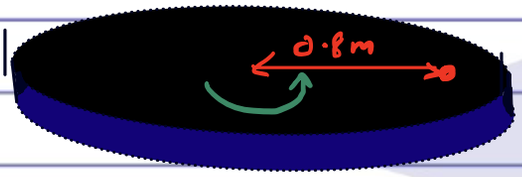


Solution.

If the frictional force b/w mass and surface which is responsible for providing the centripetal force $F_c$; hence

$$F_F = F_C$$

$$0.9W = mr\omega^2$$

$$0.9mg = mr\omega^2$$

$$0.9(9.81) = (0.8)(\omega^2)$$

$$\boxed{3.3 \text{ rad s}^{-1}}$$

$$\omega = \frac{2\pi}{T}$$

$$\boxed{T = 1.9 \text{ s}}$$

Max no of Rev

$$= \frac{60}{1.9} = 31.6$$

$$\boxed{\begin{array}{l}31 \text{ complete} \\ \text{revolutions}\end{array}}$$

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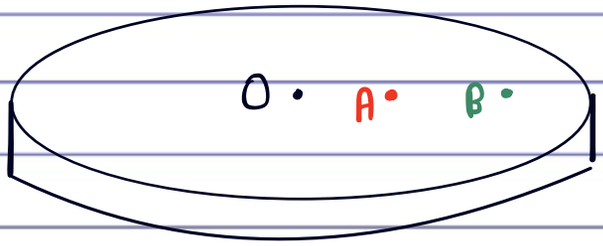
•




A and B have identical masses.

Q) The speed of Rotation is increased slowly state & explain which particle (A or B) will first slide off from the surface and why?

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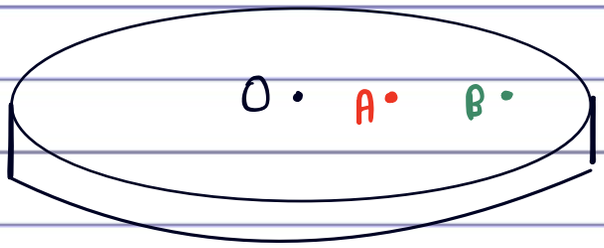


A and B have identical masses.

Q) The speed of Rotation is increased slowly state & explain which particle (A or B) will first slide off from the surface and why?

Solution

Ans - Both A and B have same Ang. velocity

according to $v = r\omega$ ; $r \propto v$ hence $v_B > v_A$

- $F_c = mr\omega^2$ so $F_c \propto r$ hence v require greate centripetal force to remain in its position.
- If friction is unable to meet the demand of $F_c$ then B slides of Before A

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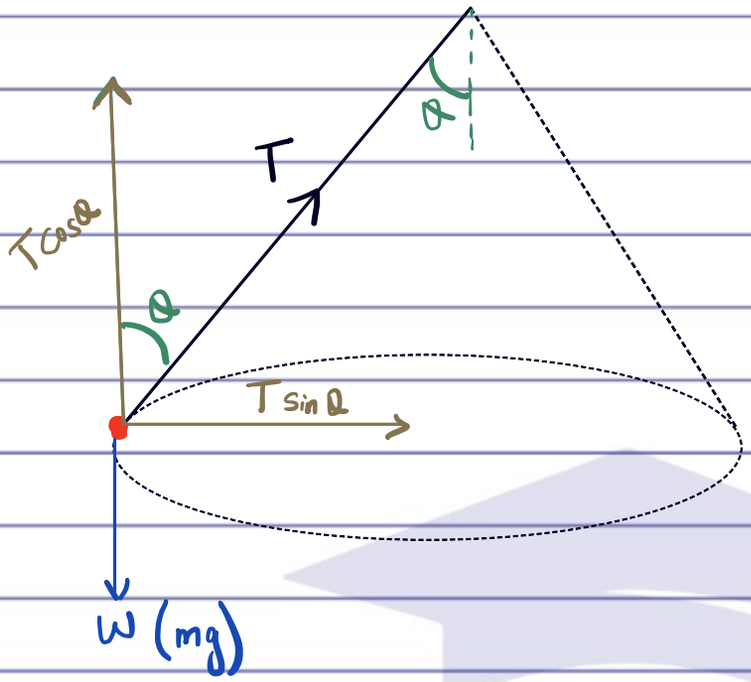
# Concept of Conical Pendulum




- Mark Forces.
- Resolve T into 2 components. (Horizontal and Vertical)

The component $T\cos\theta$ will balance out affect of weight hence

$$T\cos\theta = mg \quad \text{—— (1)}$$

Where as the component $T\sin\theta$ (which is directed towards the centre of circle provides the centripetal force hence

$$T\sin\theta = F_c \quad \text{—— (2)}$$

$$\frac{Eq\ 2}{Eq\ 1}$$

Use the above results to show that $\tan\theta = \frac{v^2}{rg}$

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

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

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# Unit 1: Motion in a Circle

**1. O/N 14/P42/Q2, O/N 14/P41/Q2**

A large bowl is made from part of a hollow sphere.

A small spherical ball is placed inside the bowl and is given a horizontal speed. The ball follows a horizontal circular path of constant radius, as shown in Fig. 2.1.

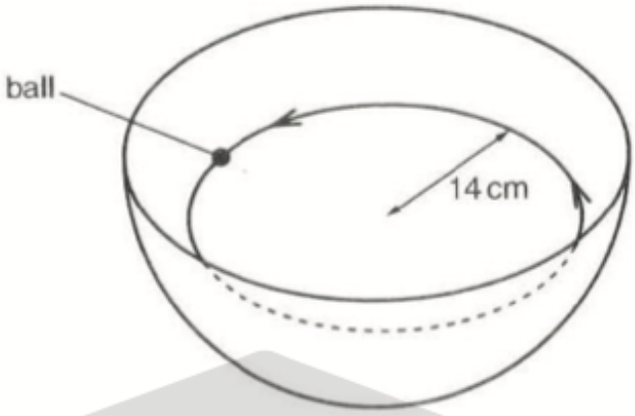


**Fig. 2.1**

The forces acting on the ball are its weight $W$ and the normal reaction force $R$ of the bowl on the ball, as shown in Fig. 2.2.

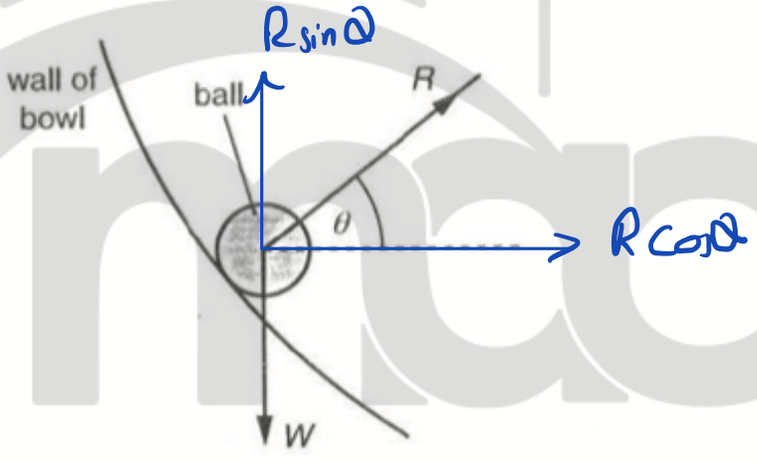


**Fig. 2.2**

The normal reaction force $R$ is at an angle $\theta$ to the horizontal.

Topic: _____ Date: _____

(a) (i) By resolving the reaction force $R$ into two perpendicular components, show that the resultant force $F$ acting on the ball is given by the expression

$$W = F \tan\theta.$$

$R\sin\theta = W$ — (1)

$R\cos\theta = F$ — (2)

$\frac{(1)}{(2)} \Rightarrow \tan\theta = \frac{W}{F}$ $\quad F\tan\theta = W$

[2]

(ii) State the significance of the force $F$ for the motion of the ball in the bowl.

The Force F provides centripetal force which is required by the object to perform circular motion. [1]

(b) The ball moves in a circular path of radius 14 cm. For this radius, the angle $\theta$ is 28°.

Calculate the speed of the ball.

$W = F\,\text{Tan}\theta$

$mg = \frac{mv^2}{r}\,\text{Tan}\theta$

$9.81 = \frac{v^2}{14\times10^{-2}} \times \text{Tan}\,28$

$v = 1.6$

speed = 1.6 $ms^{-1}$ [3]

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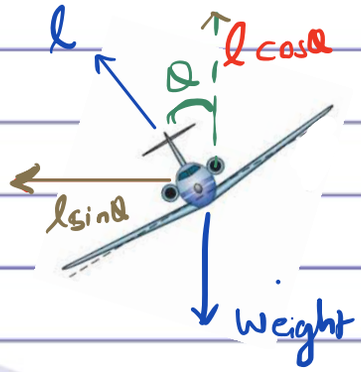
# How Horizontal Circular motion is performed by the Aircraft when tries to bend.

## Normal circumstances


Forces in vertical plane
① weight ② Lift force
[lift force name given to upthrust force]
Weight is vertically downwards where as the lift force (L) provided by the engine is always ⊥ popendicular to the wings.

## When this air craft tries to perform a Circular Motion




$l\cos\theta = mg$

$L\sin\theta = F_c$

**Conclusion:**

Pendulum: Tention Resolves to generate $F_c$

Air craft: L resolves to generate $F_c$

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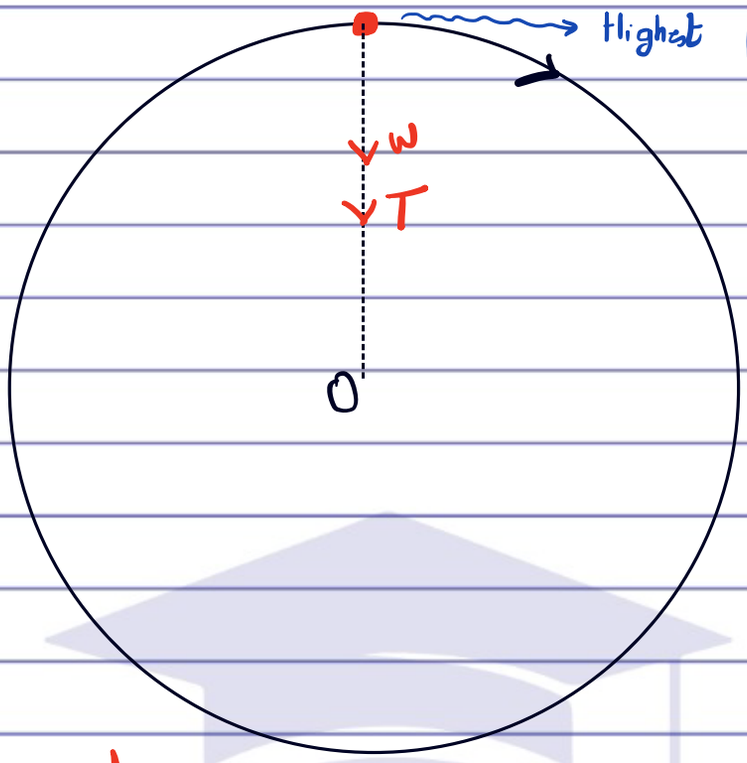
# Theory of Vertical Circular Motion (Once again)




For A (highest Pt)

$$T + W = F_c$$

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

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

⇒ At highest point both tention and weight act towards the centre Hence they collectivly provide $F_c$

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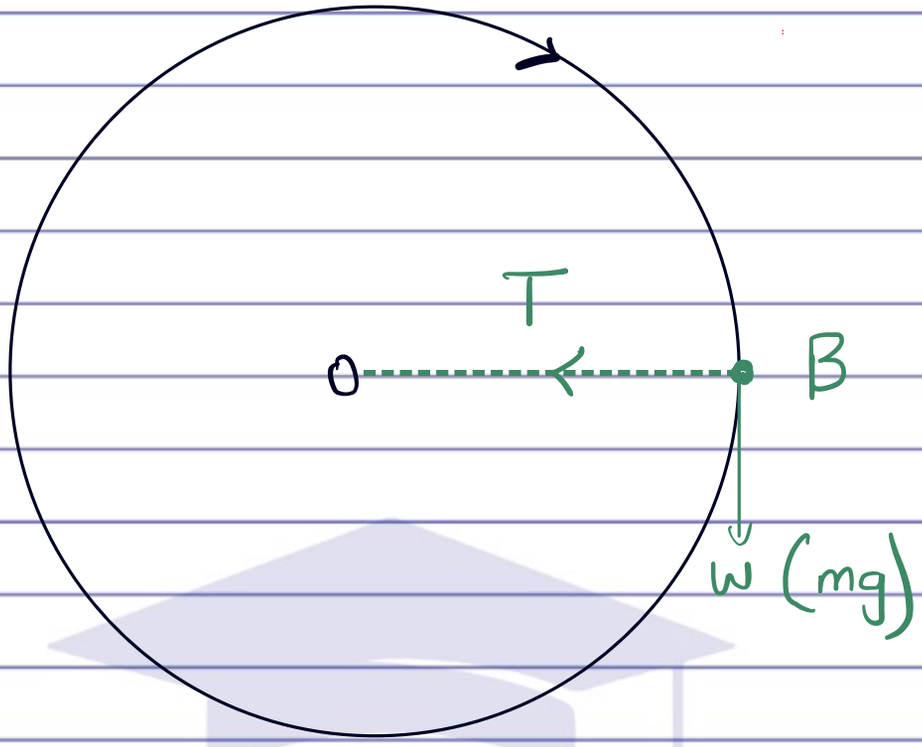


For B only tention is towards the centre hence only Tention will provide centripetal force.

$$T = F_c$$

$$\boxed{T = \frac{mv^2}{r}}$$

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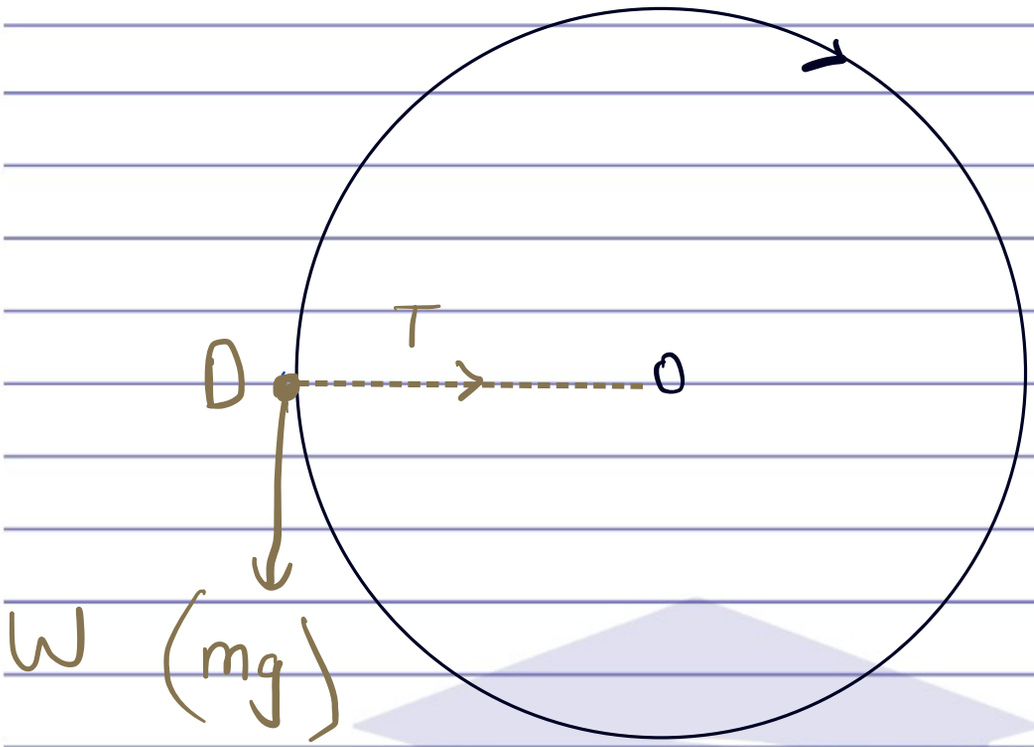


Since same as B hence.

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

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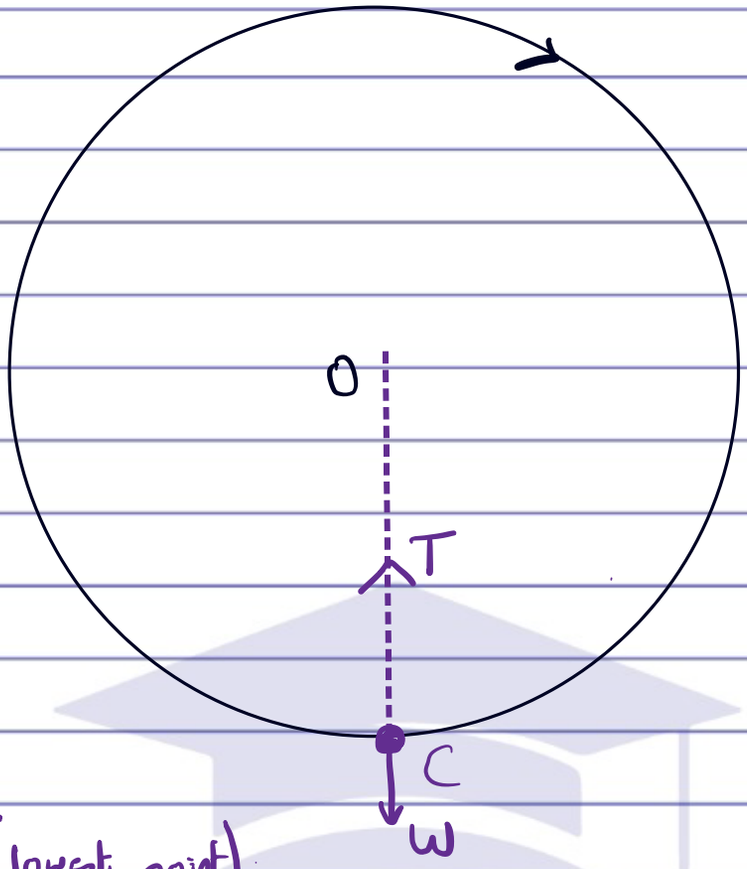


For "C" (lowest point)

Since tention and W are in opposit directions the Resultant Force (T-W) or T-mg will provide the centripetal force hence

$$T - mg = F_c$$

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

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

Conclusion

1) highest pt Tention is least ie

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

2) Lowest point : Tention is greatest ie

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

3) For other 2 points B and D (Left and Right)

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

Hence we can conclude that magnitude of tention varies as position of Particle changes.

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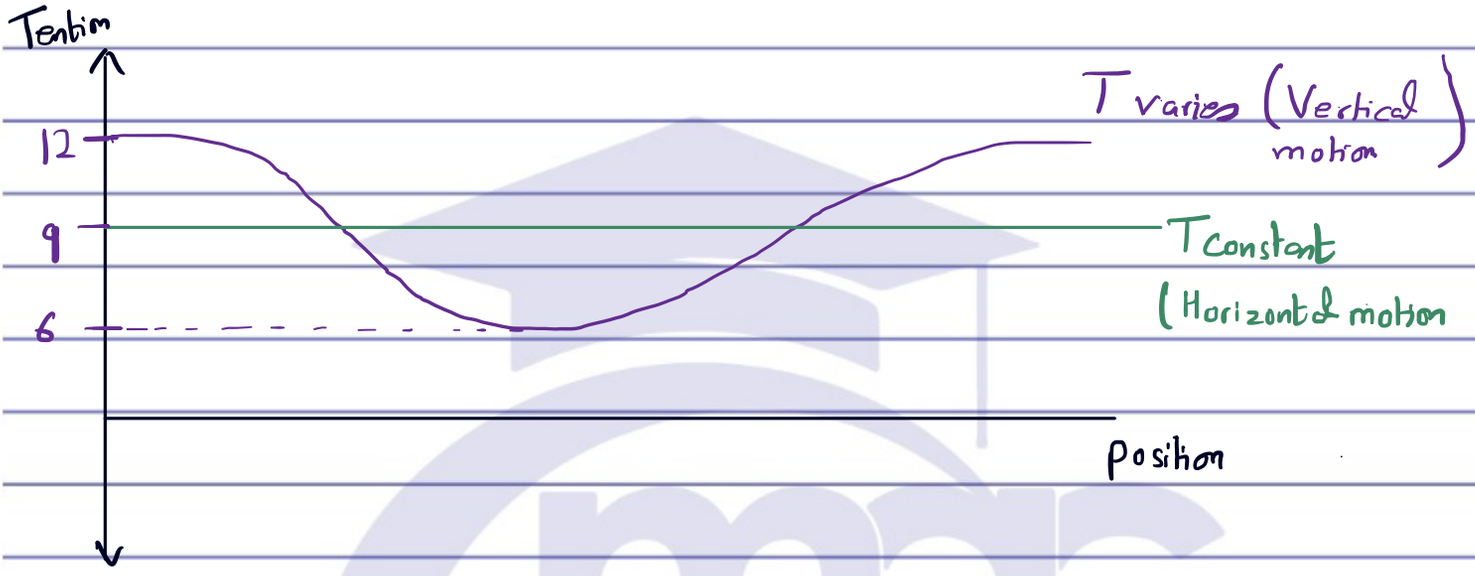
For Horizontal circular motion Tension remains constant

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

The graph below shows how Tension (T) varies in a H.C and a V.C




(ii) If radius of circle is 0.6 m

Calculate mass(m) of the object & the linear velocity (v) of the obj

$T_{max} = \frac{mv^2}{r} + mg$ [lowest]

$12 = \frac{mv^2}{r} + mg$ → (1)

$T_{min} = \frac{mv^2}{r} - mg$ [Highest point]

$6 = \frac{mv^2}{r} - mg$

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$12 = \frac{mv^2}{r} + mg$

$-6 = \frac{-mv^2}{r} \pm mg$

$6 = 2mg$ $g = 10$ (Just assuming)

$3 = mg$

$\frac{3}{10} = m$

$0.3_{kg} = m$

ii) $12 = \frac{mv^2}{r} + mg$

$12 = \frac{(0.3)(v^2)}{0.6} + (0.3)(10)$

$v = 4.24\ m/s$

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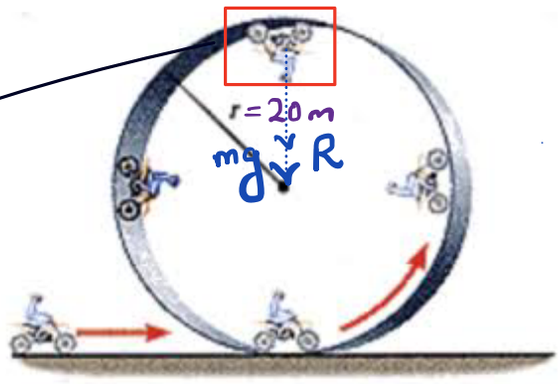
Q) The diagram below shows a Bike performing vertical circular motion with radius 20m. The Bike is in contact with the inner surface of the track.




Vertical circular loop

At one instant the bike is at its highest point as shown calculate the min velocity "v" required at the highest point to ensure bike executes its C.M without breaking its contact?

For Highest point

$$R + mg = F_c$$

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

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

* If the contact would have to break then $R = 0$ ∴
If we donot want the contact to break. then $R > 0$ [greater then zero]

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$\frac{mv^2}{r} - mg > 0$

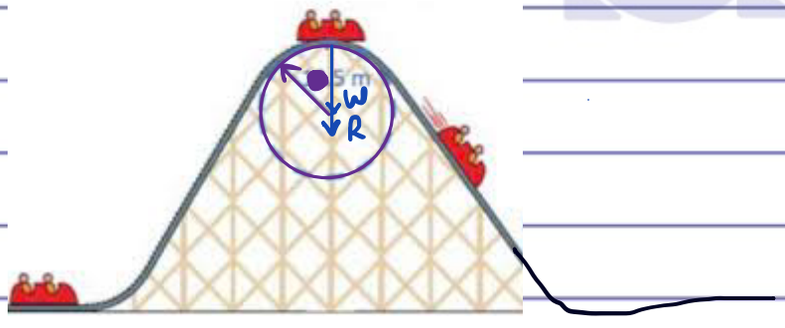
$\frac{v^2}{r} > g$

$v > \sqrt{rg}$ $r = 20$ $g = 10$

$v > \sqrt{200}$ $\Rightarrow$ 14 m/s

**Note:** This formula indicates as long as velocity of trolly remains greater then $v > \sqrt{rg}$ at highest point then the trolly will be able to execute vertical circular motion without breaking its contact with the track.

Q) The diagram below shows a car travelling over a hump on a road which forms part of a vertical circle as shown. The car is in contact with the outer side of the road.




Given that radius of the vertical circle = 5m. Calculate the maximum velocity v with which the car must travel at the highest pt to ensure that the contat remains intact.

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For the highest point

$$W - R = F_c$$

$$W - F_c = R$$

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

If contact breaks then $R = 0$

$\therefore$ if you want the contact to remain intact $R > 0$

$$R > 0$$

$$mg - \frac{mv^2}{r} > 0$$

$$v < \sqrt{rg} \qquad r = 5 \qquad g = 10$$

$$v < \sqrt{50}$$

$$v < 7.1 \text{ m/s}$$

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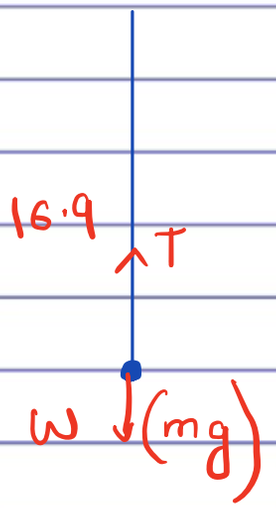
→ Property of Verticle circular motion for the particle which is connected using an Elastic String

Orignal length = 16·2 cm

mass = 0·5 kg

String extends and reaches = 16·9 cm

(i) Calculate The spring constant (k) if the system is in equllibrium.




Since Equllibrium

$T = mg$

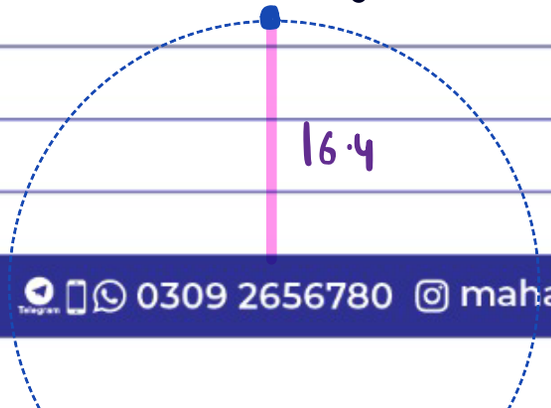
(Hooke's law)

$ke = mg$

$k\left(\frac{16.9 - 16.2}{100}\right) = (0.5)(9.81)$

$k = 700\ Nm^{-1}$ 2sf

ii) The particle is now made to perform verticle circular motion at the highest point, the length of the spring becomes 16·4 (as shown) use this information to calculate angular velocity (w) of the particle.




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

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$$k_c = mr\omega^2 - mg$$

$$700\left(\frac{16.4 - 16.2}{100}\right) = (0.5)(16.4)(\omega^2) - (0.5)(9.81)$$

$$\boxed{\omega = 8.8 \text{ rad s}^{-1}}$$

ii) Extended: What if Highest point, length of the string was given as 16.2cm

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

$$k_c = mr\omega^2 - mg$$

$$\omega^2 = \frac{g}{r}$$ Solve to calculate $\omega$

$$\omega = \sqrt{\frac{9.81}{16.2}}$$

If length of Highest point is 16.2 hence

$16.2 - 16.2 = 0$

$\boxed{e = 0}$ $\therefore k_c = 0$

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iii) The particle continues its motion and after sometime it reaches its lowest point (as shown)

Given that length of lowest pt is L. Calculate L

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