NON-uniform Circular Motion

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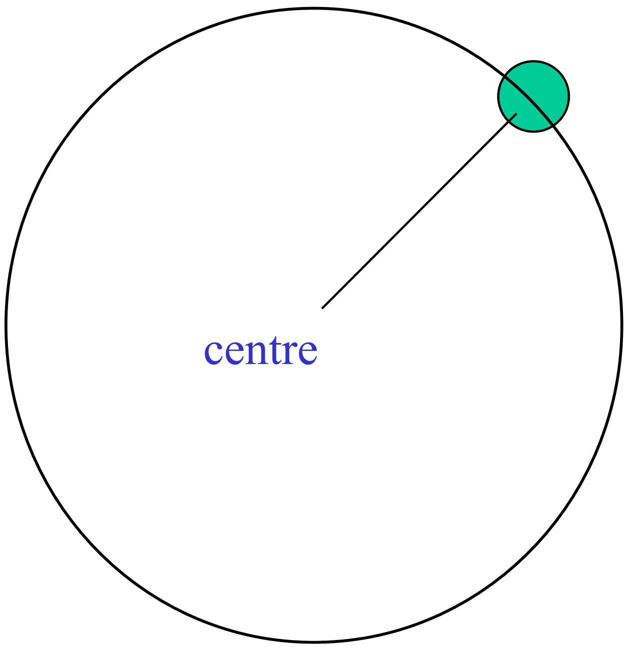

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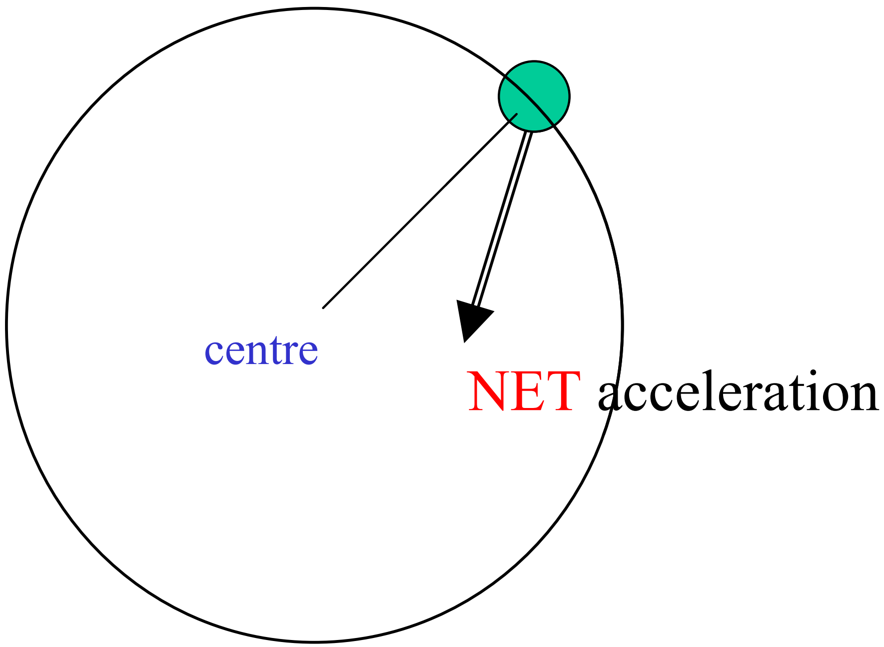

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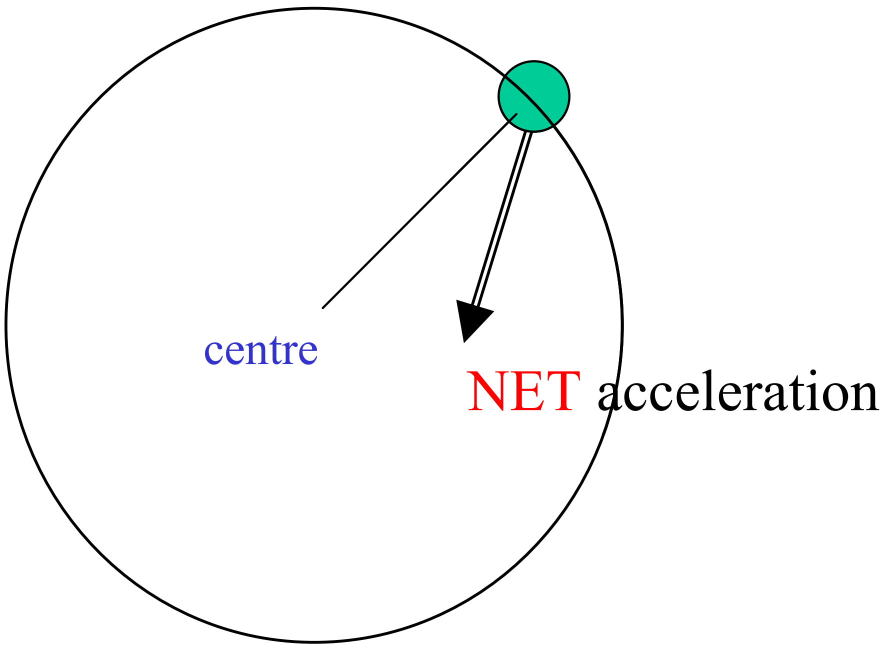
    - Radial / centripetal : due to the change in direction of velocity
    - Tangential : due to the change in magnitude of velocity



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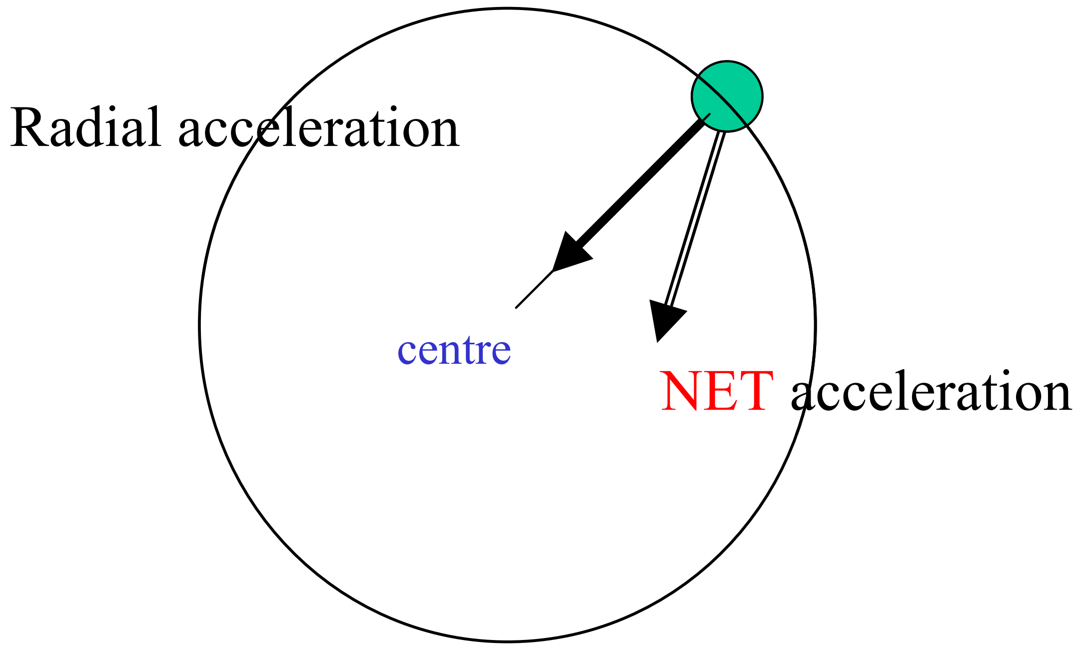

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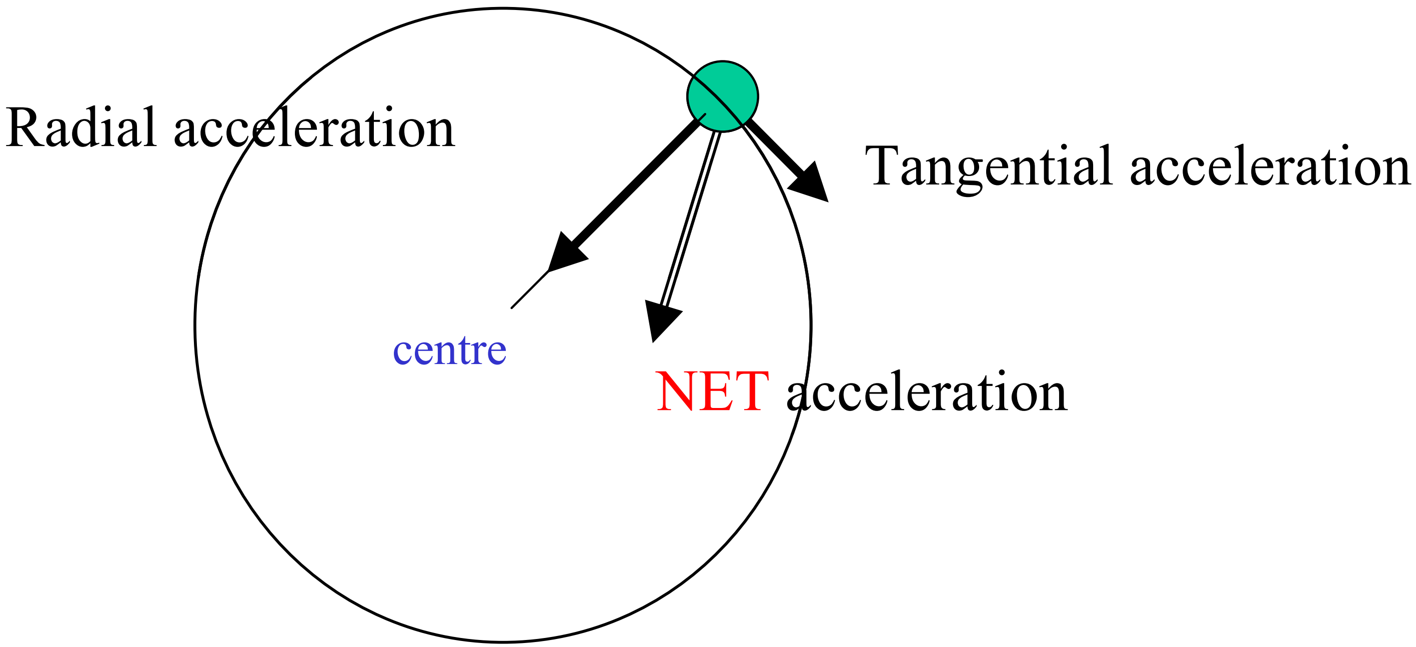

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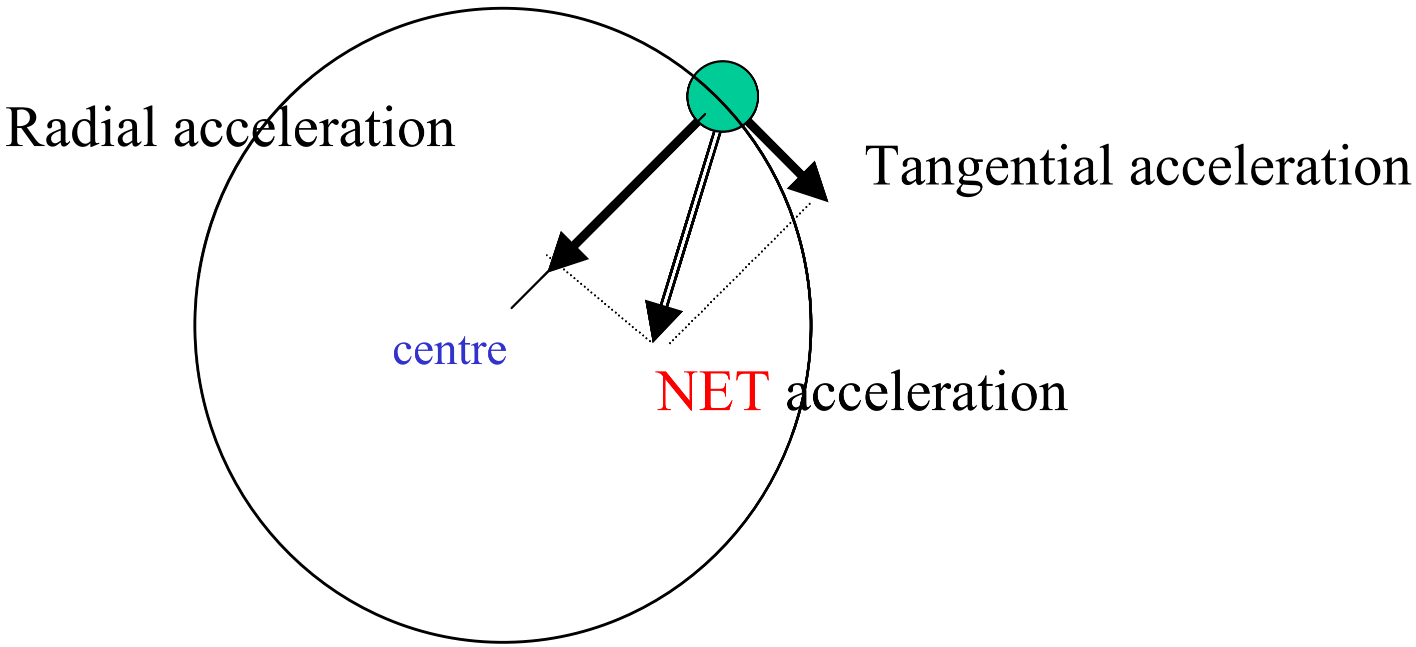

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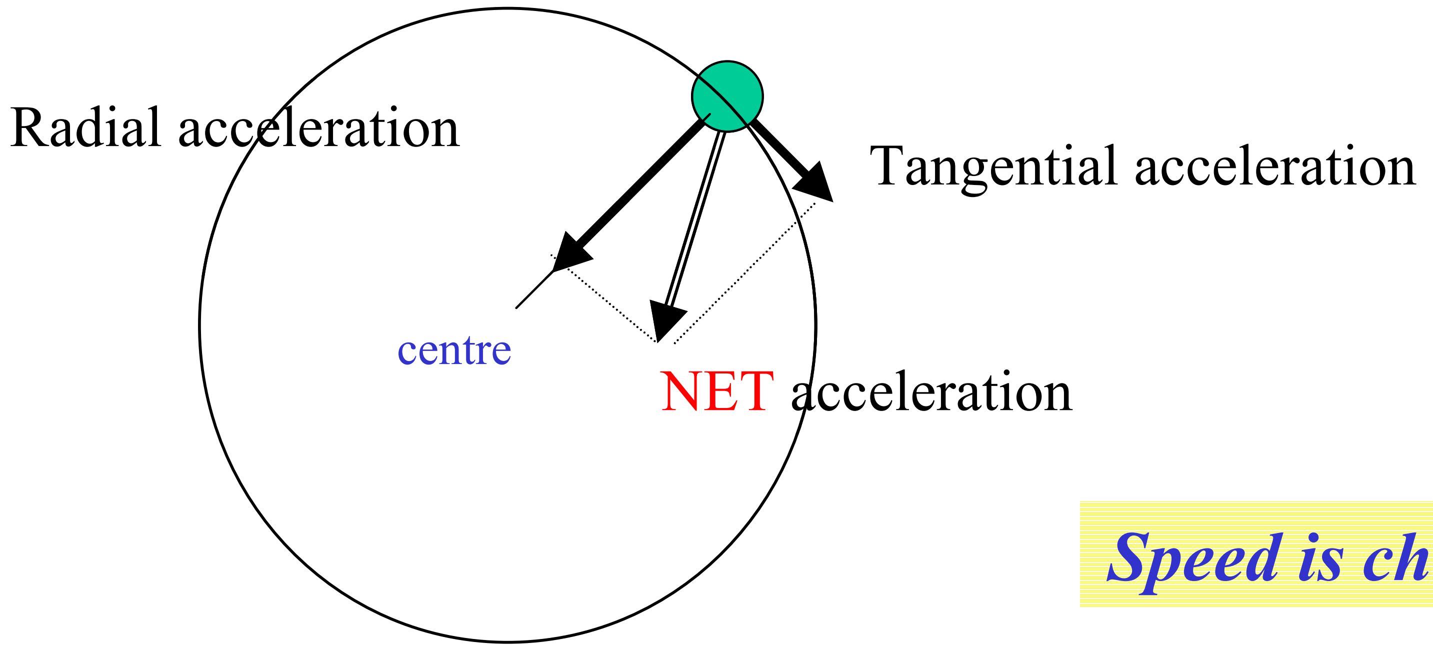
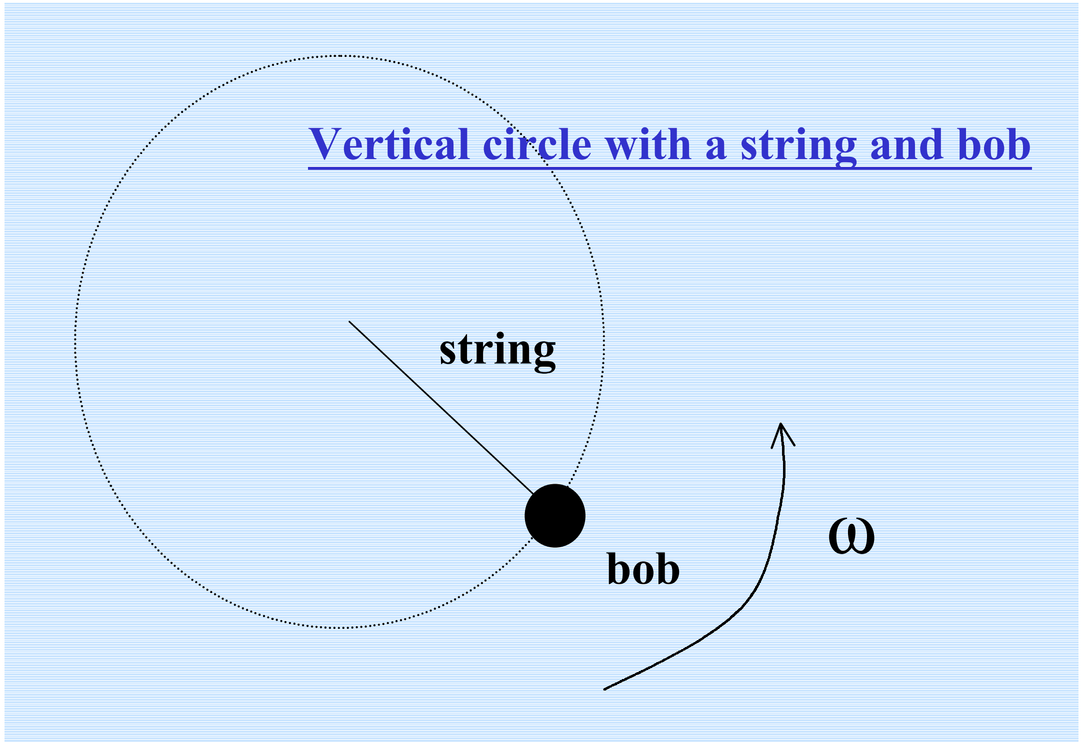


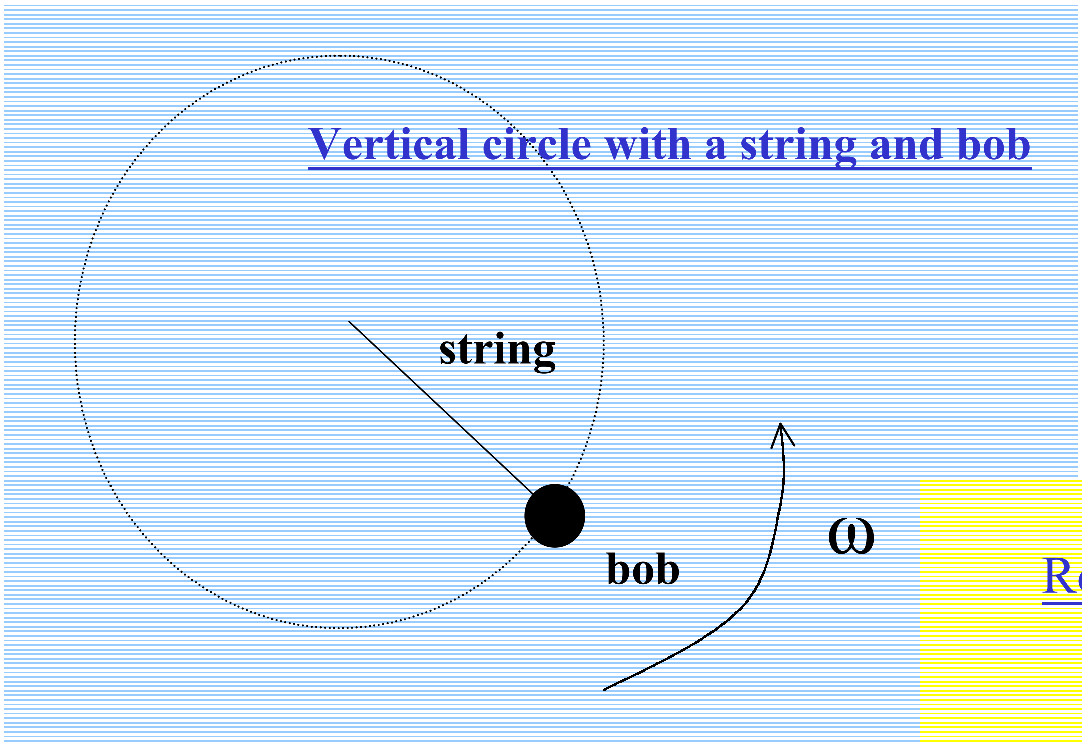
Speed is changing

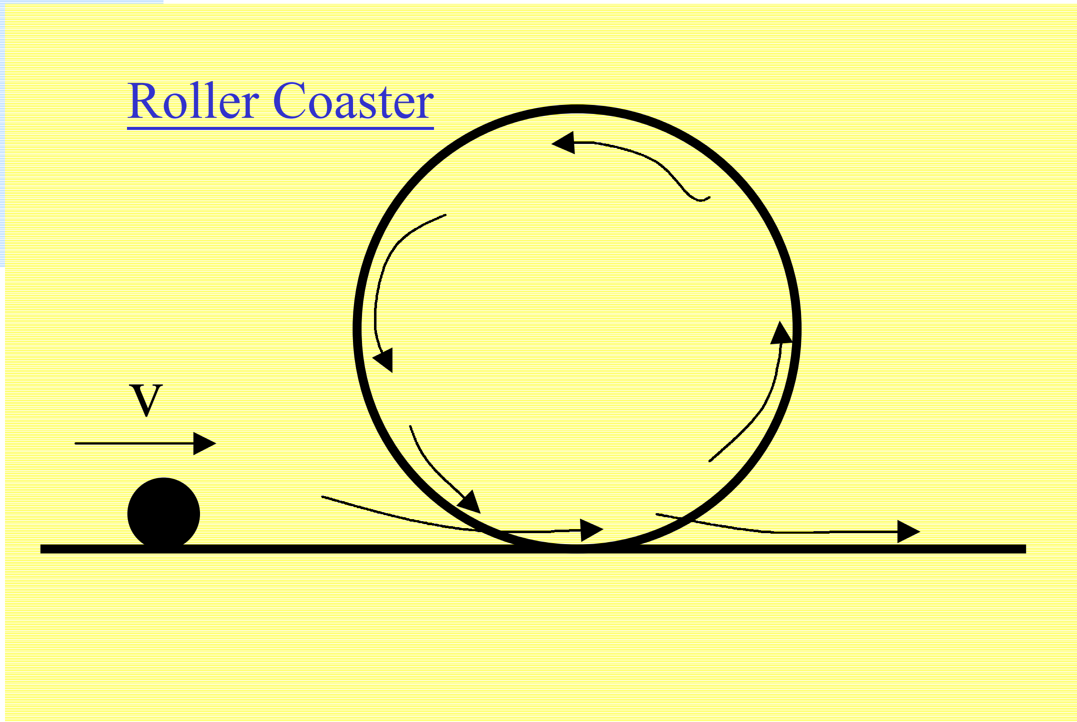
Examples of non-uniform circular motions

Examples of non-uniform circular motions

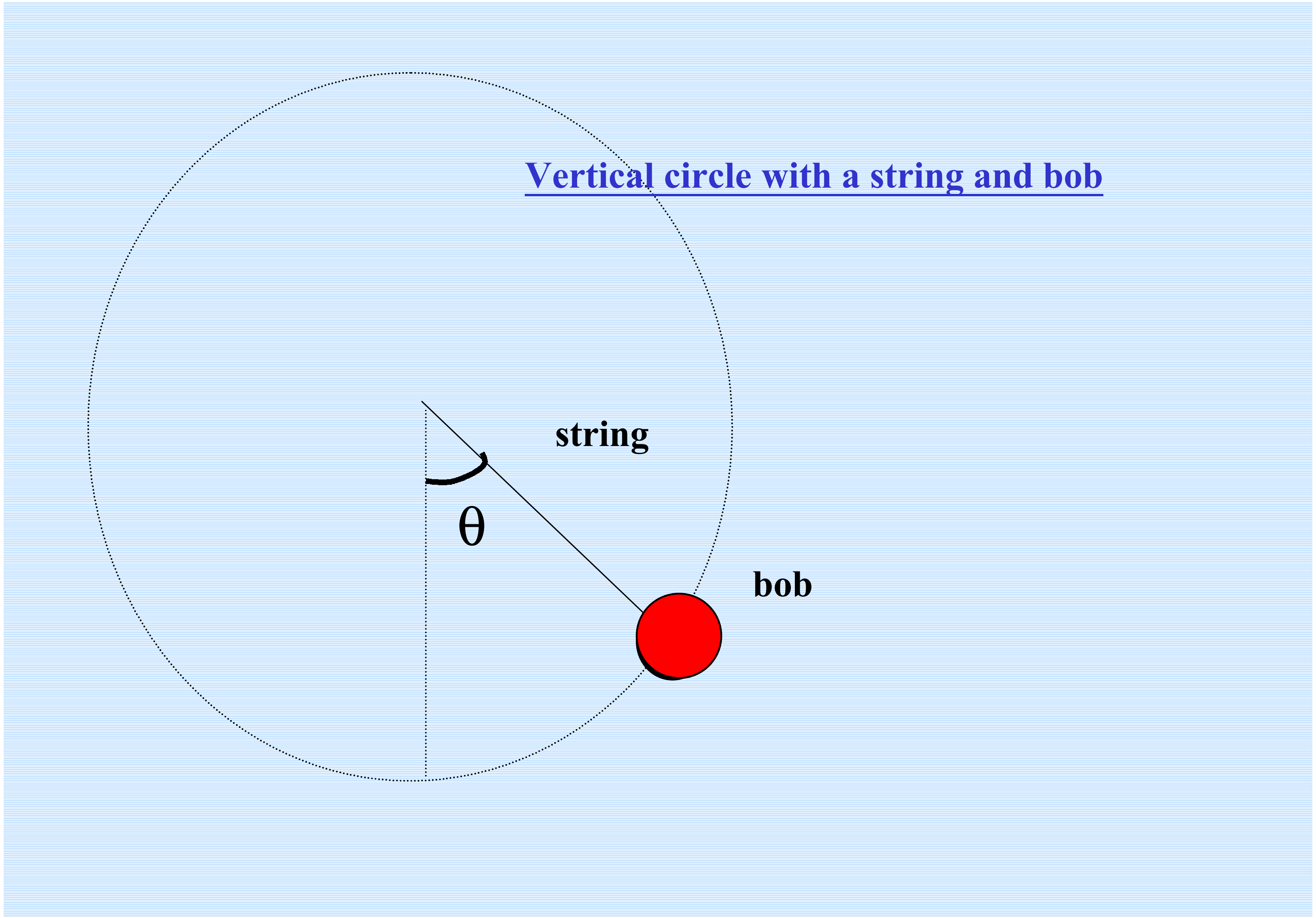


Examples of non-uniform circular motions





Free body diagram



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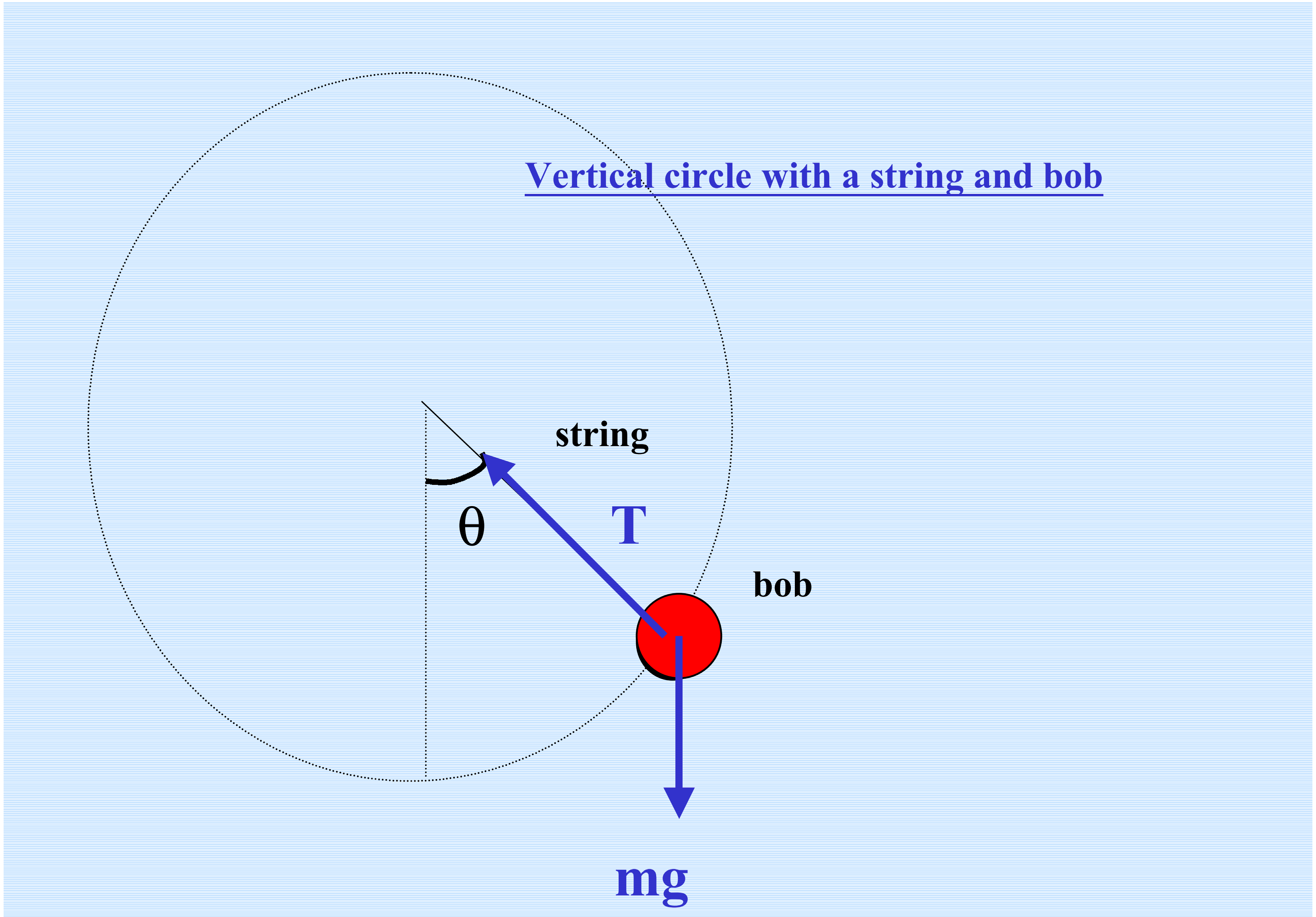

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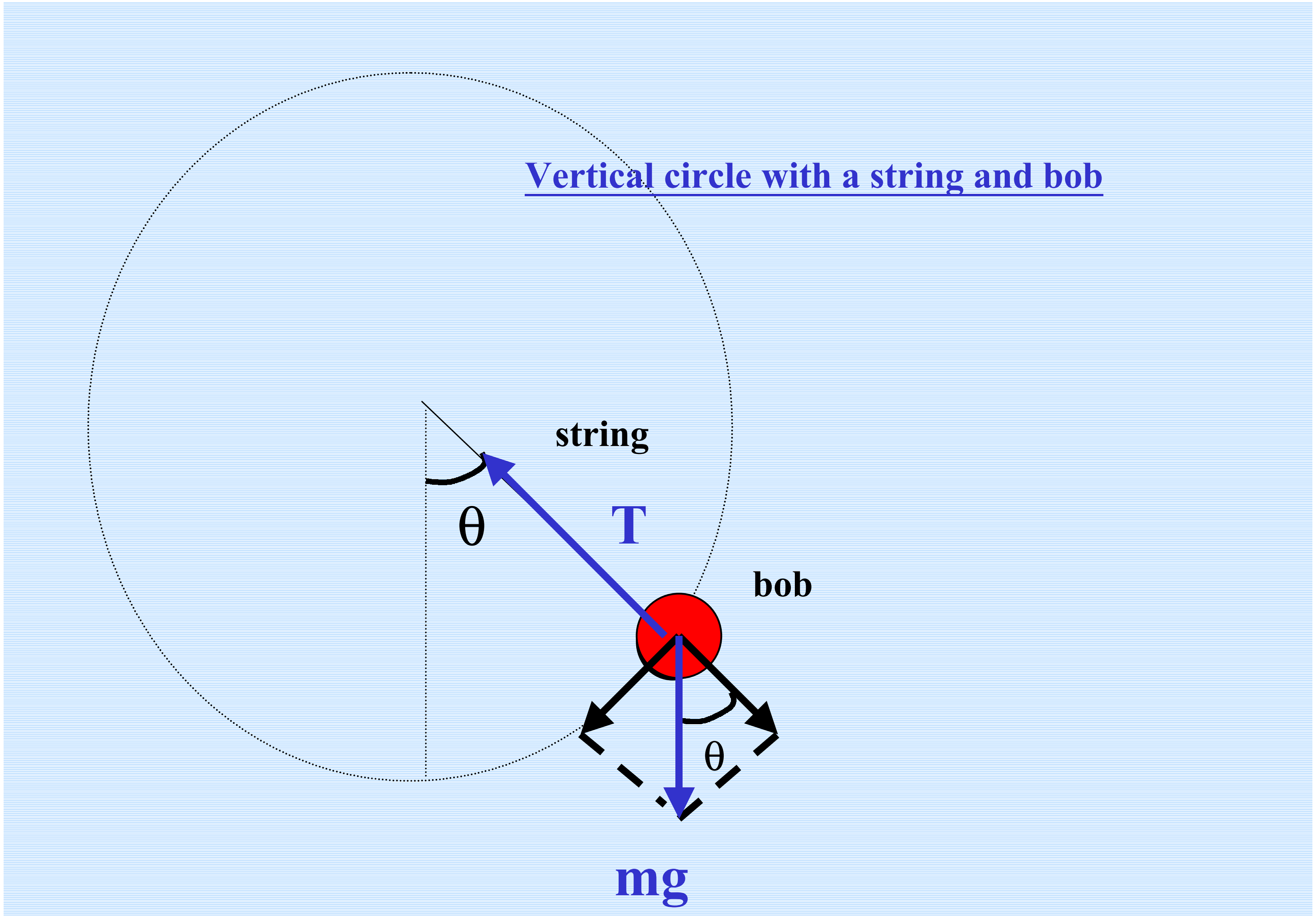

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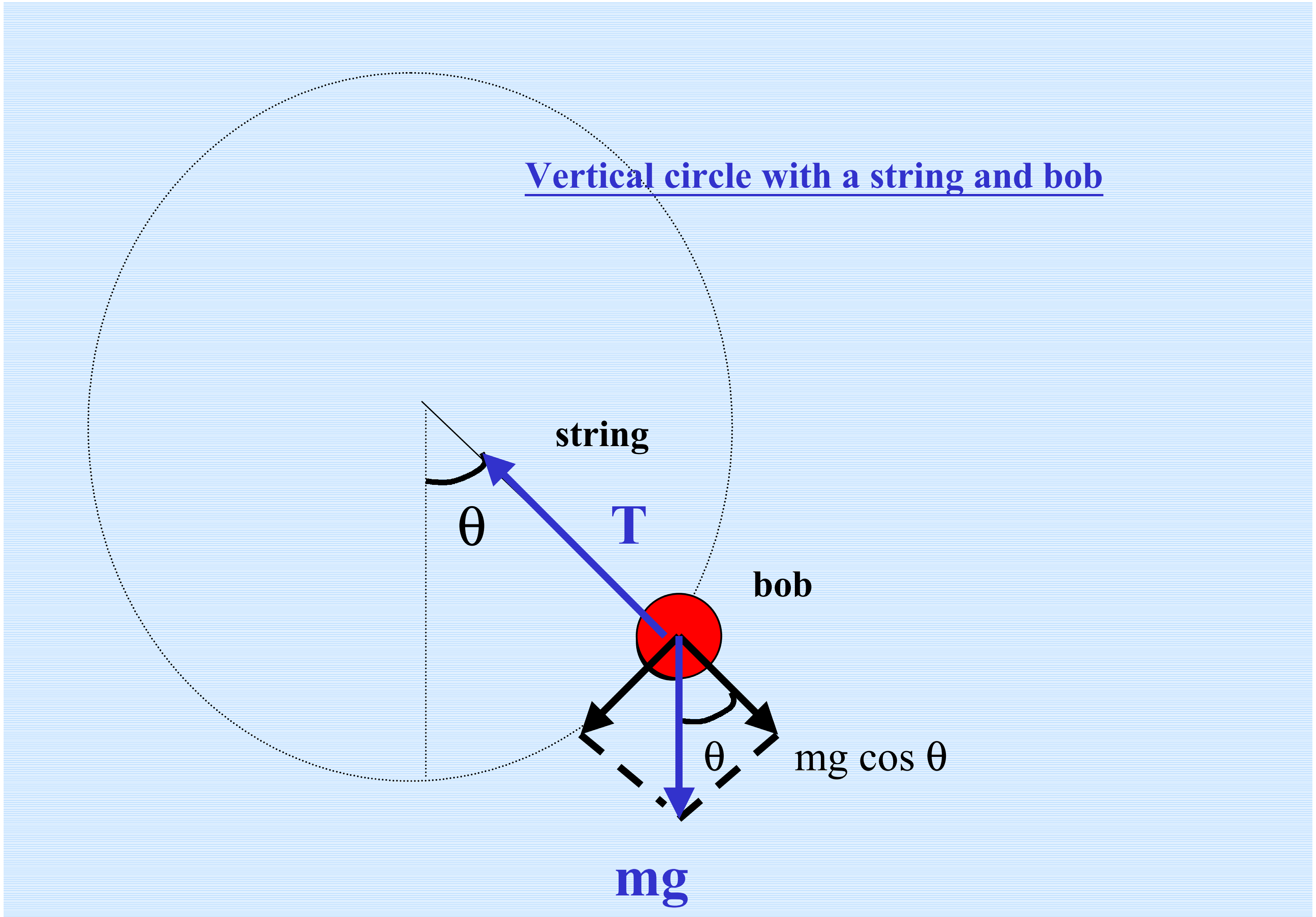

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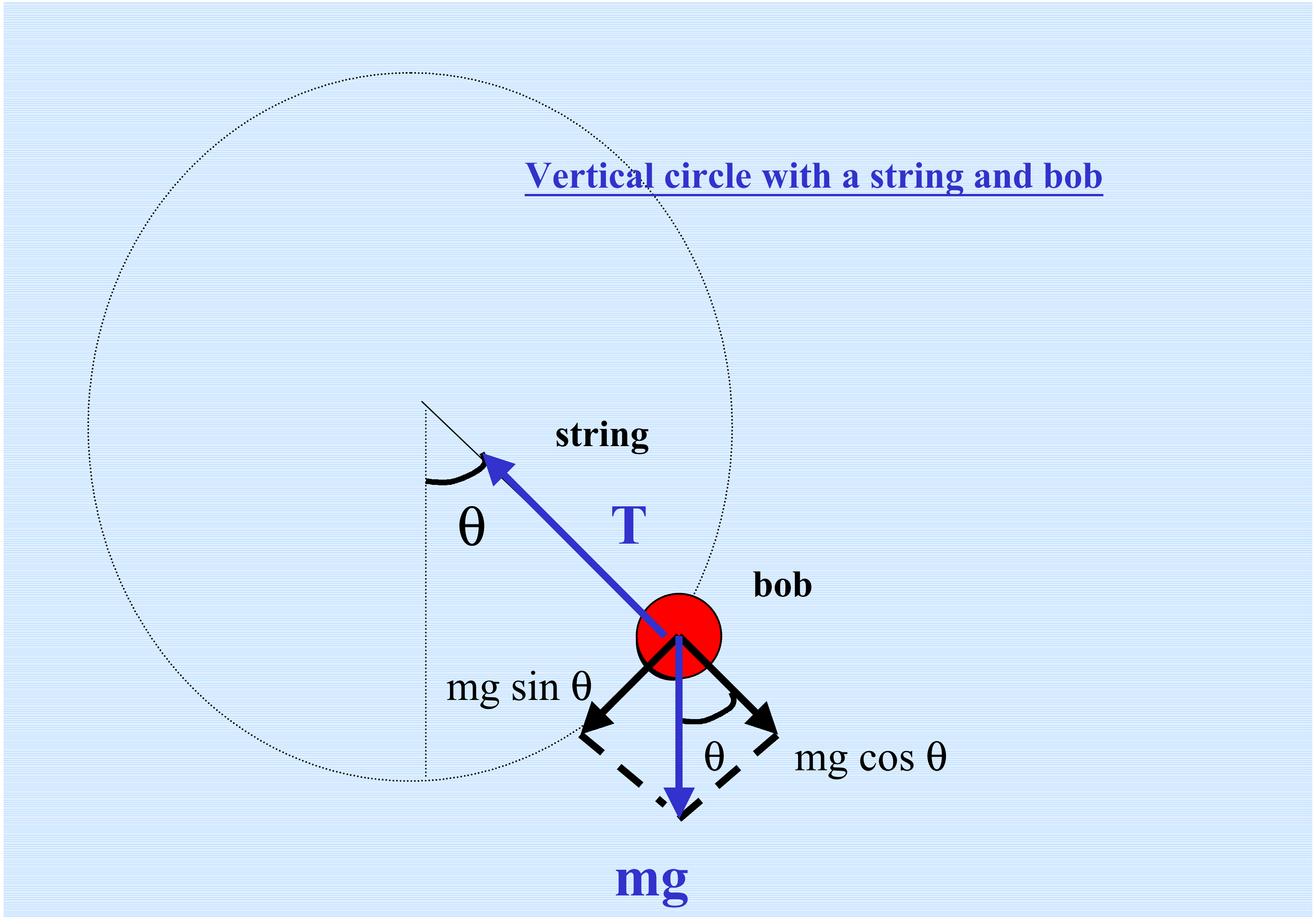

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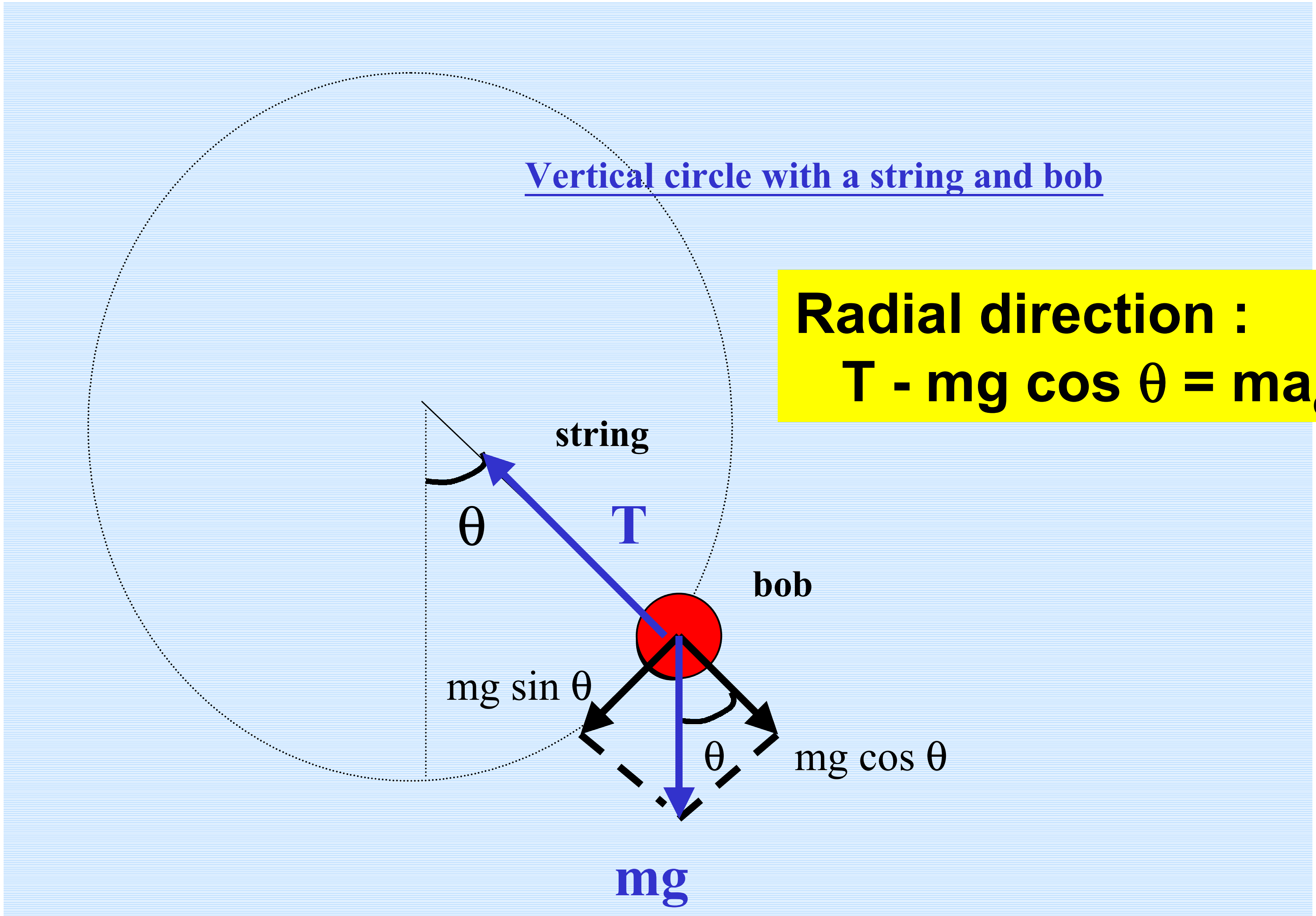
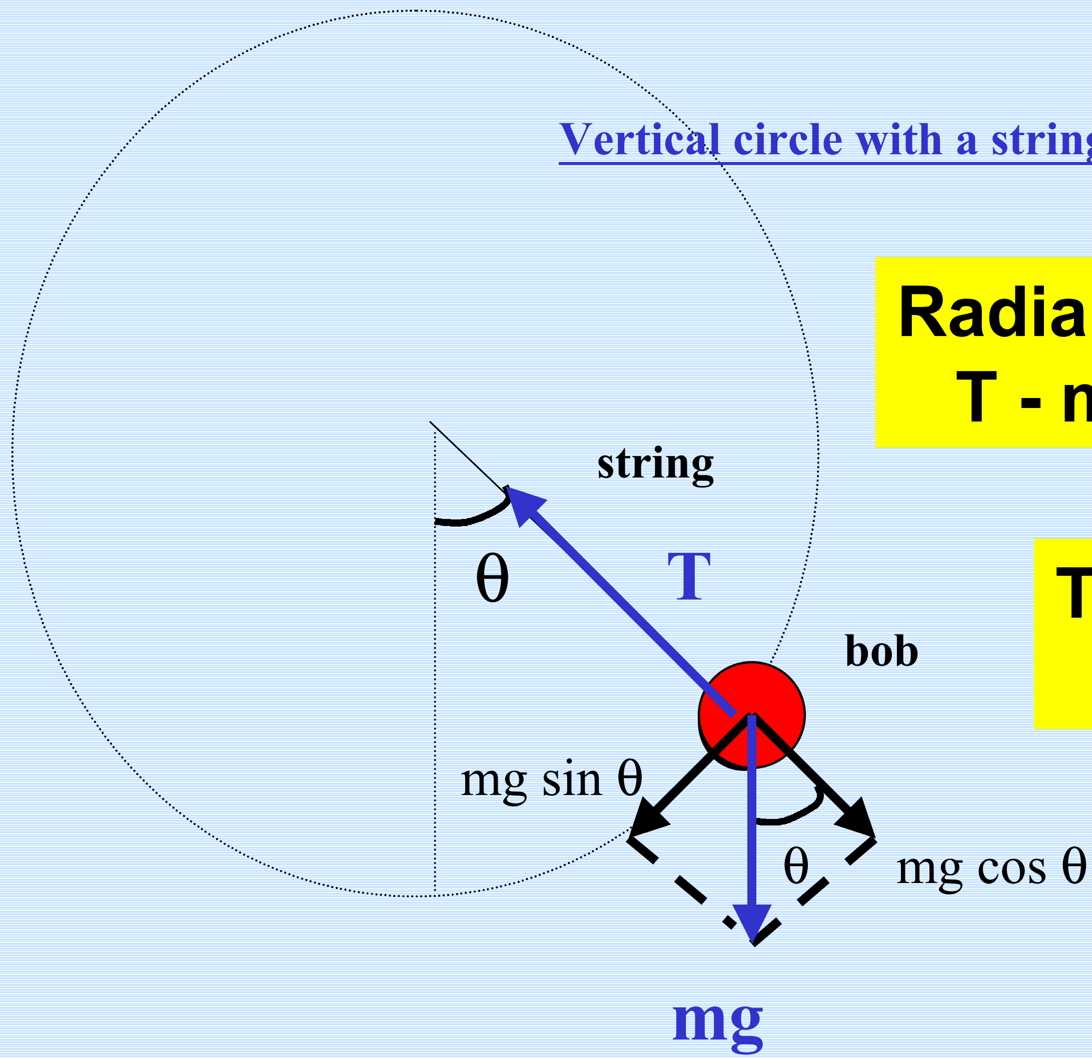


Radial direction :

$$T - mg\cos\theta = ma_c = mv^2 / r$$

Free body diagram

Vertical circle with a string and bob



Radial direction :

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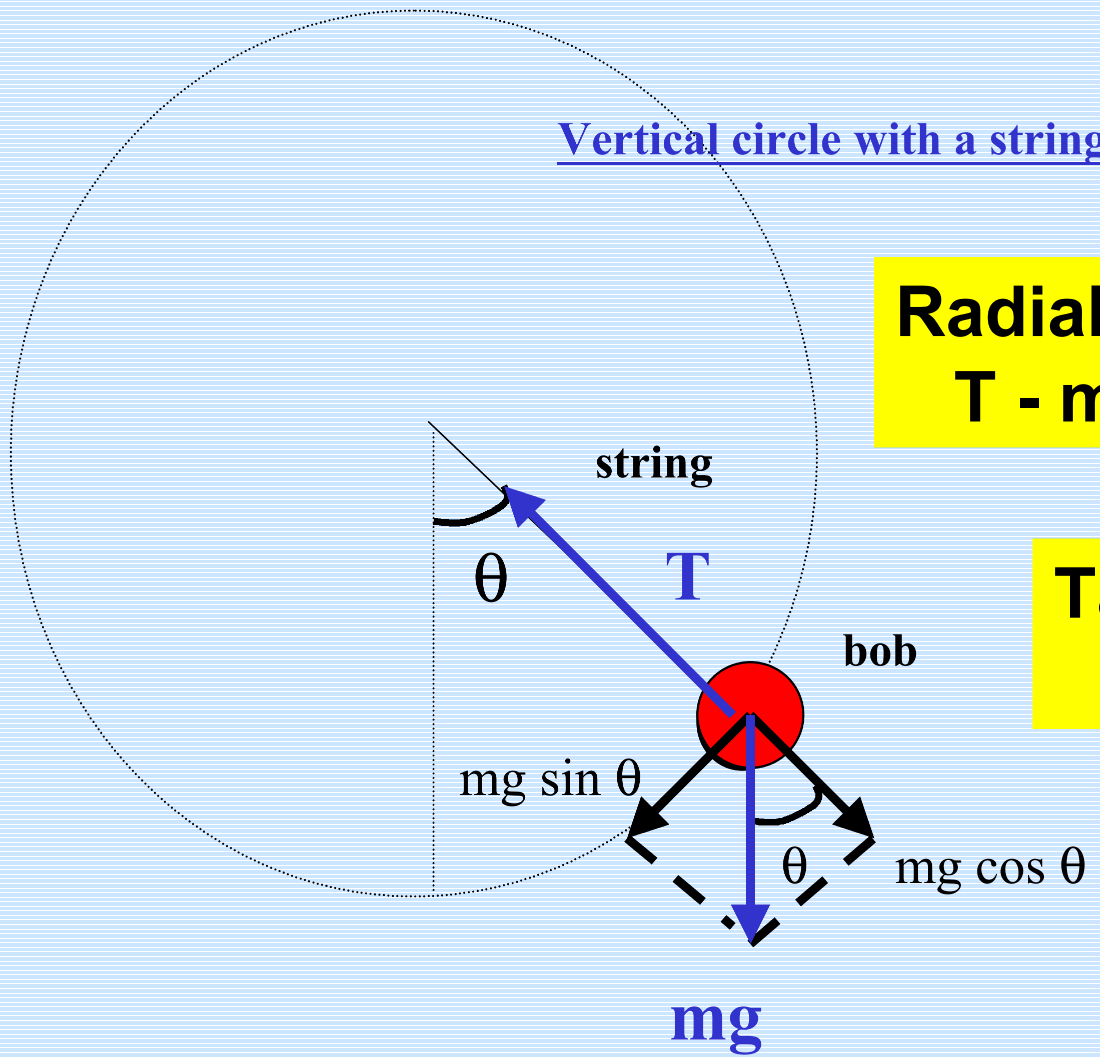
Tangential direction :

$$mg\sin\theta = ma_t$$

Free body diagram



Change in direction

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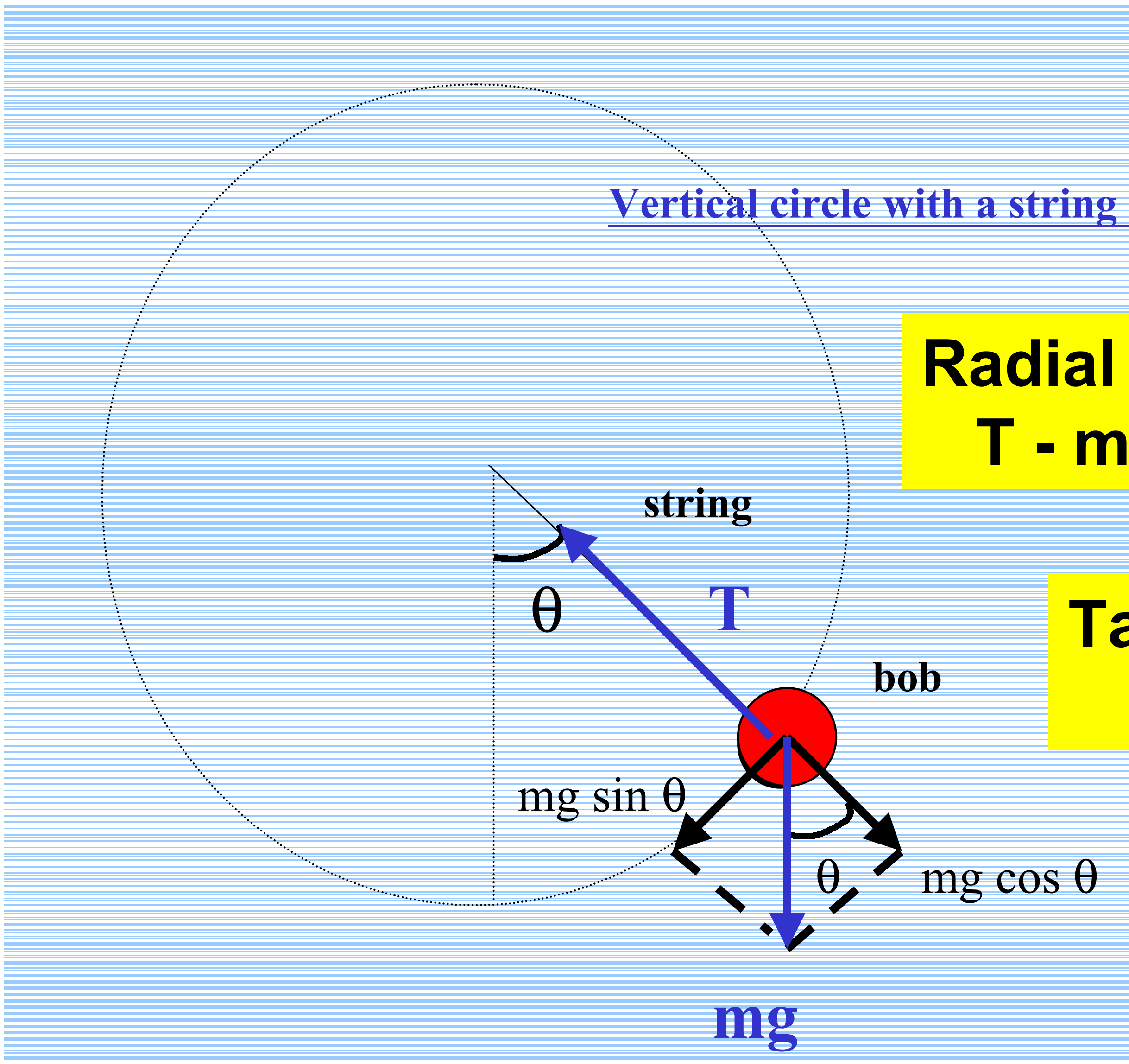

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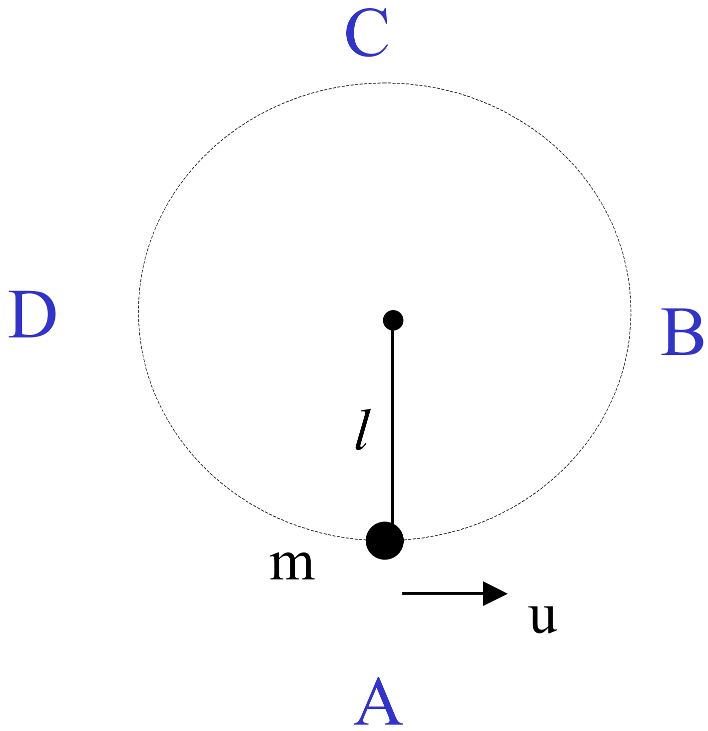
Change in speed

Can an object (mass m) go round a vertical circle of radius l if the initial speed at the bottom is u?



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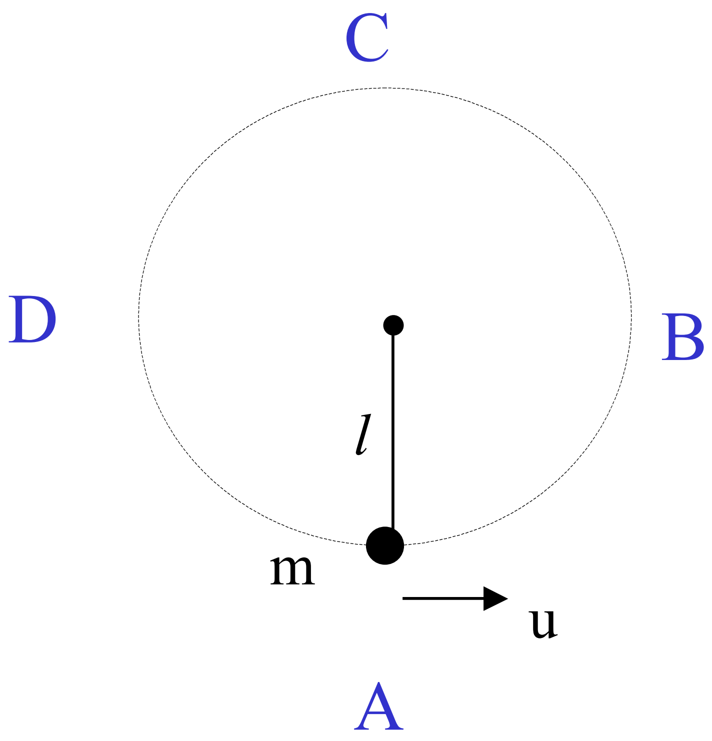

Can go round the circle :

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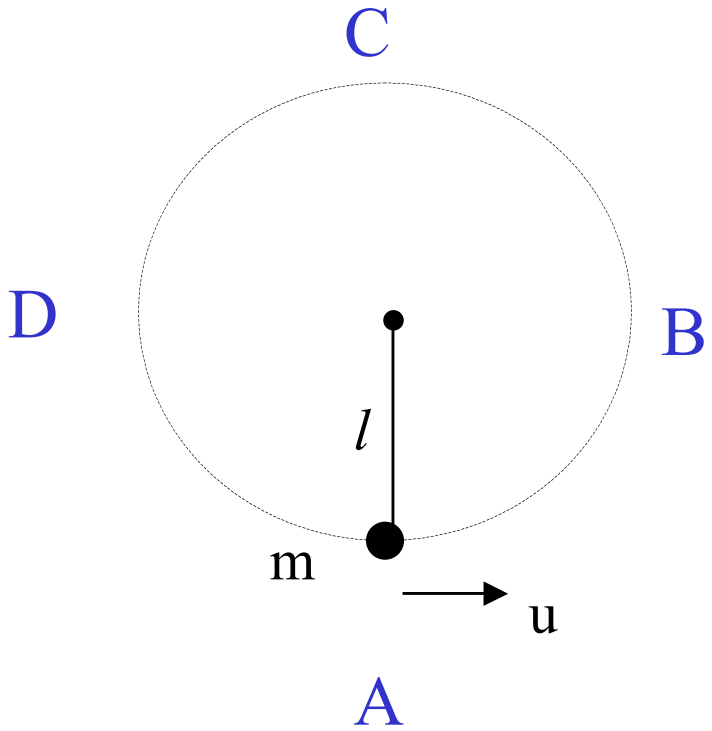

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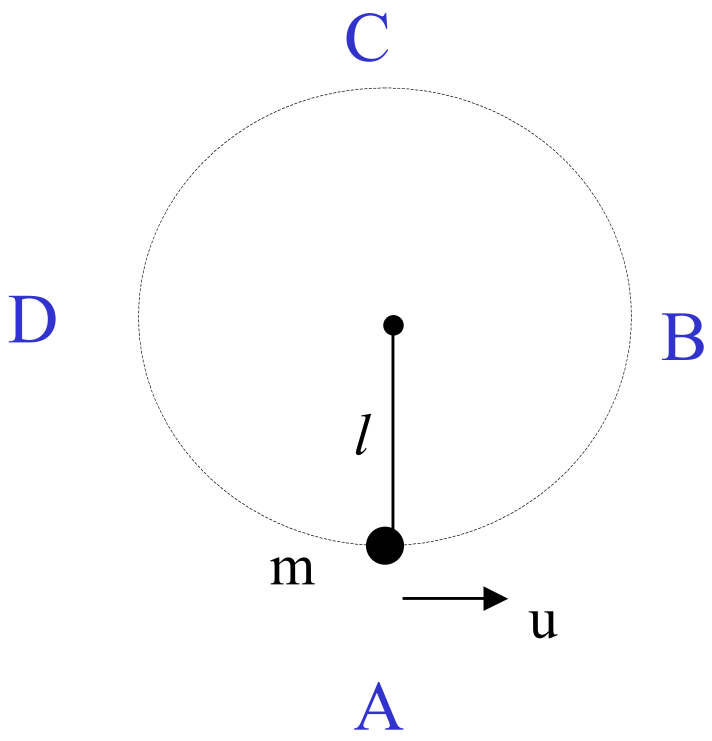

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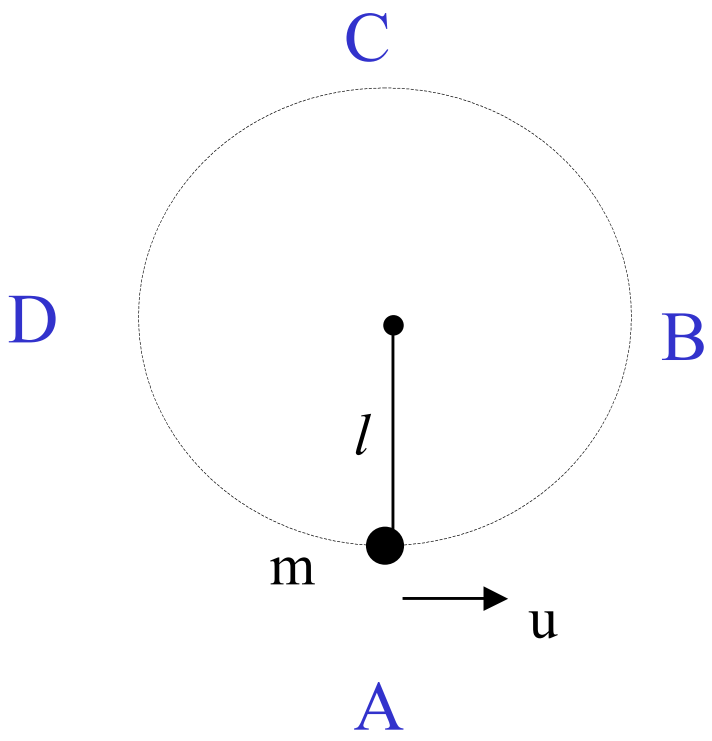

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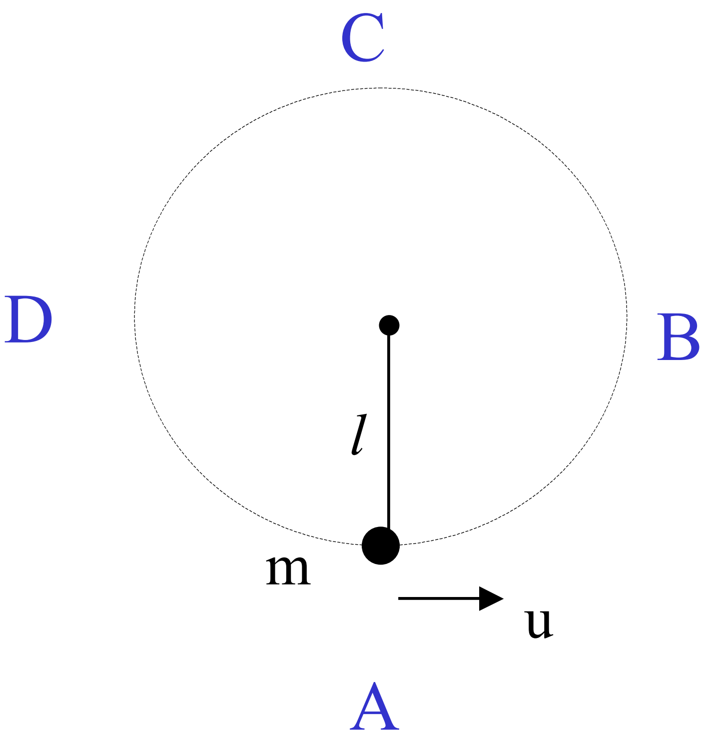

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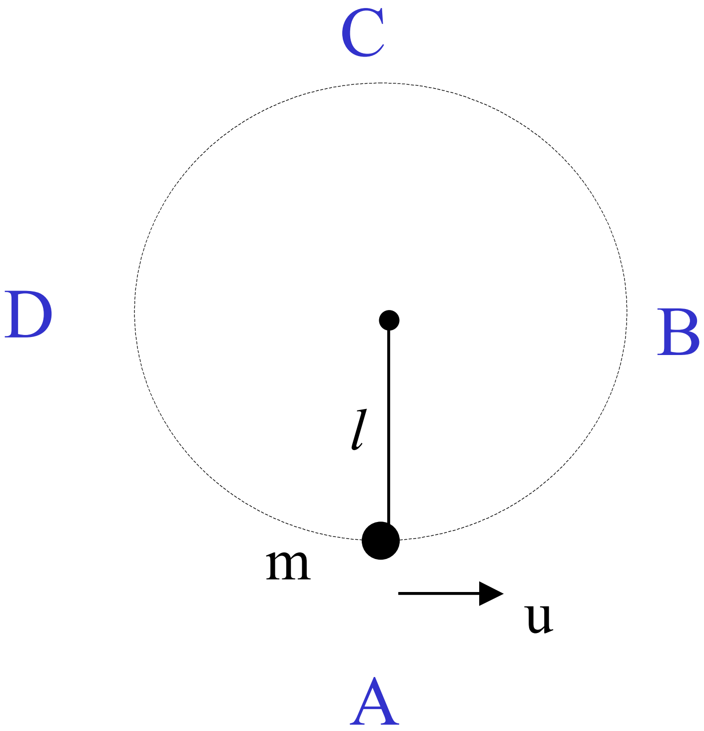

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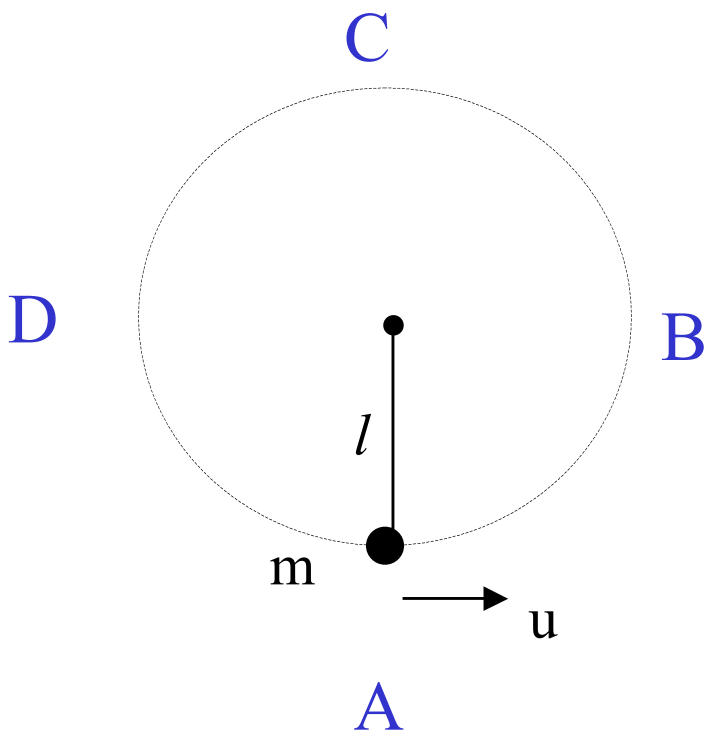

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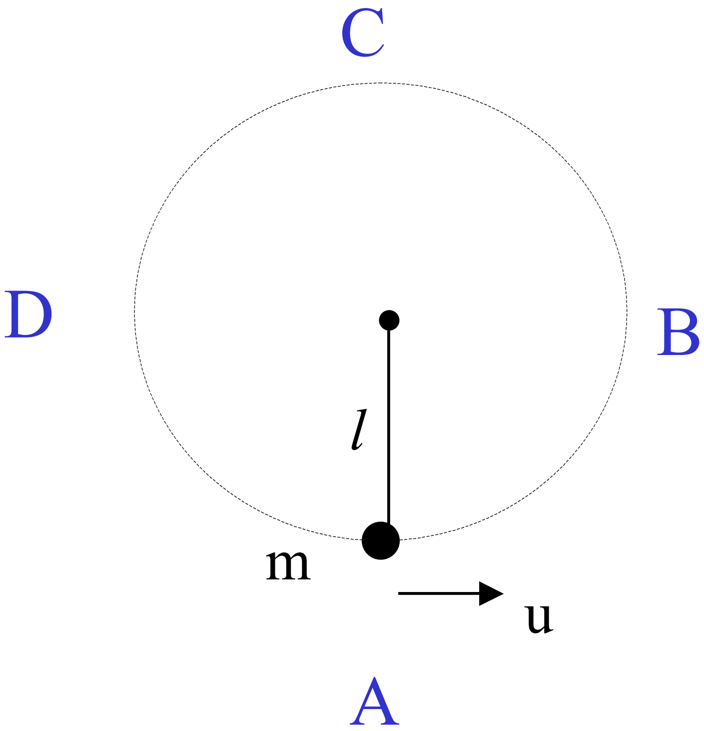

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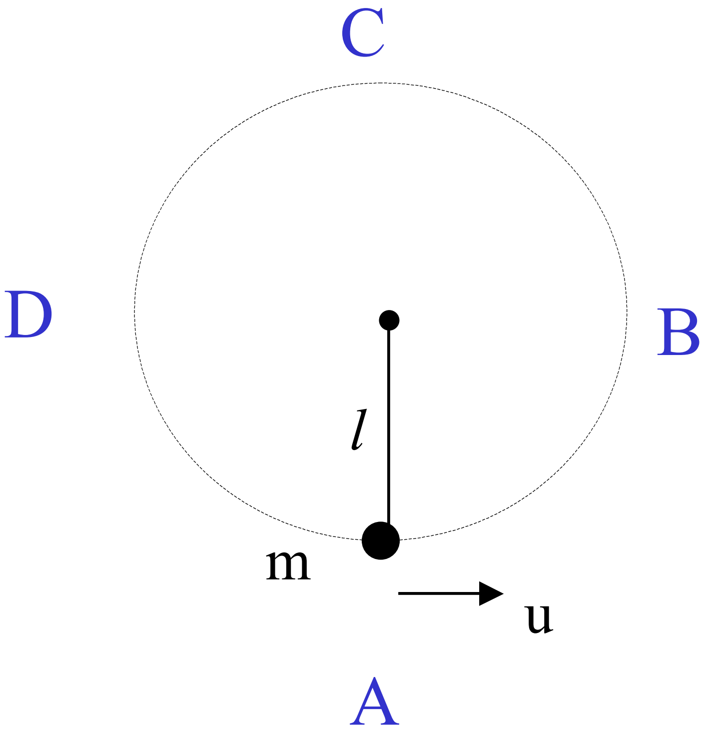

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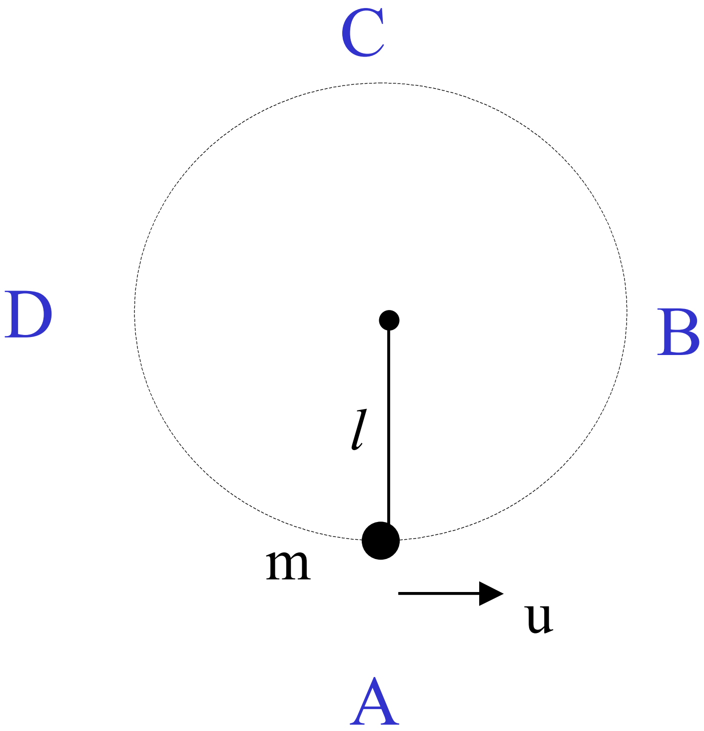

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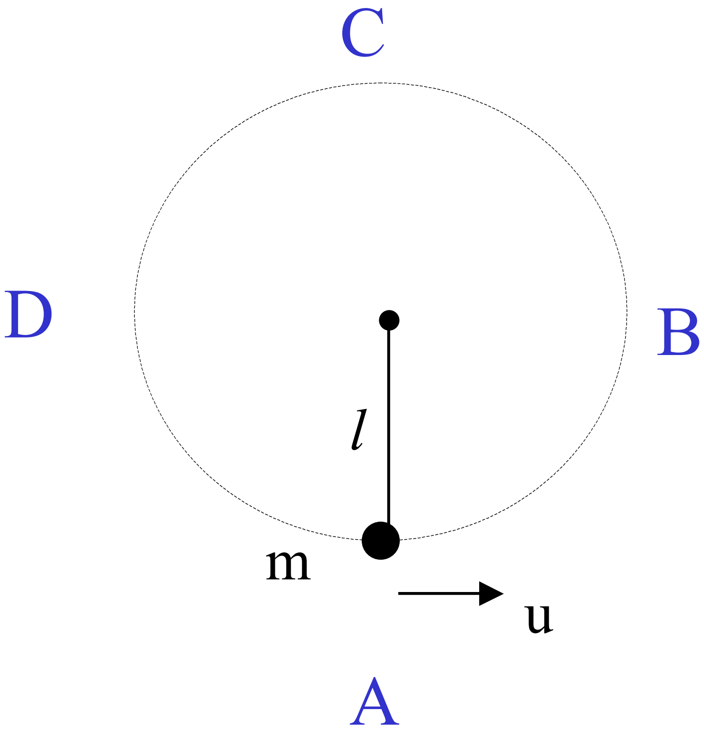

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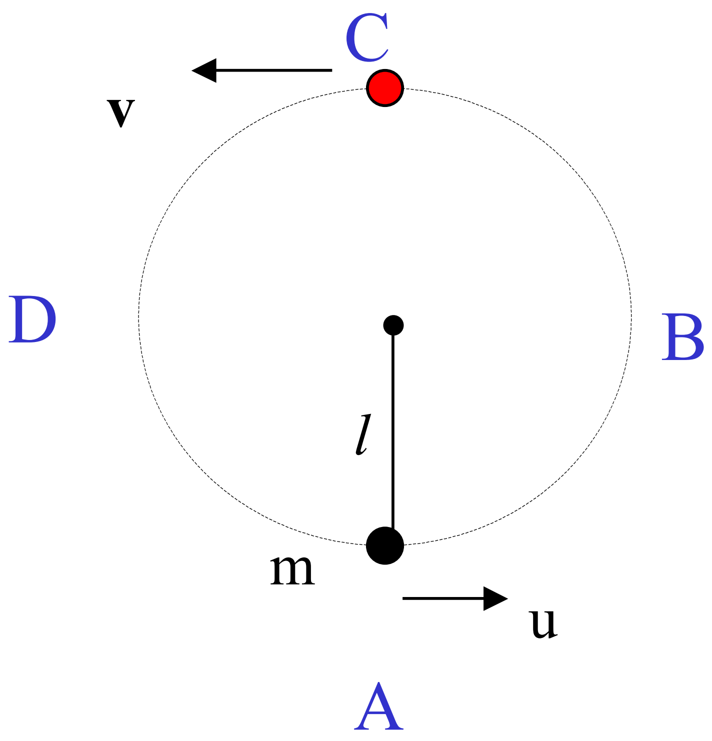

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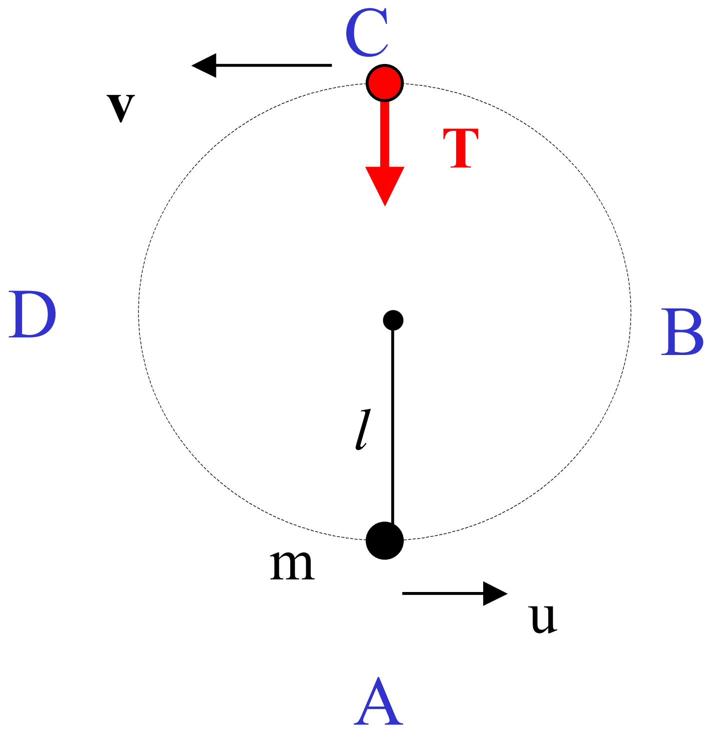

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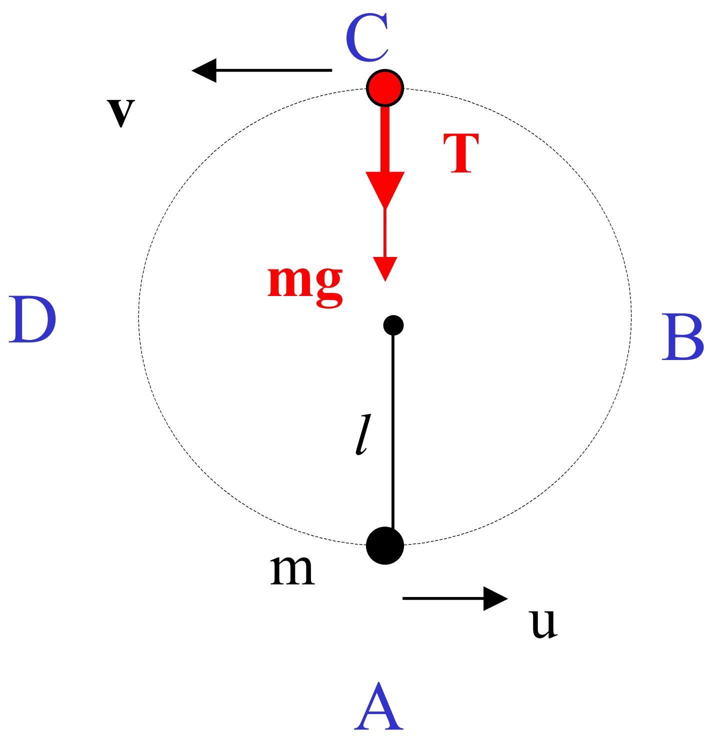

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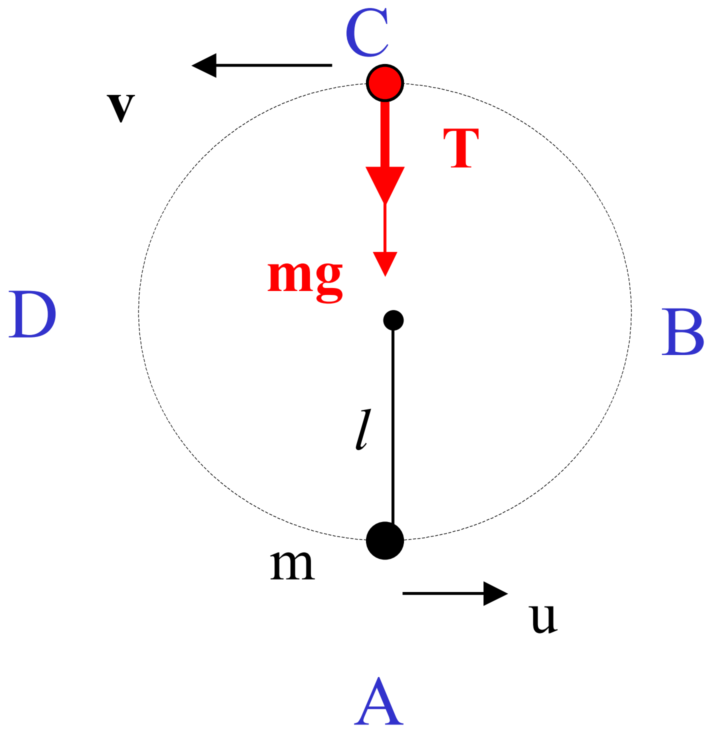

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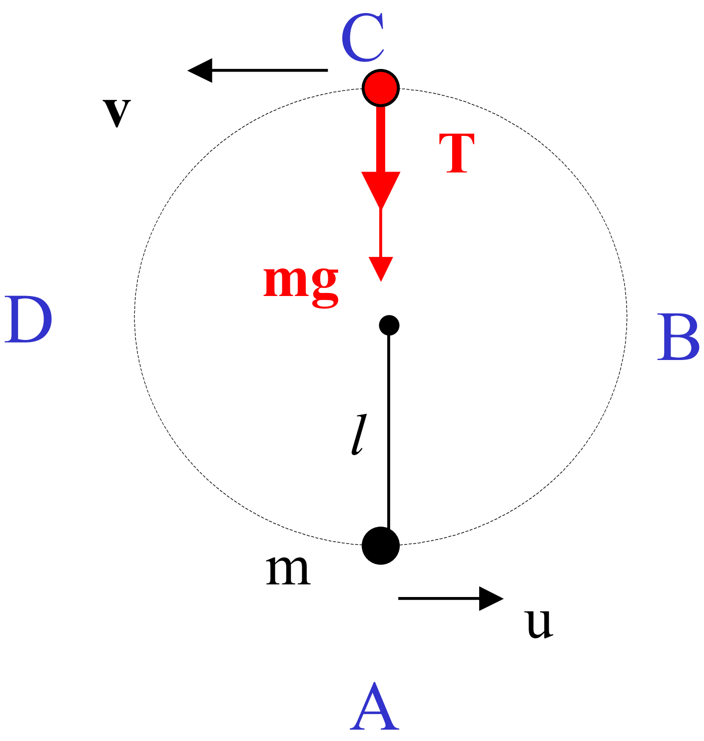

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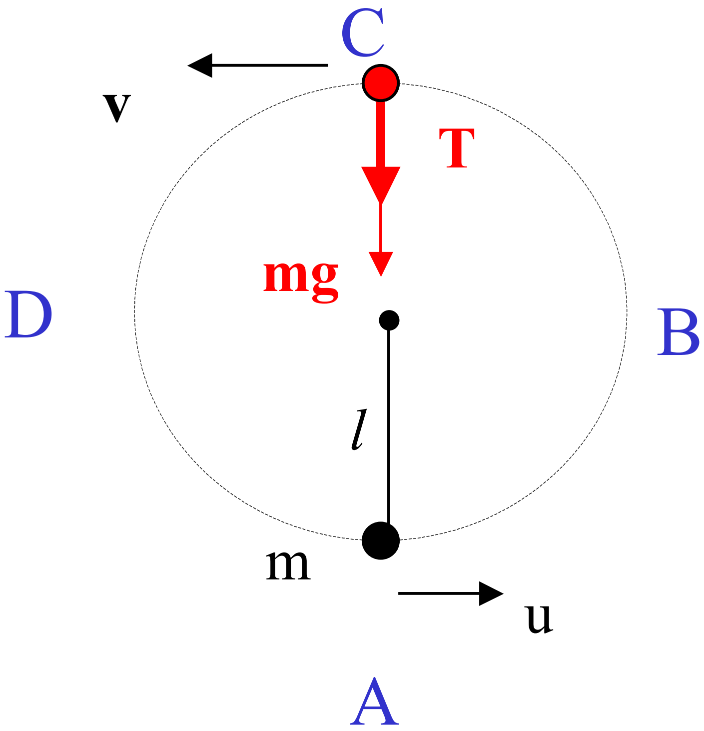

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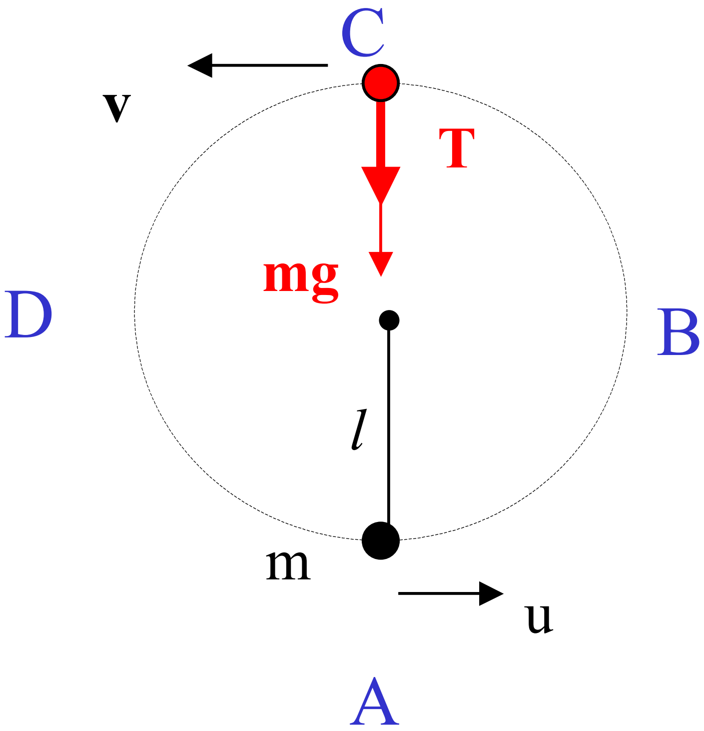

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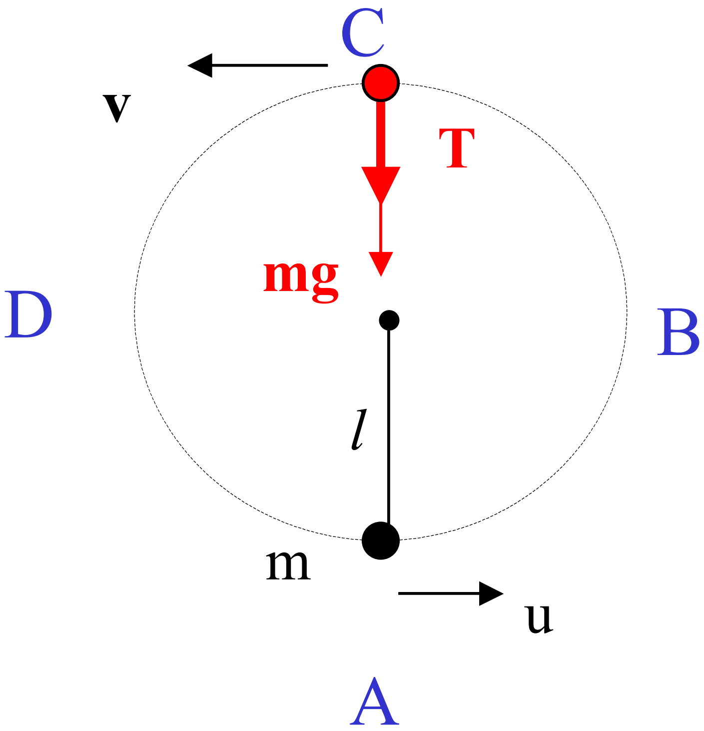

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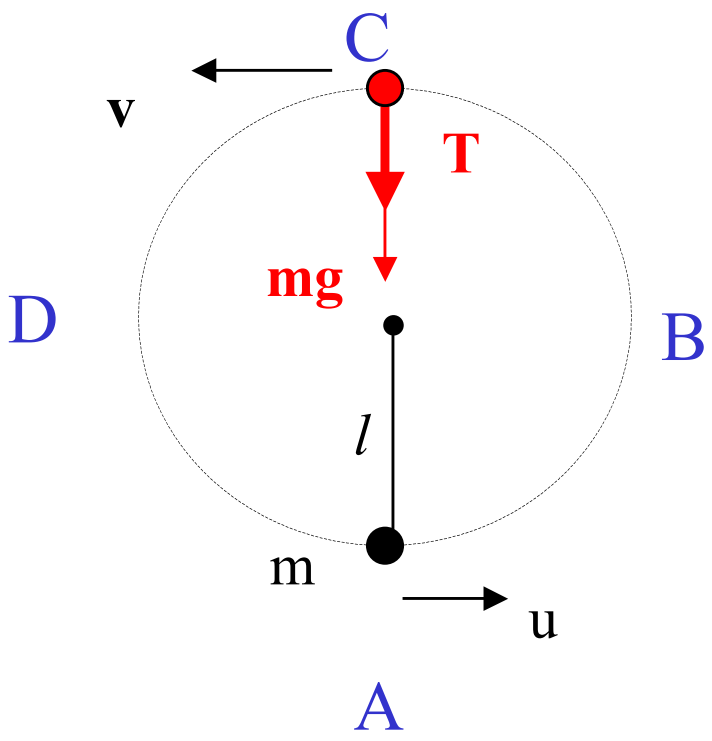

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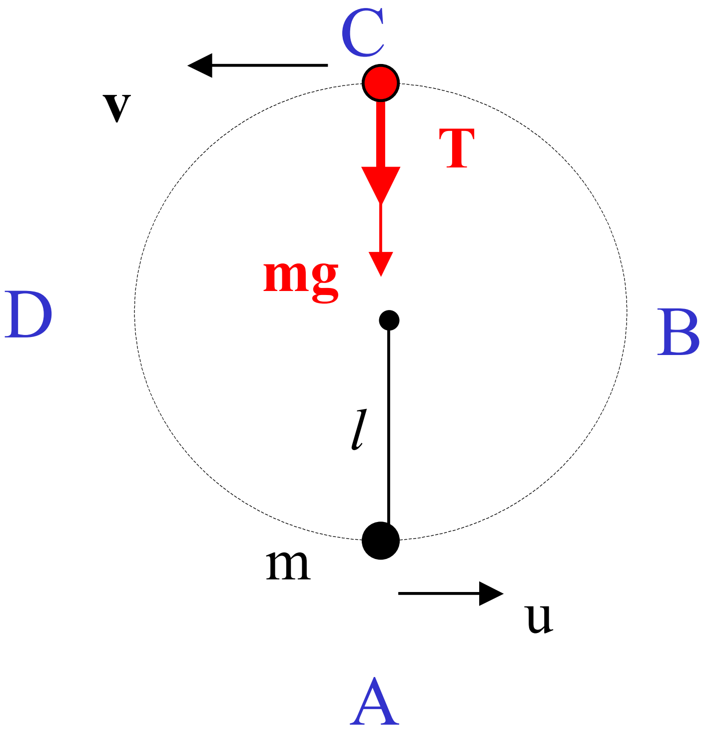

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$$u \geq \sqrt{5gl}$$

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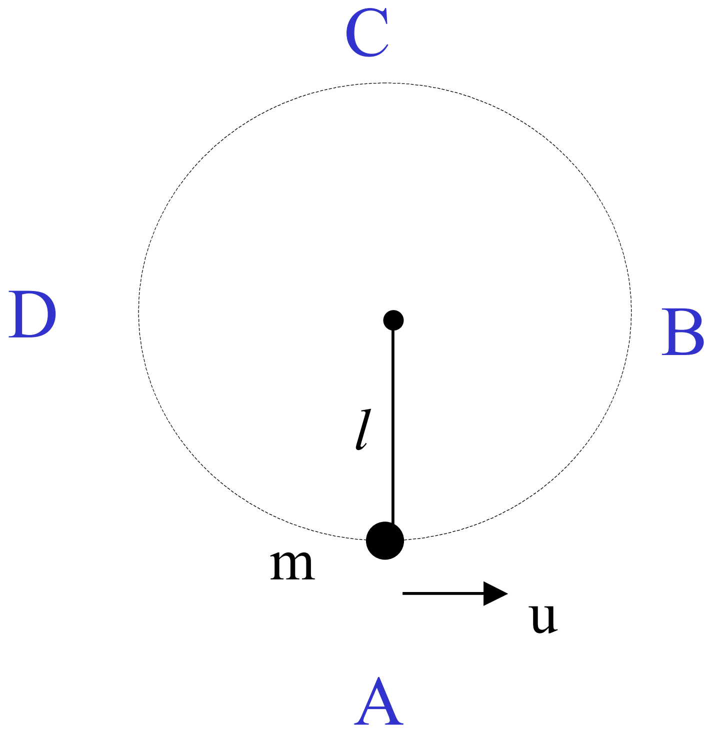

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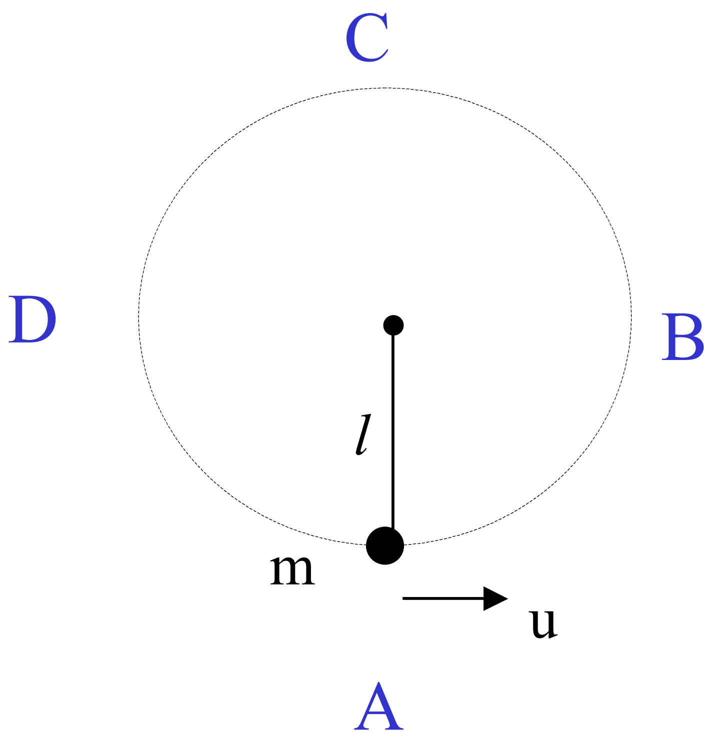

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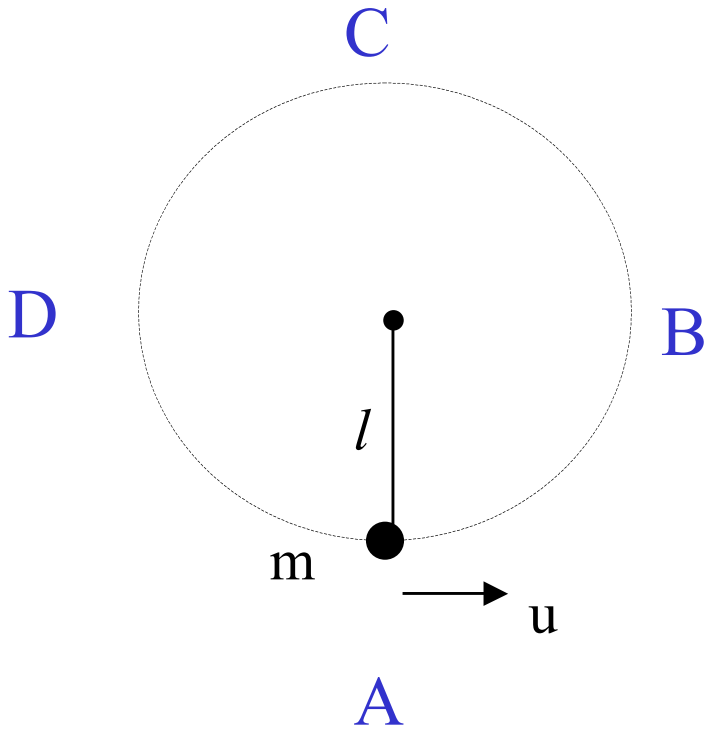

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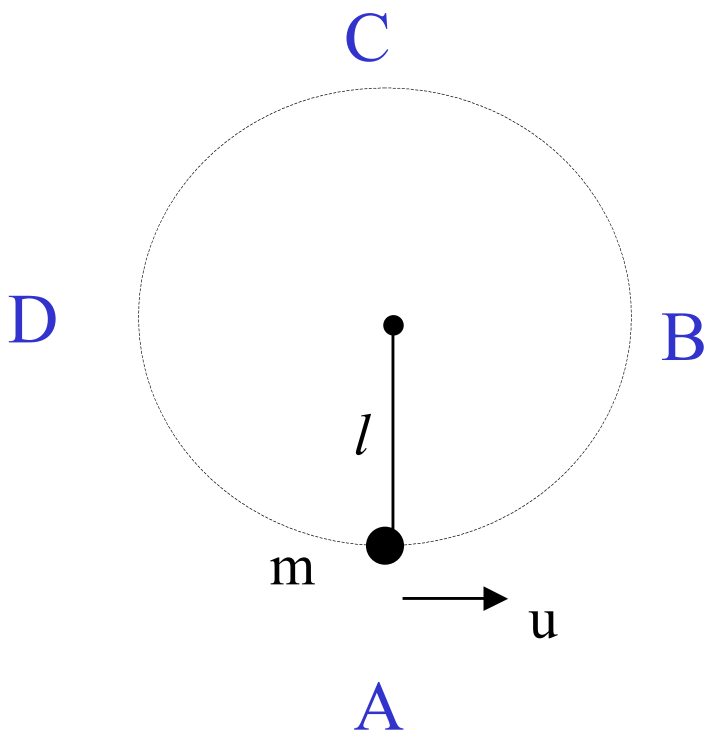

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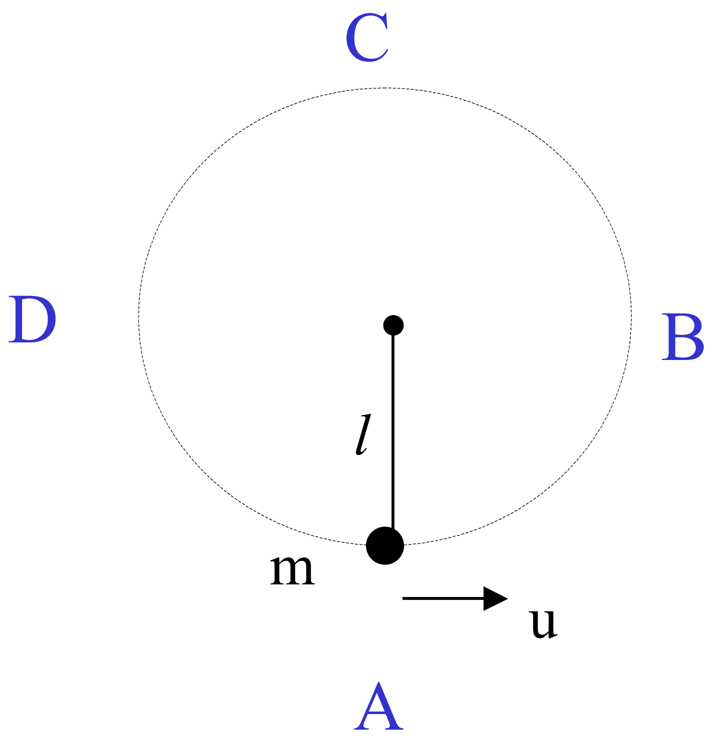
(2) Have sufficient high centripetal force to maintain the circular motion at C.

$$u \geq \sqrt{5gl}$$

Can an object (mass m) go round a vertical circle of radius l if the initial speed at the bottom is u?



Can go round the circle :

(1) Have enough energy to reach point C.

$$u \geq \sqrt{4gl}$$

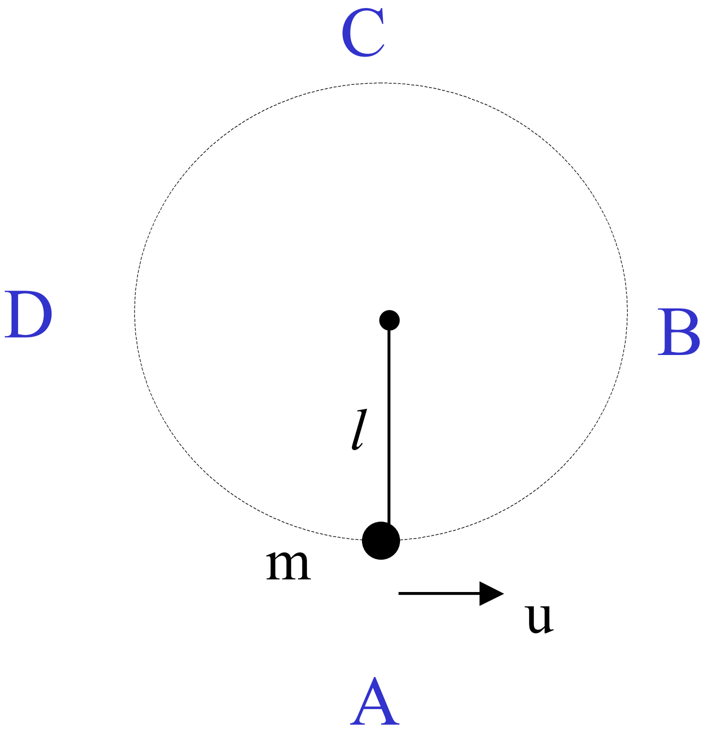
(2) Have sufficient high centripetal force to maintain the circular motion at C.

$$u \geq \sqrt{5gl}$$

The object can go round the circle if the initial speed is greater than

$$\sqrt{5gl}$$

Can an object (mass m) go round a vertical circle of radius l if the initial speed at the bottom is u?



Can go round the circle :

(1) Have enough energy to reach point C.

$$u \geq \sqrt{4gl}$$

(2) Have sufficient high centripetal force to maintain the circular motion at C.

$$u \geq \sqrt{5gl}$$

The object can go round the circle if the initial speed is greater than $\sqrt{5gl}$

What happens if u $< \sqrt{5gl}$?

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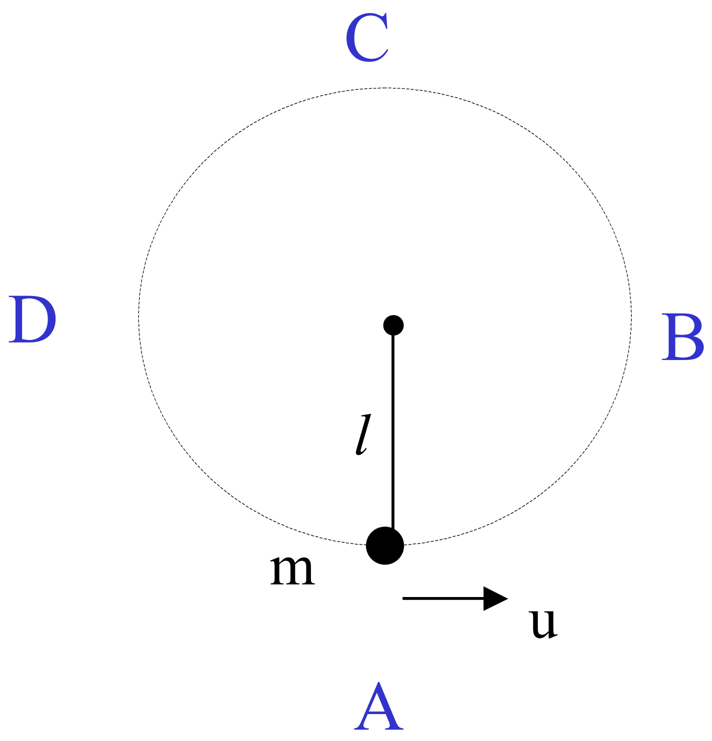
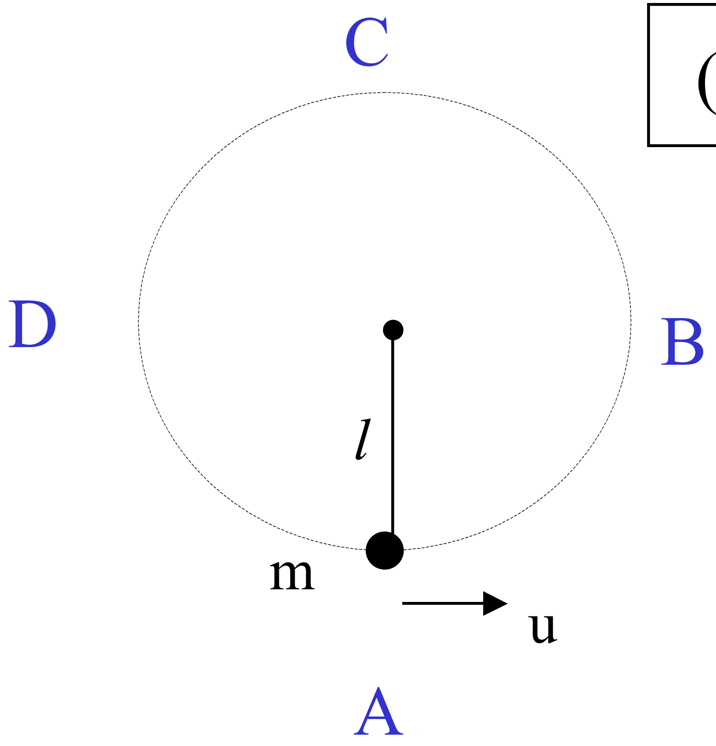
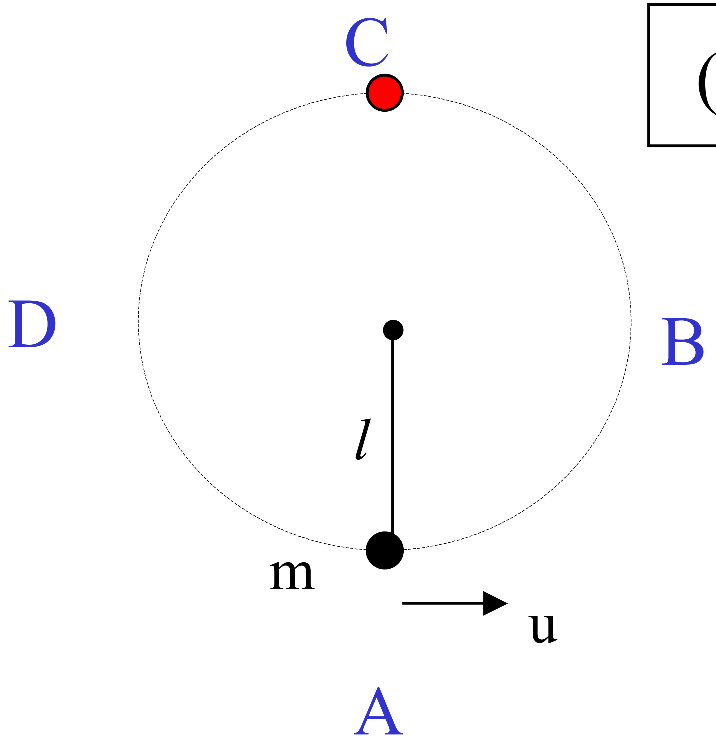


What happens if u $< \sqrt{5gl}$?



(1) $\sqrt{4gl} < u < \sqrt{5gl}$

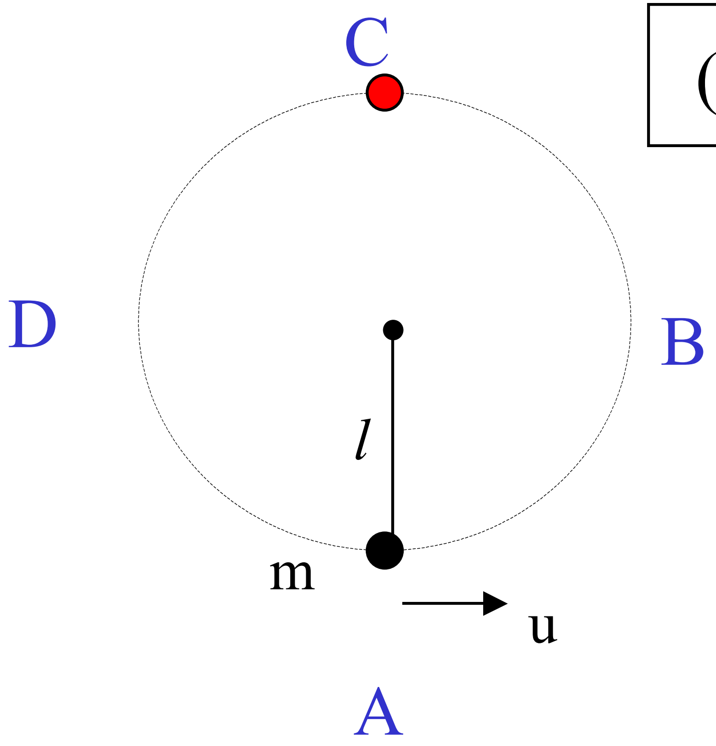
What happens if u < $\sqrt{5gl}$?



(1) $\sqrt{4gl} < u < \sqrt{5gl}$

→ Can reach C (as u > $\sqrt{4gl}$)

What happens if u $< \sqrt{5gl}$?

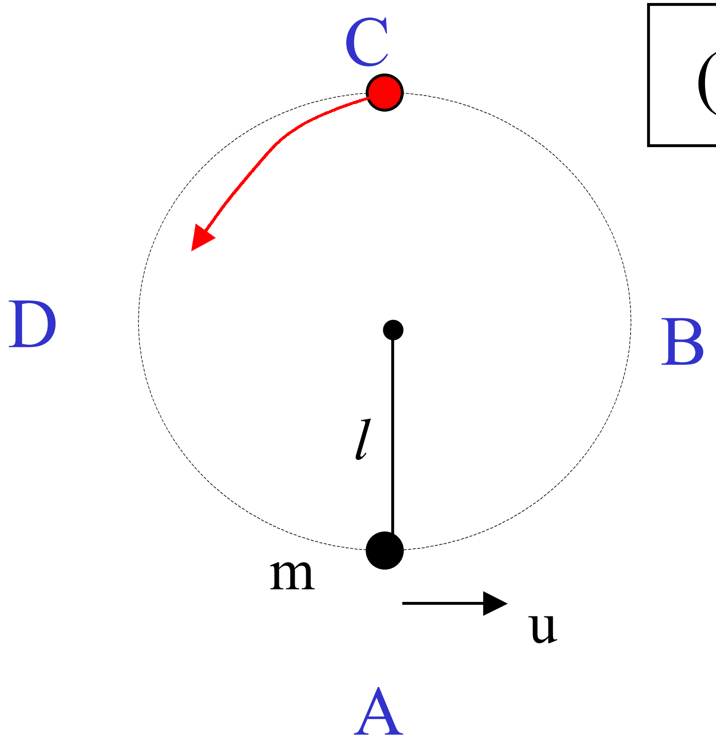


(1) $\sqrt{4gl} < u < \sqrt{5gl}$

→ Can reach C (as u $> \sqrt{4gl}$)

→ No more circular motion can be processed (as T = 0 but mg is greater than mv^2/l)

What happens if u < $\sqrt{5gl}$?



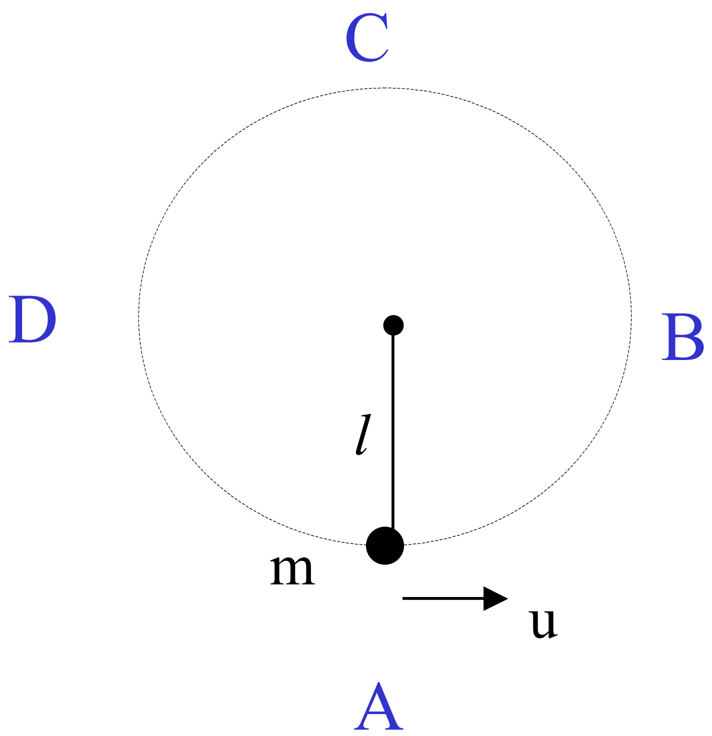
(1) $\sqrt{4gl} < u < \sqrt{5gl}$

→ Can reach C (as u > $\sqrt{4gl}$)

→ No more circular motion can be processed (as T = 0 but mg is greater than mv^2/l)

→ Projectile motion due to gravity

What happens if u $< \sqrt{5gl}$?



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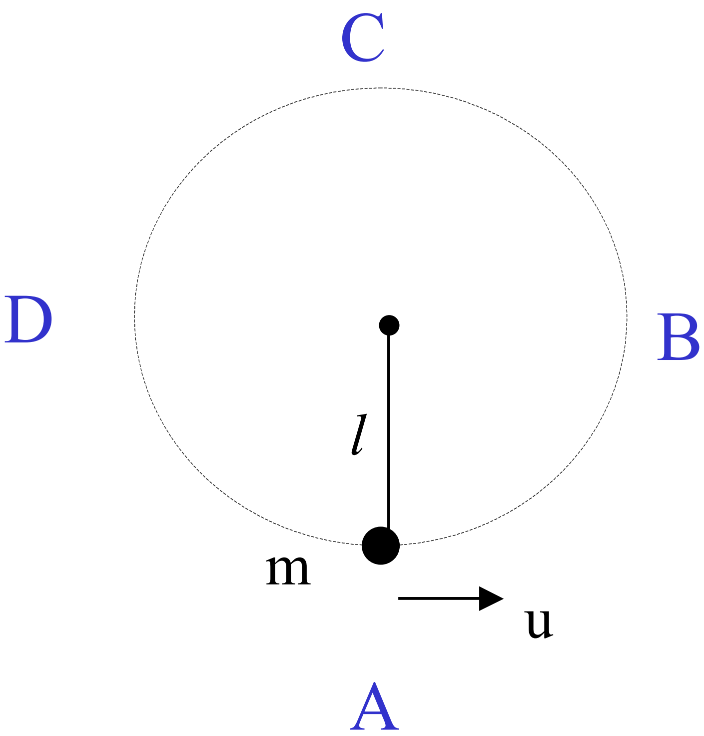


For reaching B,

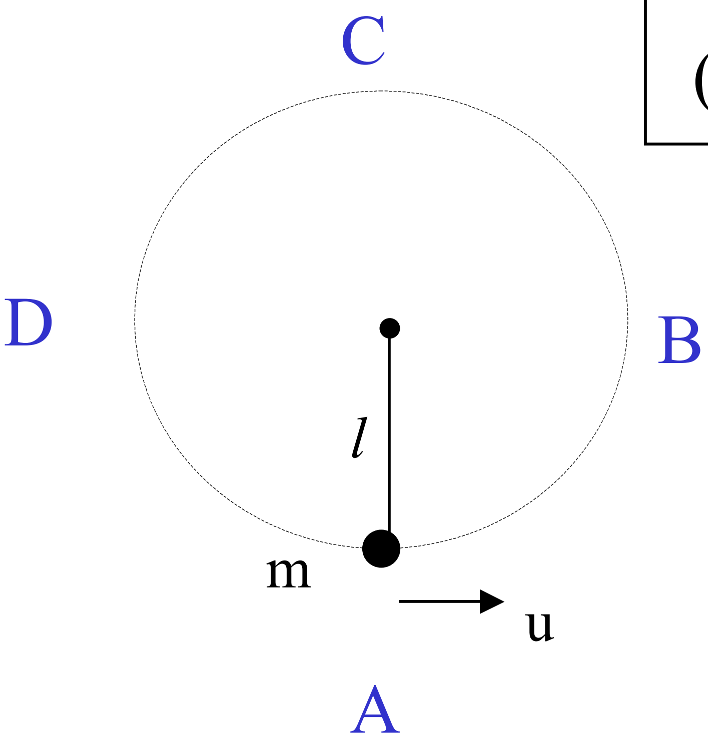
$1/2\ mu^2 = 1/2 mv_B^2 + mgl$

u^2 ❍ $2gl$

u ❍ $\sqrt{2gl}$

What happens if u $< \sqrt{5gl}$?

$$(2) \quad \sqrt{2gl} < u < \sqrt{4gl}$$



For reaching B,

$1/2\ mu^2 = 1/2 m v_B{}^2 + mgl$

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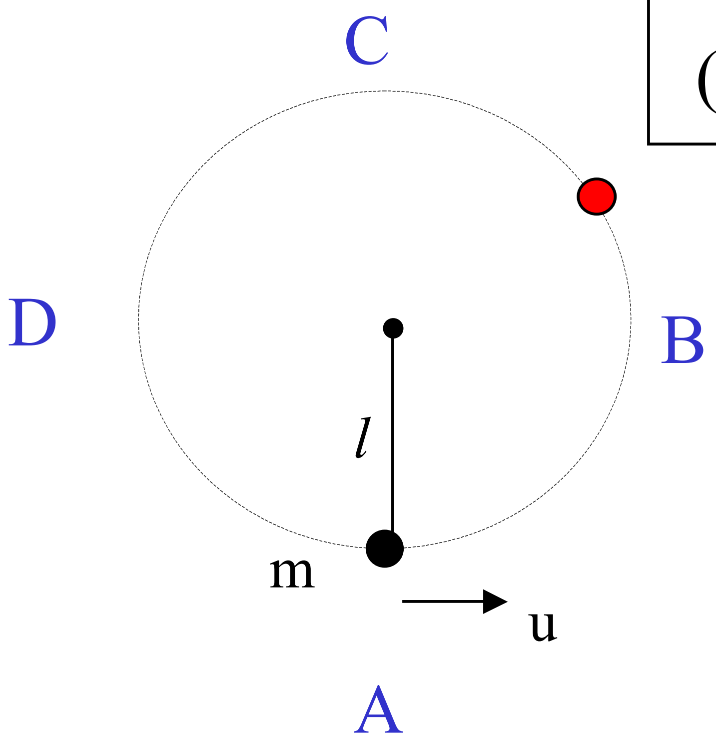
What happens if u < $\sqrt{5gl}$?



(2) $\sqrt{2gl}$ < u < $\sqrt{4gl}$

→ Between B and C(as u < $\sqrt{4gl}$)

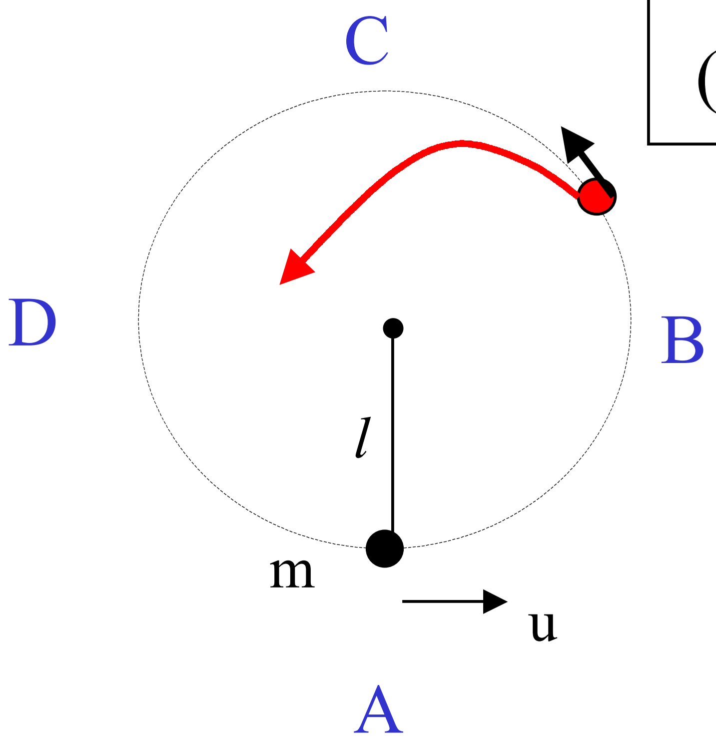
For reaching B,

$1/2\ mu^2 = 1/2mv_B^2 + mgl$

u^2 ❍ $2gl$

u ❍ $\sqrt{2gl}$

What happens if $u < \sqrt{5gl}$?



(2) $\sqrt{2gl} < u < \sqrt{4gl}$

→ Between B and C(as $u < \sqrt{4gl}$)

→ Projectile motion due to gravity

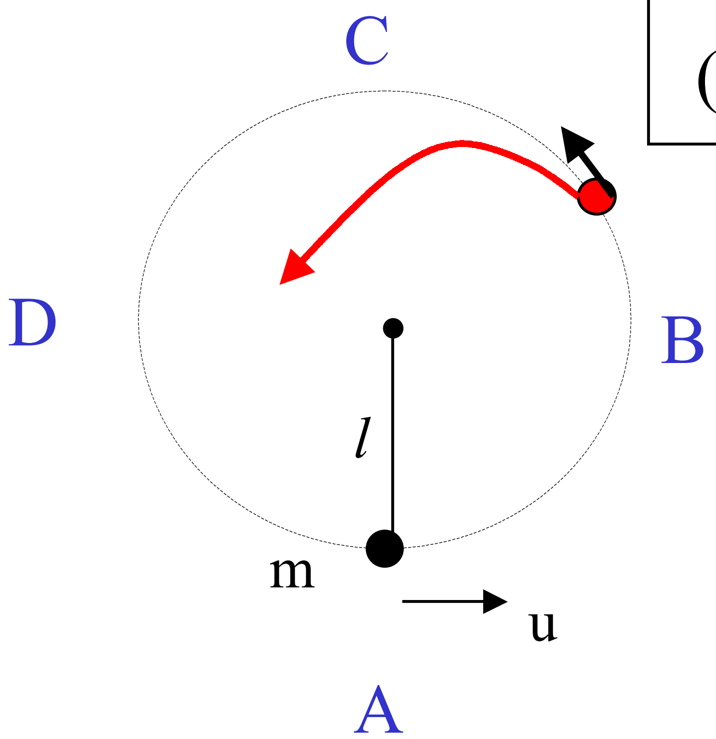
For reaching B,

$1/2\ mu^2 = 1/2 m v_B^2 + mgl$

$$u^2 \geq 2gl$$

$$u \geq \sqrt{2gl}$$

What happens if u < $\sqrt{5gl}$?



(2) $\sqrt{2gl} < u < \sqrt{4gl}$

→ Between B and C(as $u < \sqrt{4gl}$)

→ Projectile motion due to gravity

(3) $u < \sqrt{2gl}$

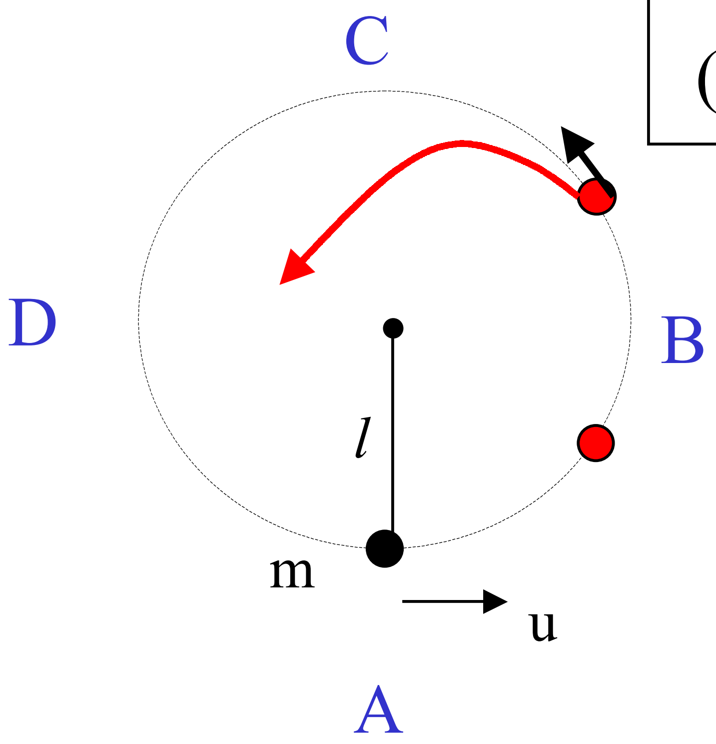
For reaching B,

$1/2\ mu^2 = 1/2 m v_B^2 + mgl$

u^2 ❍ $2gl$

u ❍ $\sqrt{2gl}$

What happens if u $< \sqrt{5gl}$?



(2) $\sqrt{2gl} <$ u $< \sqrt{4gl}$

→ Between B and C(as u $< \sqrt{4gl}$)

→ Projectile motion due to gravity

(3) u $< \sqrt{2gl}$

→ Cannot reach B

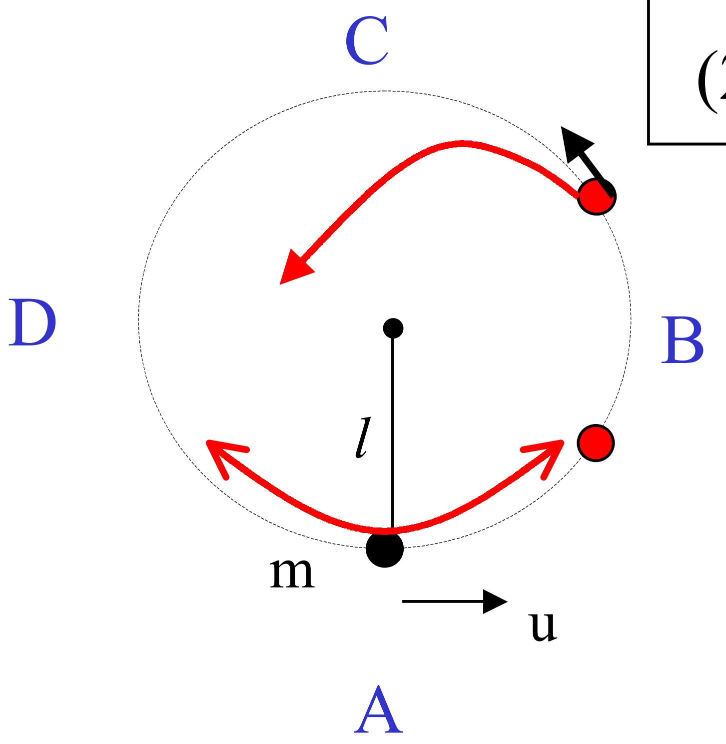
For reaching B,

$1/2\ mu^2 = 1/2 m v_B^2 + mgl$

$$u^2 \geq 2gl$$

$$u \geq \sqrt{2gl}$$

What happens if $u < \sqrt{5gl}$?



(2) $\sqrt{2gl} < u < \sqrt{4gl}$

→ Between B and C(as $u < \sqrt{4gl}$)

→ Projectile motion due to gravity

(3) $u < \sqrt{2gl}$

→ Cannot reach B

→ Swing about A between B and D

For reaching B,

$1/2\ mu^2 = 1/2 m v_B^2 + mgl$

u^2 ❍ $2gl$

u ❍ $\sqrt{2gl}$

More about Circular Motion

* A astronaut feels weightless in a spaceship which is moving with uniform circular motion about the Planet, say the Earth.

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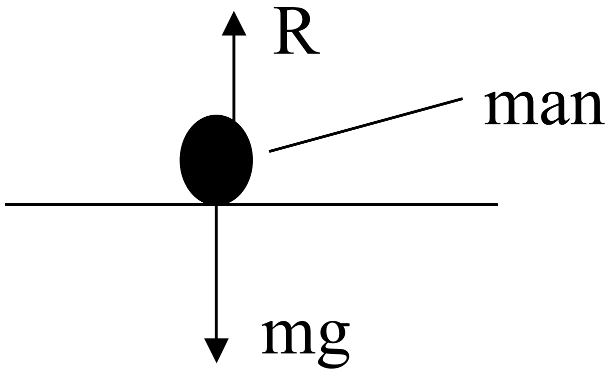

$R = 0$ for weightless

More about Circular Motion

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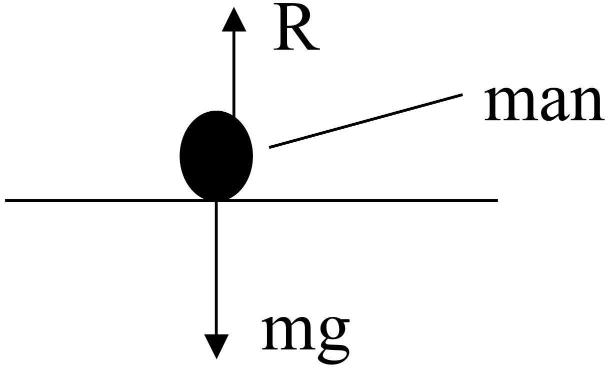

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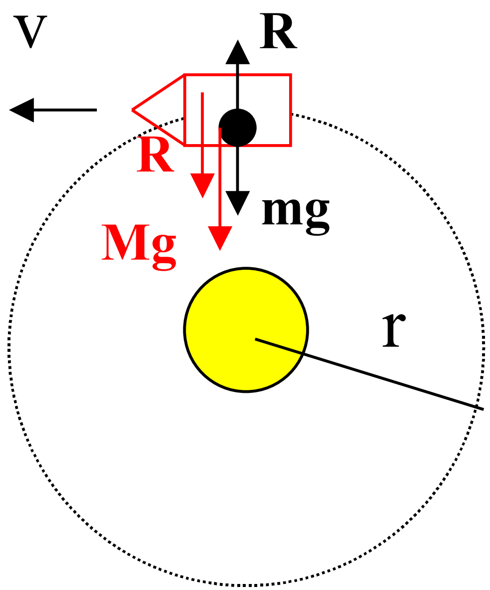

More about Circular Motion

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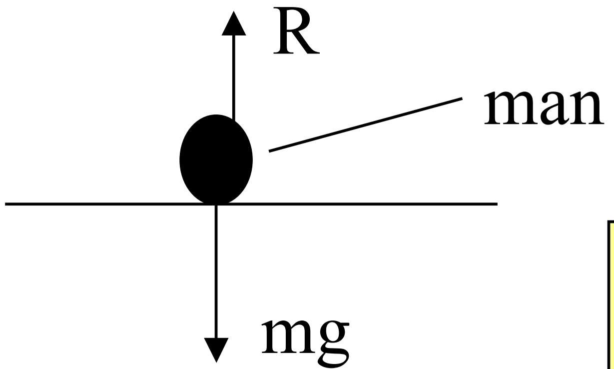

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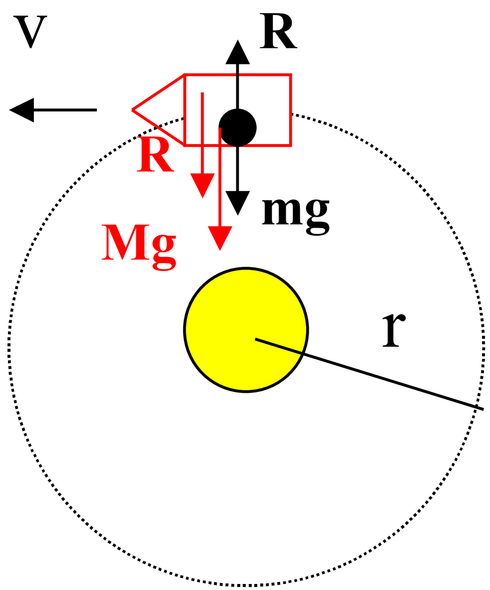

Consider the whole system (spaceship and man),

Consider the man only,

More about Circular Motion

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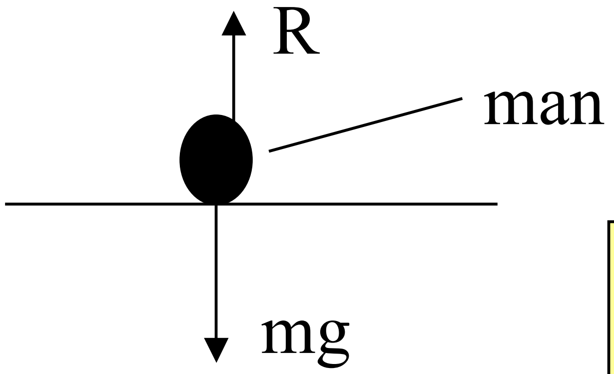

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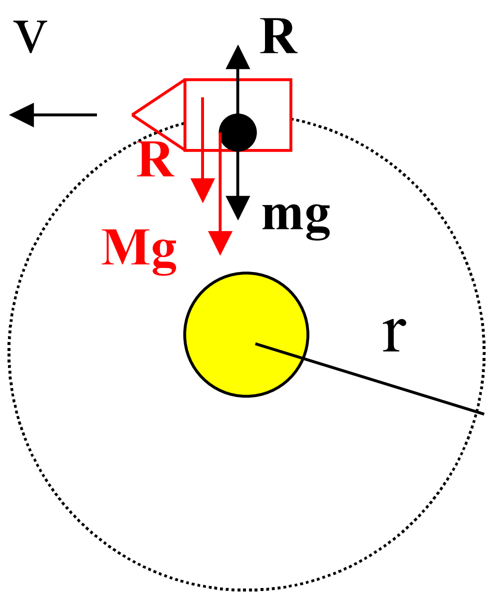

Consider the whole system (spaceship and man),

$$\mathbf{Mg + mg = (M+m)\, v^2 / r}$$

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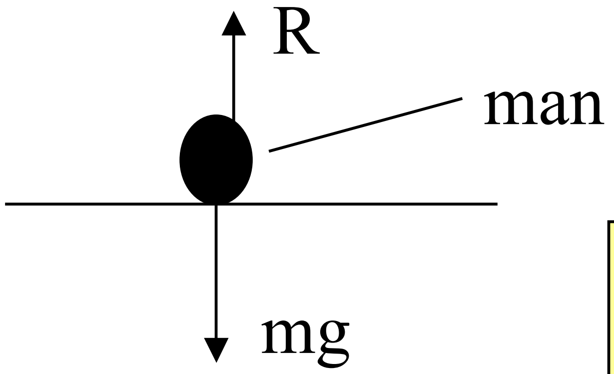

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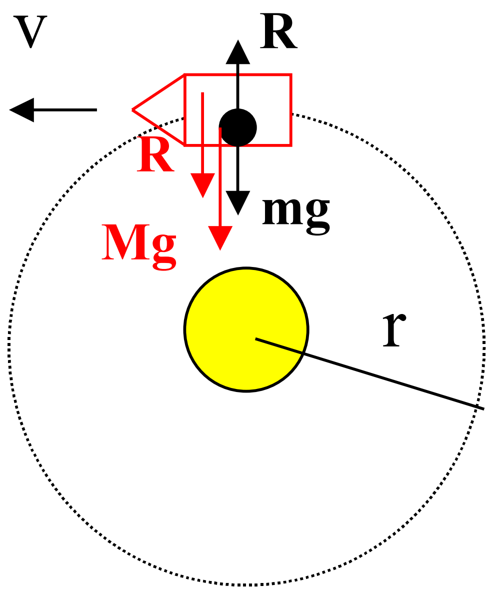

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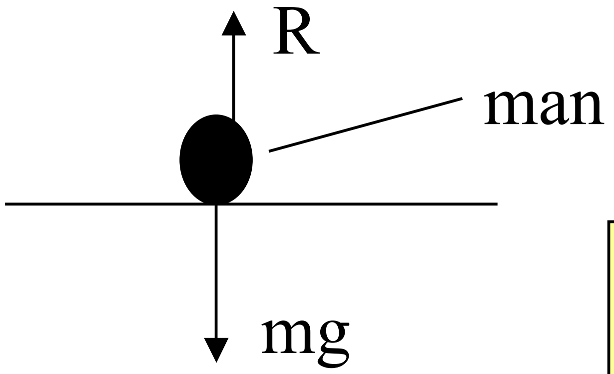

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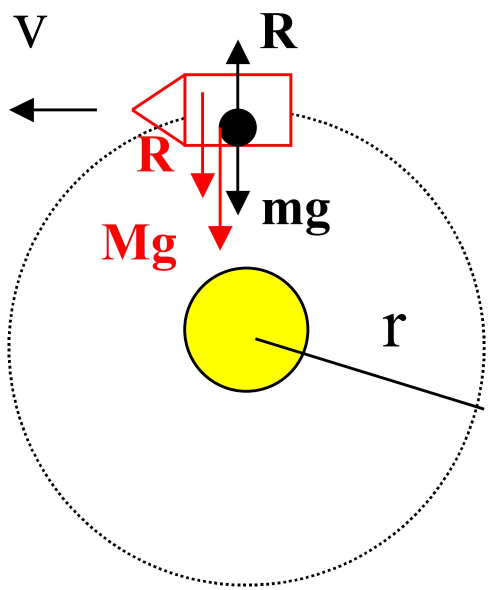

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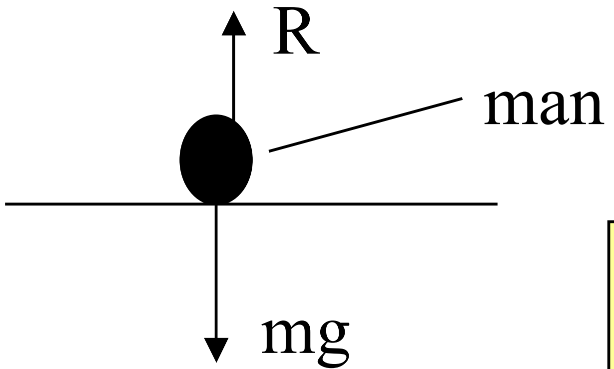

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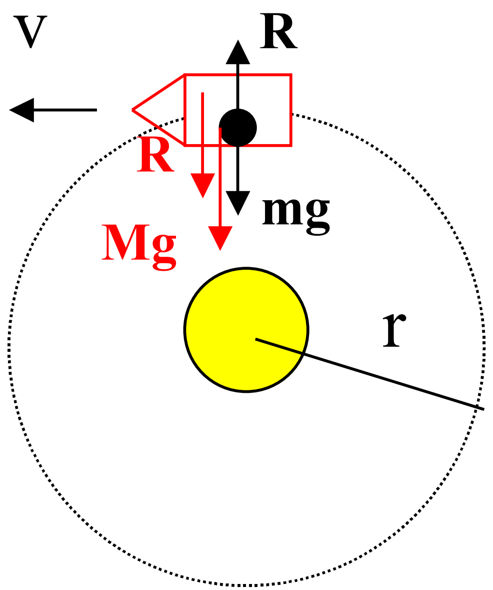

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Consider the man only,

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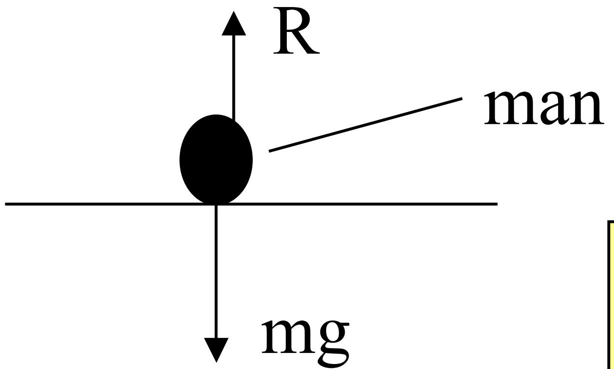

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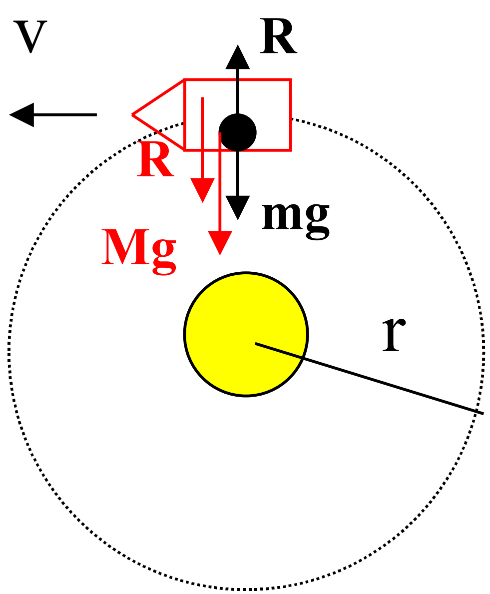

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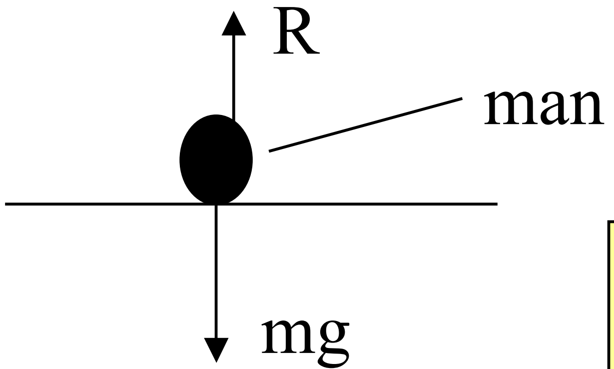

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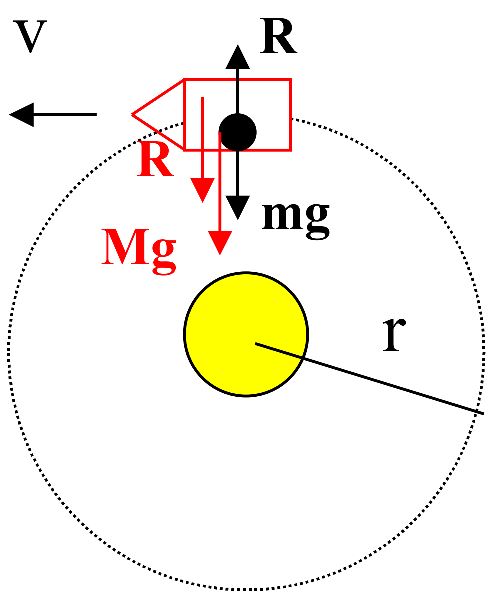

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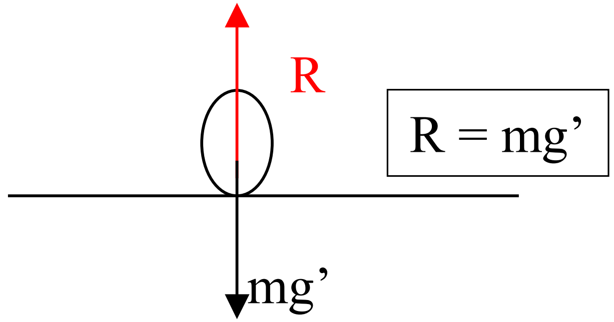
$$mg - R = mg$$

$$R = 0$$

More about Circular Motion

* Artificial gravity made for Space stations

More about Circular Motion



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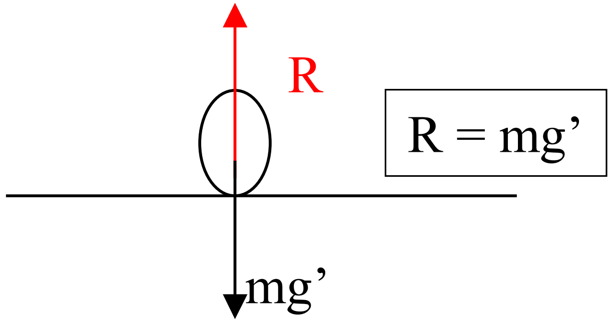
More about Circular Motion



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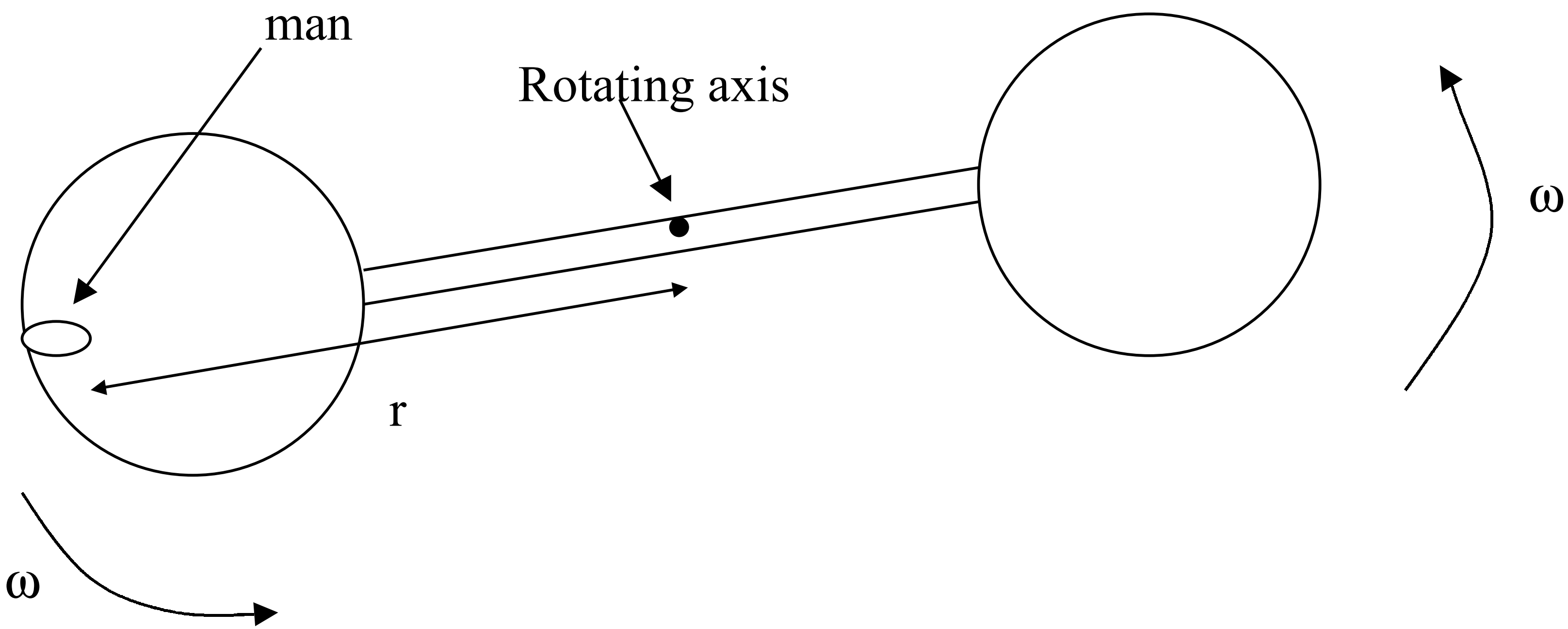
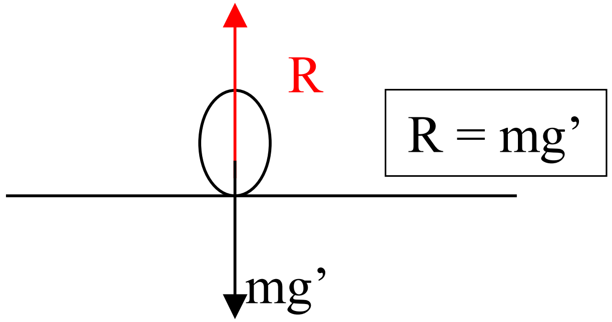


More about Circular Motion



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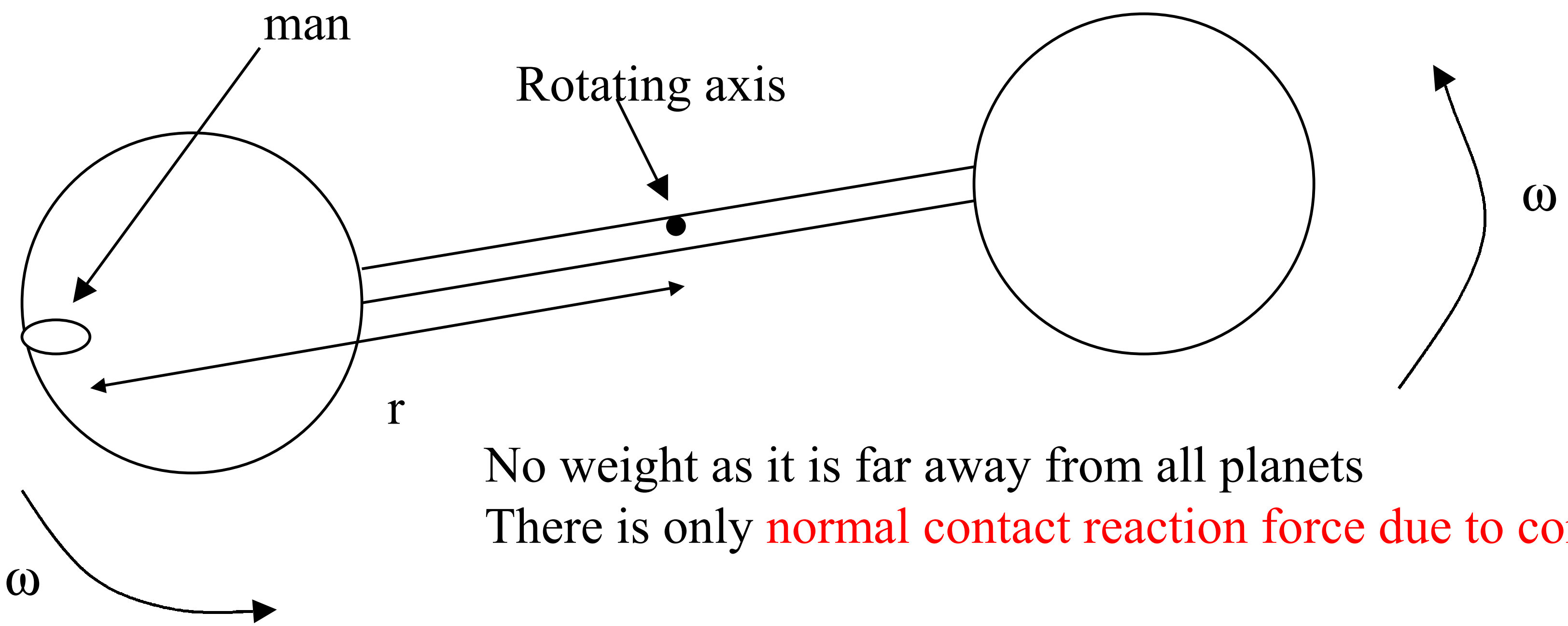
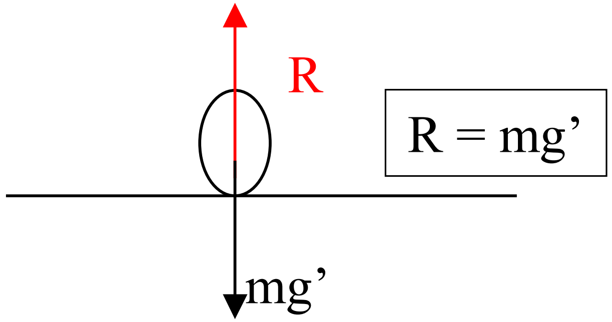


No weight as it is far away from all planets

There is only normal contact reaction force due to contact N.

More about Circular Motion



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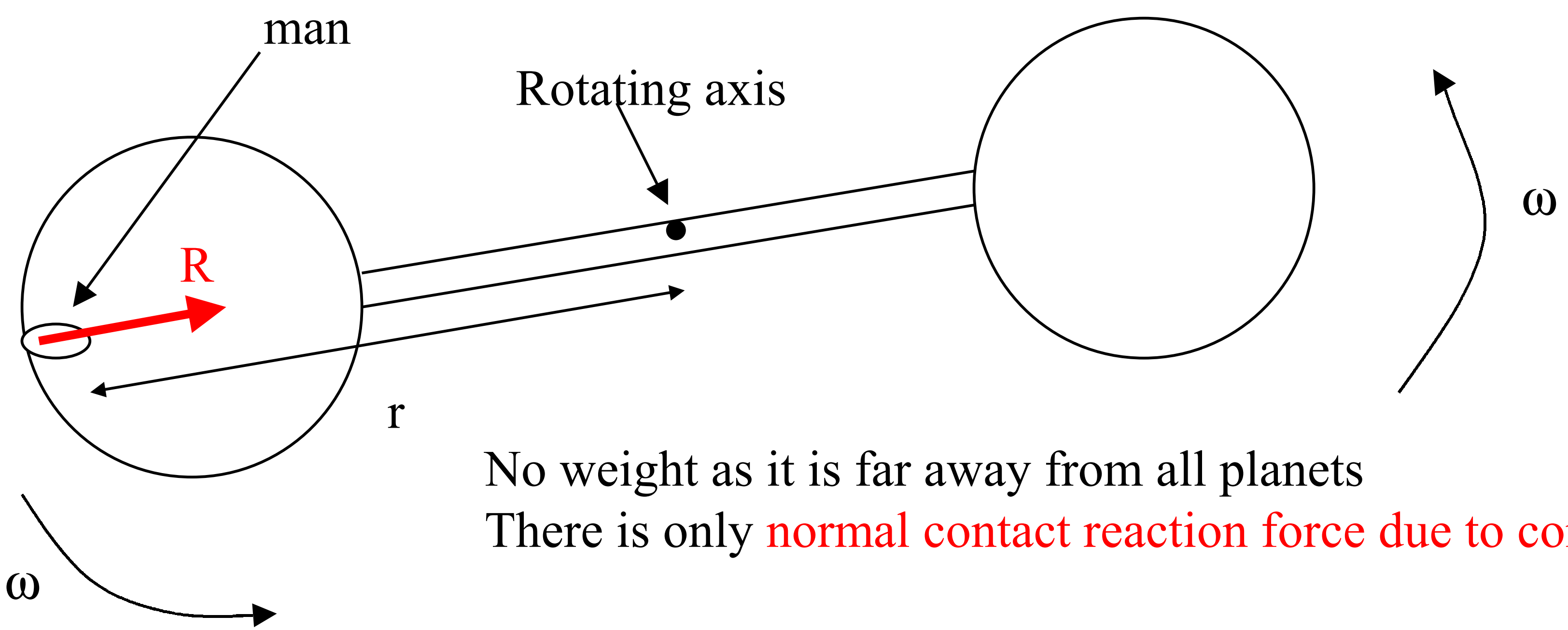

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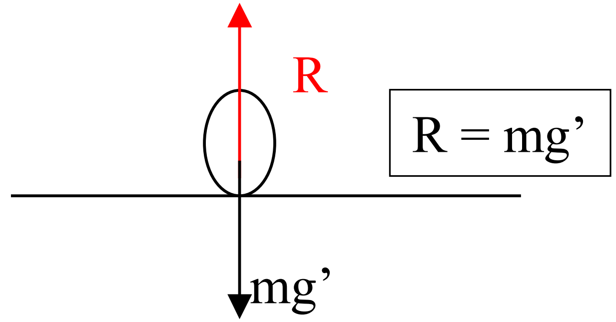

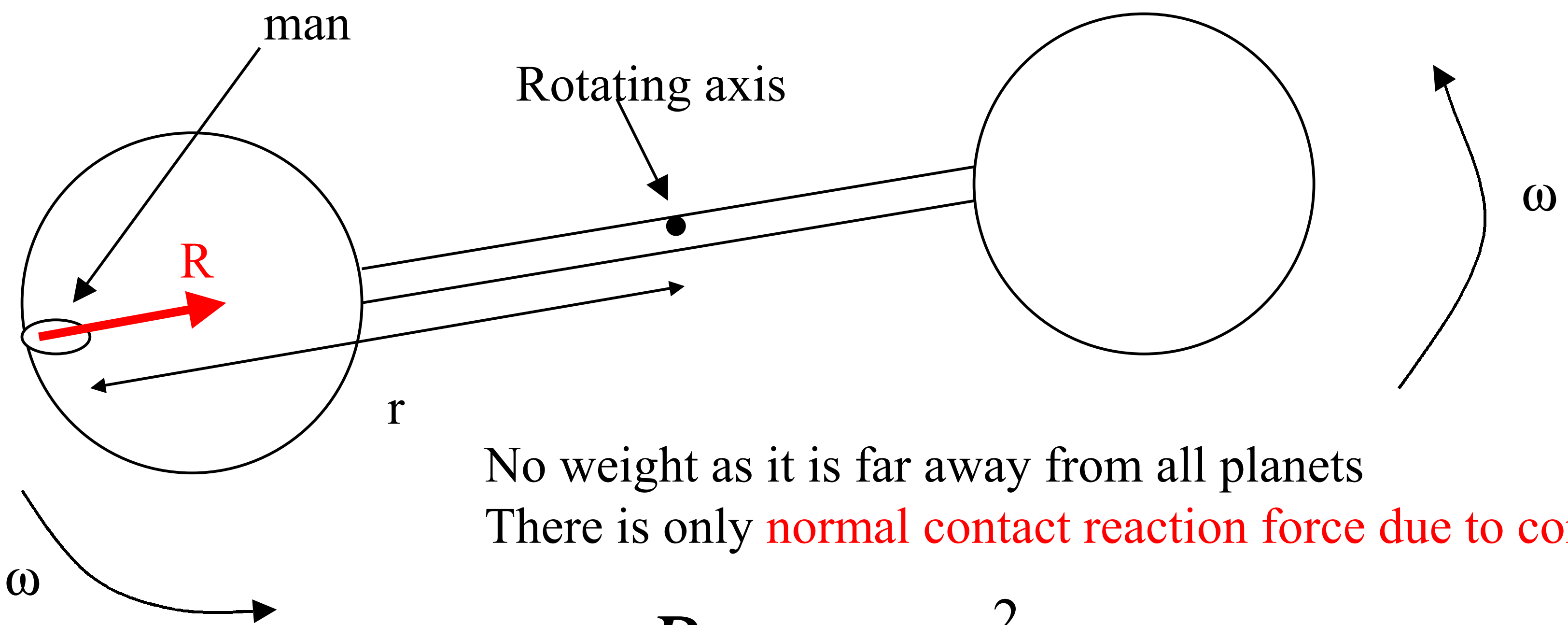

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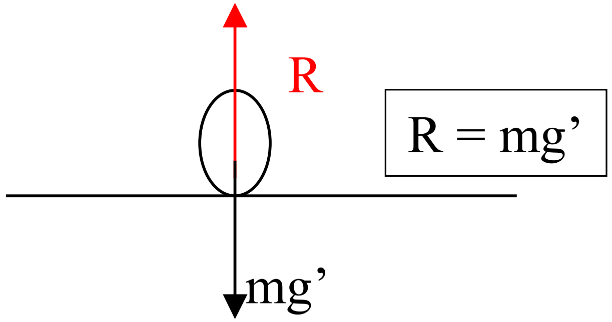
$$R = mr\omega^2$$

More about Circular Motion



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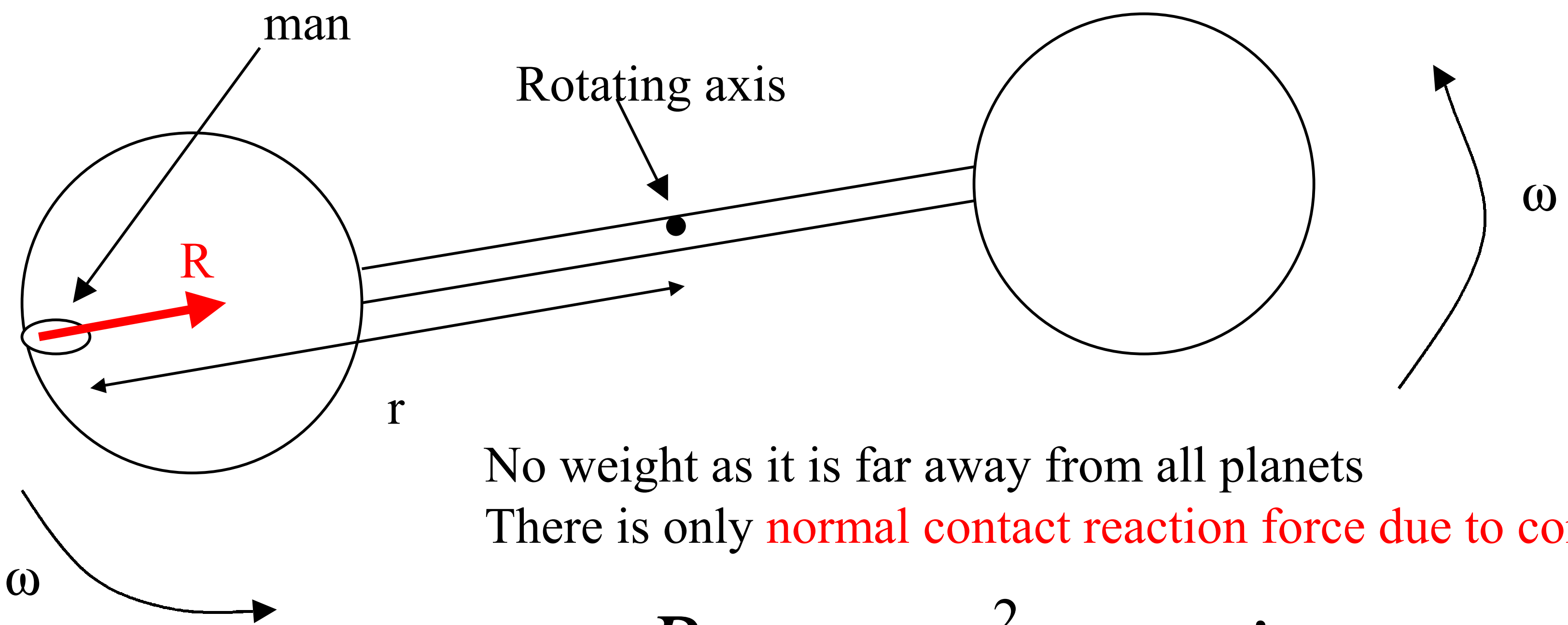
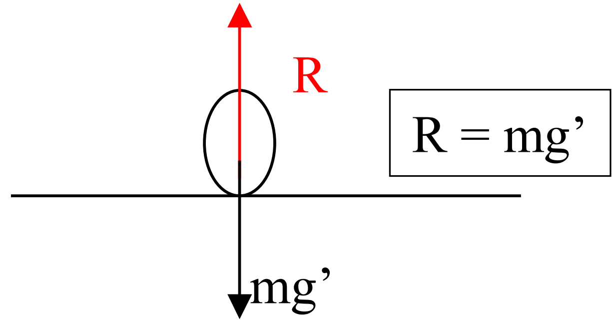


No weight as it is far away from all planets

There is only normal contact reaction force due to contact N.

$$R = mr\omega^2 = mg'$$

More about Circular Motion



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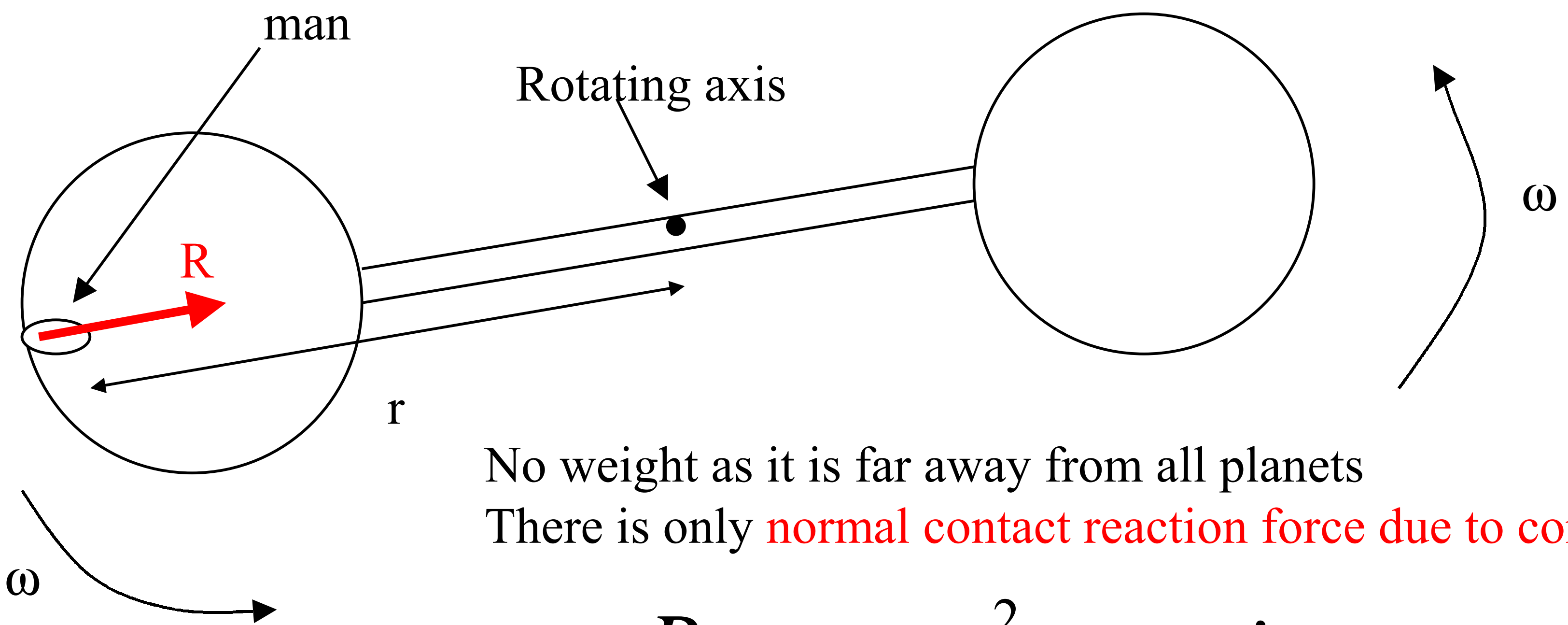


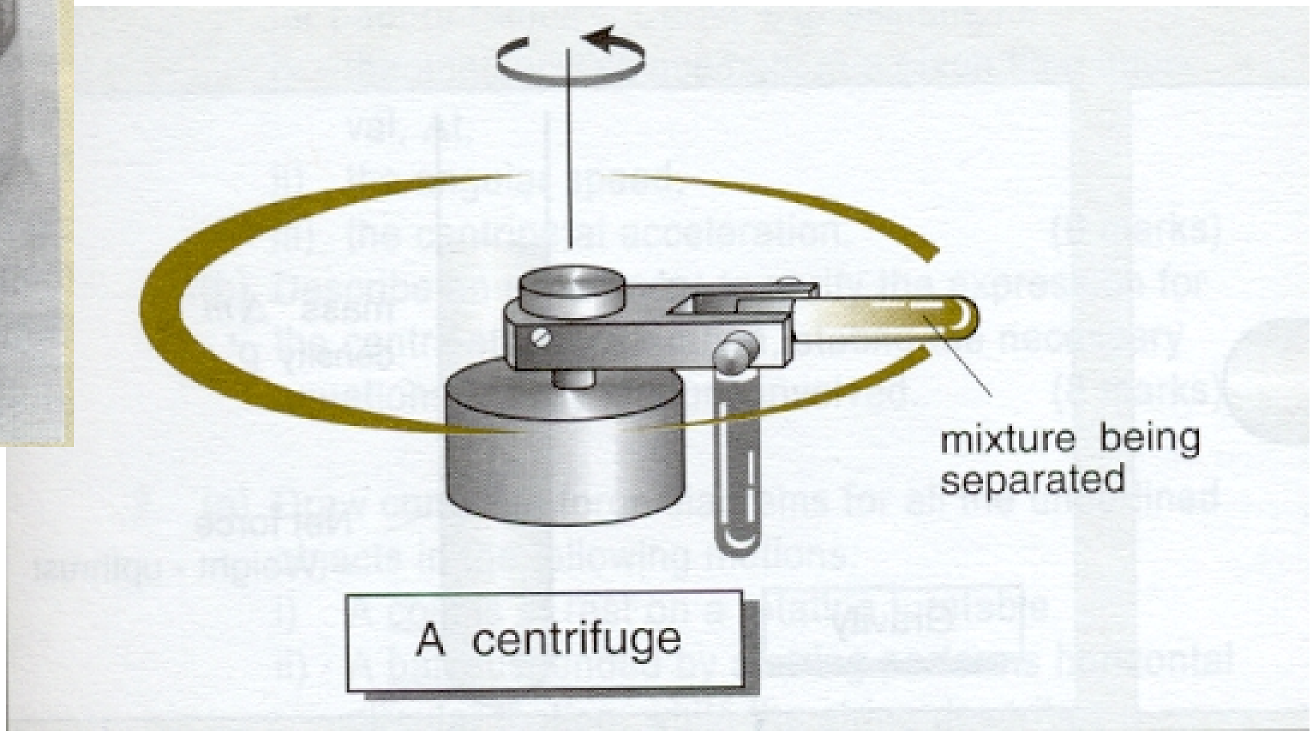
No weight as it is far away from all planets
There is only normal contact reaction force due to contact N.

$$R = mr\omega^2 = mg'$$

$$r\omega^2 = g' = 9.8ms^{-2}$$

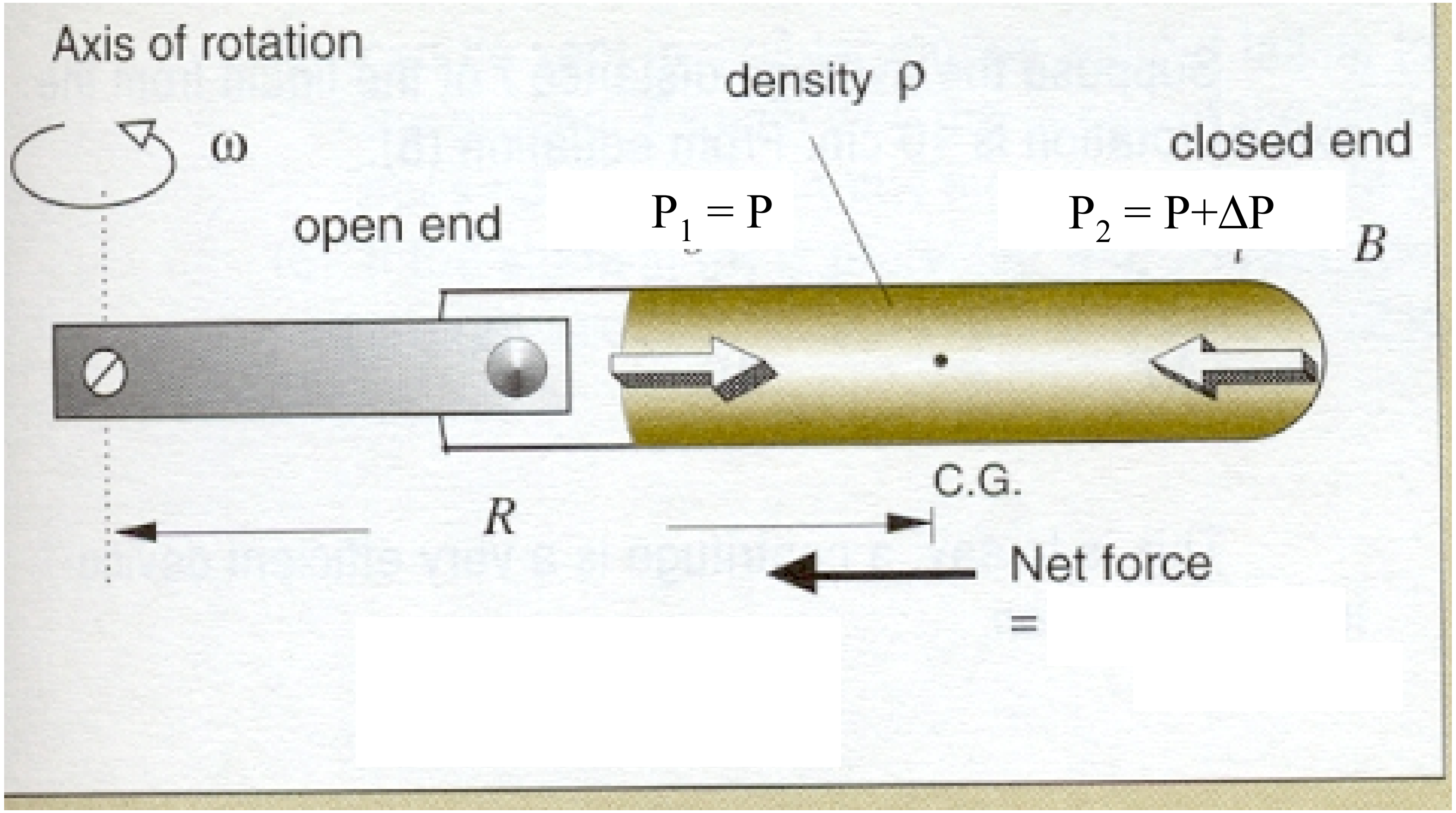
More about Circular Motion

* Working principle of a centrifuge



* Working principle of a centrifuge

(1) Assume it is **horizontally** aligned with liquid of density ρ inside.



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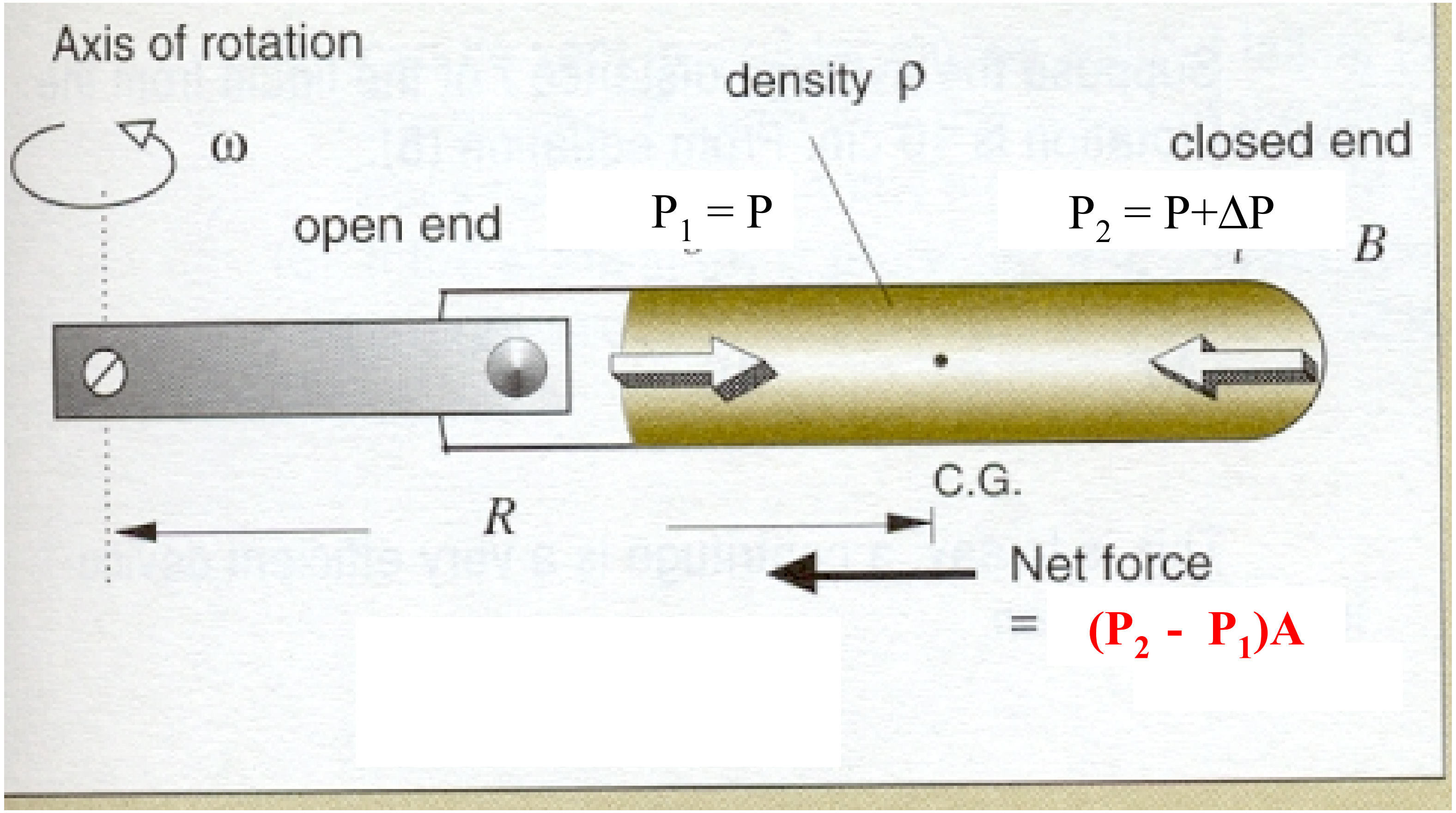

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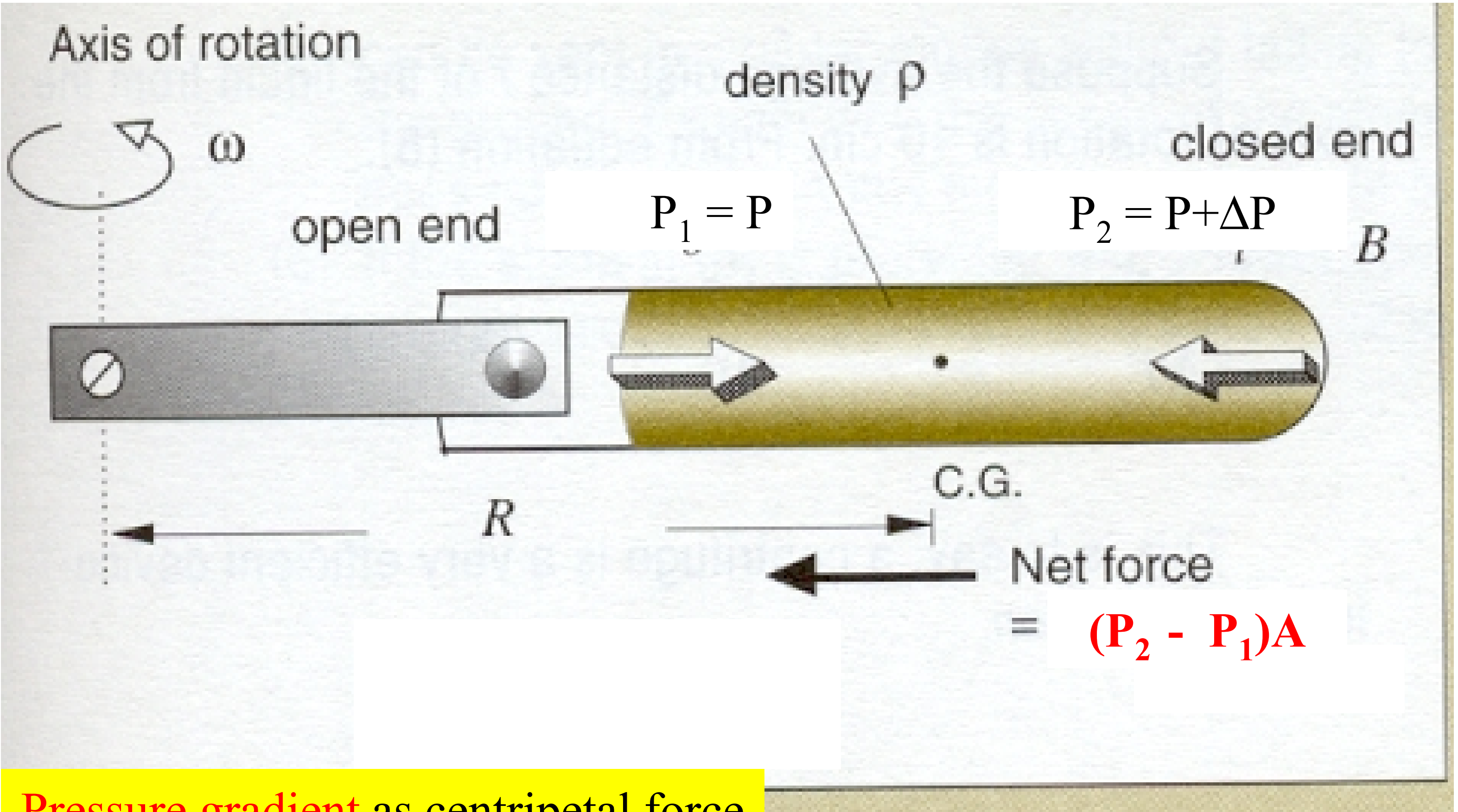

Pressure gradient as centripetal force

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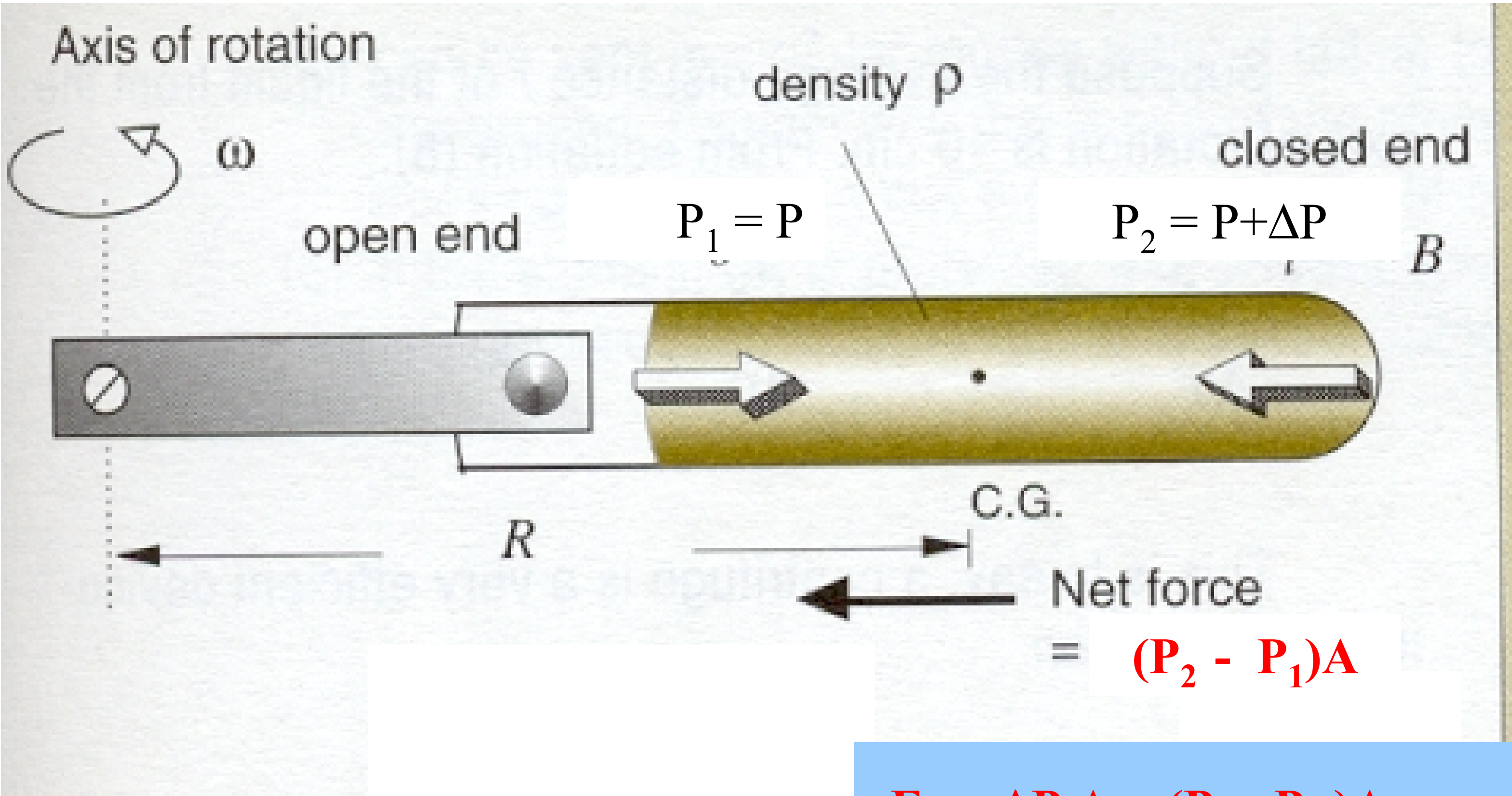


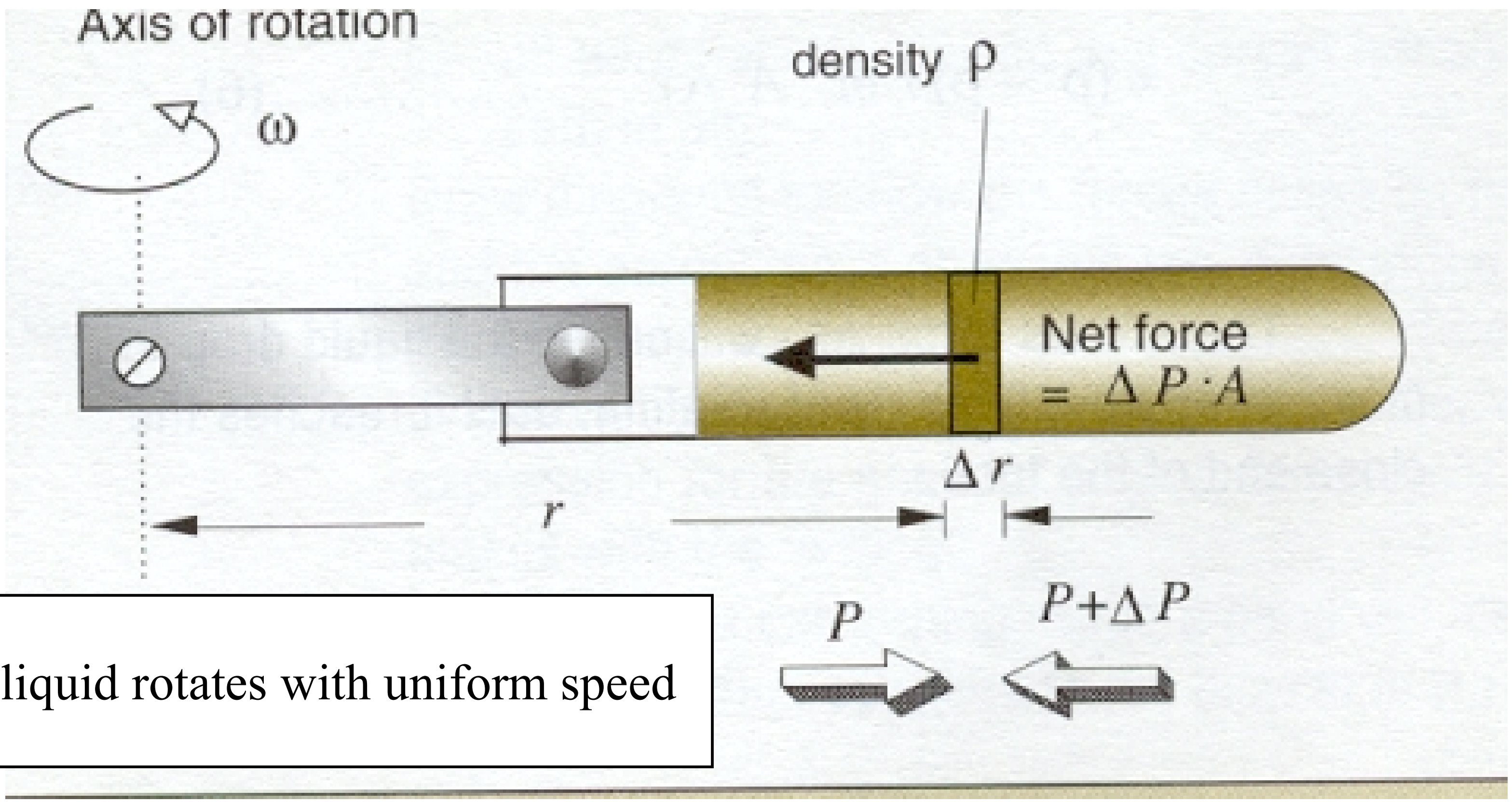
Pressure gradient as centripetal force

$$F_C = \Delta P\ A = (P_2 - P_1)A = mr\omega^2$$

The pressure gradient increases with the distance from the rotating axis

* Working principle of a centrifuge

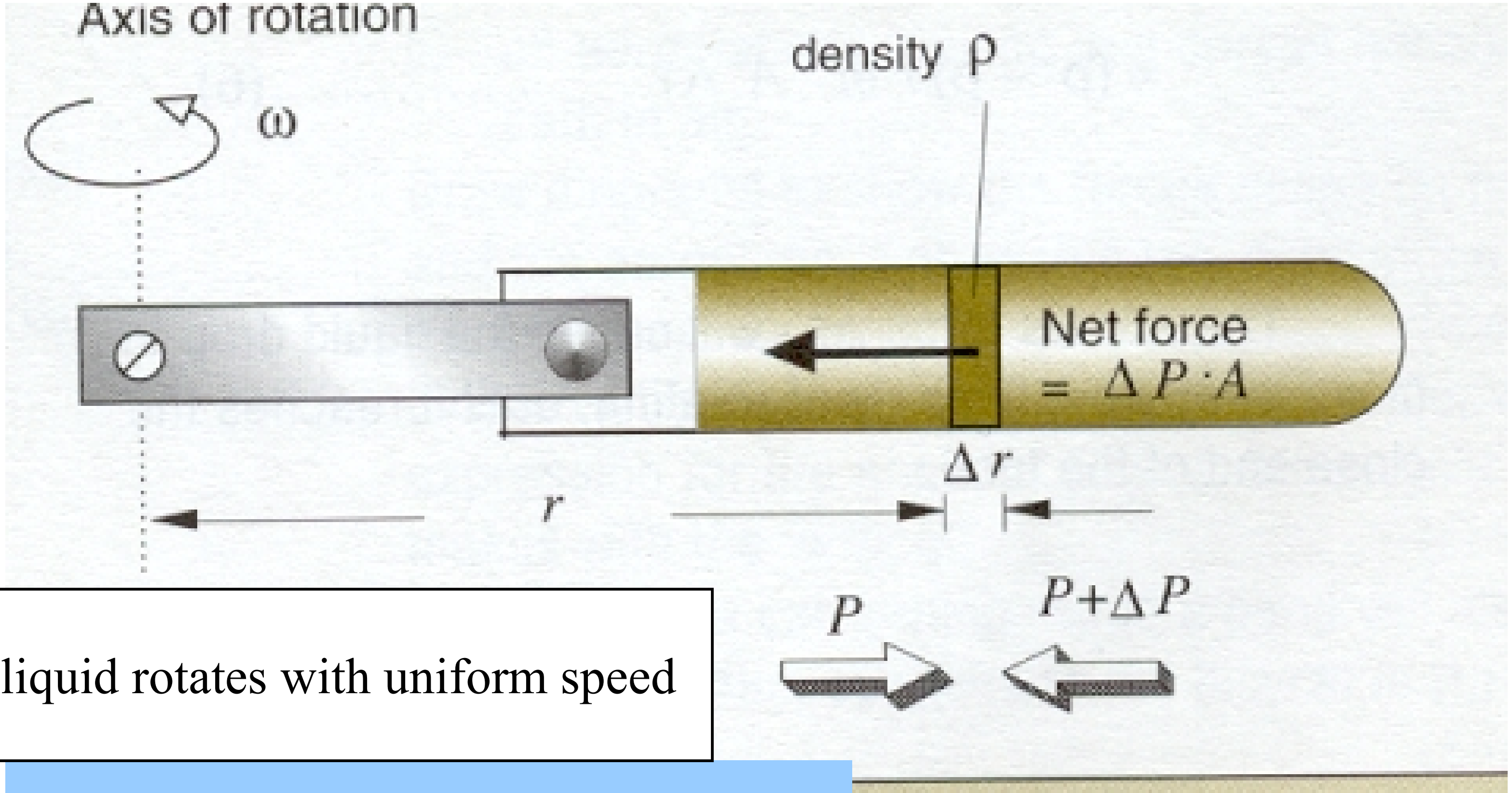
(2) Consider ***an element of the liquid of density*** ρ inside.



All liquid rotates with uniform speed

* Working principle of a centrifuge

(2) Consider ***an element of the liquid of density*** ρ inside.



All liquid rotates with uniform speed

Net force = $(P_2 - P_1)A$

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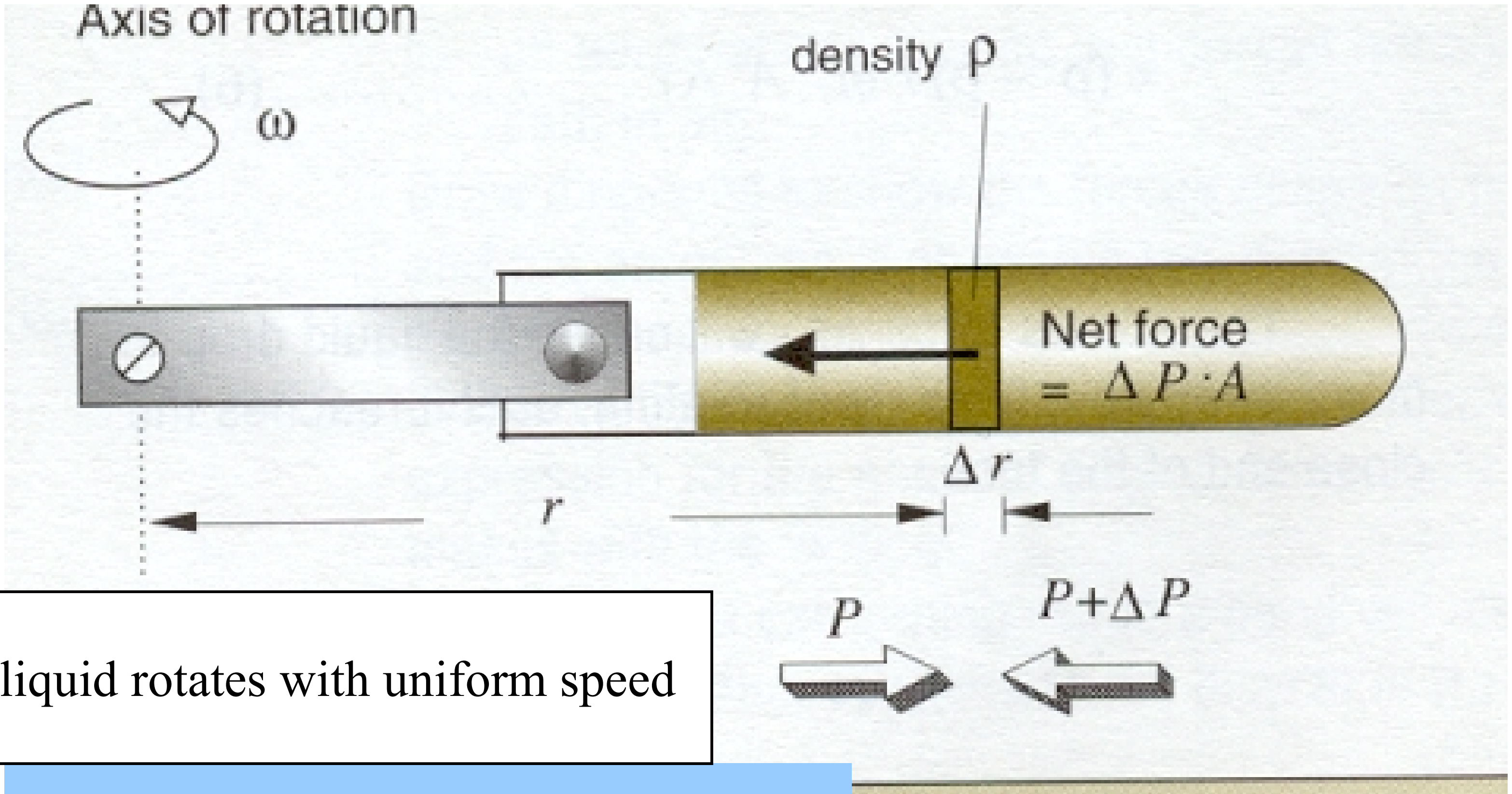

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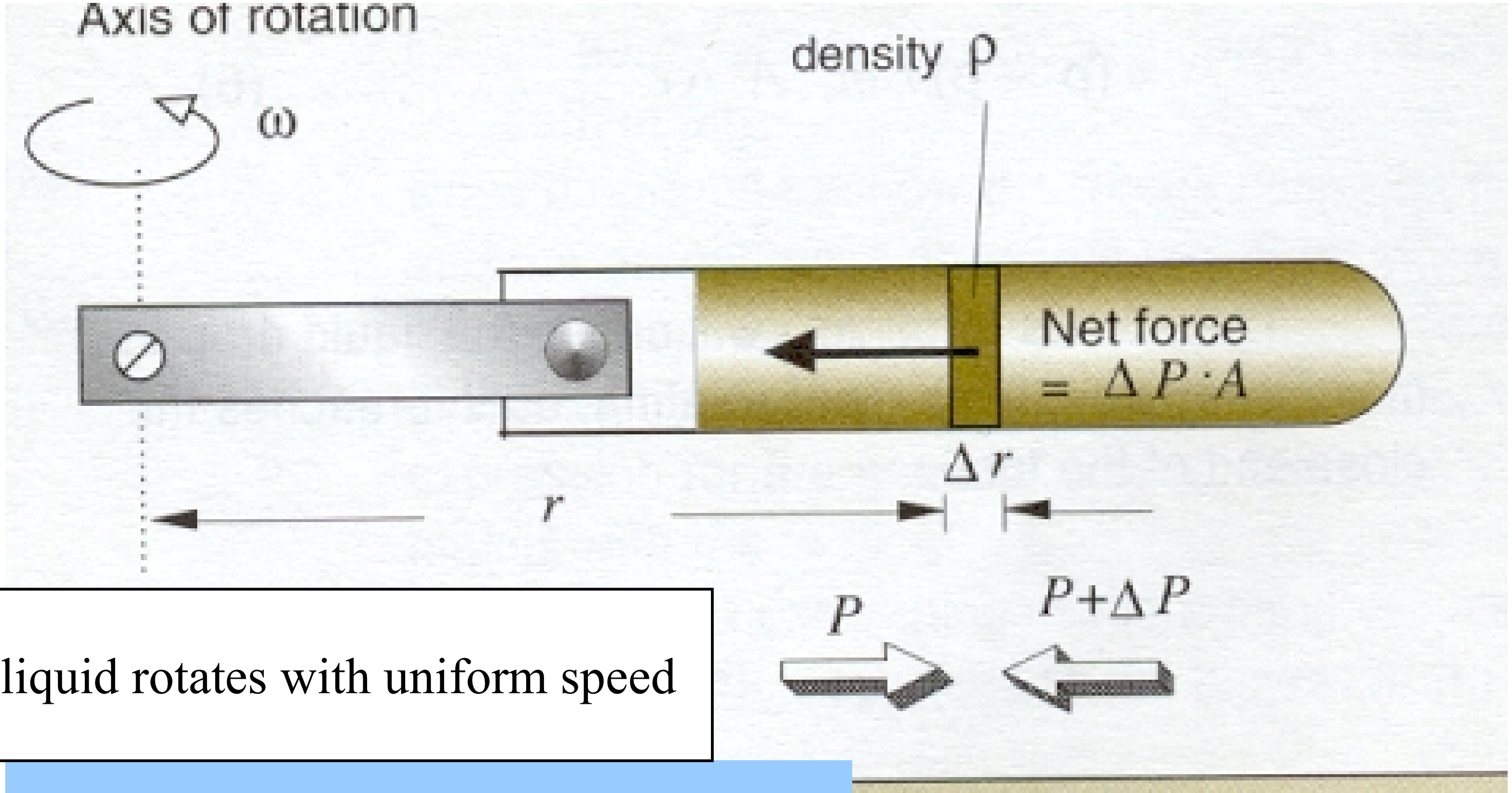

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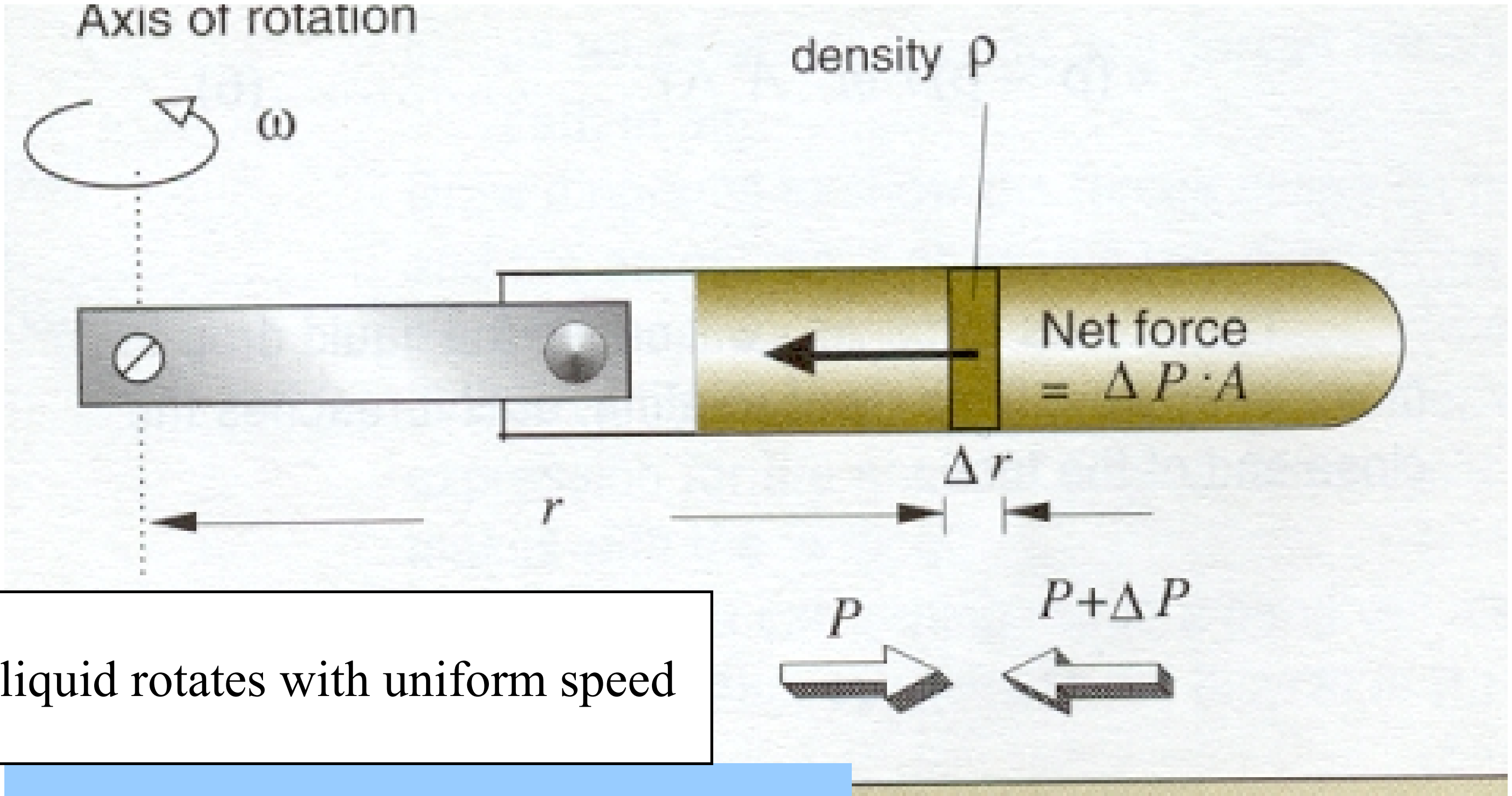

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$$\text{Net force} = (P_2 - P_1)A$$
$$= [m]\, r\, \omega^2$$
$$= [\rho\, \Delta V]\, r\, \omega^2$$
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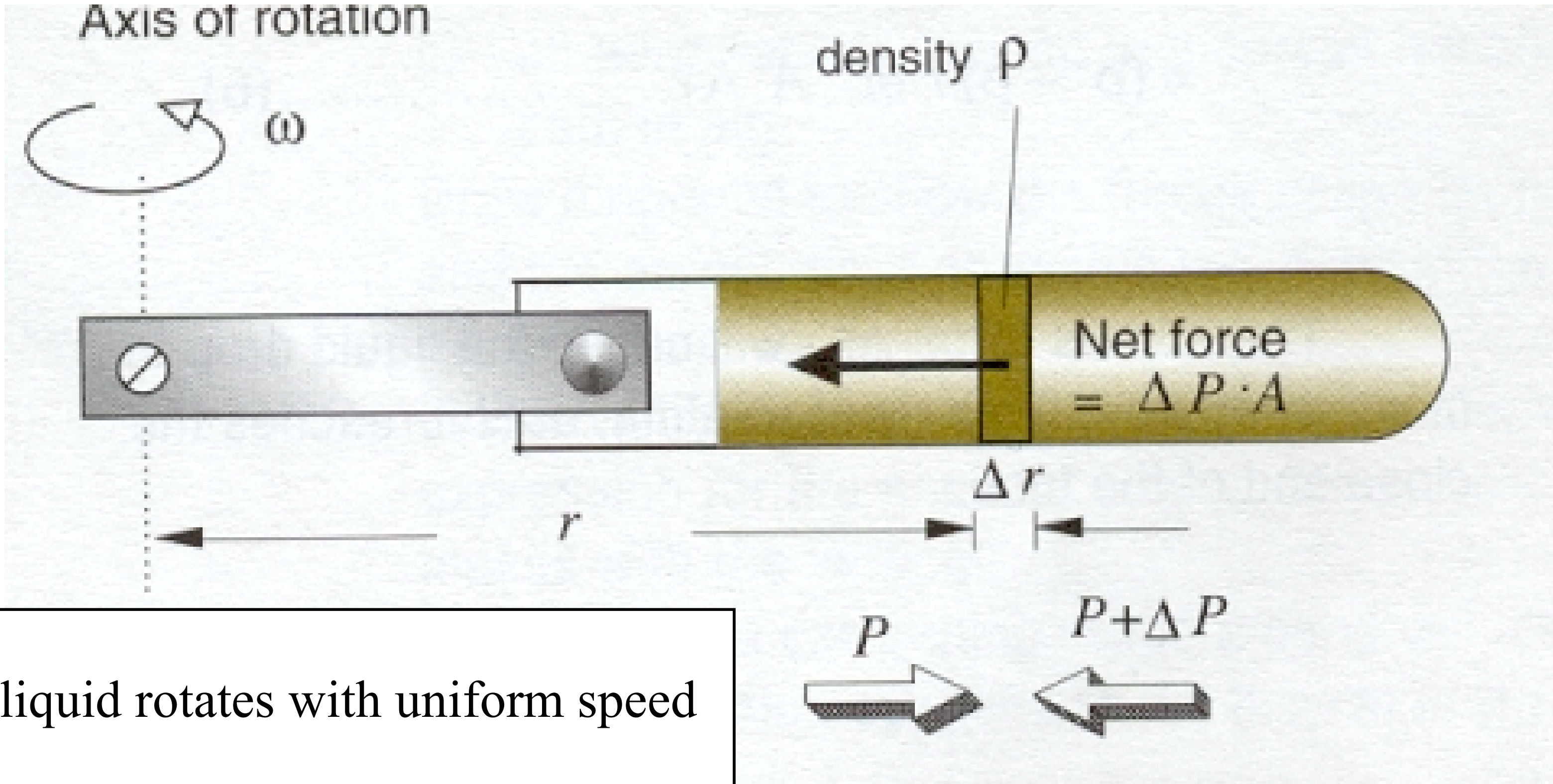

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$= [m]\, r\, \omega^2$
$= [\rho\, \Delta V]\, r\, \omega^2$
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Net force due to pressure gradient
$= \rho\, r\, A\, \omega^2\, \Delta r$

* Working principle of a centrifuge

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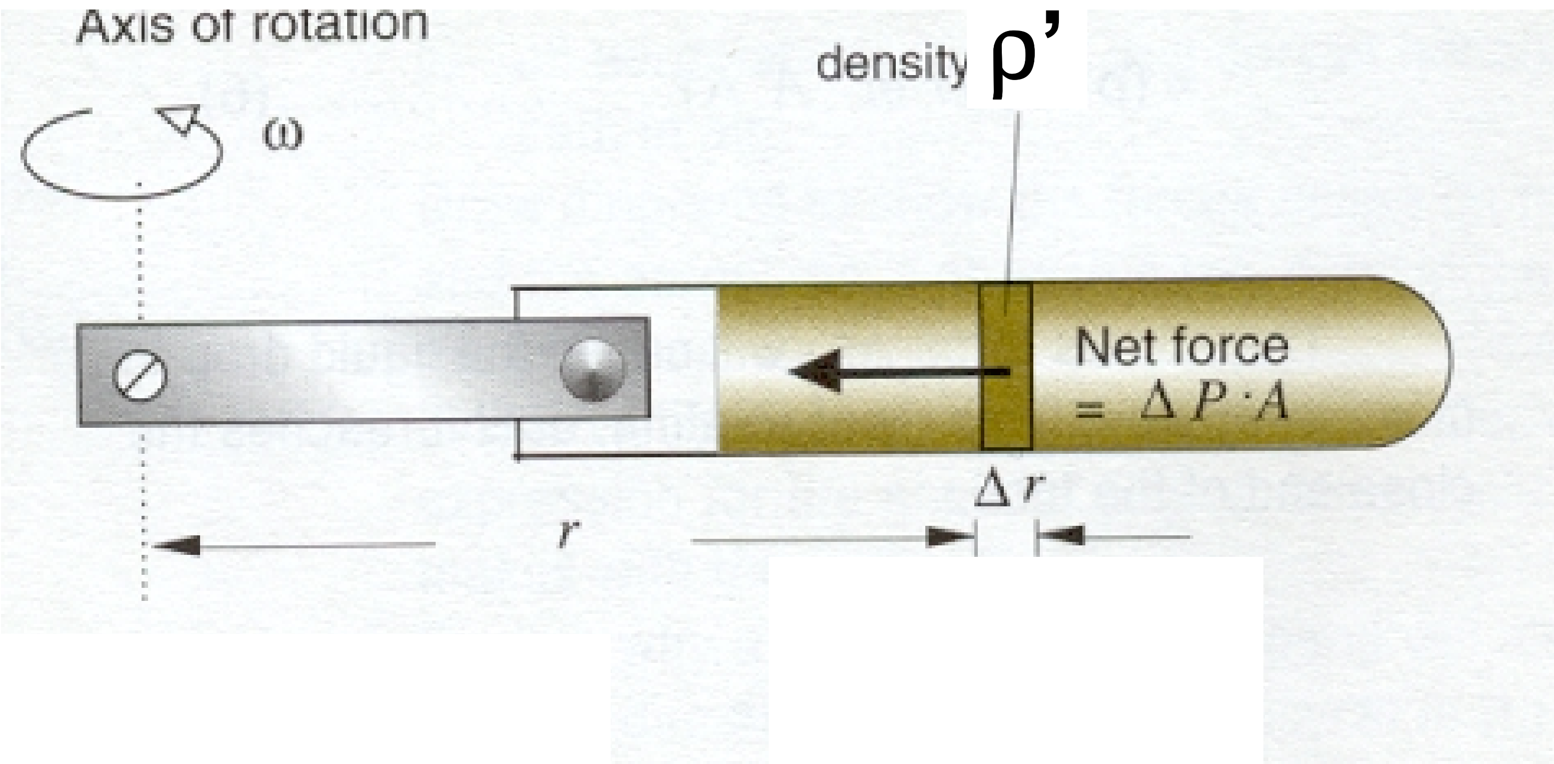

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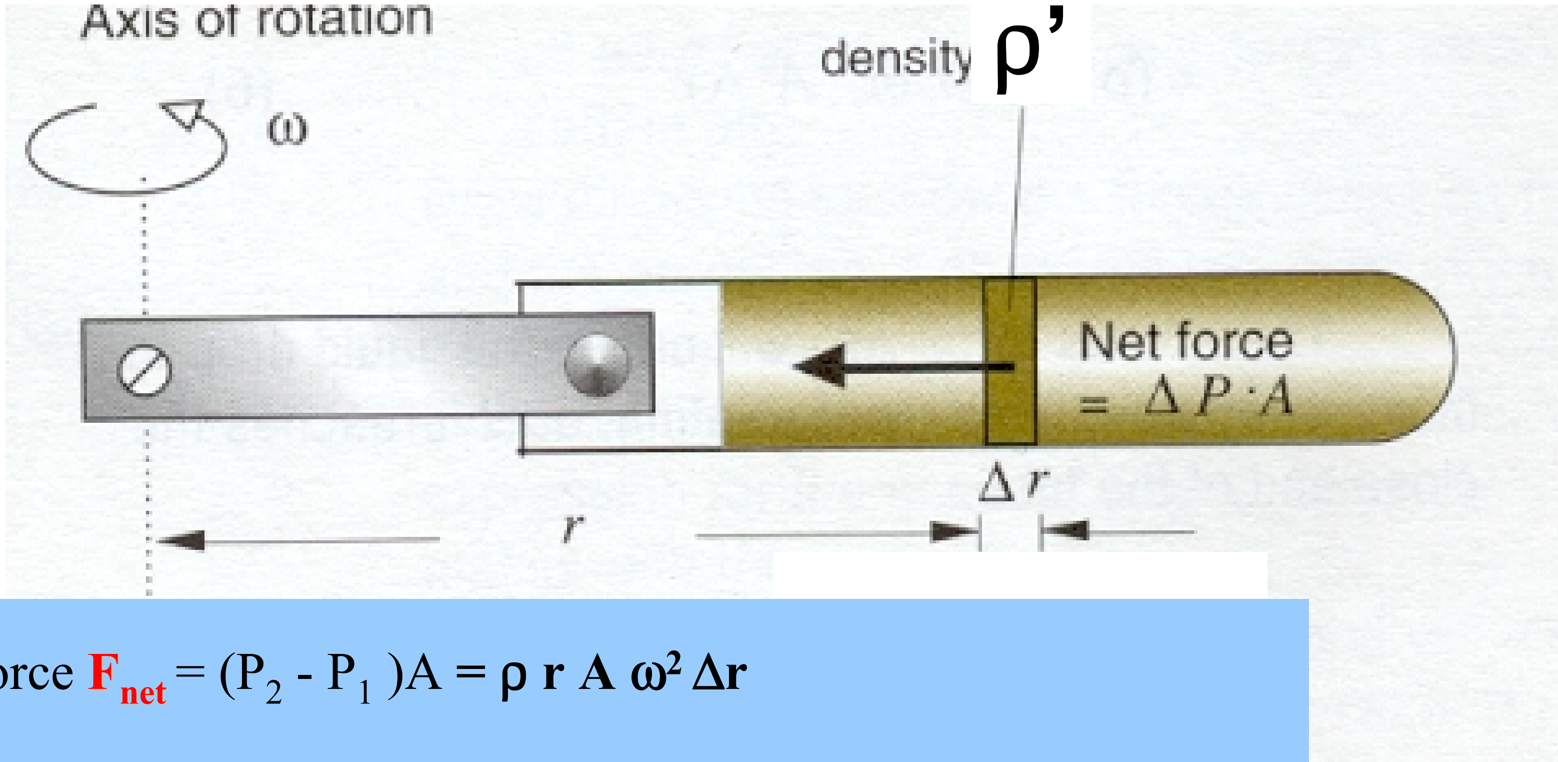

Net force $F_{net} = (P_2 - P_1)A = \boldsymbol{\rho\, r\, A\, \omega^2 \Delta r}$

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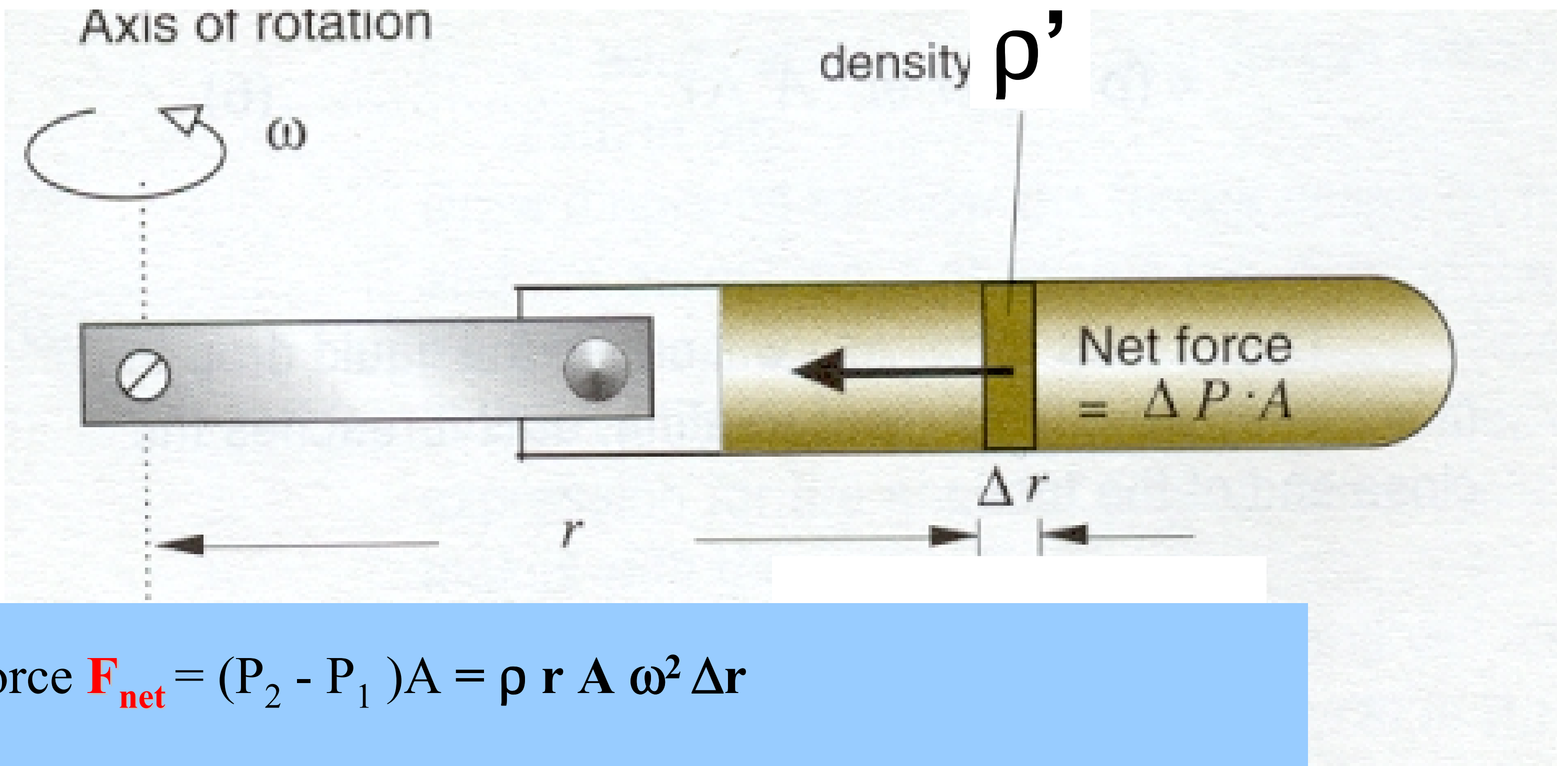

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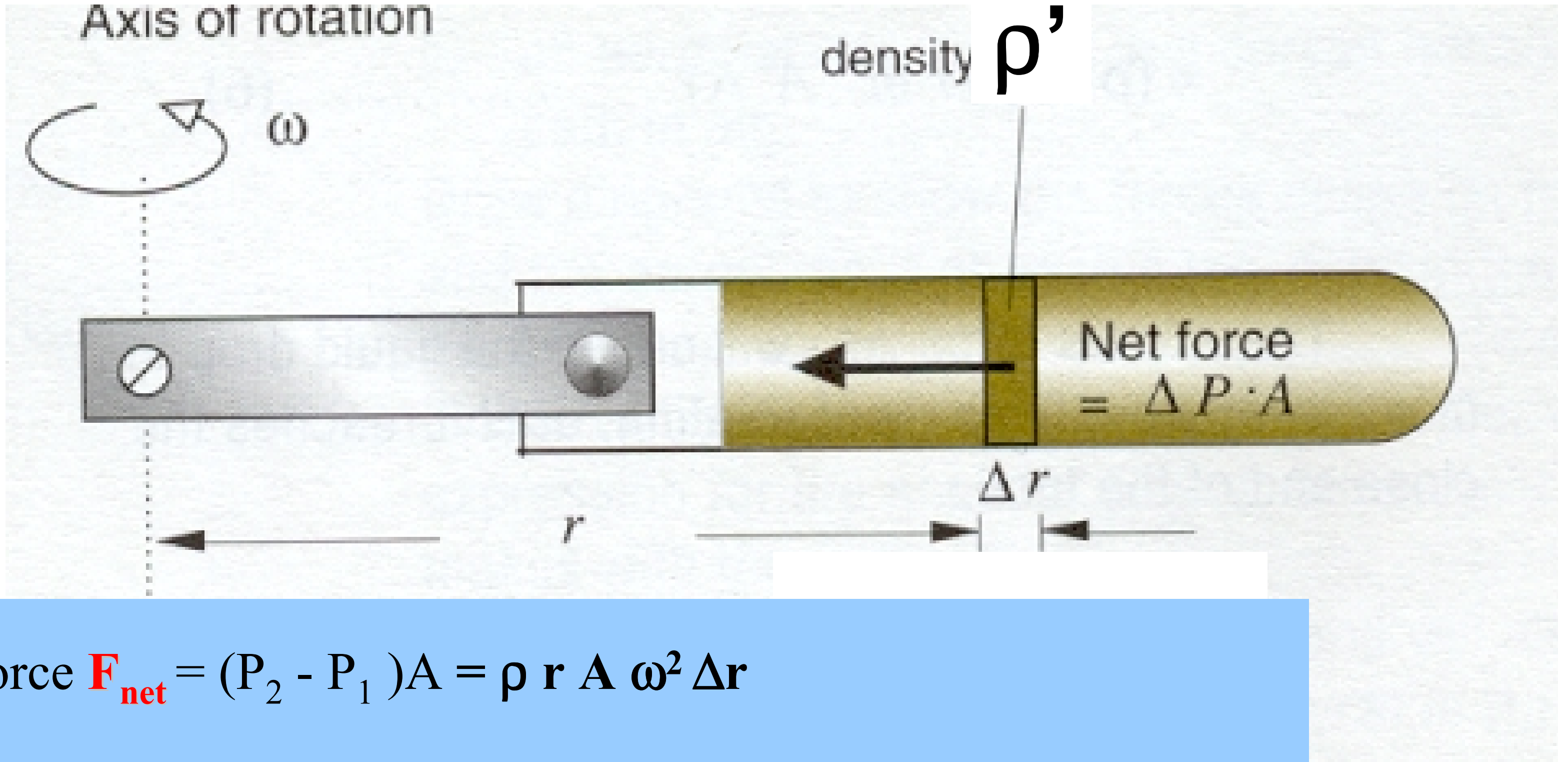

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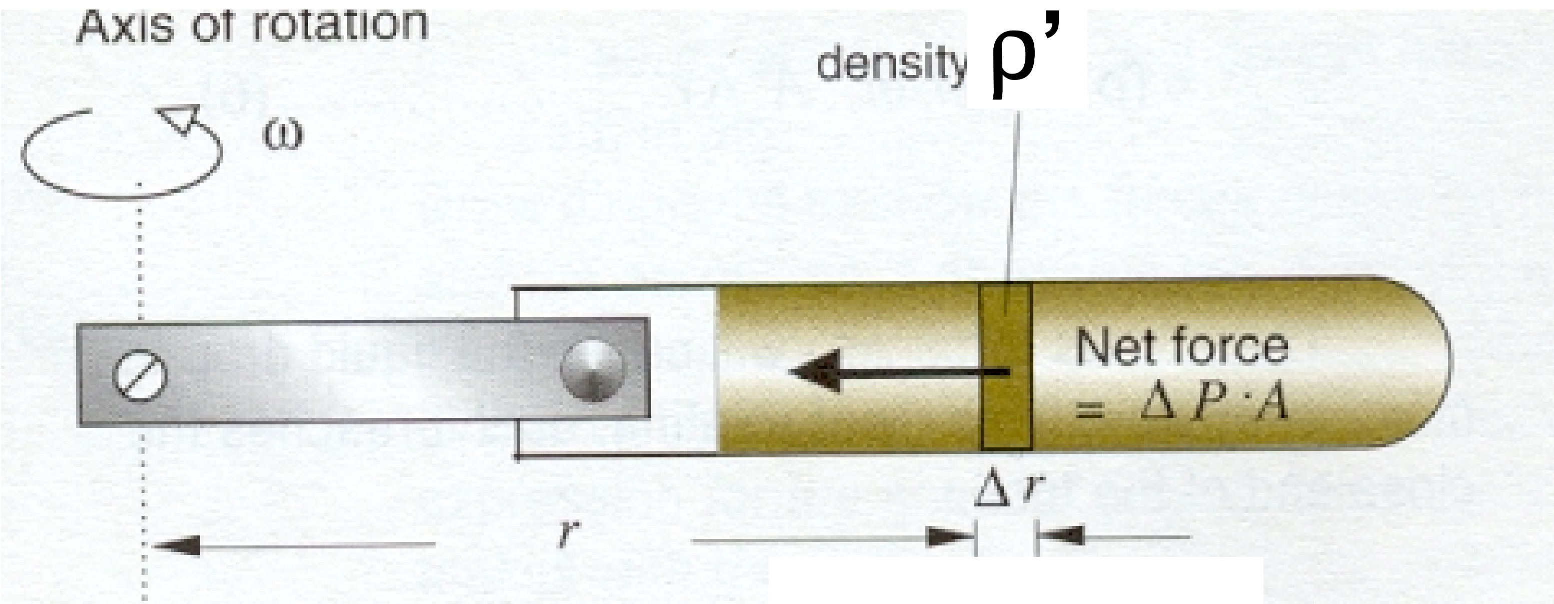

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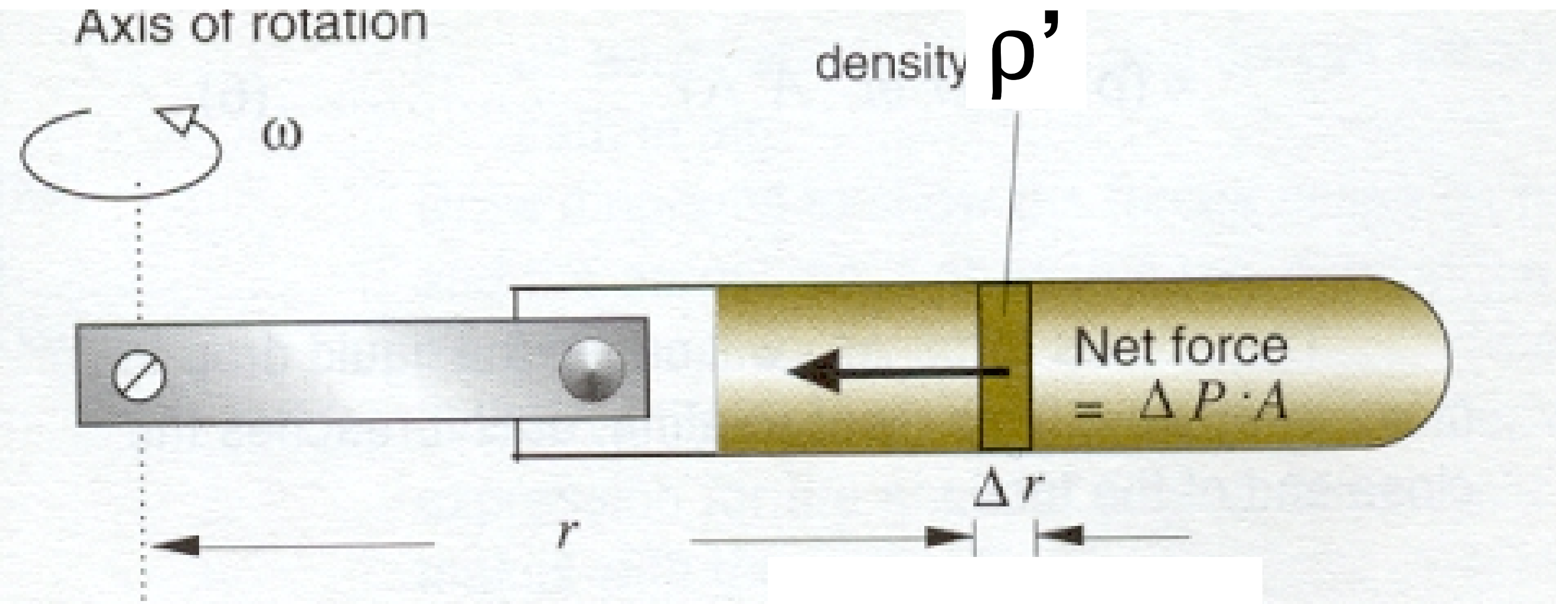

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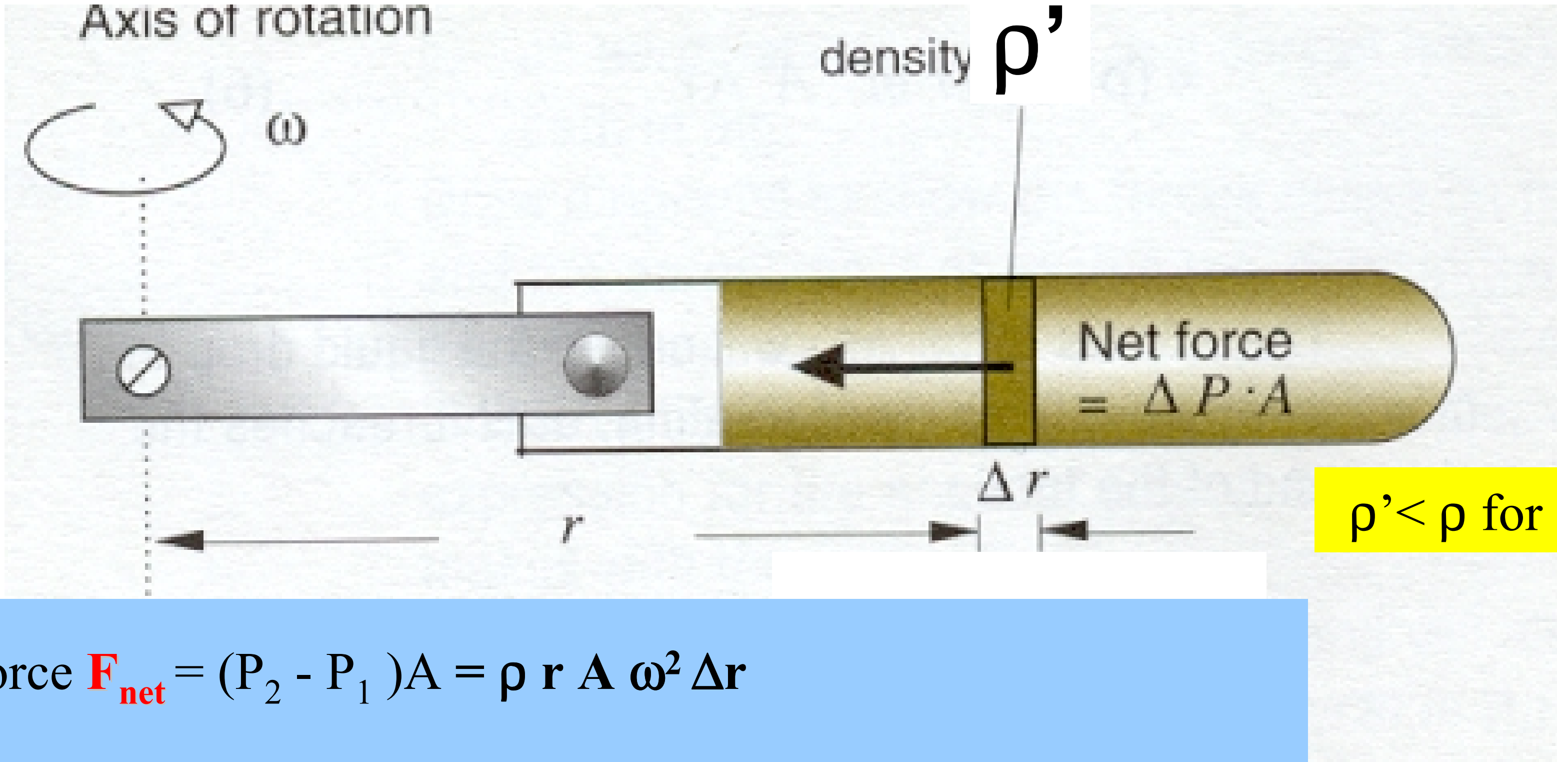

ρ'< ρ for less dense object

Net force F_{net} = $(P_2 - P_1)A$ = $\boldsymbol{\rho\, r\, A\, \omega^2 \Delta r}$

Required centripetal force F_c = $[m']\, r\, \omega^2$

= $[\rho'\, \Delta V]\, r\, \omega^2$

= $\rho'(A\, \Delta r)\, r\, \omega^2$ = $\boldsymbol{\rho'\, r\, A\, \omega^2 \Delta r}$

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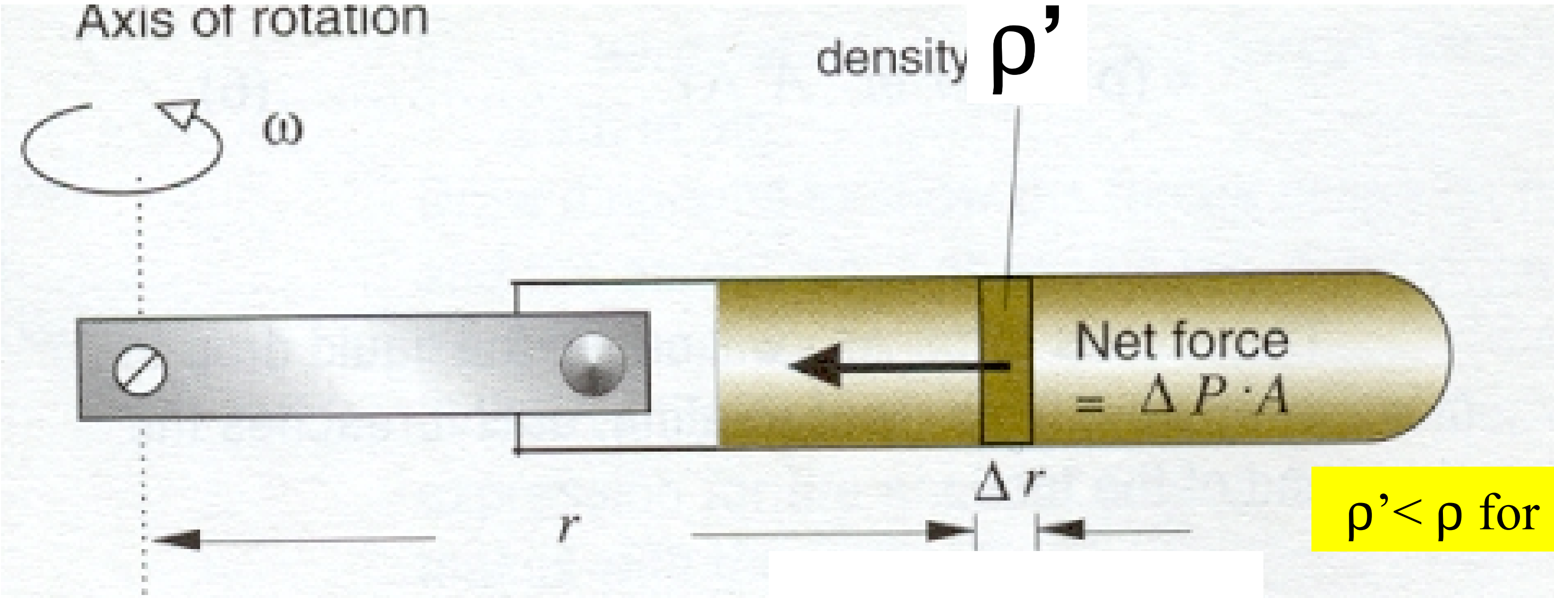

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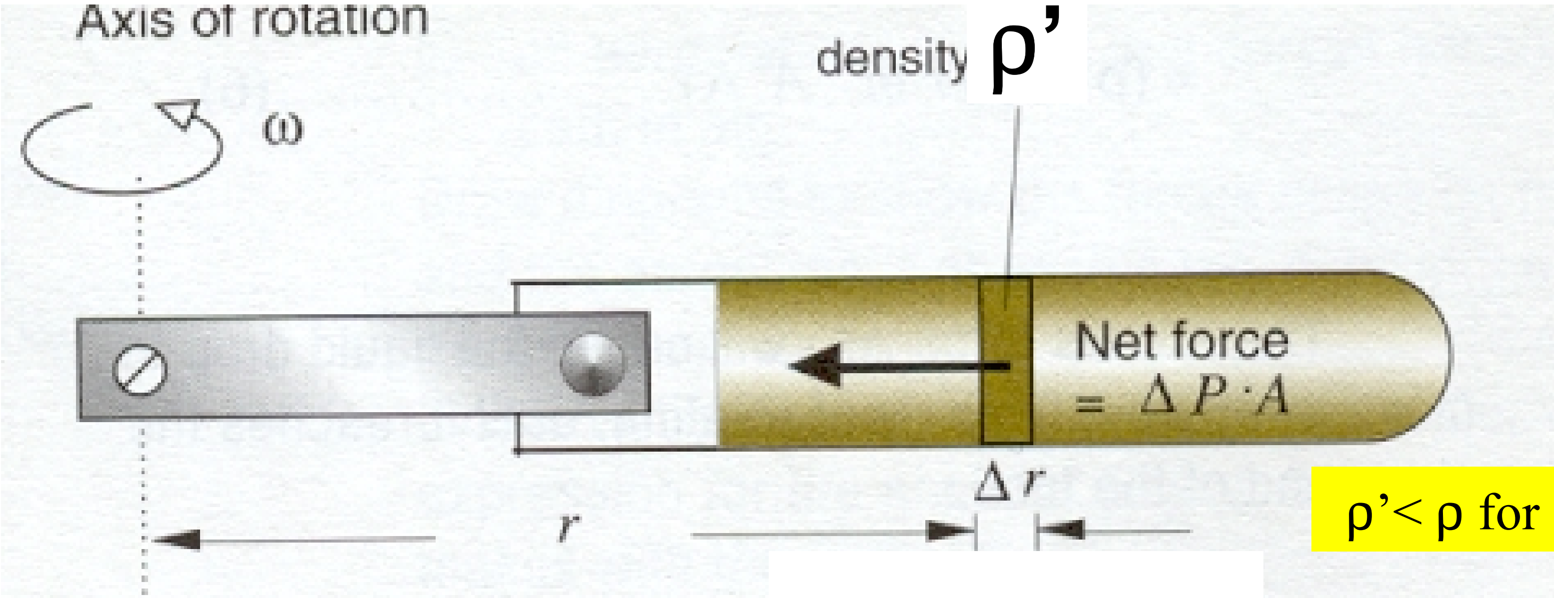

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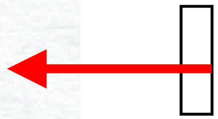

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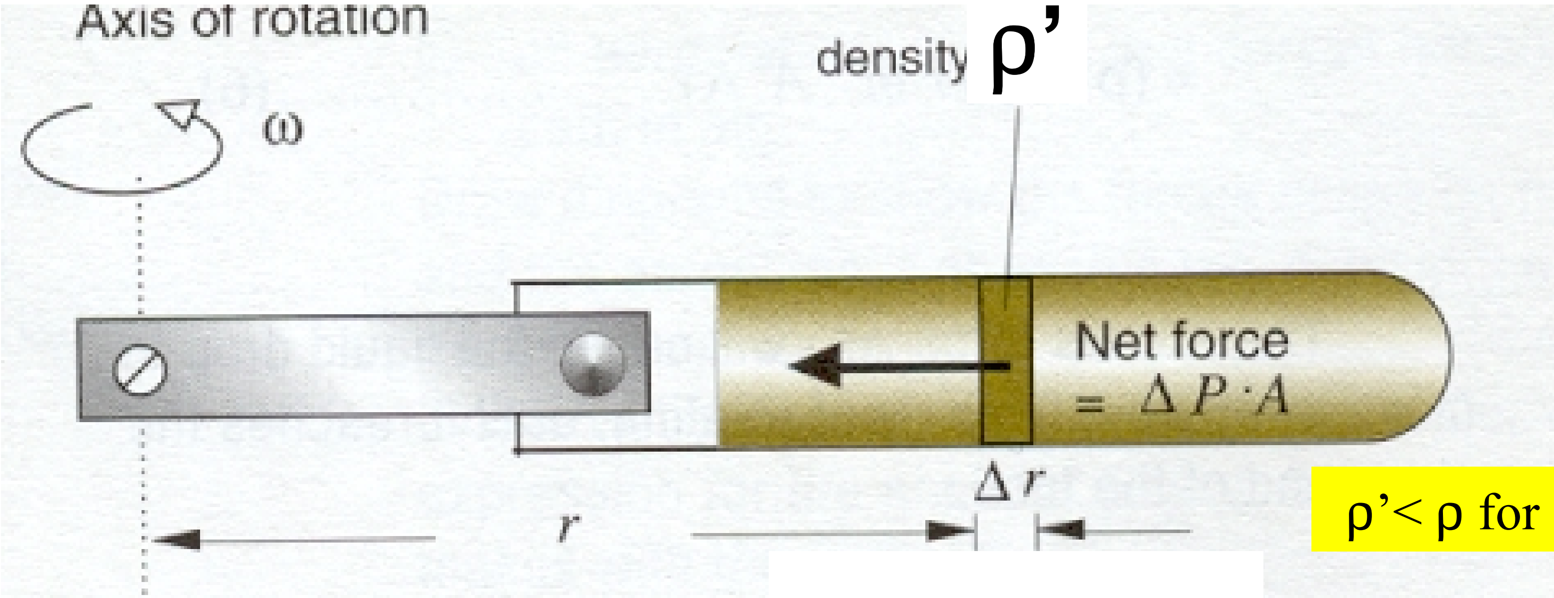

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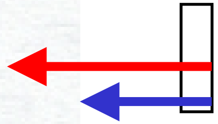

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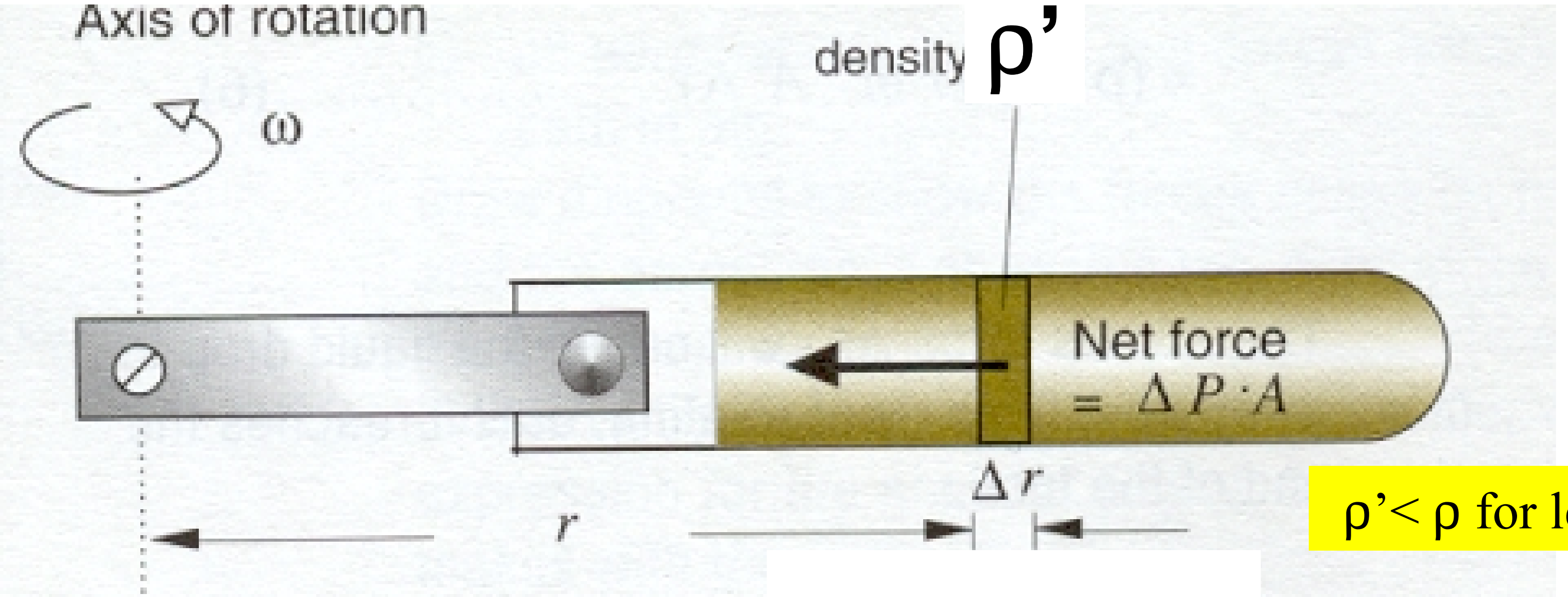

$\rho' < \rho$ for less dense object

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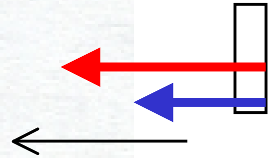

Move towards the axis

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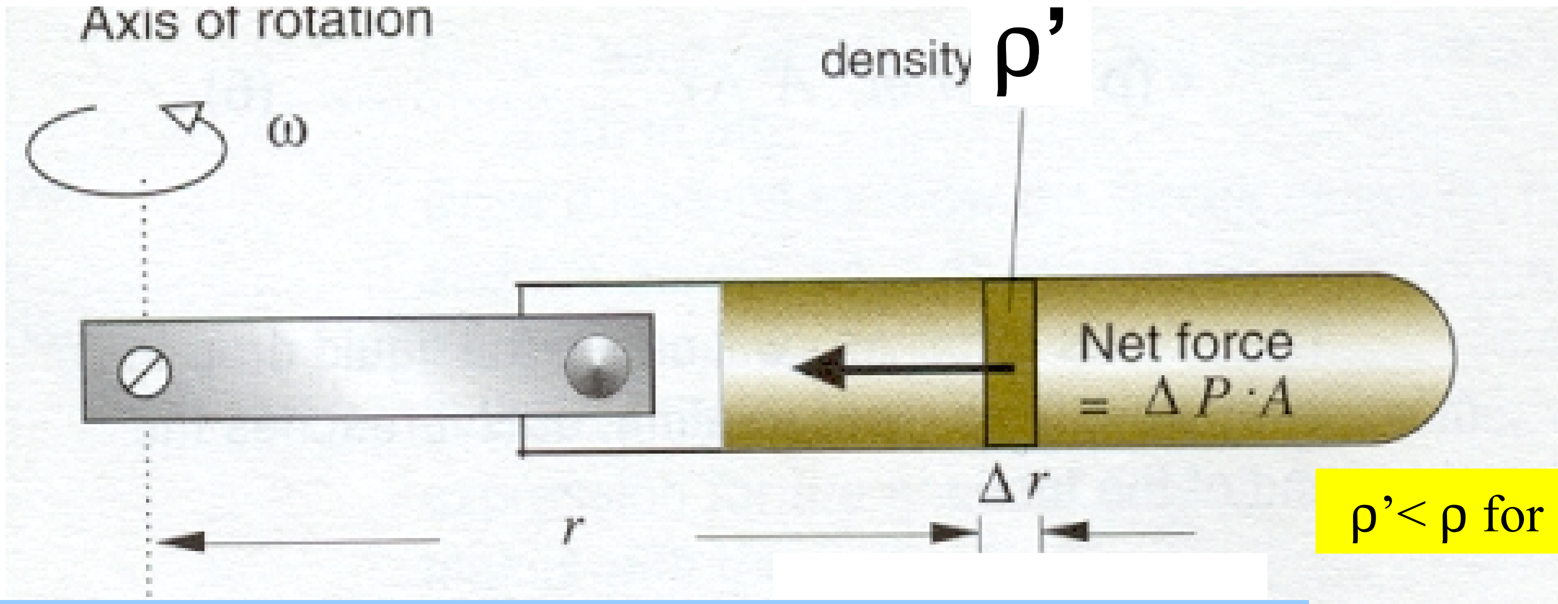
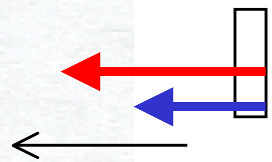


ρ’< ρ for less dense object



Move towards the axis

ρ’> ρ for denser object

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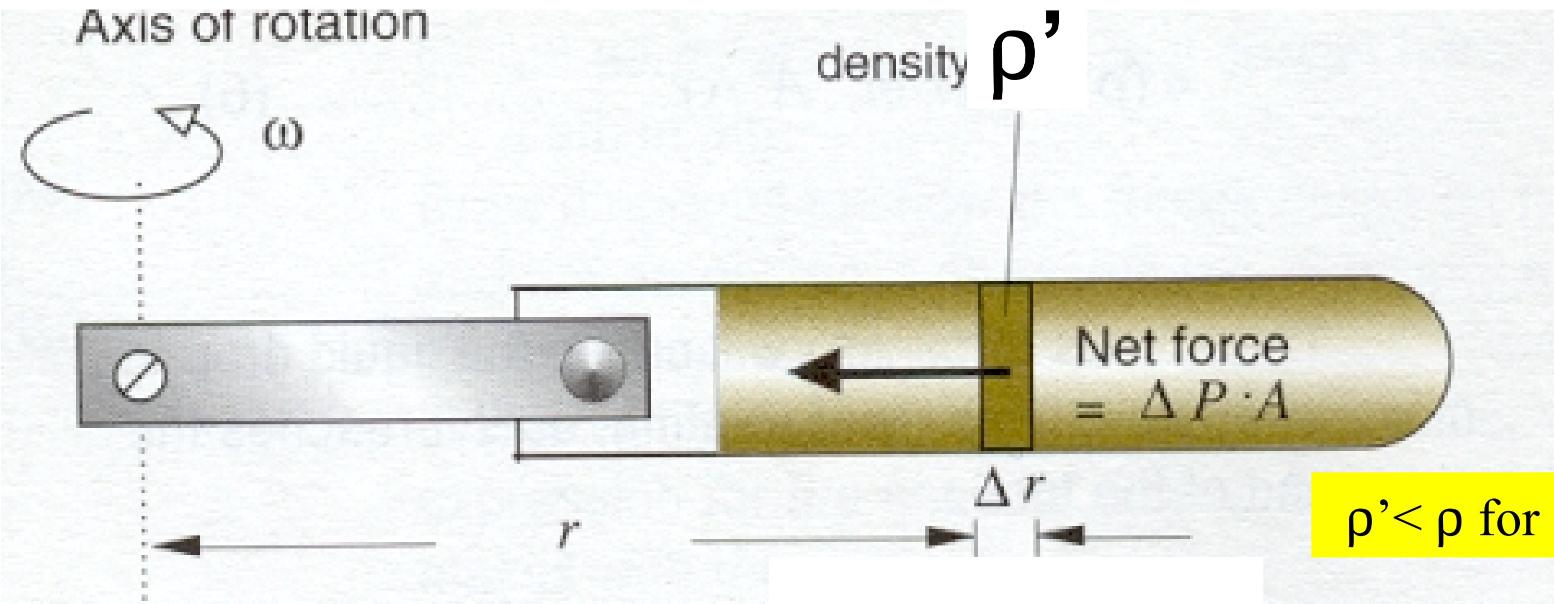

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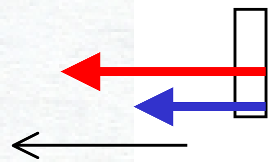

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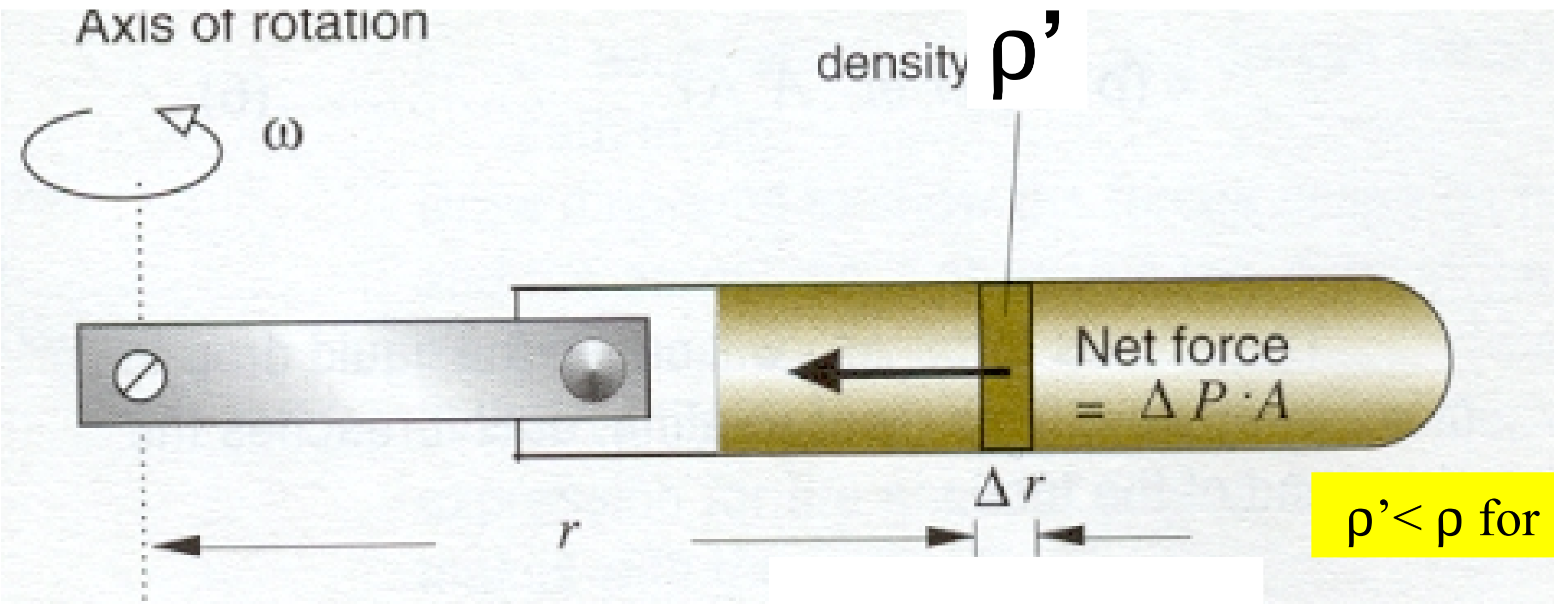

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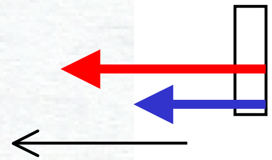

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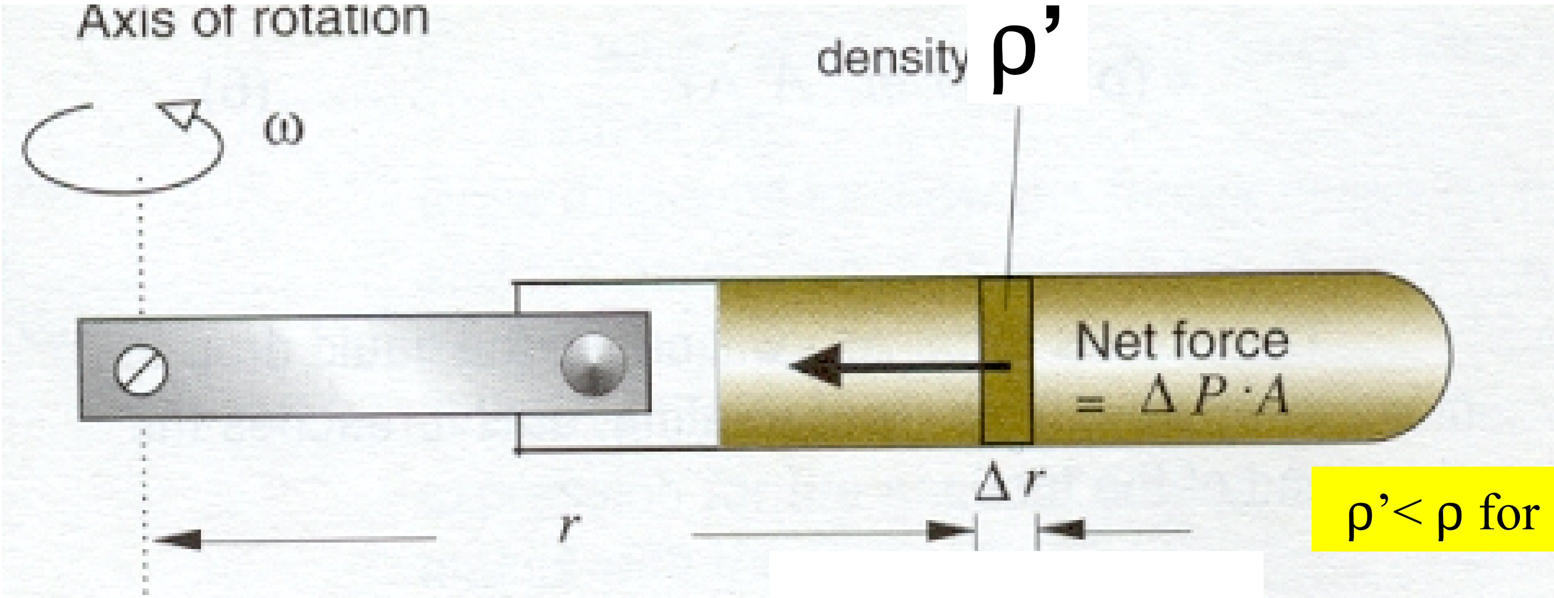

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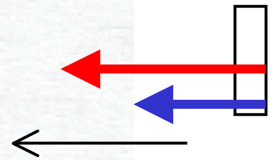
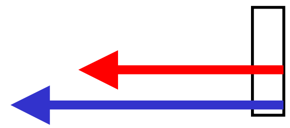


Move towards the axis

$\rho' > \rho$ for denser object



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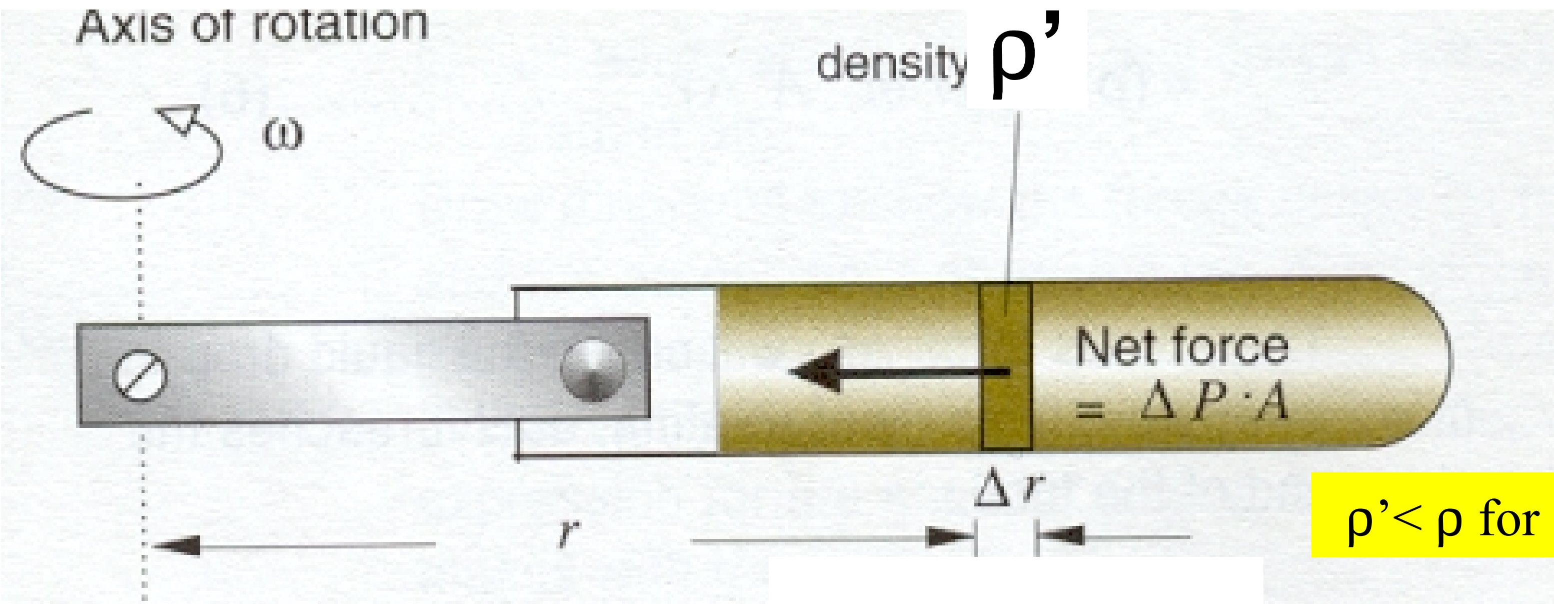

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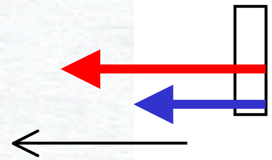
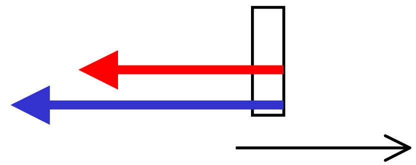


Move towards the axis

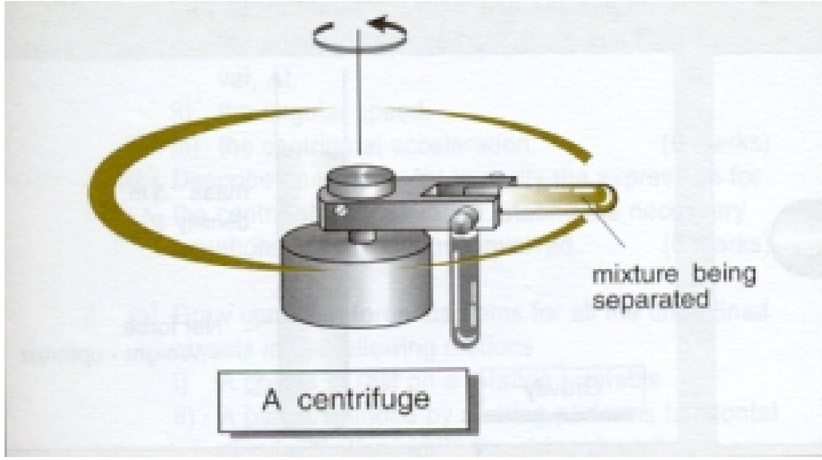
$\rho' > \rho$ for denser object

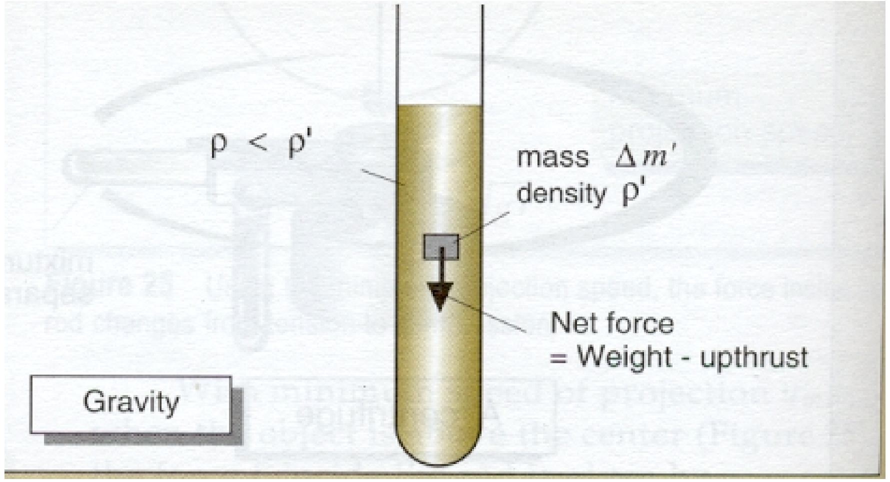


Move away from the axis

More about Circular Motion

* Why centrifuge ?





More about Circular Motion

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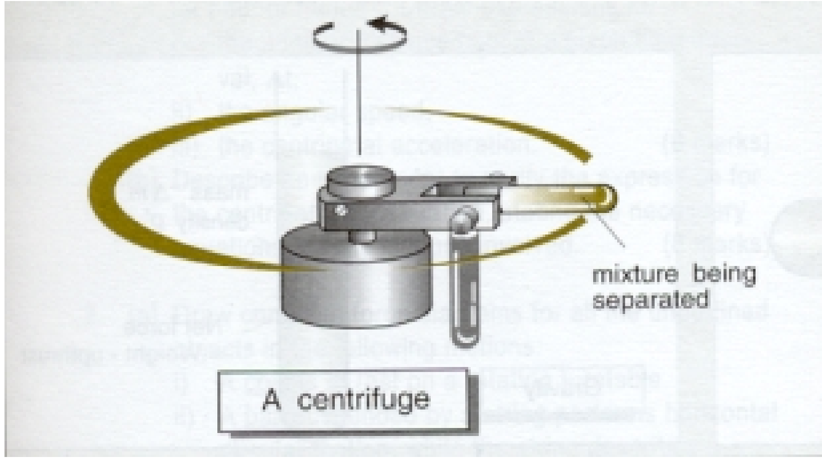

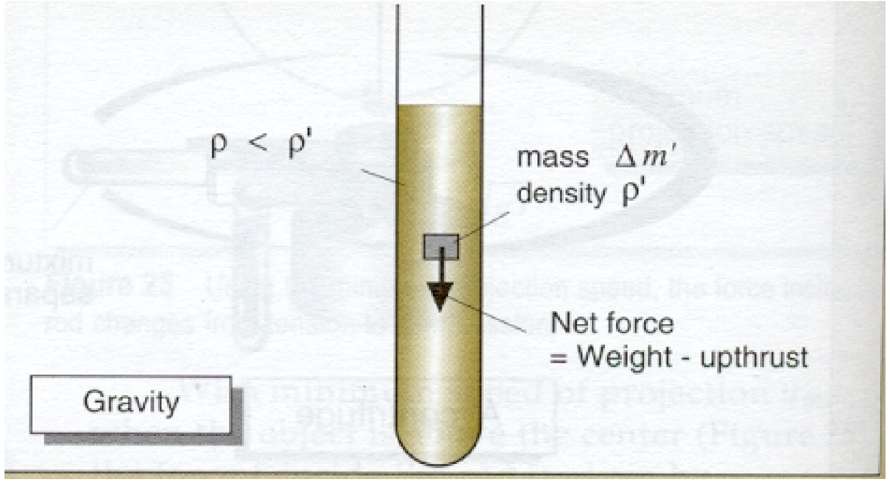

$$F_C = \rho' \, r \, A \, \omega^2 \, \Delta r$$

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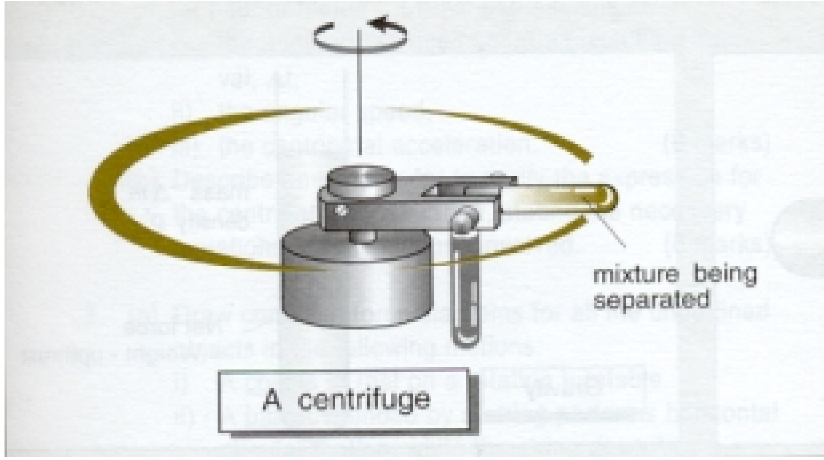

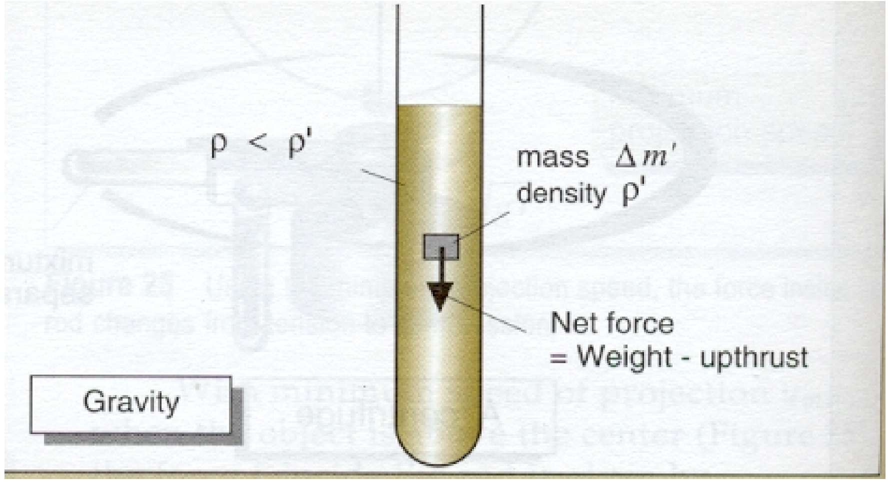

$$F_c = \rho' \, r \, A \, \omega^2 \Delta r$$

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Assume $\rho' > \rho$

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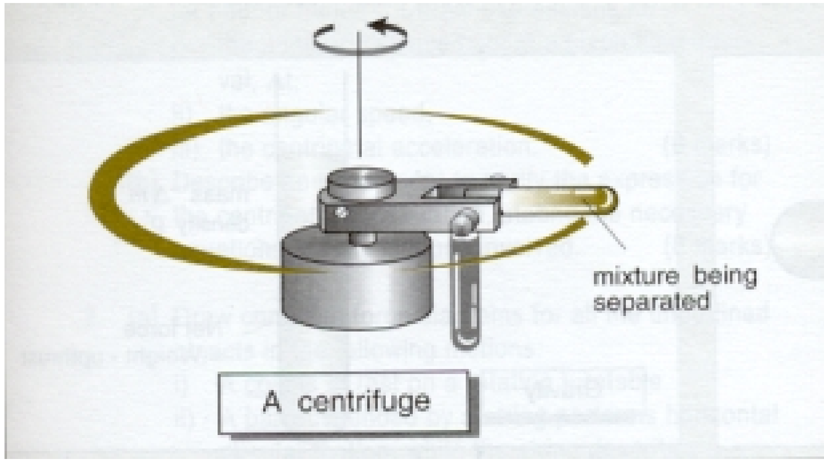

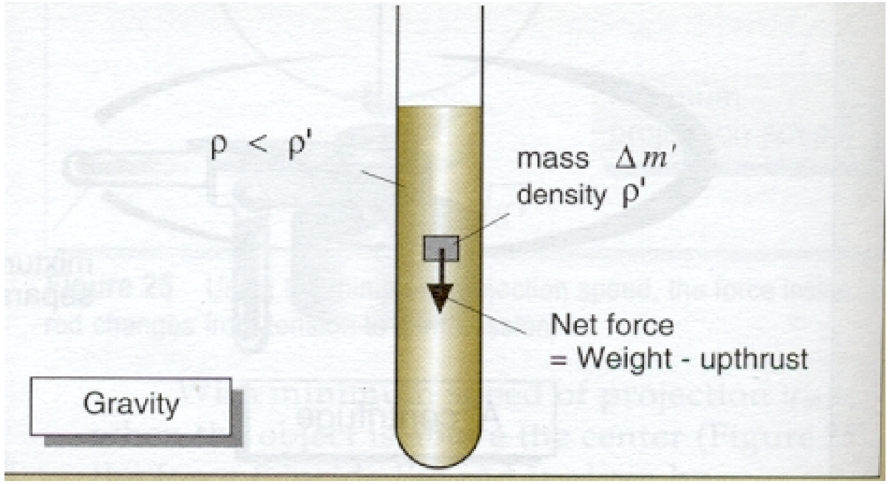

$F_C = \rho' r A \omega^2 \Delta r$

$F_{net} = \rho r A \omega^2 \Delta r$

Assume $\rho' > \rho$

Excess force for separation ΔF_c

$= (\rho' - \rho) r A \omega^2 \Delta r$

More about Circular Motion

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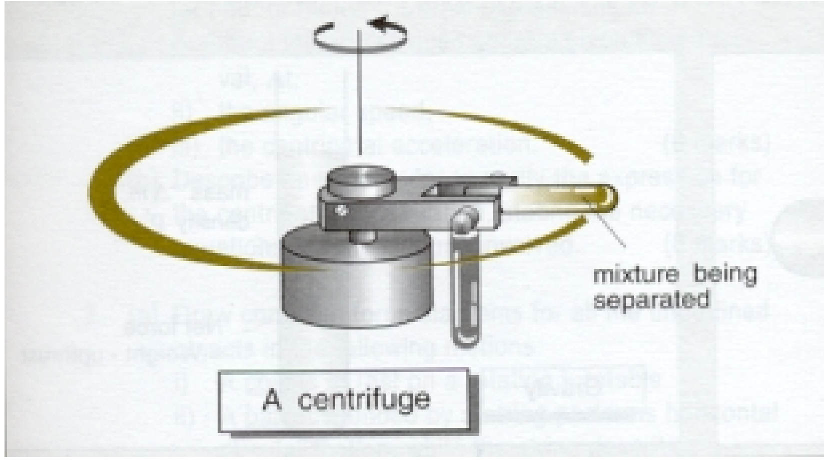
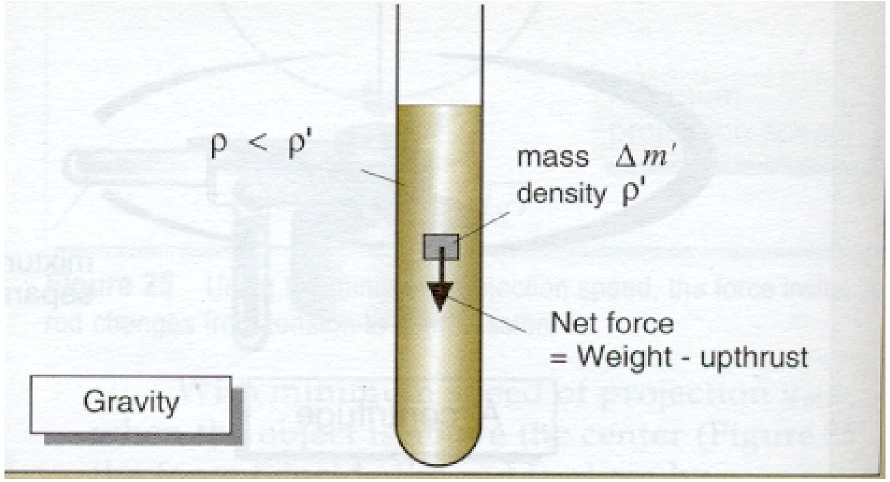




Excess force for separation ΔF_g
= weight - upthrust

$F_c = \rho' r A \omega^2 \Delta r$

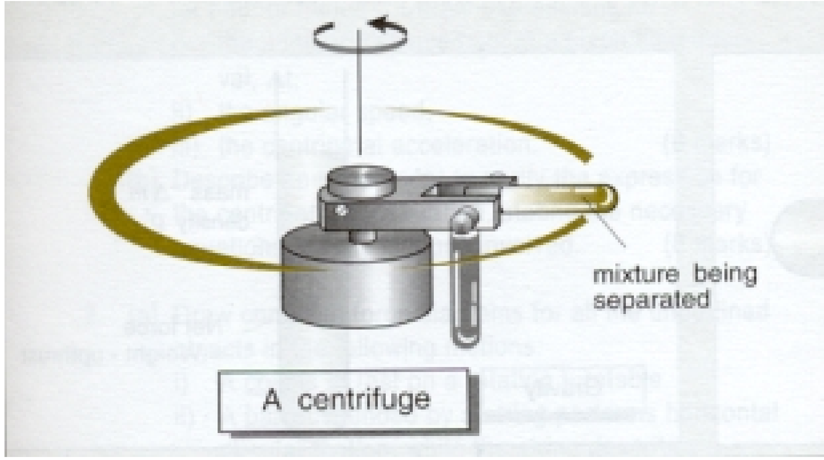
$F_{net} = \rho r A \omega^2 \Delta r$

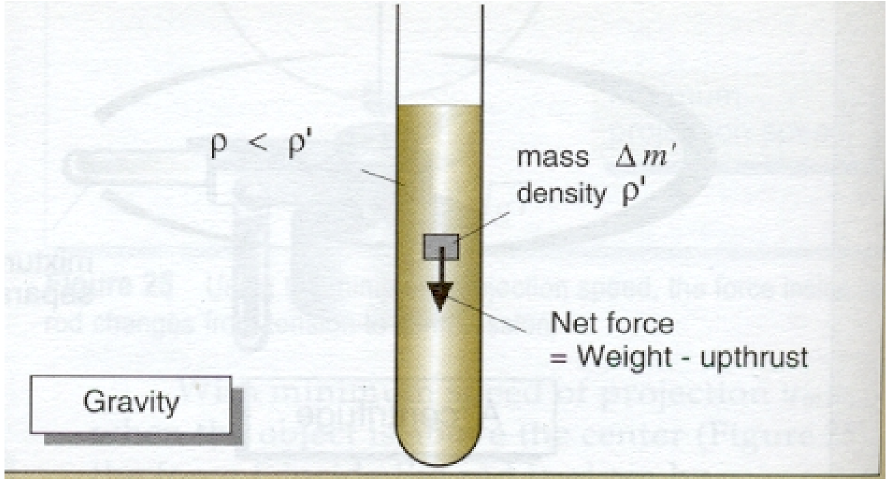
Assume $\rho' > \rho$

Excess force for separation ΔF_c
$= (\rho' - \rho) r A \omega^2 \Delta r$

More about Circular Motion

* Why centrifuge ?





$F_c = \rho' \, r \, A \, \omega^2 \Delta r$

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Assume $\rho' > \rho$

Excess force for separation ΔF_c

$= (\rho' - \rho) \, r \, A \, \omega^2 \Delta r$

Excess force for separation ΔF_g

= weight - upthrust

$= (\rho' A \Delta r g) - (\rho A \Delta r g)$

More about Circular Motion

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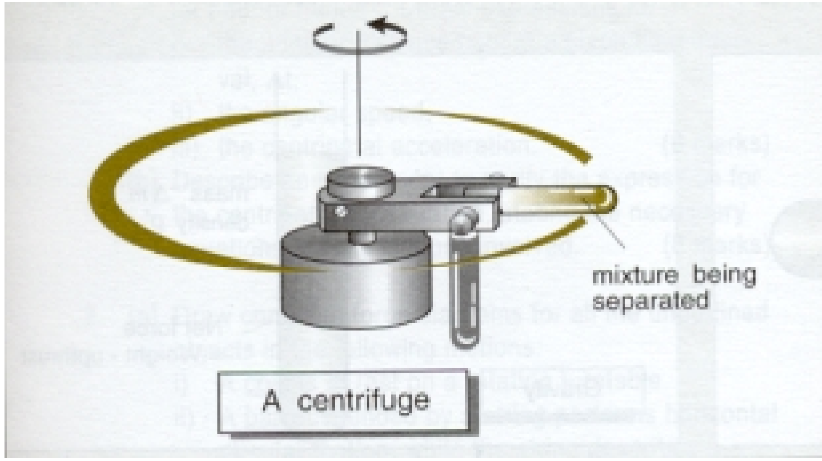

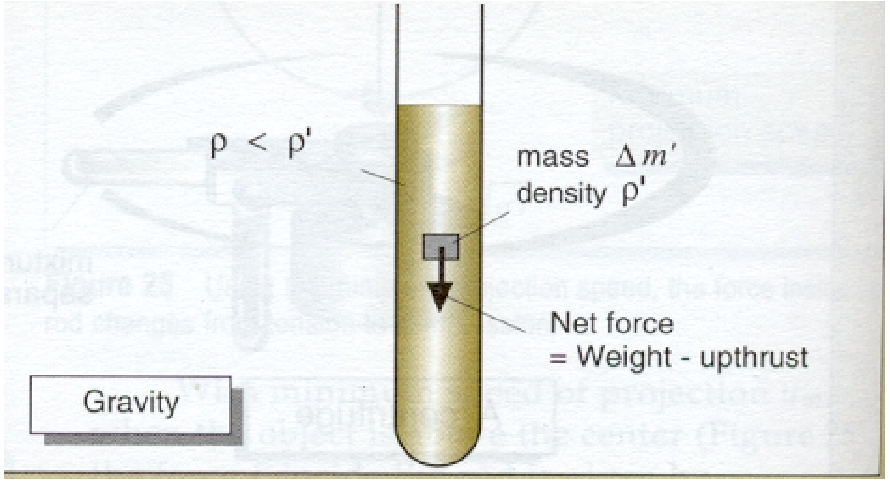

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Assume $\rho' > \rho$

Excess force for separation ΔF_c

$= (\rho' - \rho) \, r \, A \, \omega^2 \Delta r$

Excess force for separation ΔF_g

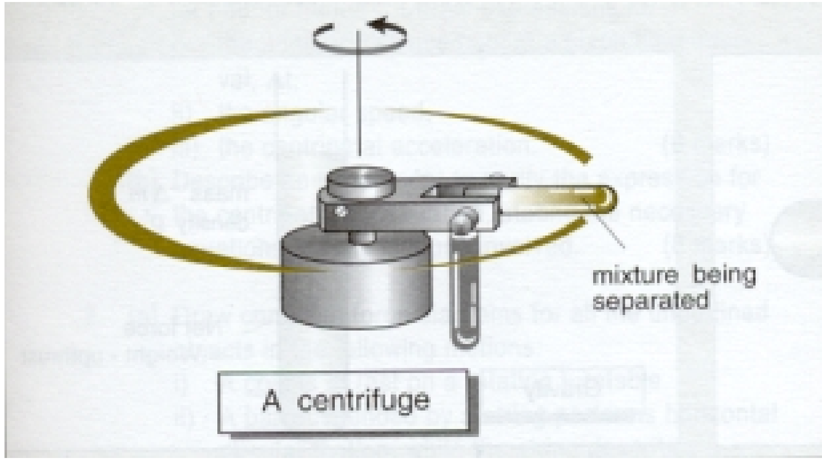
= weight - upthrust

$= (\rho' A \Delta r g) - (\rho A \Delta r g)$

$= (\rho' - \rho) A g \Delta r$

More about Circular Motion

* Why centrifuge ?



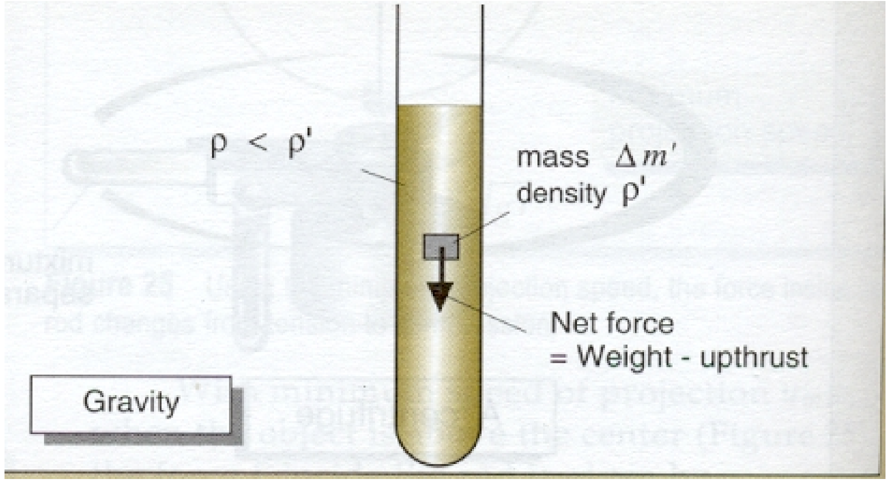
$F_C = \rho' r A \omega^2 \Delta r$

$F_{net} = \rho r A \omega^2 \Delta r$

Assume $\rho' > \rho$

Excess force for separation ΔF_c

$= (\rho' - \rho) r A \omega^2 \Delta r$



Excess force for separation ΔF_g

= weight - upthrust

$= (\rho' A \Delta r g) - (\rho A \Delta r g)$

$= (\rho' - \rho) A g \Delta r$

$$\frac{\Delta F_c}{\Delta F_g} = \frac{(\rho' - \rho) r \omega^2 A \Delta r}{(\rho' - \rho) A g \Delta r}$$

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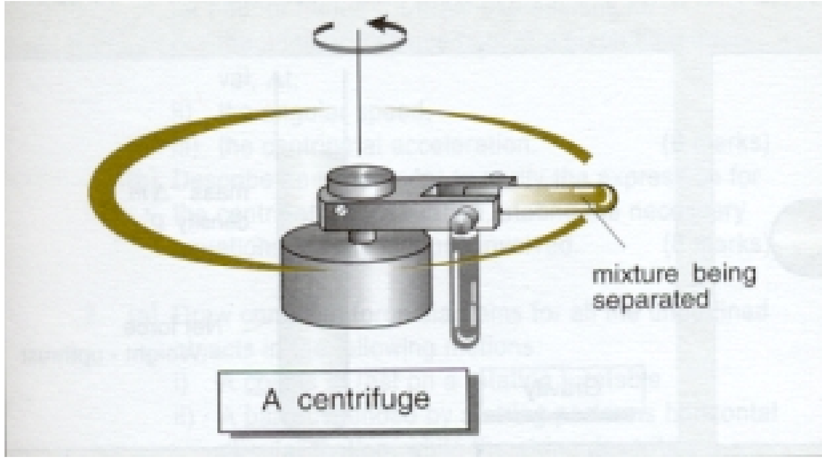

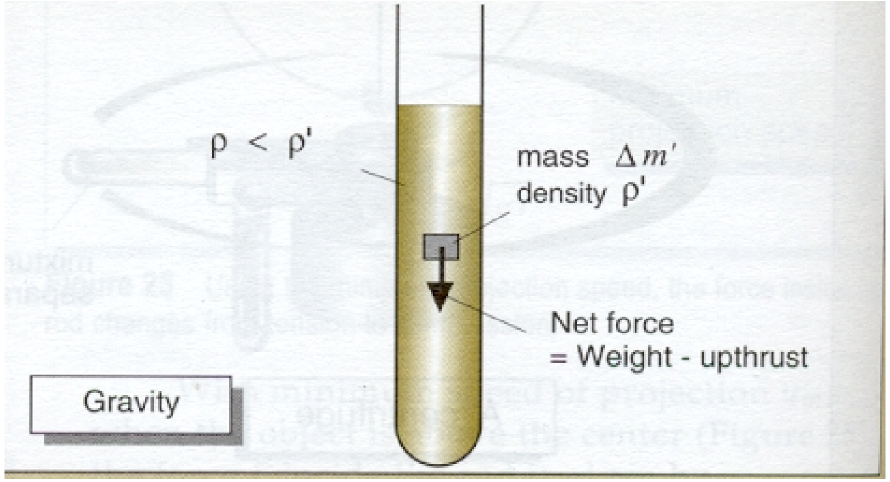

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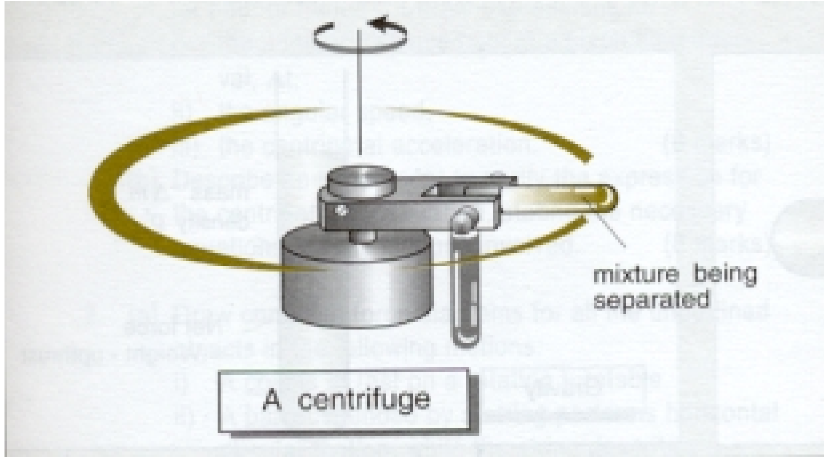

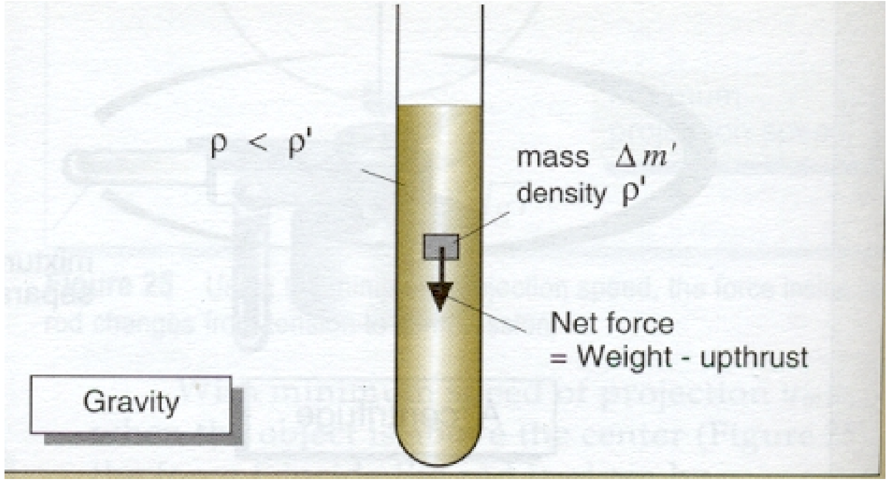

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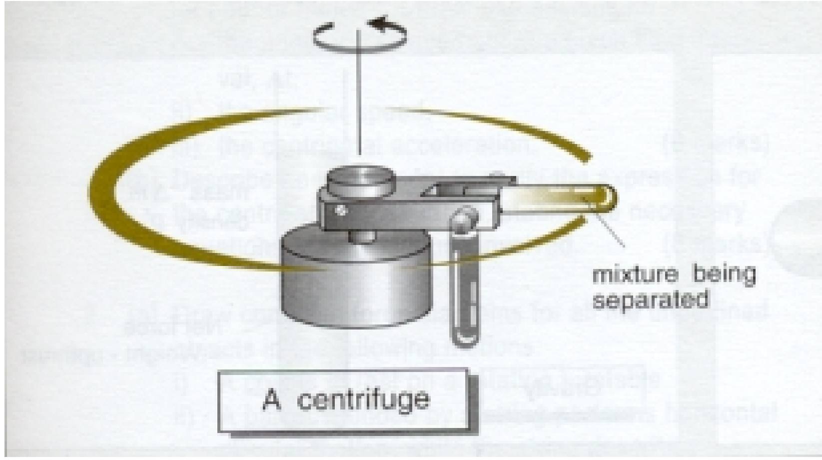

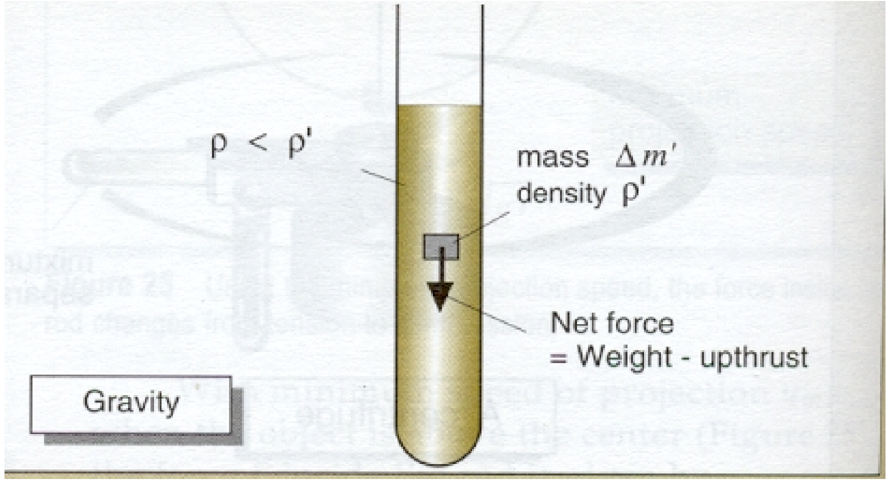

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$$\frac{\Delta F_c}{\Delta F_g} \sim 700 / 1$$