Lab 6 is in SCI 134

Please, login into webassing, locate LectureMCQ_L13 (PY105) and answer question 1 (**but ONLY Q1!**).

Pleas sign in using the sign-in sheets on the bench. Thank you

Note: exam room change:
Exams 2, 3 take place in STO B50

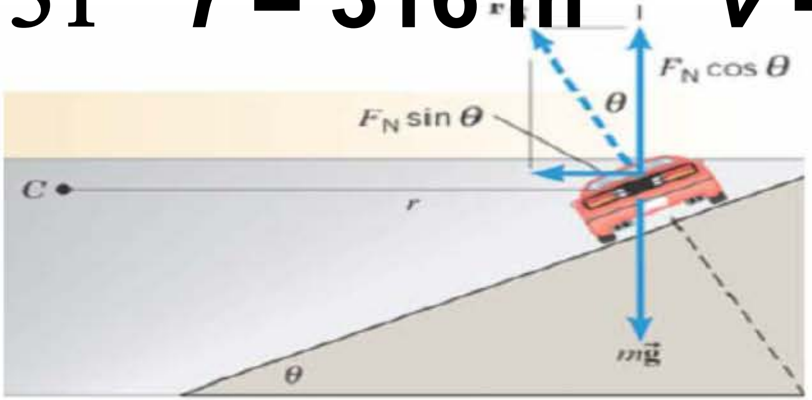
Good morning!

http://www.atlasobscura.com/articles/behind-the-strange-and-controversial-ritual-when-you-cross-the-equator-at-sea

Time to reflect upon the past and plan ahead!

Crossing into a new zone of the journey!

$\theta = 31^0$ $r = 316$ m $v = ?$



The turns at the Daytona International Speedway have a maximum radius of 316 m and are steely banked at 31°.

Suppose these turns were frictionless.

As what speed would the cars have to travel around them?

$$\boxed{\frac{mg}{F_N} = \cos\theta}$$

$$ma_c = F_N \sin\theta$$

Let's write the Newton's II law in the projection on the direction of the centripetal acceleration: $ma_c = F_N \sin\theta$, hence $mV^2/R = F_N \sin\theta$

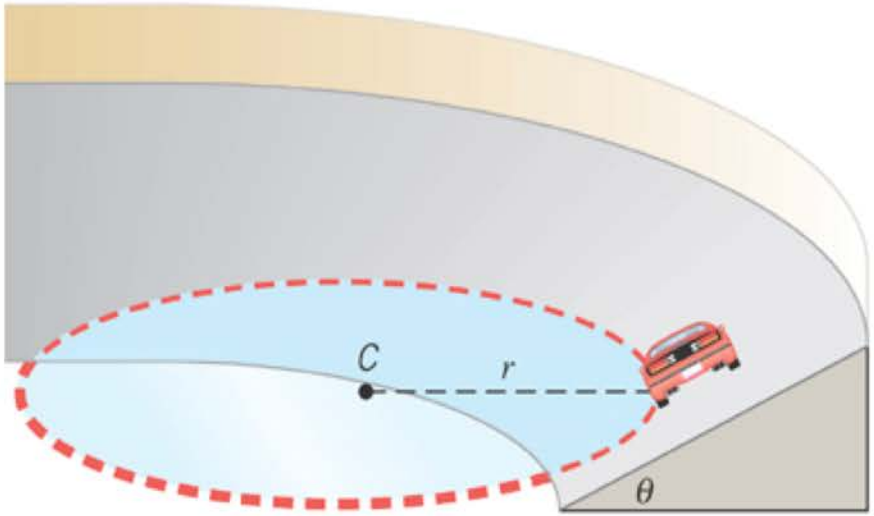
Now let's write the Newton's II law in the projection on the direction of the force of gravity: $m*0 = mg - F_N \cos\theta$

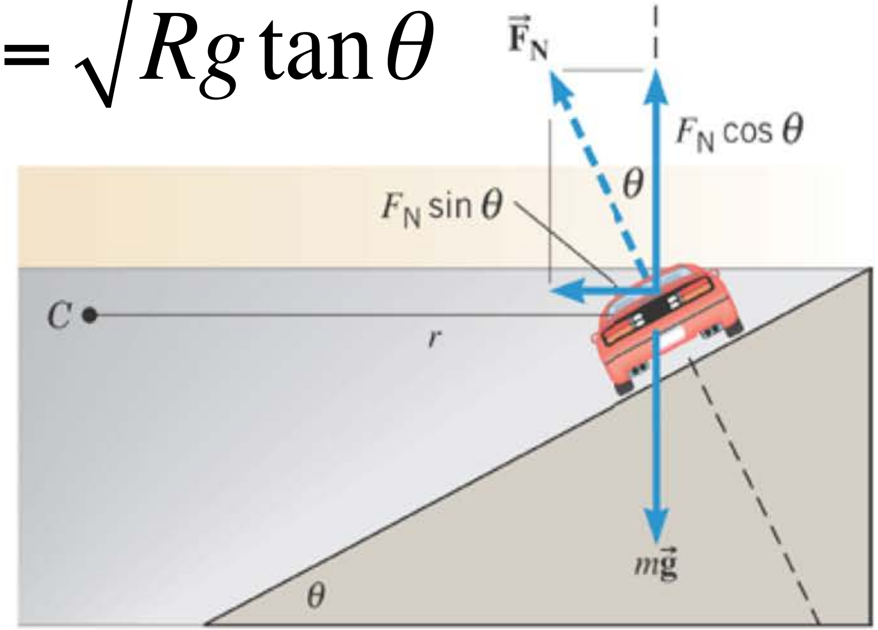
Now we can solve this system for the variable V.

$$V = \sqrt{\frac{RF_N \sin\theta}{m}} = \sqrt{\frac{gRF_N \sin\theta}{mg}} = \sqrt{\frac{gRF_N \sin\theta}{F_N \cos\theta}} = \sqrt{\frac{gR\sin\theta}{\cos\theta}} = \sqrt{Rg\tan\theta}$$ **= 43 m/s**

On a frictionless banked curve, the centripetal force is the horizontal component of the normal force. The vertical component of the normal force balances the car's weight

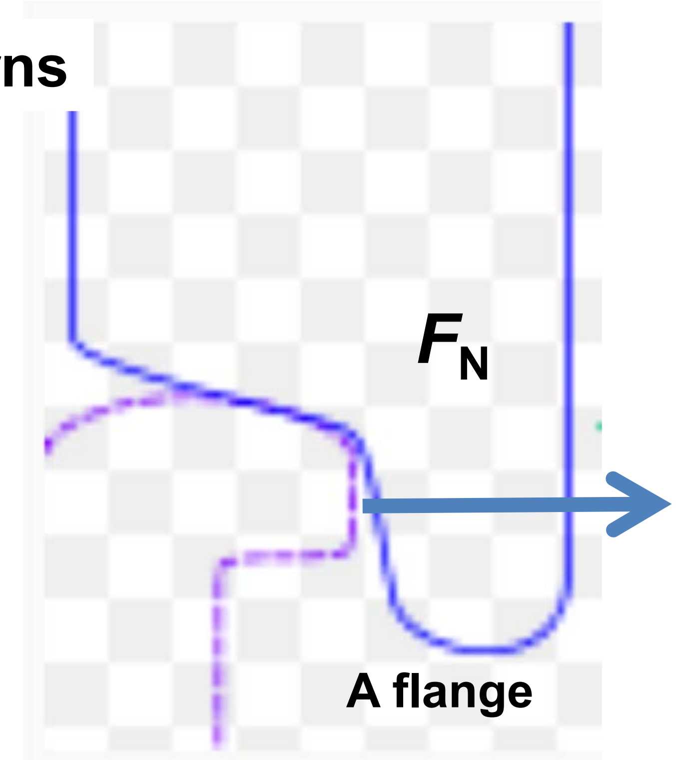
When the speed is *optimal* $v = \sqrt{Rg\tan\theta}$

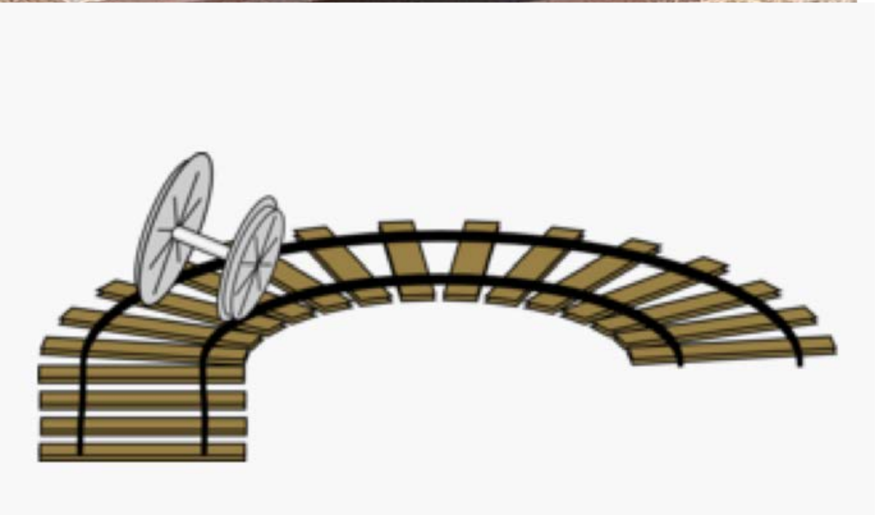




No friction is needed for moving with no sliding up or down!

Trains making turns





The road is *banked*!

There is an <u>optimal</u> speed!

Carnival ride

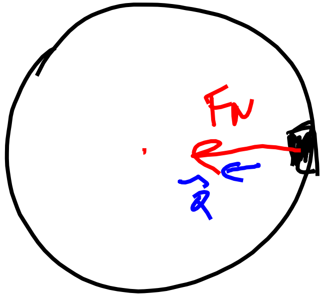
The simples case: In the horizontal ride people get spun so fast that fast that then the “floor” opens down no one slides down the ground.

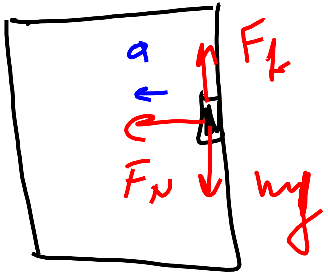
How does it work?

Carnival ride

$F_{fr} = mg$; $0 < F_{fr} < F_{max} = \mu \cdot F_N$

$F_N = m \cdot a_c = m \frac{v^2}{R}$; $v \downarrow \Rightarrow F_N \downarrow$





$F_{max\,fr} = mg$

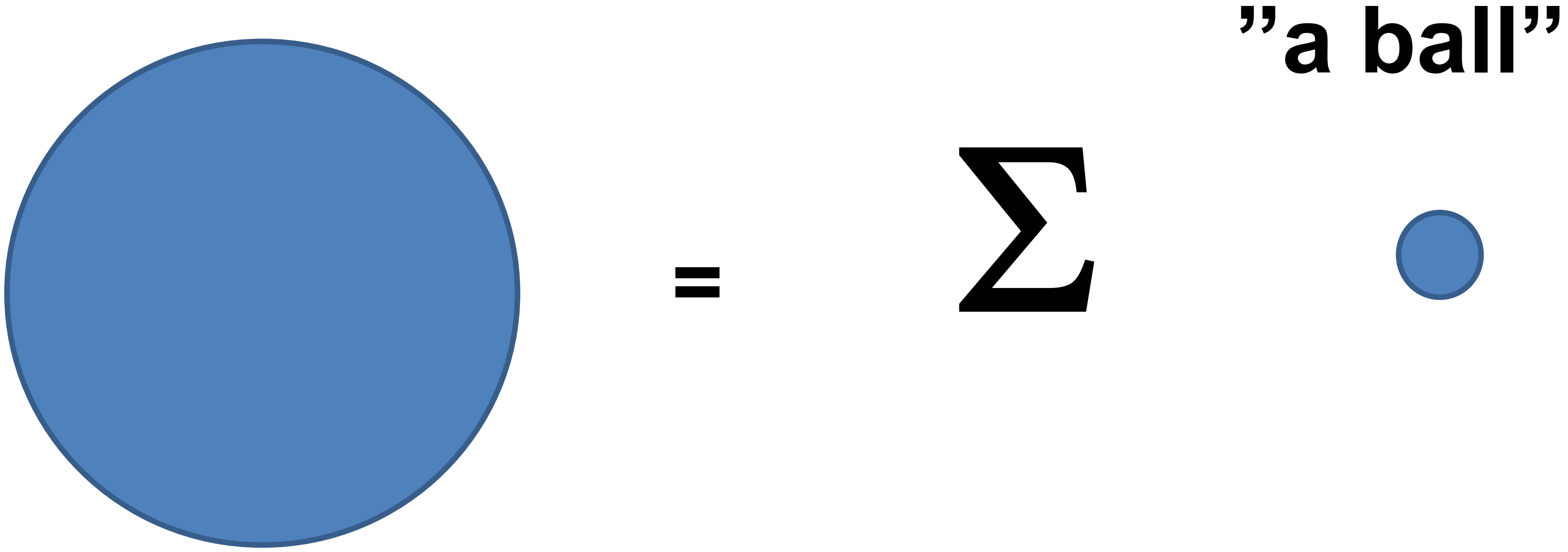
$\mu \cdot F_N = mg$

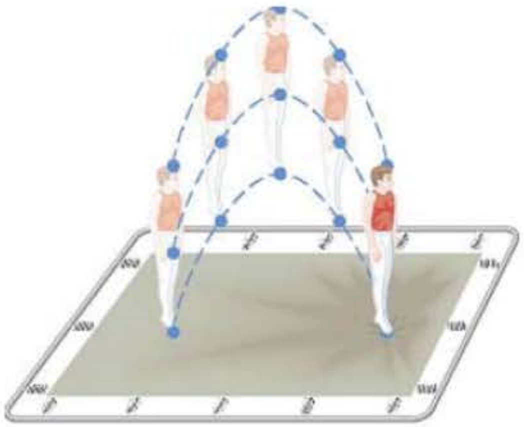
$\mu \cancel{m} \frac{v_c^2}{R} = \cancel{m} g \Rightarrow v_c = \sqrt{\frac{R \cdot g}{\mu}}$

The new topics (do not read this slide)

A solid object, rotational motion, axis of rotation, an arc, angular displacement, angular velocity, angular acceleration, degrees vs. radians, connections RM to LM, torque, lever arm, calculating torque, rotational inertia (RI), Newton's 1^{st} law for RM, Newton's 2^{nd} law for RM, static equilibrium, conditions for static equilibrium, solving problems on static equilibrium, Table of RI, parallel axis theorem, applications of Newton's laws for RM, Atwood's machine, angular momentum, rotational kinetic energy, rotational impulse, rotational work, work-kinetic energy theorem, rolling, rolling without slipping, special cases of rolling (a spool, racing objects), law of conservation of energy, law of conservation of angular momentum. ***(the last topic of test 2)***

”a disk”
(a.k.a. disc)

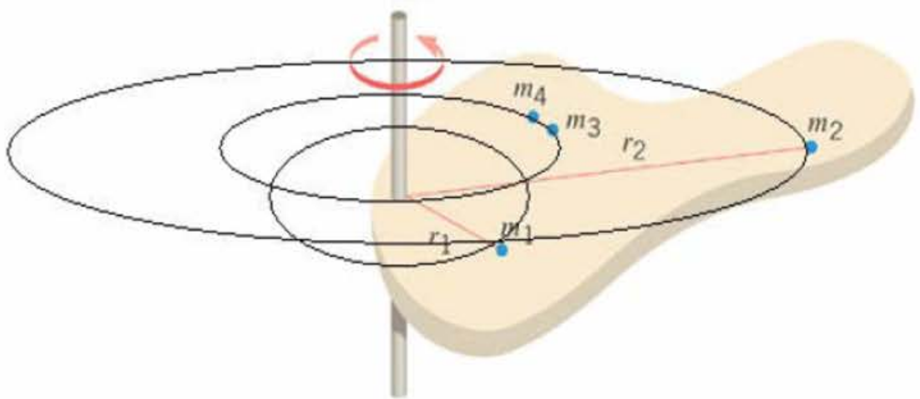



Translation

Translational Motion

In translational motion, all points on an object travel on parallel paths (the trajectories are alike).

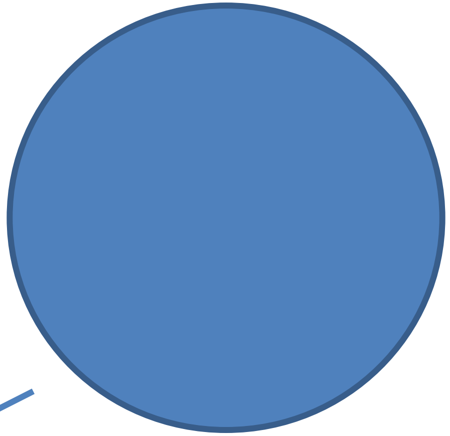
Rotational motion



In rotational motion, all points on an object travel on circular paths, and all the circle are parallel to each other and have the same axis of rotation.

”a ball”

rotation!



”a disk”
(a.k.a. disc)

A ***small*** object => ***Circular*** motion

A ***large*** object => ***Rotational*** motion

Grammarist

A "fun" fact

SPELLING

Disc vs. disk

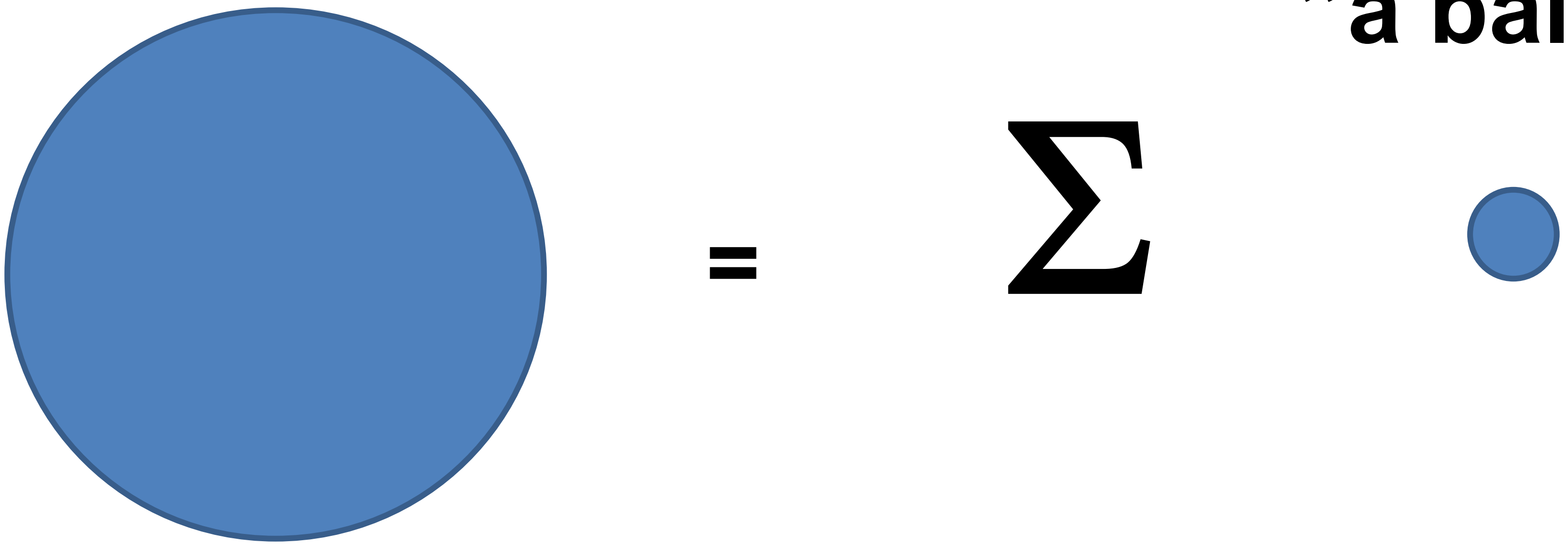
There is no consensus on the difference between ***disc*** and ***disk***, and in many contexts the two are used interchangeably. *Disk* is the standard spelling for computer-related terms such as *hard disk* and *floppy disk*. *Disc* is the standard spelling for phonograph records, albums (in the figurative sense—a group of songs presented in sequence), and components of plows and brake systems. But both spellings are commonly used for (1) CDs, DVDs, and other compact optical disks; (2) flat, plate-like bones; (3) flat, circular objects, and (4) disk-shaped celestial bodies. There are trends: *disc* is more common than *disk* for CDs, DVDs, etc. and plate-like bones, and *disk* is more common for disk-shaped things in outer space. But these trends are not so pronounced as to be conclusive.

”a disk”
(a.k.a. disc)

What to do if

$|V| \neq$ const

”a ball”

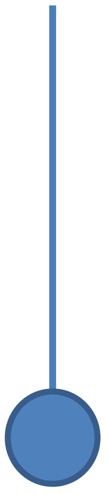


Circular motion with $|v| \neq$ const

Webassign: L13 Q2

A small object attached to a string is pushed once and slides on a table clockwise (as shown in the experiment). Its speed …

1. Does not change
2. Changes: the object slows down
3. Changes: the object speeds up



A small object attached to a string is pushed once and slides on a table clockwise. Its speed …

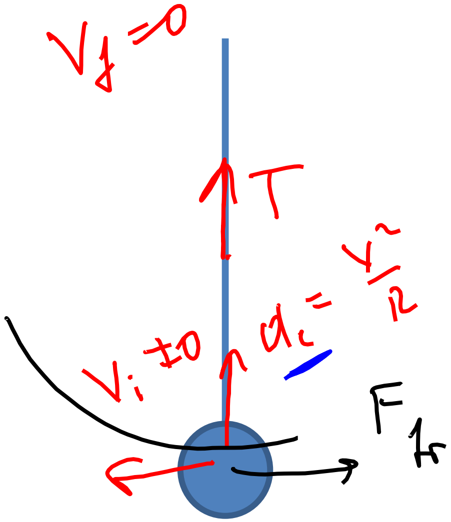
1. Does not change
2. Changes: the object slows down
3. Changes: the object speeds up

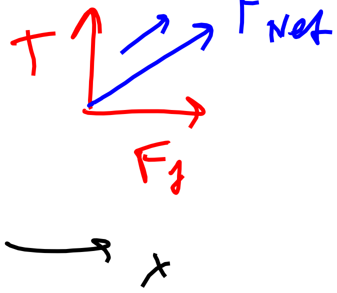
Webassign: L13 Q2

$F_{fr} = m \cdot a_x = m \cdot a_t$

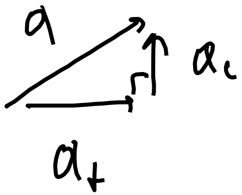
$v_i \neq 0$ to $v_f = 0$

$a_t = \frac{\Delta |v|}{\Delta t}$ $\to \Delta t \to 0$





$\vec{a} = \frac{\vec{F}_{net}}{m}$



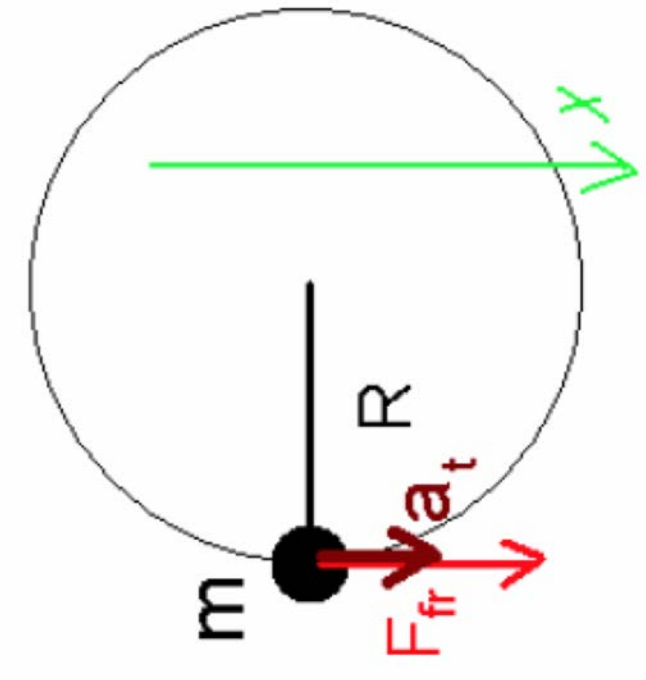
$a = \sqrt{a_t^2 + a_c^2}$

Circular motion with $|v| \neq$ const

A puck attached to a string is pushed once and slides on a table clockwise.

Its speed …

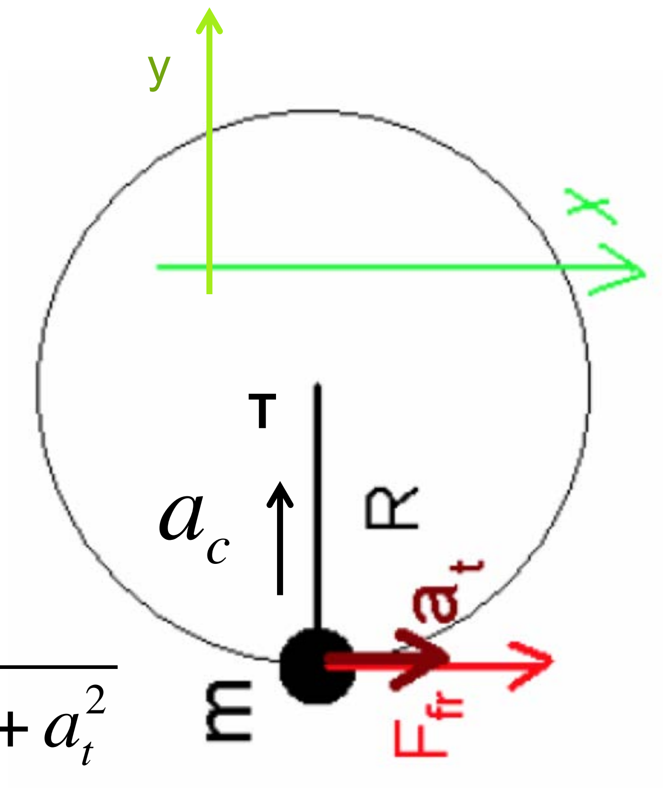
1. Does not change
2. Changes: the object slows down
3. Changes: the object speeds up



Circular motion with |*v*| ≠ const for a small object.

$$F_{fr} = ma_t \qquad T = ma_c$$

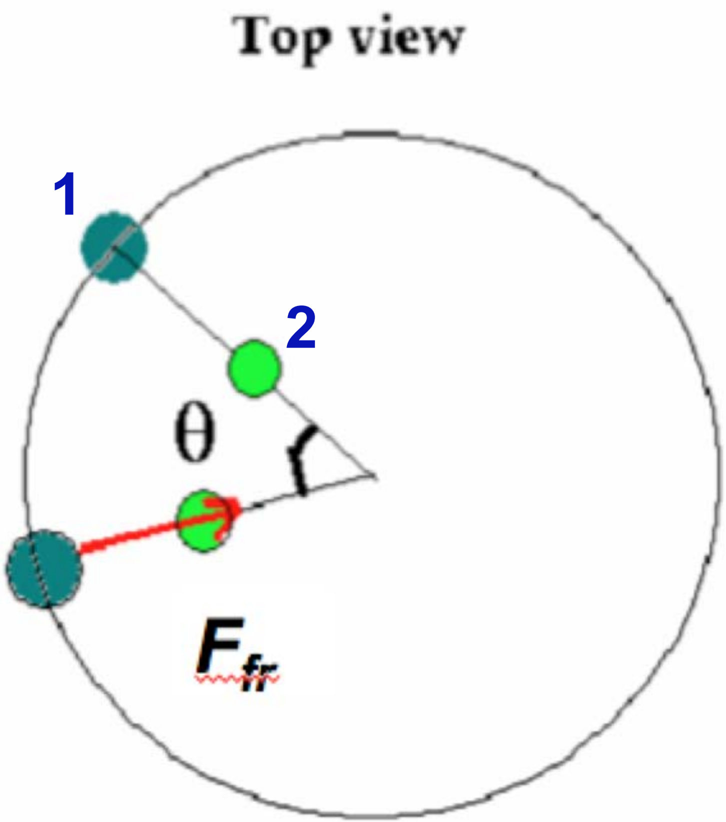
$$a_c = \frac{v^2}{R}$$



$$a = \sqrt{a_c^2 + a_t^2}$$

MCAT

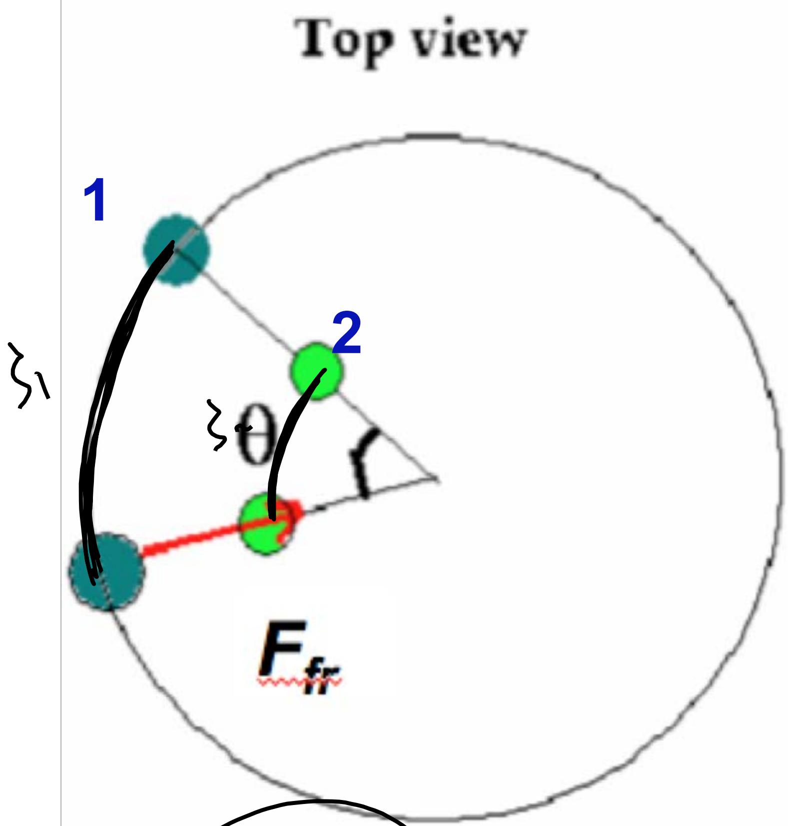
For ALL particles inside a disk the <u>equations</u> are the same.
But will the <u>parameters</u> be the same as well?



Two small identical masses are placed on rotating table. When the table was turned ***which mass traveled longer distance*****?**

[Webassign: L13 Q3]

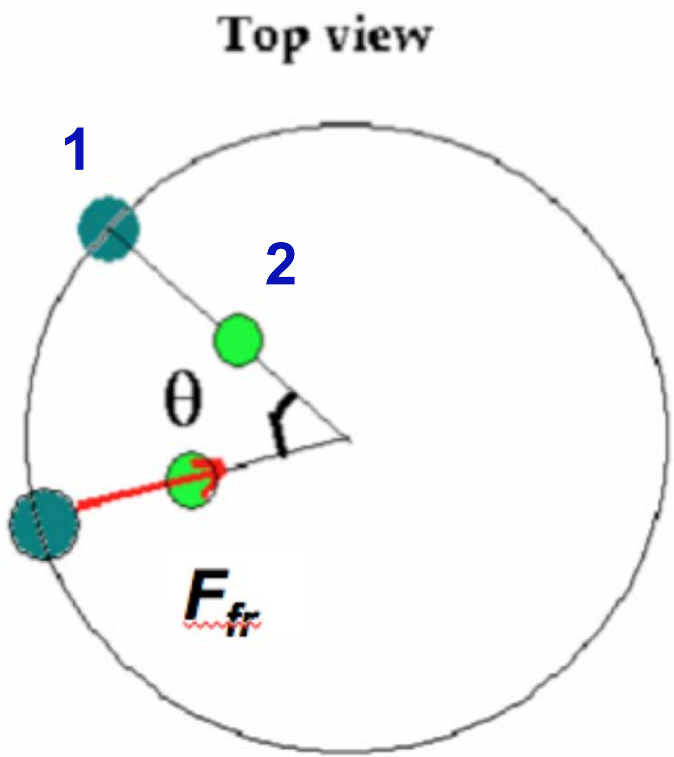
1. **2.** **3. the distance is the same**



$s_1 > s_2$

Two small identical masses are placed on rotating table. When the table was turned *which mass traveled longer distance*?

1. ~~**2.**~~ ~~**3. the distance is the same**~~



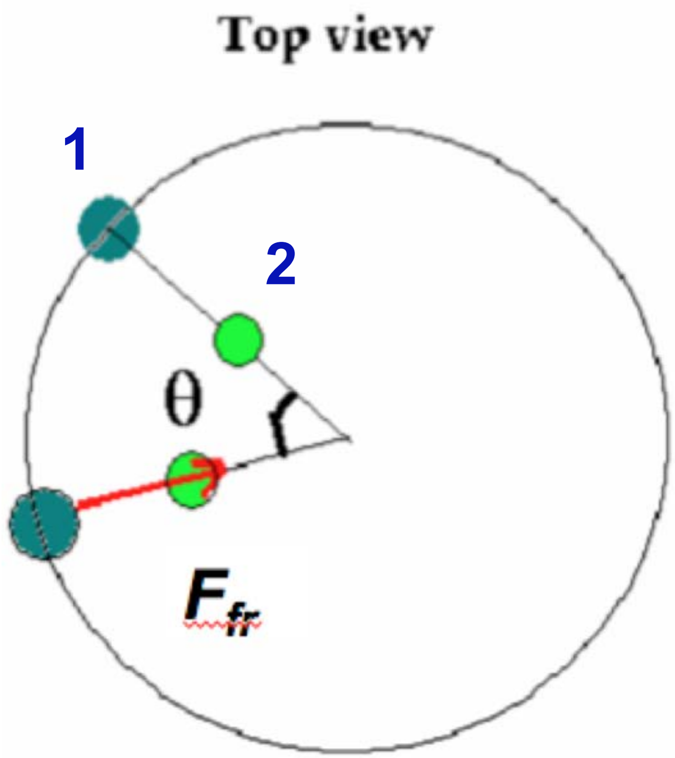
$$T = ma_c$$

$$F_{fr} = ma_t$$

$$a_c = \frac{v^2}{R}$$

Different points in a disk travel different distance, have different speed, …

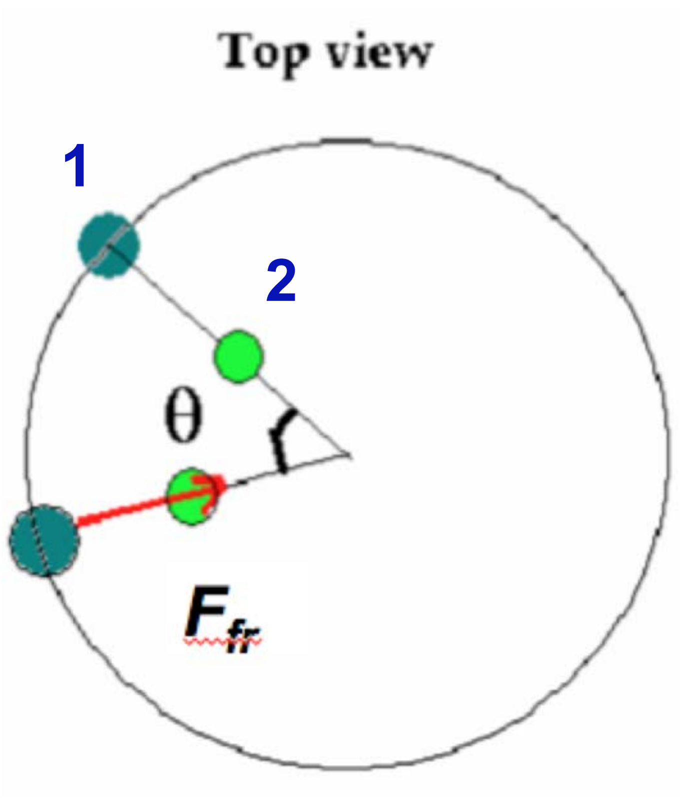
Is there *something* <u>the same</u> for both??



Different points in a disk travel different distance, have different speed, …

Is there *anything* <u>the same</u> for both??

The Angle!



Different points in a disk travel different distance, have different speed, …

Is there *anything* <u>the same</u> for both??

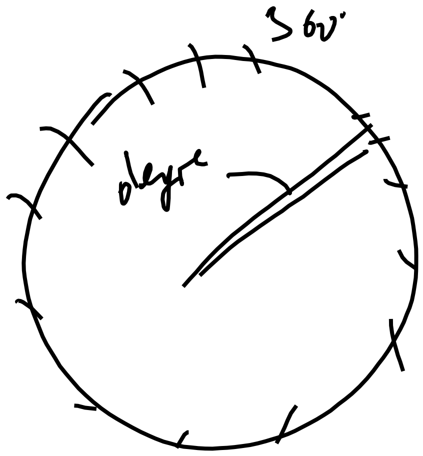
The Angle!

From S, v, a to equivalent <u>angular</u> variables

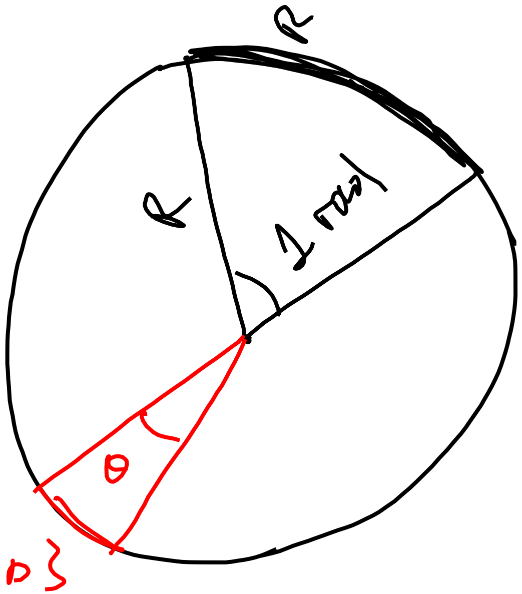
Kinematics of circular motion

A measure of angular displacement

The definition of Radians !!



rad



$$\Delta\theta_{(rad)} = \frac{\Delta s}{R}$$

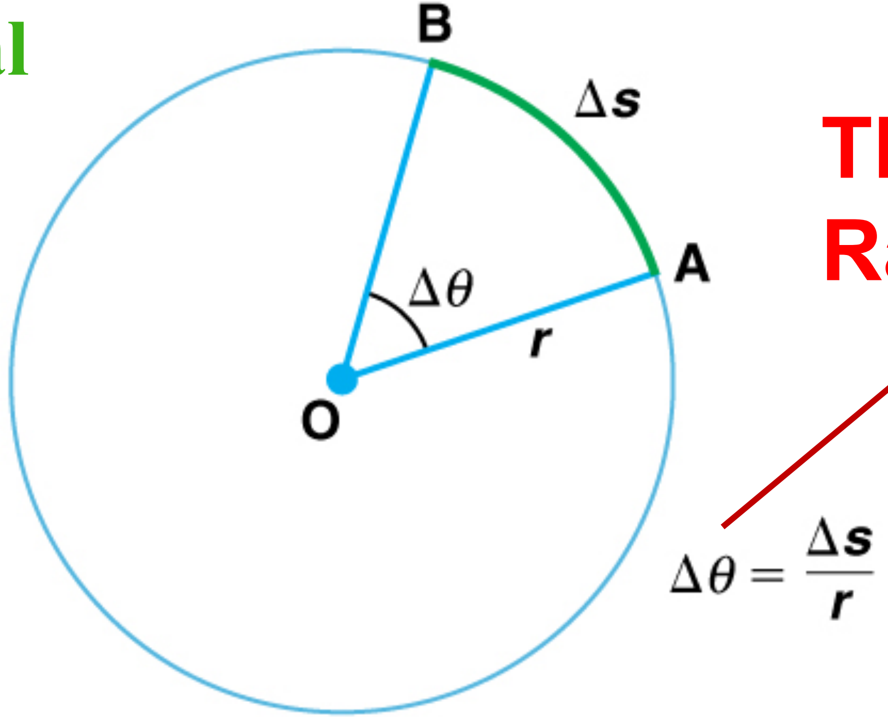
π rad = 180°

Kinematics of circular motion

$1\ \text{rev} = 2\pi\ \text{rad} = 360^0$

The fundamental connection between linear and angular variables.

$$\boxed{\Delta\theta = \Delta s/r}$$

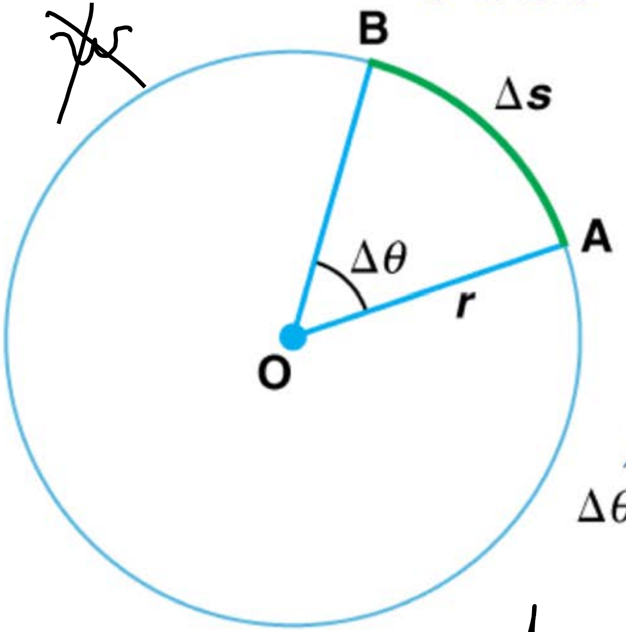


The definition of Radians !!

r **is the radius of a circle; an object is rotated through an angle $\Delta\theta$. The arc length Δs is a part of the circumference.**

1 rev = 2π rad = 360^0

For a *uniform* circular motion:



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

Radians !!

$$\boxed{\Delta\theta = \Delta s/r}$$

$|v|$ = const

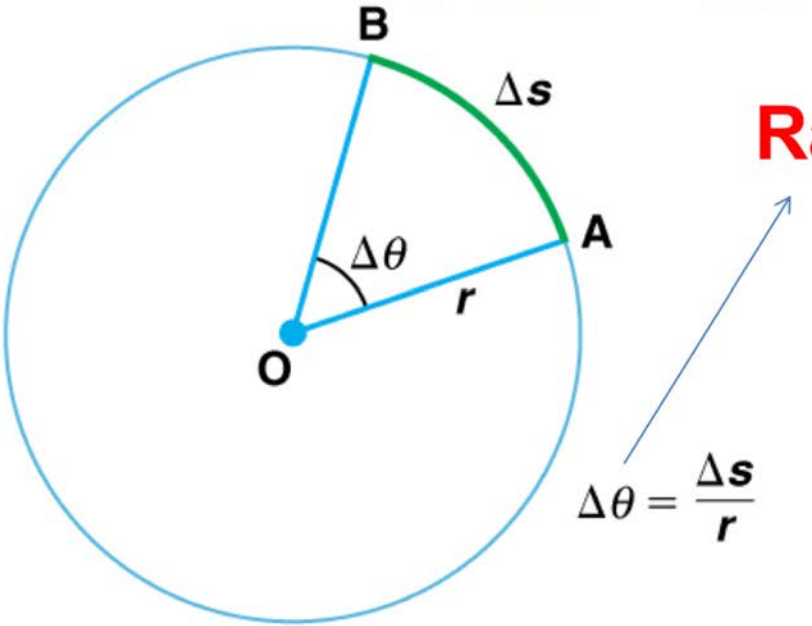
Period $T = \frac{t}{N} = \frac{1}{f}$

Frequency $f = \frac{N}{t} = \frac{1}{T}$

Speed $v = \frac{\Delta s}{\Delta t}$

***Angular* Speed** $\omega = \frac{\Delta\theta}{\Delta t} = \frac{\Delta s}{r\Delta t} = \frac{v}{r}$

1 rev = 2π rad = 360^0



Radians !!

For a *uniform* circular motion:

$|v|$ = const

Period = time to complete one revolution;

$T = t/N$

$\Delta\theta = \Delta s/r$

Frequency = number of revolutions per 1 s;

$f = n = \nu = N/t = 1/T$

Speed (a.k.a. *linear* speed) $v = S/t = 2\pi r/T = 2\pi r f$

***Angular* Speed** $\omega = \theta/t = 2\pi/T = 2\pi f = v/r$

RHR = "right-hand rule"

Directions for angular variables

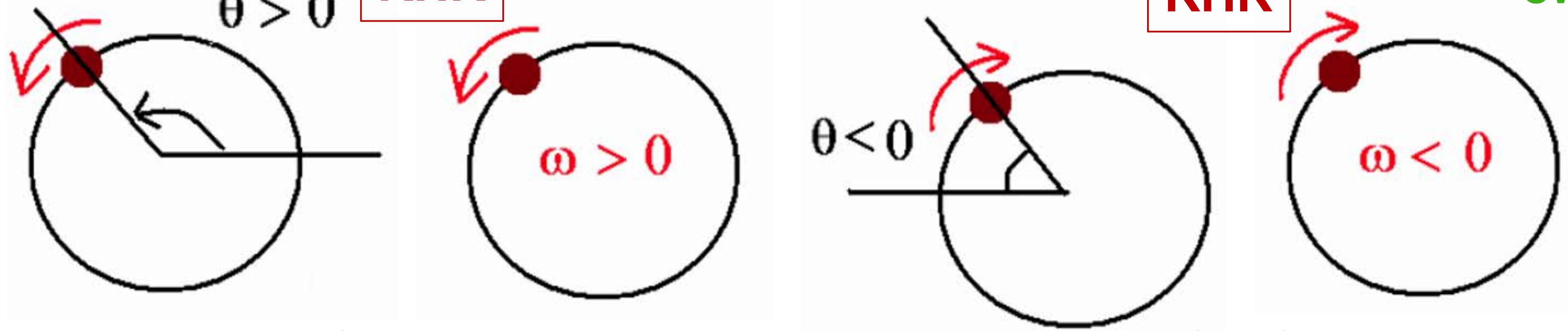
Standard choice(a.k.a. a definition)

CCW

RHR

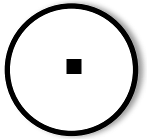
RHR

CW



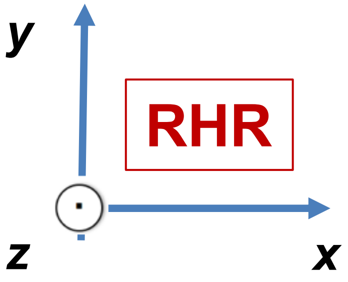
Relative to US, watching this motion, seeing the CIRCLE!

To us (from the screen)



"out"

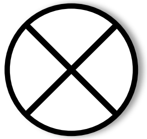
"positive"



RHR

From us (in the screen)

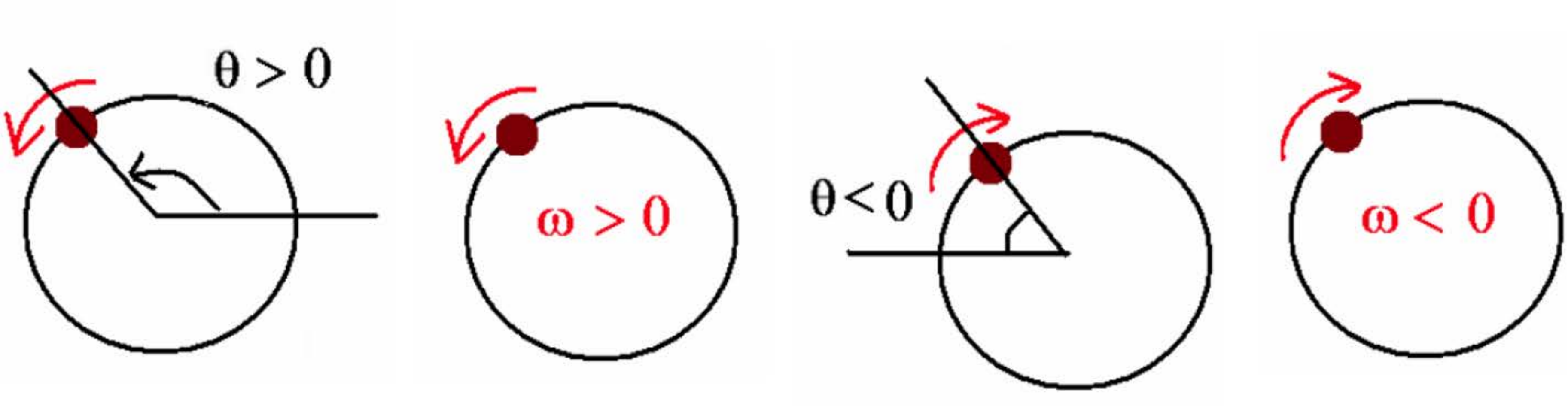
"into"



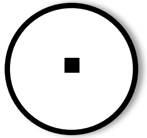
"negative"

Directions for angular variables

Standard choice

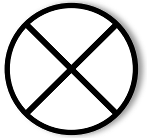


To us (from the screen) **From us (in the screen)**



“out”

“into”



When $|\omega| \uparrow$ (speeding up), $\alpha \uparrow\uparrow \omega$

When $|\omega| \downarrow$ (slowing down), $\alpha \uparrow\downarrow \omega$

Kinematics of a *uniform* circular motion:

Top view

π rad = 180^0

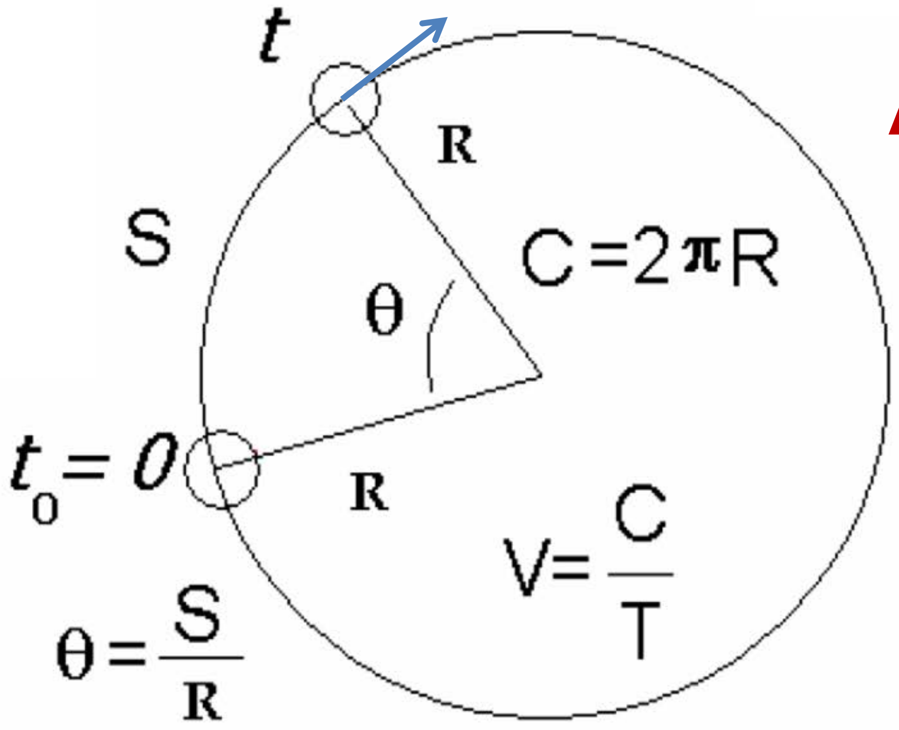
$\Delta\theta = \Delta s/r$

$|v|$ = const

"CCW" > 0

"CW" < 0

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



t/N = T period

N/t = n frequency

n = 1/T

V = 2πr/T

$$S = Vt \qquad \theta = \frac{S}{R} = \frac{Vt}{R} = \frac{V}{R}t = \omega t \qquad \text{where} \qquad \omega = \frac{V}{R} \text{ is angular velocity}$$

angular velocity is a rate of the change of angular displacement

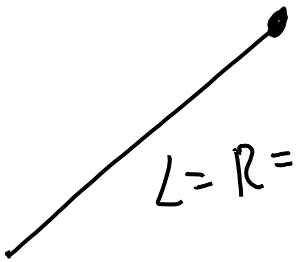
$$1 \text{ rev} = 2\pi \text{ rad} = 360^0$$

A 50 g ball is attached to a string and movies in UCM. It takes 2 s for the ball to make 3 whole revolutions. If the string is 50 cm long, find … everything!

A 50 g ball is attached to a string and movies in UCM. It takes 2 s for the ball to make 3 whole revolutions. If the string is 50 cm long, find everything!

$|v| = \text{const}$

$a_t = \phi$



$m = 0.05\,kg$

$L = R = 0.5\,m$

$N = 3_{rev} \qquad t = 2\,s$

$T = \frac{t}{N} = \frac{2}{3}\,\frac{s}{rev} = \frac{2}{3}\,s$

$n = \nu = f = \frac{N}{t} = \frac{1}{T} = \frac{3}{2} = 1.5\,\frac{1}{s} = 1.5\,s^{-1} = 1.5\,Hz$

$v = \frac{s}{t} = \frac{3 \cdot C}{2} = \frac{3 \cdot 2 \cdot \pi \cdot r}{2}$

$\omega = \frac{v}{r}$ or $\omega = \frac{\theta}{t} = \frac{3 \cdot 2 \cdot \pi}{2}\,\frac{rad}{s}$; $a_c = \frac{v^2}{R} = \frac{(\omega \cdot r)^2}{r} = \omega^2 \cdot r$

$F_T = \cancel{a}\ m \cdot a_c$

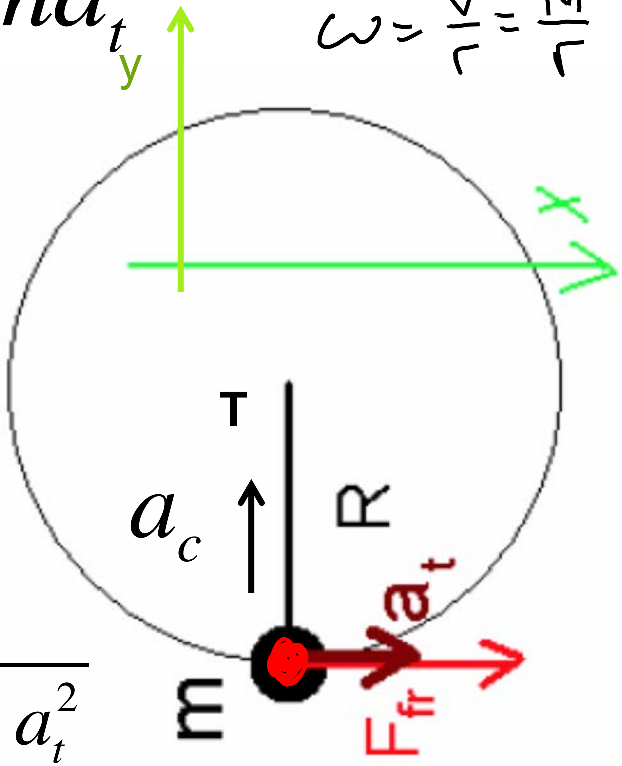
Circular motion with $|v| \neq$ const for a small object => rewritten in <u>angular</u> variables.

$$F_{fr} = ma_t$$

$$a_c = \frac{v^2}{R}$$

$$T = ma_c$$

$$a = \sqrt{a_c^2 + a_t^2}$$



$\Delta\theta = \Delta s/r$

$\omega = \frac{v}{r} = \frac{|v|}{r}$

$\omega = \frac{\Delta\theta}{\Delta t}$; $\alpha = \frac{\Delta\omega}{\Delta t} = \varepsilon$ $\qquad \Delta t \to 0$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\Delta\frac{|v|}{r}}{\Delta t} = \frac{1}{r}\frac{\Delta|v|}{\Delta t} = \frac{a_t}{r}$$

MCAT

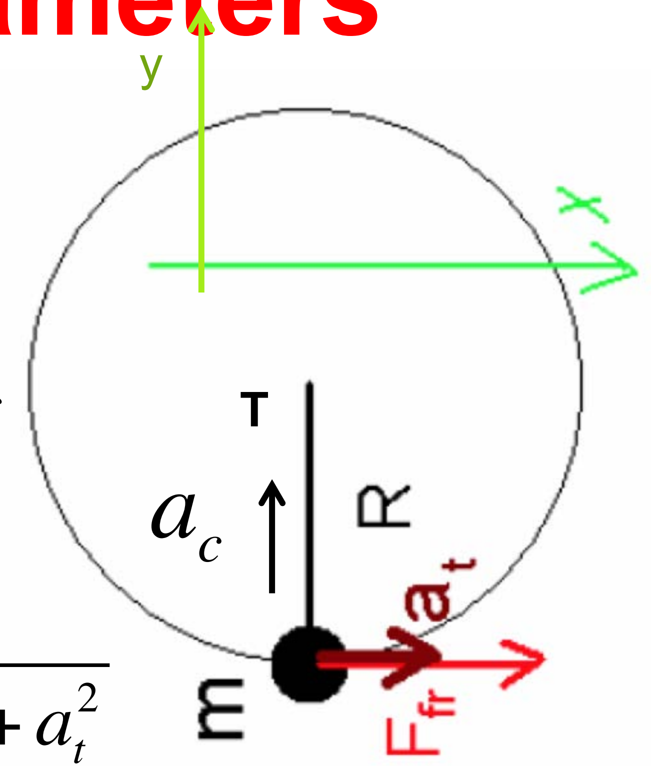
Circular motion with |*v*| ≠ const for a small object in terms of angular parameters

$$\omega = v / r$$

$$a_c = \frac{v^2}{R}$$

$$T = ma_c$$

$$a = \sqrt{a_c^2 + a_t^2}$$



$$F_{fr} = ma_t$$

$$\boxed{\frac{a_t}{r} = \alpha}$$

$$F_{fr} = m\alpha r$$

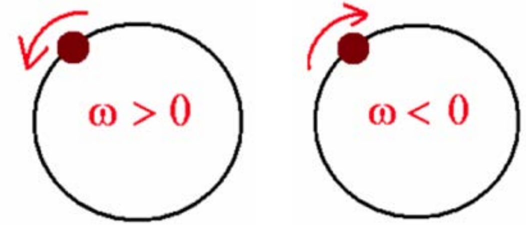
$$F_{fr} r = m\alpha r^2 = \boldsymbol{mr^2\alpha}$$

Because of …

$$\boldsymbol{\tau = I\alpha} \rightarrow \textbf{The same for ALL points!}$$

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions. **Webassign: L13_Q4**

During the 2nd revolution, the motion of a small red spot at the rim of the turntable is



1. **A uniform circular motion (UCM)**
2. **Not a uniform circular motion (non-UCM)**

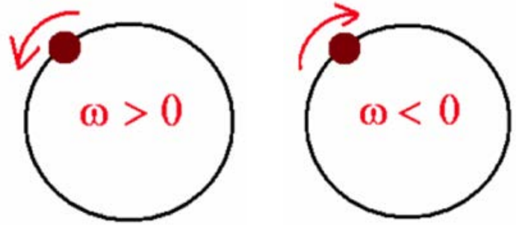
Webassign: L13_Q5

The angular *acceleration* of the turntable is …

1. Zero 2. CCW("+") 3. CW("-") 4. Centripetal

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions. **Webassign: L13_Q4**

During the 2nd revolution, the motion of a small red spot at the rim of the turntable is



1. A uniform circular motion (UCM)
2. Not a uniform circular motion (non-UCM)

$\omega_0 = 5\ \frac{rad}{s}$ .... $\omega_f = 0$

$\omega \downarrow \Rightarrow |v| \downarrow \Rightarrow$ Non-UCM

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions.

Speed went from NOT-0 to 0 => changed!

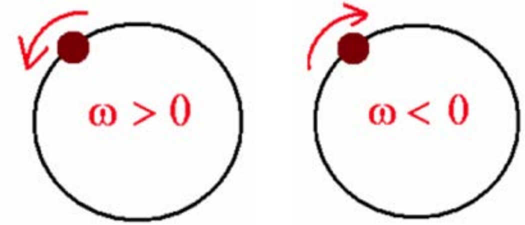
During the 2nd revolution, the motion of a small red spot at the rim of the turntable is

1. ~~A uniform circular motion (UCM)~~
2. Not a uniform circular motion (non-UCM)

$|V| \neq const$

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions.

During the 2nd revolution, the motion of a small red spot at the rim of the turntable is



1. A uniform circular motion (UCM)
2. Not a uniform circular motion (non-UCM)

Webassign: L13 Q5

The angular *acceleration* of the turntable is …

1. Zero   2. CCW(“+”)   3. CW(“-”)   4. Centripetal

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions.

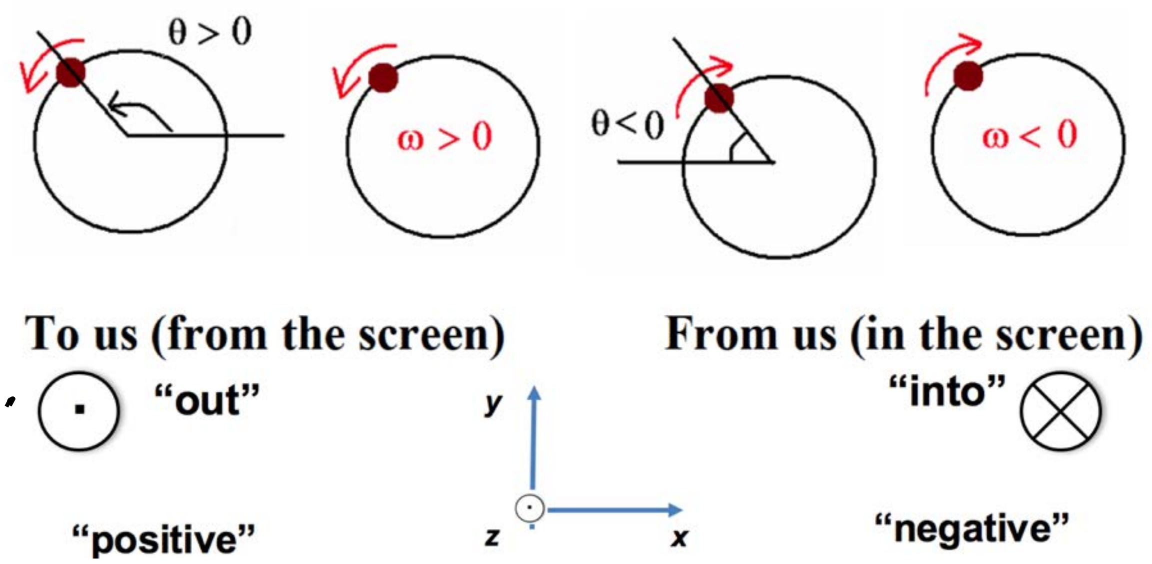
The angular *acceleration* of the turntable is …

ω "ccw" "+"

$\omega \downarrow$

$\Downarrow$

$\alpha \uparrow\downarrow \omega \Rightarrow$ "cw" $\Rightarrow$ "-"

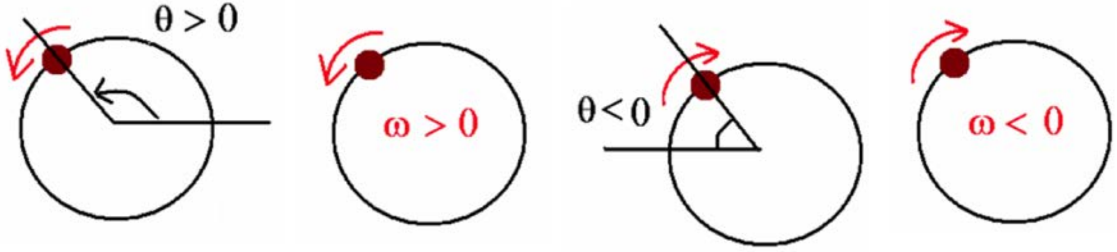


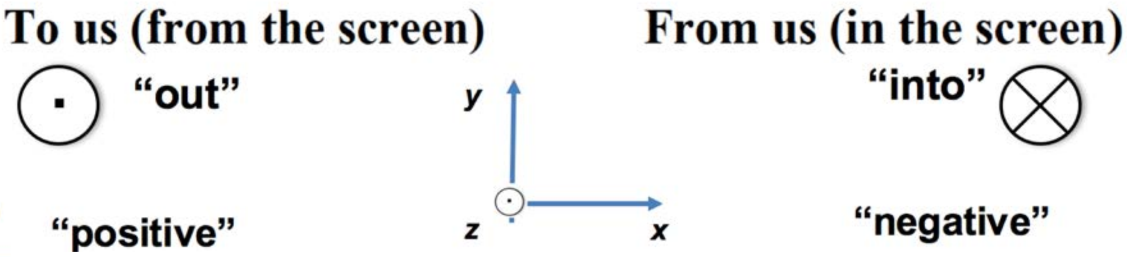
You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW).

Then it stopped after making 3 revolutions.

The angular *acceleration* of the turntable is …

1. Zero
2. CCW (i.e. "+")
3. CW (i.e. "-")
4. Centripetal





When $|\omega| \uparrow$ (speeding up), $\alpha \uparrow\uparrow \omega$

When $|\omega| \downarrow$ (slowing down), $\alpha \uparrow\downarrow \omega$

You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions.

Find ………………………… Everything

BTW: Mathematically equivalent!

You pushed a box with initial speed of 5 m/s and it stopped after traveling 3 m.

Analogies for constant angular acceleration situations

α = const

$\Delta\theta = \Delta s / r$

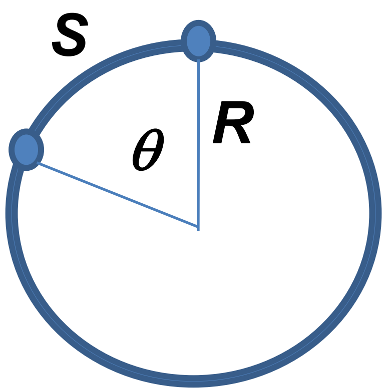
"Straight-line" motion	Rotational motion
$v = v_o + a_l t$	$\omega = \omega_o + \alpha t$
$s = v_o t + \frac{1}{2} a_l t^2$	$\theta - \theta_o = \omega_o t + \frac{1}{2} \alpha t^2$ or $(\theta_o = 0)$ $\theta = \omega_o t + \frac{1}{2} \alpha t^2$
$v^2 = v_o^2 + 2 a_l s$	$\omega^2 = \omega_o^2 + 2 \alpha (\theta - \theta_o)$ or $(\theta_o = 0)$ $\omega^2 = \omega_o^2 + 2 \alpha \theta$

(we can set $\theta_o = 0$ for almost all problems!)

$$\text{"Rot"} = \frac{\text{"Lin"}}{R}$$

$$\theta = \frac{S}{R} \qquad \omega = \frac{V}{R}$$

$$\alpha = a_l / R$$



You brought a turntable into a motion by giving to it an initial angular velocity of 5 rad/s, counterclockwise (CCW). Then it stopped after making 3 revolutions. Calculate the angular acceleration of the turntable, and how much time was it moving.

A MCA (angular MCA)

$$\omega^2 = \omega_o^2 + 2\,\alpha\,\theta$$

$0 \qquad 5\,\frac{rad}{s} \rightarrow rad$

$$|\theta| = 3\,rev = 3 \cdot 2 \cdot \pi = 6\pi\ rad$$

$$0 = 5^2 + 2 \cdot \alpha \cdot 6\pi$$

$$\alpha = -\frac{25}{12 \cdot \pi}\ \frac{rad}{s^2}$$

$$\alpha = \frac{\omega - \omega_0}{t}$$

$$-\frac{25}{12 \cdot \pi} = \frac{0 - 5}{t}$$

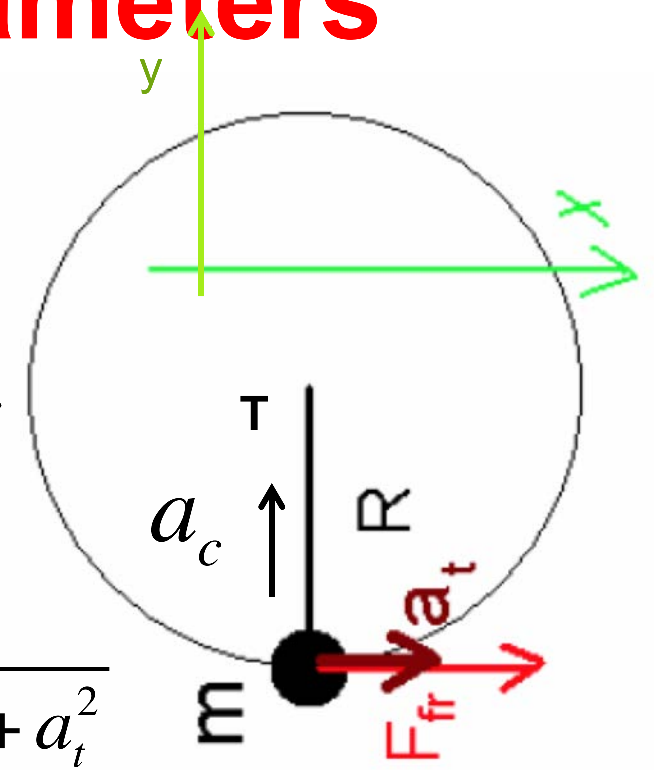
Circular motion with $|v| \neq$ const for a small object in terms of angular parameters

$$\omega = v / r$$

$$a_c = \frac{v^2}{R}$$

$$T = m a_c$$

$$a = \sqrt{a_c^2 + a_t^2}$$



$$F_{fr} = m a_t$$

$$\boxed{\frac{a_t}{r} = \alpha}$$

$$F_{fr} = m \alpha r$$

$$F_{fr} r = m \alpha r^2 = \boldsymbol{m r^2 \alpha}$$

Because of …

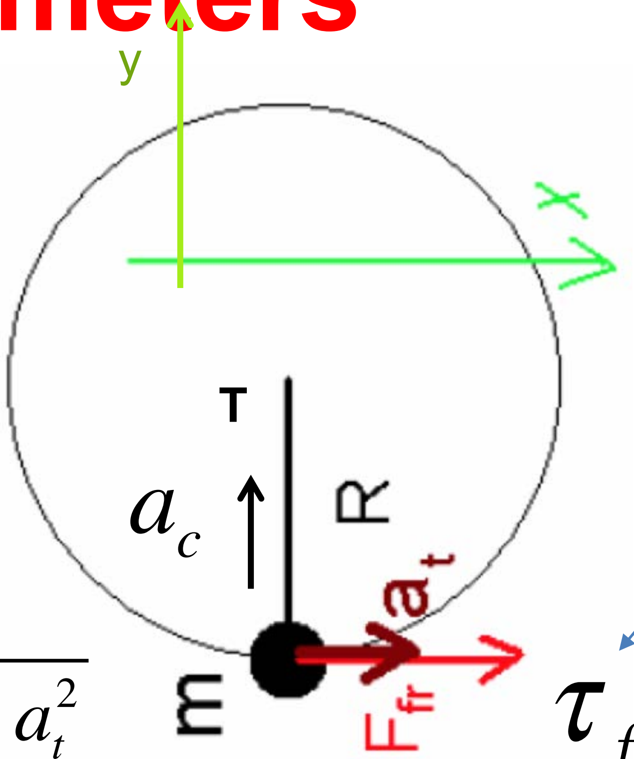
$$\boldsymbol{\tau = I\alpha} \rightarrow$$ **The same for ALL points!**

Circular motion with |*v*| ≠ const for a small object in terms of angular parameters

$\omega = v / r$

$$a_c = \frac{v^2}{R}$$

$$T = ma_c$$



$$a = \sqrt{a_c^2 + a_t^2}$$

$$F_{fr} = ma_t$$

$$\boxed{\frac{a_t}{r} = \alpha}$$

$$F_{fr} = m\alpha r$$

$$F_{fr} r = m\alpha r^2$$

$$\tau_{fr} = (mr^2)\alpha$$

Leap! **For a "<u>disk</u>"**

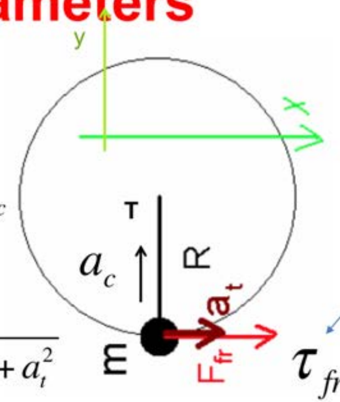
Circular motion with |v| ≠ const for a small object in terms of angular parameters

$\omega = v / r$

$a_c = \dfrac{v^2}{R}$

$T = ma_c$

$a = \sqrt{a_c^2 + a_t^2}$



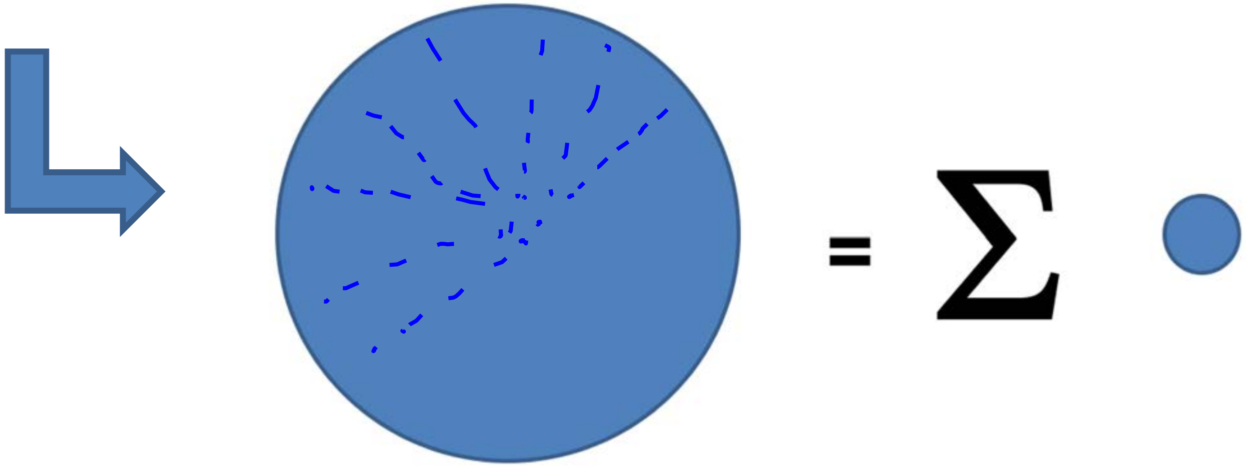
$F_{fr} = ma_t$

$$\boxed{\frac{a_t}{r} = \alpha}$$

$F_{fr} = m\alpha r$

$F_{fr} r = m\alpha r^2$

$\tau_{fr} = (mr^2)\alpha$ Leap! **For a "disk"**



For one point

$$\tau = I\alpha$$

For many points

$$\sum \tau = \sum I \alpha$$

$$\sum \tau = \alpha \cdot \sum I$$

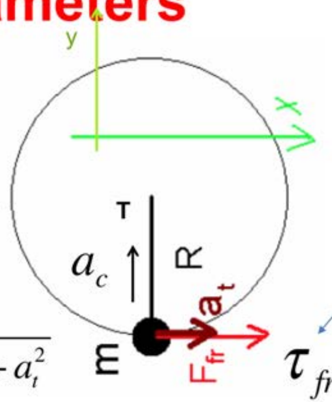
Circular motion with $|v| \neq$ const for a small object in terms of angular parameters

$\omega = v / r$

$a_c = \frac{v^2}{R}$

$T = ma_c$

$a = \sqrt{a_c^2 + a_t^2}$



$$F_{fr} = ma_t$$

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$$F_{fr} = m\alpha r$$

$$F_{fr} r = m\alpha r^2$$

$$\tau_{fr} = (mr^2)\alpha$$

Leap! For a "**disk**"

For one point

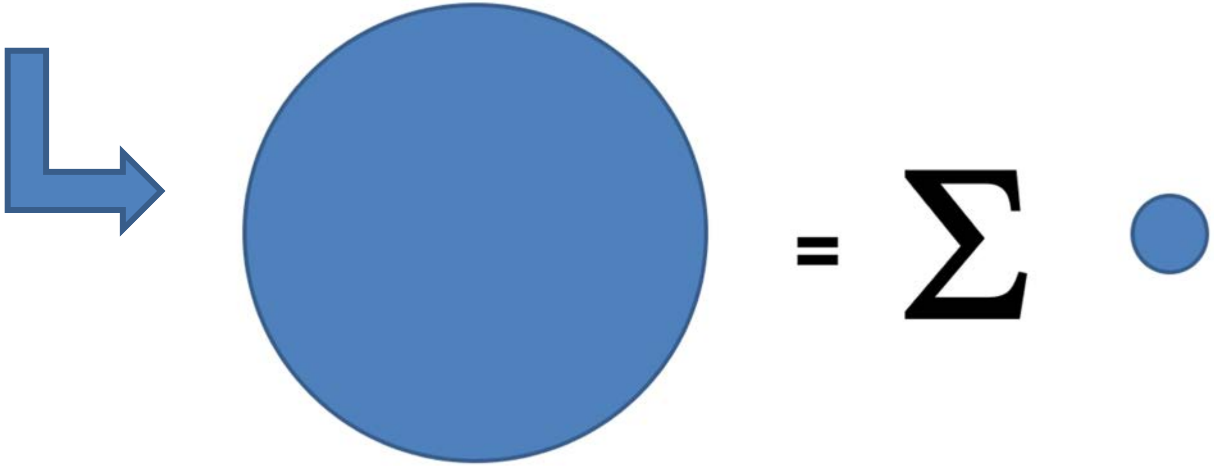
$$\tau = I\alpha$$

For many points

$$\Sigma\tau = \Sigma I\alpha$$

α **is the same for all points**

$$\Sigma\tau = (\Sigma I)\alpha$$



$$\Sigma\tau = \Sigma Fr = \tau_{\mathbf{net}}$$

$$\Sigma I = \Sigma mr^2 = I$$

$$\boxed{\vec{\tau}_{net} = I\vec{\alpha}}$$

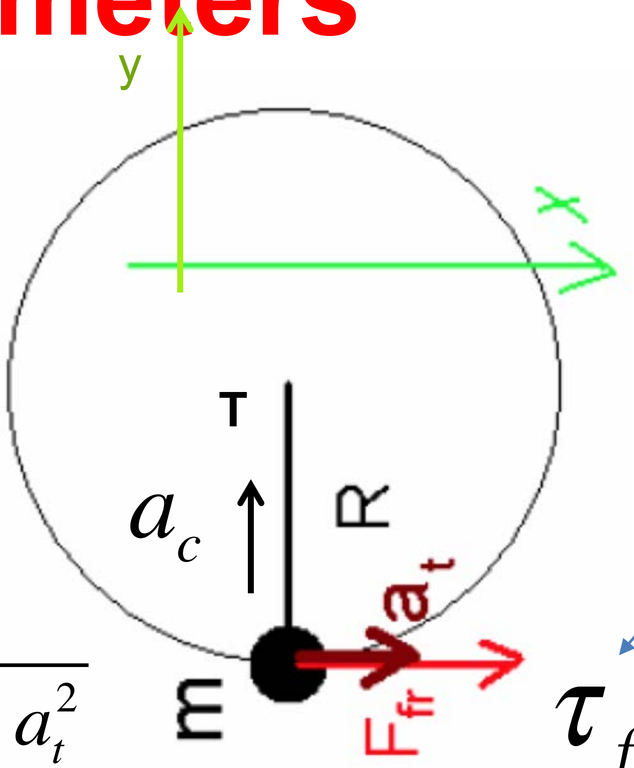
Circular motion with $|v| \neq$ const for a small object in terms of angular parameters

$$\omega = v / r$$

$$a_c = \frac{v^2}{R}$$

$$T = ma_c$$

$$a = \sqrt{a_c^2 + a_t^2}$$



$$F_{fr} = ma_t$$

$$\boxed{\frac{a_t}{r} = \alpha}$$

$$F_{fr} = m\alpha r$$

$$F_{fr} r = m\alpha r^2$$

For a "disk"

$$\tau_{fr} = (mr^2)\alpha$$

Torque

Leap!

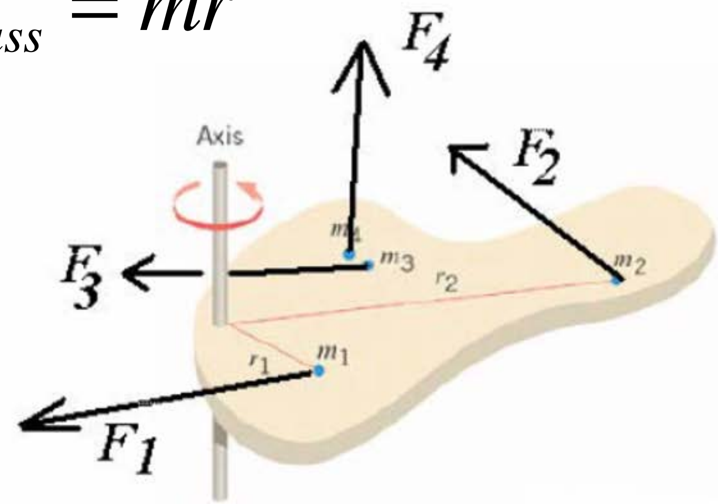
$$\boxed{\vec{\tau}_{net} = I\vec{\alpha}}$$

Newton's Second Law for Rotation

$$\tau_{one\ \text{point}} = (mr^2)\alpha$$

$$I = \Sigma mr^2 = CMR^2$$

$$I_{small\,mass} = mr^2$$



When the axis *passes* CofM (!):

$$I_{rod} = \frac{1}{12} mL^2$$

$$I_{sph} = \frac{2}{5} mr^2$$

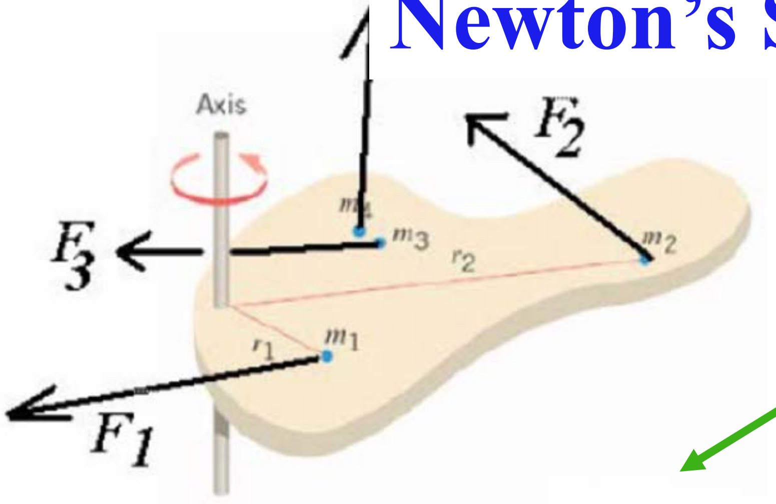
$$I_{hollow\ cyl} = I_{ring} = mr^2$$

$$\vec{\tau}_{Net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \ldots$$

$$\boxed{\vec{\tau}_{Net} = I\vec{\alpha}}$$

$$I_{disc} = I_{cyl} = \frac{1}{2} mr^2$$

Newton's Second Law for Rotational Motion



$$\vec{\tau}_{Net} = I\vec{\alpha}$$

Equilibrium

$$\vec{\tau}_{Net} = 0$$

and

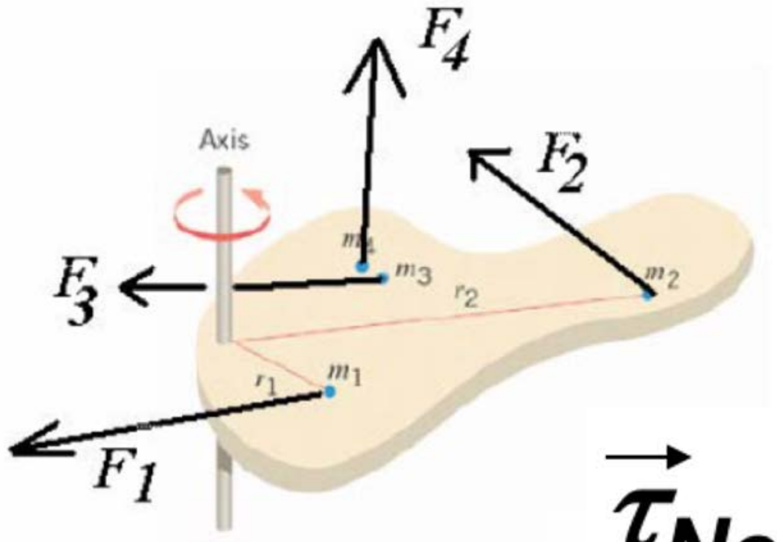
$$\omega = 0$$

=> A rigid object is <u>at rest</u>

Non-Equilibrium

$$\vec{\tau}_{Net} \neq 0$$

The meaning of torque



$$\vec{\tau}_{Net} = I\vec{\alpha}$$

$$\vec{\tau}_{Net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \dots$$

$F_{fr} r$

$\tau_{fr} = (m$

Torque

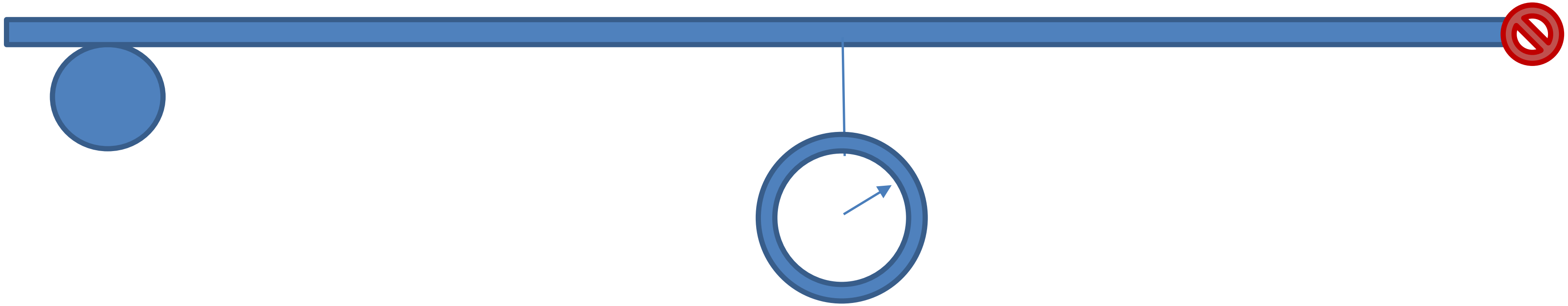
generalization

Torque of a force, in general

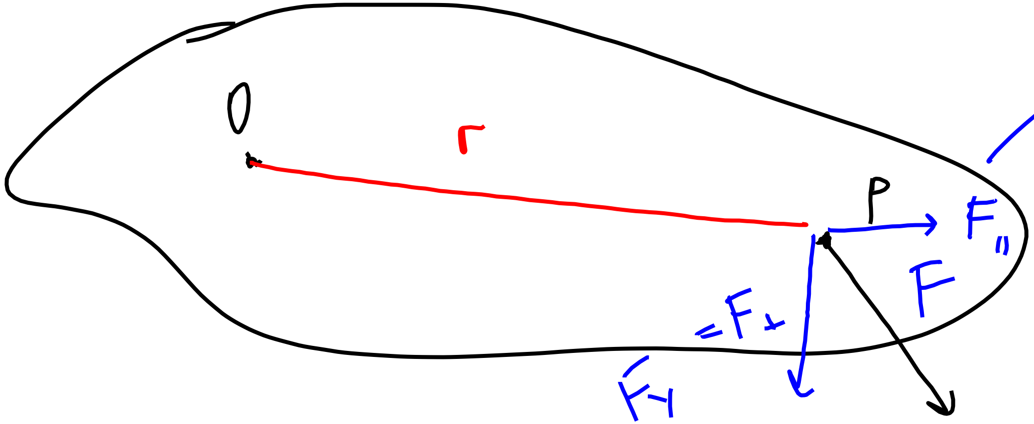
$$\tau = Fr$$

Where, *F* and *r* are …

An investigation



<u>Torque</u> - DEFINITION: <u>*magnitude*</u>

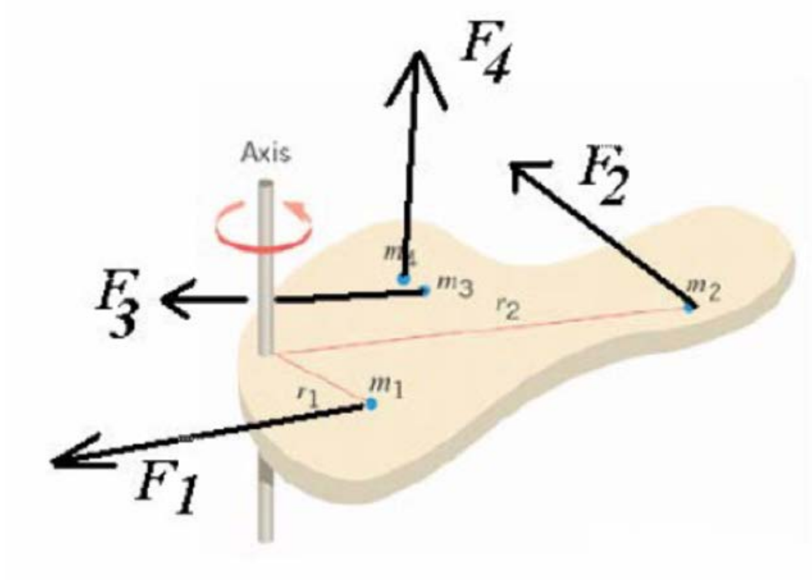


does not matter

$\Downarrow$

$$r \cdot F_{\perp} = \tau_F$$

“torque” is a shortcut for



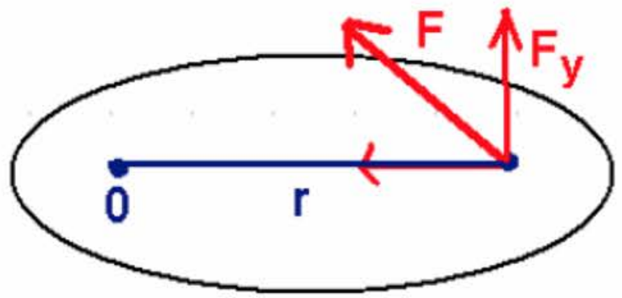
“THE TORQUE OF this FORCE REALTIVE TO this AXIS”

The actual (physical) axis of rotation is not always equal to the abstract (mathematical) axis of rotation.

You can choose the axis of ration!

! The *actual* (physical) axis of rotation is not always equal to the *abstract* (mathematical) axis of rotation. !

Torque - DEFINITION: *magnitude*



The torque τ of the force F is a vector with the magnitude of

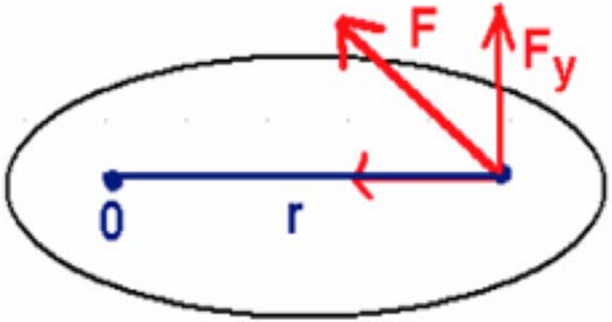
$$\boxed{|\tau| = r\,|F_y|}$$

r is the distance from the point of application of the force to the axis of rotation

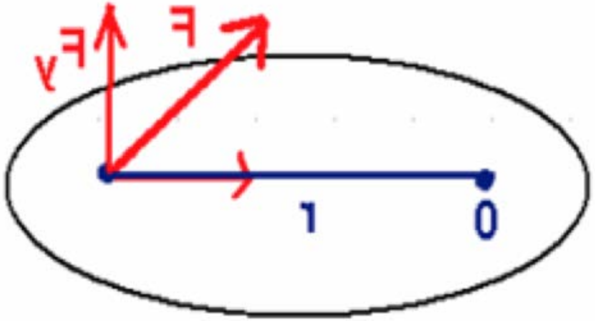
F_y is the component of the force perpendicular to the line connecting the point of application and the axis of rotation.

Torque - DEFINITION: *direction*

CCW => "+"

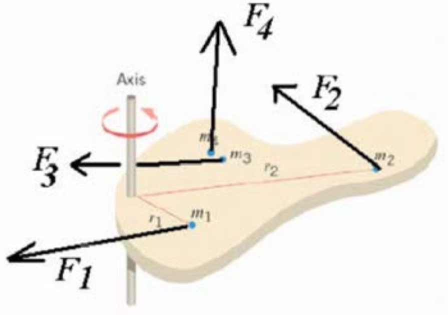


CW => "-"



! The *actual* (physical) axis of rotation is not always equal to the *abstract* (mathematical) axis of rotation. !

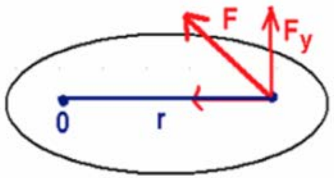
When solving a problem – *select* the axis of rotation and do NOT change it until the *end*!



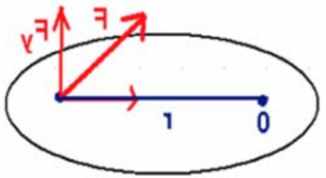
Equilibrium

$$\tau = r\,F_y$$

CCW => "+"



CW => "-"



$$\vec{\tau}_{Net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \ldots$$

$$\vec{\tau}_{Net} = 0$$

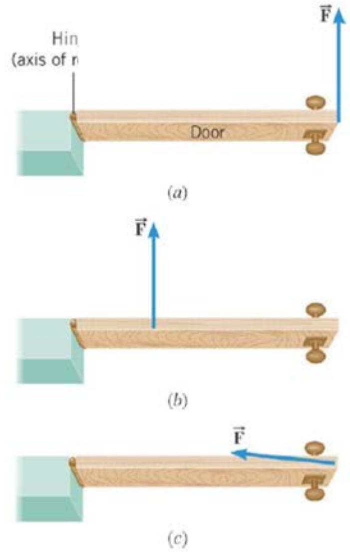
and

$$\omega = 0$$

=> A rigid object is <u>at rest</u>

ALL problems on static equilibrium of a rigid object start from this equations.

Torque



According to Newton's second law, a net force causes an object to have an acceleration.

What causes an object to rotate?

The force alone does not provide the answer.

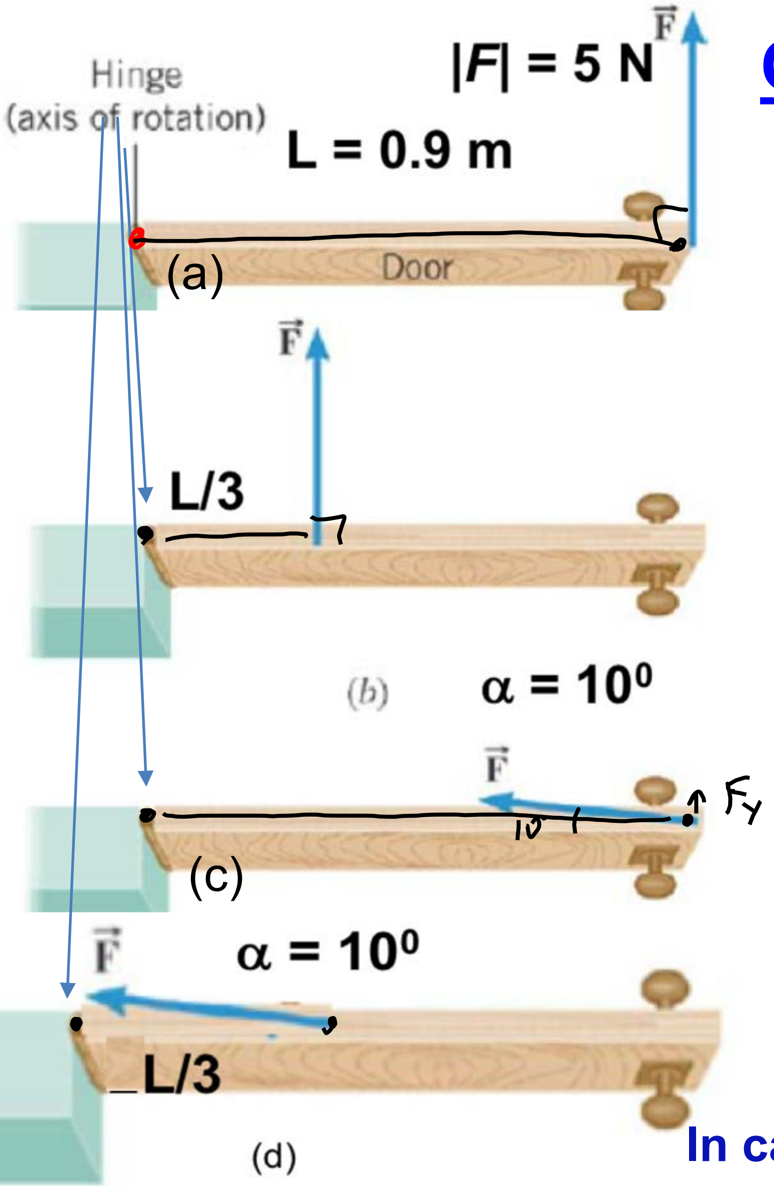
The rotational effect of the force depends on the orientation of the force!

(d)

$|F|$ = 5 N, the door is 0.9 m long. In cases (b, d) the force is 2/3 closer to the hinge as in case (a); in cases (c, d) the angle is 10^0. Calculate the applied torque relative to the *hinge* (in all cases).

In cases (a, c) assume the doorknob is at the edge of the door.

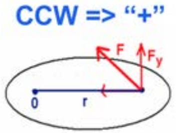
$$|\tau| = r|F_y|$$

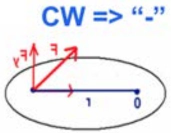


Calculate torque relative to the *hinge*

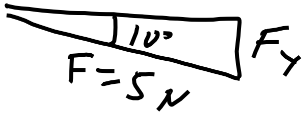
$$|\tau| = r\,|F_y|$$

a) ⇒ $|\tau_a| = 0.9 \cdot 5 = 4.5\ \underline{m.N}$





b) ⇒ $|\tau_b| = \frac{1}{3} \cdot 0.9 \cdot 5 = 1.5\ m\,N$



c) ⇒ $|\tau_c| = 0.9 \cdot 5 \cdot \sin 10$

d) ⇒ $|\tau_d| = \frac{1}{3} \cdot 0.9 \cdot 5 \cdot \sin 10°$

In cases (a, c) assume the doorknob is at the edge of the door.