Announcements – Thurs, 22 Oct 2009

1. **CAUTION**: Starting with HW 14 (due Tuesday), some of your HW answers will need to be written in **scientific notation**. Do this with "e" notation, not with "x" signs. For example, if the answer range says

   5.00×10^{33}, 9.00×10^{33} kg·m^2/s

   and you get 6.57×10^{33} kg·m^2/s as your answer…

   if negative exp: 6.57e-33

   …then you should type in the answer as **6.57E33**

   not 6.57 x 10^33

   No spaces, no "x"s!

   If you put any spaces or x's in your answer, the computer will mark it wrong.

2. **TA-led Exam Review session—results of doodle.com voting**

   a. Day/Time: Friday 4-5^{30} pm

   b. Place? room C295 ESC TA: Adam Bracken

   and Tuesday 7-8^{30} pm
   room C247 ESC TA: Rich Hansen
   also room C285 ESC TA: Jeff Kitchen

Which part of today's assignment was particularly hard or confusing?

I couldn't see the video.

Will there be a time where something works against [conservation of ang. mom.] - like work in mechanical energy? Or will we just always assume it is conserved? Also, the book gave an example of a diver doing somersaults saying that the gravitational force went through her center of gravity - will there be a time where it does not go through the center of gravity…? Always

Do we need to know about gyroscopes and precession for the class or the exam?

General comments:

Should ralph extra credit points be posted yet? Yes

Is this test going to be WAY harder? This stuff is much harder that the previous stuff.

going back to the demo last class with objects rolling/sliding down a slope; if the slope really was frictionless as we assumed (since we wanted ideal circumstances so the book would win), why wouldn't the sphere also just slide down the slope? why would it spend energy rotating when it too could just slide?

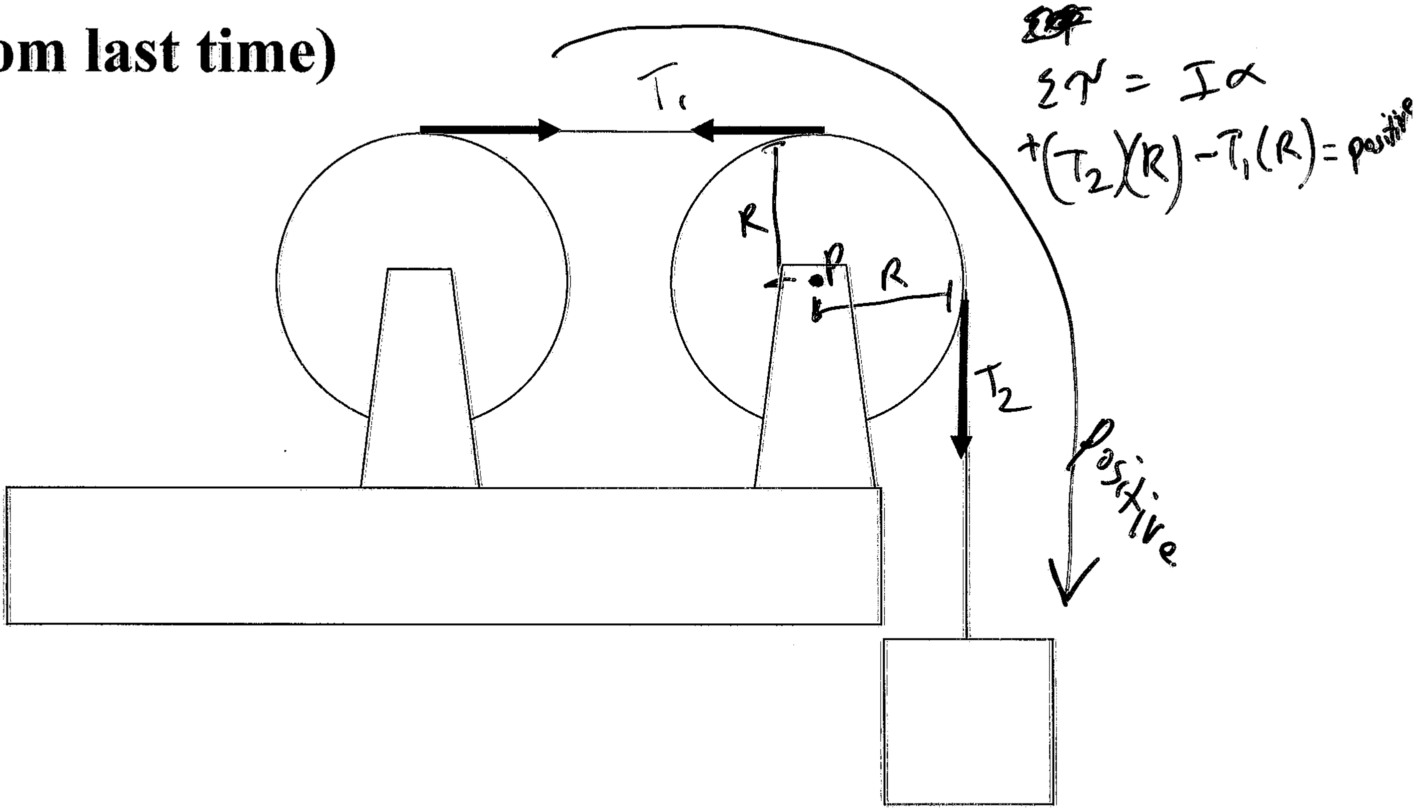
It would!

saturday midnight

What time is the extra credit due on ~~Friday~~?

If we turn in part of an assignment on time and the other part late, do we get full-credit for what we did on time and then half credit for what we turned in late? Yes

(From last time)



The left disk has a rope wrapped around its edge and the rope passes over a second disk. The two disks are identical and their **mass is significant**. As the system accelerates there is no slipping of the rope on either wheel and both wheels accelerate the same. The tension in the rope is

a. Largest between the disks
b. Largest above the mass
c. The same in both places.

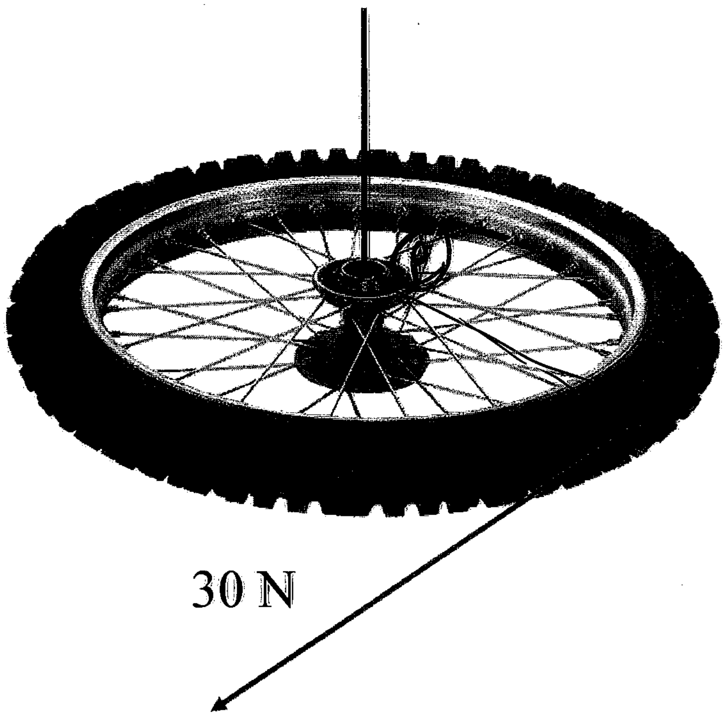
Hint: apply N2 for torques to the right-hand disk

What's different with our old "massless pulleys"? $\rightarrow I = 0$

$$T_2(R) - T_1(R) = 0$$

$$T_2 = T_1$$

Another review problem: A bicycle tire (r = 0.4 m, I = 0.8 kg·m^2) is hanging from a string from the ceiling, not moving. You push on the edge with a 30 N force for 0.3 seconds. What is ω_f? (*Hint*: because time is given, do it with N2, not energy.)



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

$$(30\text{N})(.4\text{m}) = (.8\,\text{kgm}^2)\alpha$$

$$\alpha = \frac{(30)(.4)}{(.8)} = 15\,\frac{\text{rad}}{\text{s}^2}$$

$$v_f = \cancel{v_0} + at$$

$$w_f = \cancel{w_0} + \alpha t$$

$$= (15\,\tfrac{\text{rad}}{\text{s}^2})(.3\,\text{sec})$$

$$= \boxed{4.5\,\frac{\text{rad}}{\text{s}}}$$

Answer: 4.5 rad/s

Angular Correspondences Review

Kinematics

Distance: x

Velocity: v

Acceleration: a

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v = v_0 + at$$

$$v^2 = v_0{}^2 + 2a(x - x_0)$$

Angle: θ

Angular velocity: ω

Angular acceleration: α

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0{}^2 + 2\alpha(\theta - \theta_0)$$

Mass

Mass: m

Moment of inertia: I

Force/Newton's 2nd Law

Force: F

$$\sum \vec{F} = m\vec{a}$$

Torque: τ

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

Energy

$$KE_{trans} = \frac{1}{2}mv^2$$

$$KE_{rot} = \frac{1}{2}I\omega^2$$

Momentum…

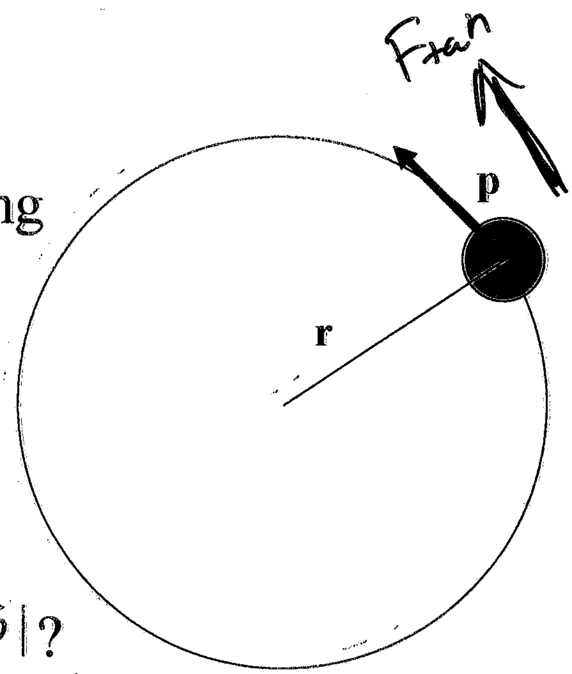
Momentum: p $(= mv)$

Angular momentum??

L $(= I\omega\ ?)$

yes

Angular momentum



Imagine a mass *m* on a thin rod moving in a circle, with constant speed v. It has linear momentum $\vec{p} =$ $m\vec{v}$.

Is $\vec{p}$ constant? No

Is $|\vec{p}|$ constant? Yes
(magnitude)

What do we need in order to affect $|\vec{p}|$?

tangential force → applies a torque

Force-momentum relationship	**Torque-ang. mom. relationship**

Start with Newton 2:

$$\sum \vec{F} = m\vec{a}$$

$$= m\frac{\Delta \vec{v}}{\Delta t}$$

$$= \frac{\Delta(m\vec{v})}{\Delta t}$$

$$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t}$$

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

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

$$= \frac{\Delta(I\omega)}{\Delta t}$$

$$\tau_{net} = \frac{\Delta L}{\Delta t}$$

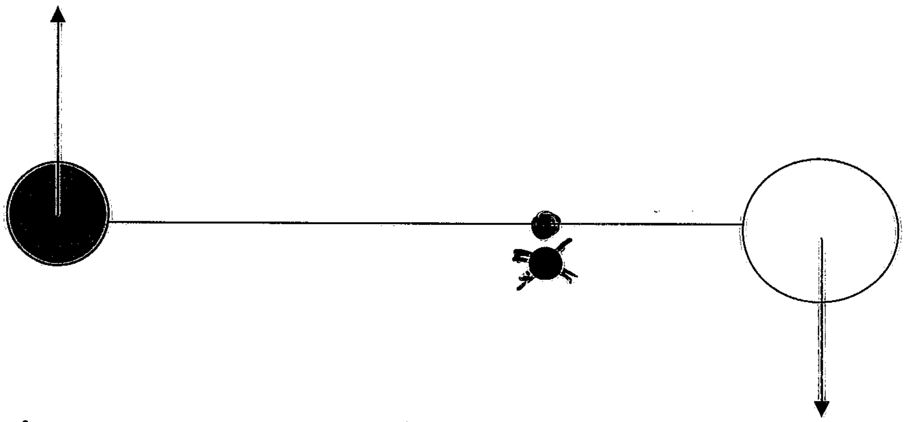
Define $\boxed{L = I\omega}$

> If no net external force, no change in momentum

> If no net external *torque*, no change in *angular* momentum

Conservation of Angular momentum

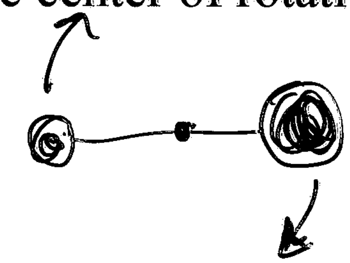
$$\boxed{\Sigma L_{bef} = \Sigma L_{aft}}$$ → if and only if *no net external torques*



Two space stations are connected by a cable. They are rotating about their center of mass. Someone in the blue station pulls the cable in so they are each closer to the center of rotation. What happens?

$L_{bef} = L_{aft}$

$I_{bef}\,\omega_0 = \underbrace{I_{aft}}_{\text{reduced}}\ \underbrace{\omega_f}_{\text{increased!}}$



Demo: Hoberman sphere

Clicker quiz: Is rotational kinetic energy conserved? The total energy afterwards is:

a. more
b. less
c. the same

Hint: is there any non-conservative work done?

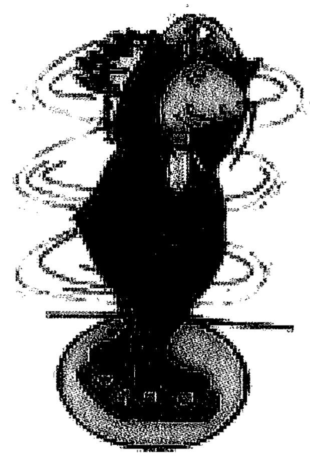
Spinning

From warmup. Rotating stool, student with weights. Her arms are extended, holding the weights as far from her body as possible. She then pulls the weights in close to her body, she will rotate faster. What happens to her moment of inertia as she pulls in the weights?

a. increases
b. decreases
c. remains the same

From warmup. What happens to her rotational speed as she pulls in the weights?

a. increases
b. decreases
c. remains the same



Application to skaters? (frictionless ice)

Demo: spinning chair

From warmup: What happens to her rotational kinetic energy as she pulls in the weights?

a. increases
b. decreases
c. remains the same

Worked Problem: A skater has an initial ω of 2 rad/s and $I = 30\ \text{kg}\cdot\text{m}^2$. When she brings in her arms, $I = 10\ \text{kg}\cdot\text{m}^2$. What is her final ω?

after

bef

$$\Sigma L_{bef} = \Sigma L_{aft}$$

$$I_o \omega_o = I_f \omega_f$$

$$(30\,kg\,m^2)(2\,\tfrac{rad}{s}) = (10\,kg\,m^2)\,\omega_f$$

$$\omega_f = 6\ rad/s$$

How much work did it take to do this?

$$E_{bef} + W = E_{aft}$$

$$\tfrac{1}{2} I_o \omega_o^2 + W = \tfrac{1}{2} I_f \omega_f^2$$

$$\tfrac{1}{2}(30)(2^2) + W = \tfrac{1}{2}(10)(6^2)$$

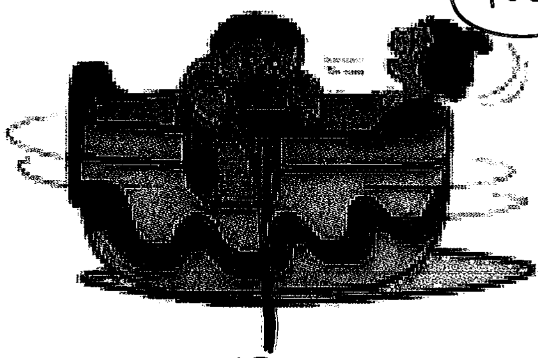
$$60\,J + W = 180\,J$$

$$W = 120\,J$$

Answers: 6 rad/s, 120 J

Is L conserved in these cases?

No

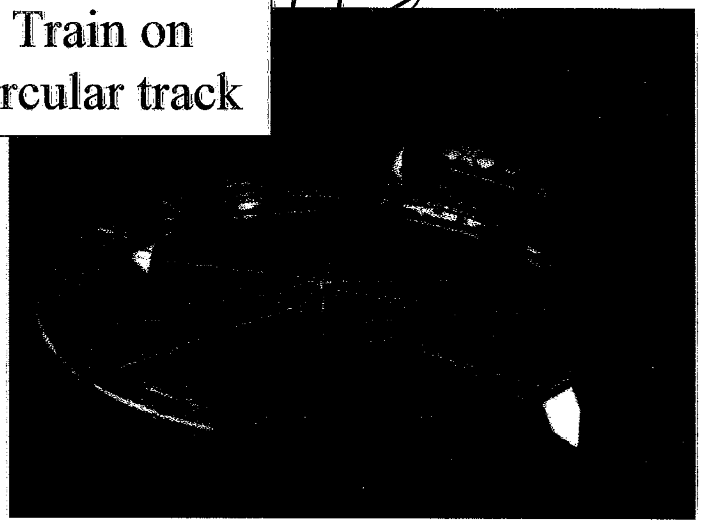


"Teacups": central post is connected to the platform floor

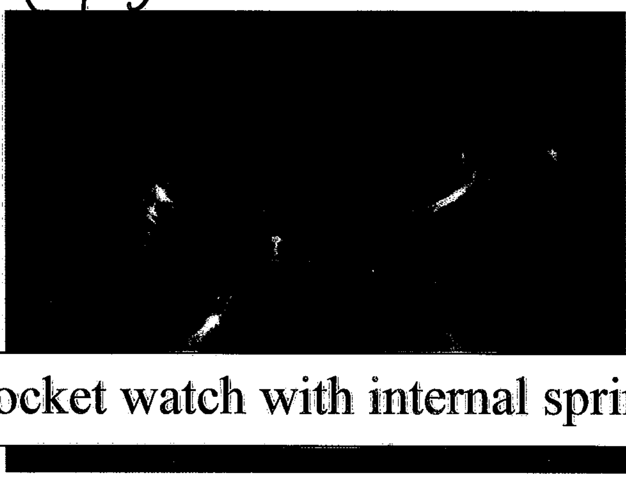
external torque

yes

Train on circular track



yes



Pocket watch with internal spring

Yo-yo

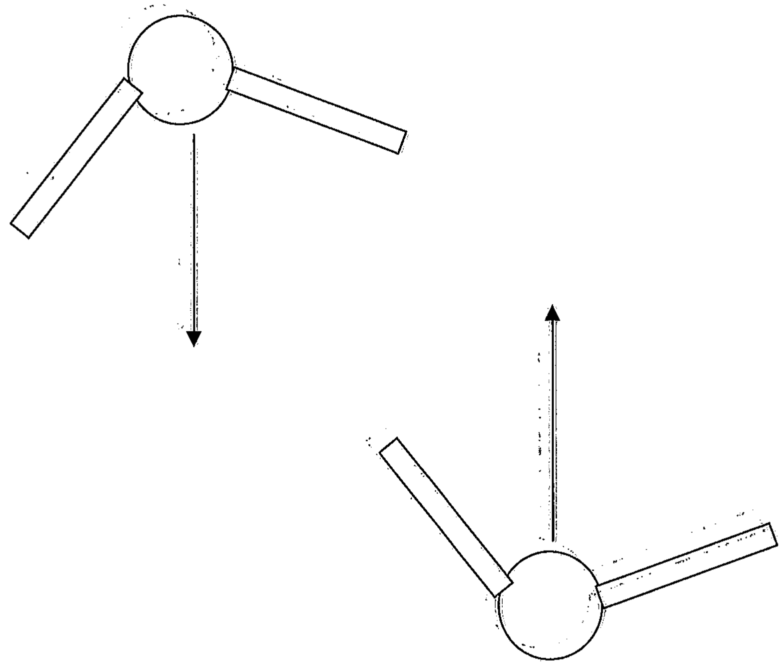
T = provides torque

No

Videos: train on circular track, pocket watch

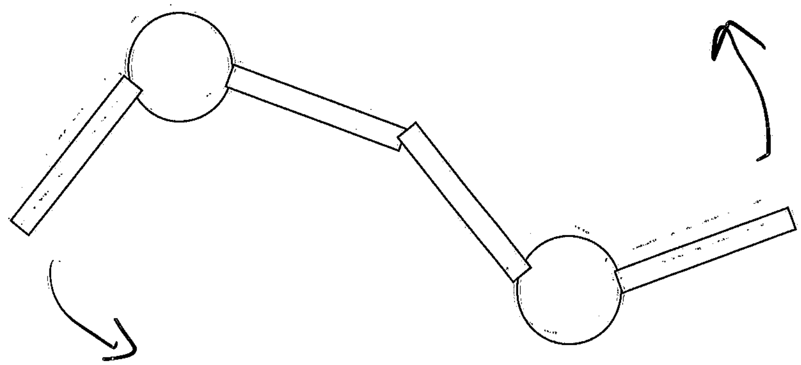
Food for thought: two skaters joining hands
((frictionless ice)

Before



Any L? Yes

After



Any L? Yes

Was angular momentum conserved? (system: both skaters)

→ It must be, if there is no net external torque

Clicker quiz: Is there an external torque here? I.e. was angular momentum conserved?

a. Yes external torque/not conserved

b. No external torque/yes conserved

Another expression for L…

Start with

$$\tau = r_\perp F$$

$$= r_\perp \left(\frac{\Delta p}{\Delta t}\right)$$

$$= \frac{\Delta(r_\perp p)}{\Delta t}$$

must be angular momentum

Remember

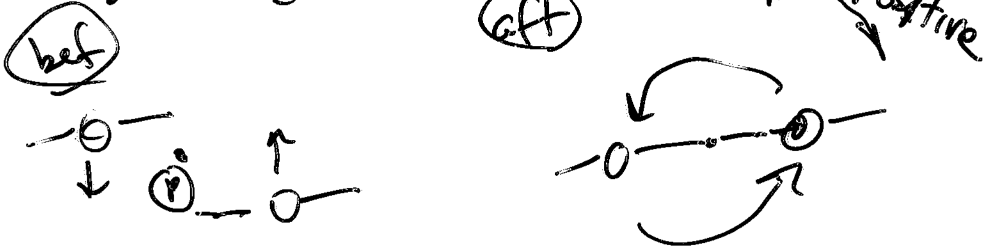
$$F_{net} = \Delta p / \Delta t$$

$$\tau_{net} = \Delta L / \Delta t$$

compare

Result: $\boxed{L = r_\perp p}$ $\qquad (= r p_\perp = r p \sin\theta)$

Worked Problem: Skaters on previous page have 0.7 m arms and are each 62 kg. They come together at 3.5 m/s. How fast (rad/s) are they turning afterwards?



$$\Sigma L_{bef} = \Sigma L_{aft}$$

$$(.7\,m)(62\,kg \times 3.5\,\tfrac{m}{s}) + (.7\,m)(62\,kg \times 3.5\,\tfrac{m}{s}) = (I_1 + I_2)\,\omega_f$$

$$I_1 \rightarrow mr^2 \qquad I_2 \rightarrow mr^2$$

$$'' \qquad\qquad '' \qquad = \left[(62)(.7)^2 + 62(.7)^2\right]\omega_f$$

Answer: 5 rad/s

$$\omega_f = 5\,\frac{rad}{s}$$

Comment on vectors… (aka L has a direction!)

Does ω have a direction? yes : CCW or CW

Therefore $I\omega = L$ has a direction CCW or CW

Thus with **no external torques**…

both magnitude of L } stay the same
and direction of L }

Demos: gyroscope

With external torque?

Demo: briefcase

To fully describe what happens to angular momentum with external torque takes more math than we have… just understand that strange things can happen. ☺

From warmup: http://science.howstuffworks.com/gyroscope1.htm

Ralph watched the video with the bicycle wheel, but became very confused. He had learned that angular momentum is conserved, but in this case isn't the angular momentum of the wheel constantly changing in direction as the wheel spins around. What's up?

Answer from the class:

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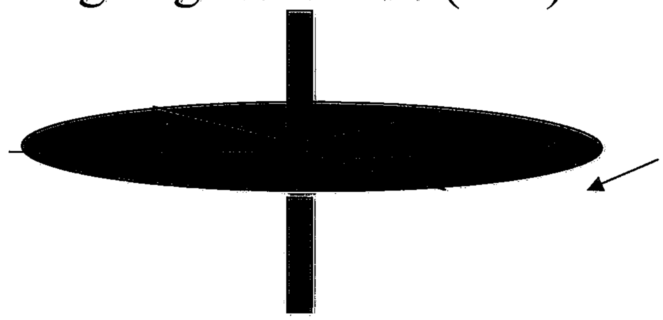
Dear Ralph: Angular momentum is NOT conserved in this case. There IS an external torque-the support string. Here, the change in angular momentum is illustrated by a change in -direction-, rather than a change in -speed-. Hope that helped!

-your friend

Demo: bicycle wheel

José sits still on frictionless ice, holding a bicycle wheel that's already spinning. View from above it is going **clockwise** (CW).



Clicker quiz: If he grabs on to the wheel edge firmly and stops it from spinning he will:

a. Start to turn CW (viewed from the top)
b. Start to turn CCW
c. Remain sitting without turning

Clicker quiz: If, instead of stopping the wheel, he carefully turns it over so it is going CCW (viewed from the top), he will start to:

a. Turn CW, but slower than in the previous problem
b. Turn CCW, but slower than in the previous problem
c. Turn CW, but faster than in the previous problem
d. Turn CCW, but faster than in the previous problem
e. Remain sitting without turning

Demos: rotating platform, bicycle wheel
Demo: double bicycle wheels