# Announcements – Thurs, 23 Oct 2014

1. **Exam 2** starts Oct 30, a week from today.
   a. Late fee on Monday Nov 3, after 2 pm
   b. Closes on Tuesday Nov 4, 2 pm
   c. Jerika exam reviews, both in room C295 ESC:
      i. Wed Oct 29 7 - 8:30 pm
      ii. Thurs Oct 30 5:30 - 7 pm
   d. Exam covers through today's lecture
      i. Ch. 5, 6, 7.1-7.3, 8
      ii. HW 10-17

2. Equations from last time:

Energy: $KE_{trans} = \frac{1}{2}mv^2$ $\qquad KE_{rot} = \frac{1}{2}I\omega^2$

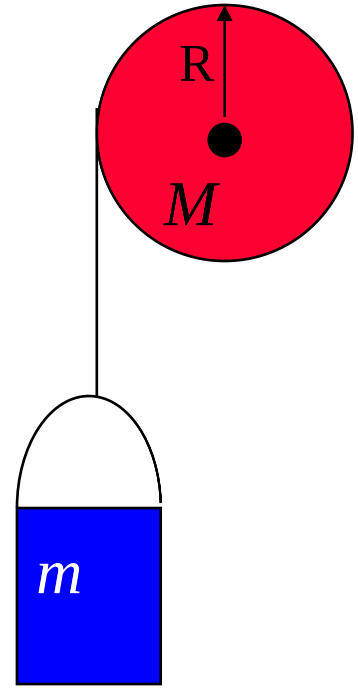
Force: $\sum \vec{F} = m\vec{a}$ $\qquad \sum \tau = I\alpha$

3. Equation from today:

Momentum: $p = mv$ $\qquad$ ang. momentum = ??

“Which of the problems from last night's HW assignment would you most like me to discuss in class today?”

**Worked problem from last time:** A falling mass starts a cylinder rotating (not a "massless pulley"). What is the acceleration of *m*?




**Draw FBDs**

**Write equations, plug in $\alpha$ = *a/r*…**

Cylinder

$$\Sigma\tau_p = I\alpha$$

$$TR = \left(\tfrac{1}{2}MR^2\right)\left(\frac{a}{R}\right)$$

Pail

$$\Sigma F = ma$$

$$mg - T = ma$$

Solve simultaneous equations for a (and T, if desired)

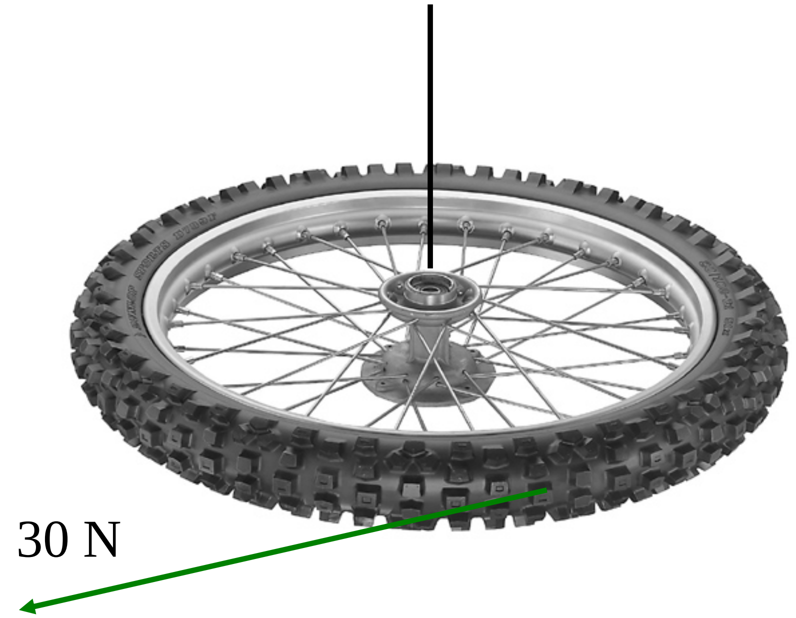
Answer: $a = \frac{m}{m + M/2}g$

# What if you just want to know $v_f$ (given a distance d)?

Answer: $v_f = \sqrt{\dfrac{mgd}{\frac{1}{2}m + \frac{1}{4}M}}$

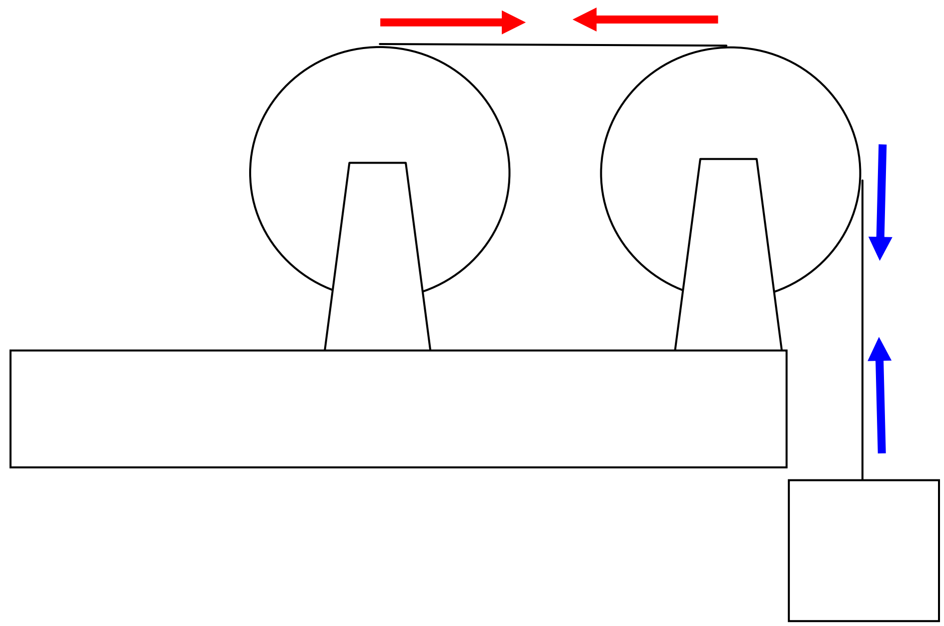
# Worked Problem

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 tangentially on the edge with a 30 N force for 0.3 seconds. What is $\omega_f$? (*Hint*: because time is given, might be simplest to do it with N2, not energy.)




Answer: 4.5 rad/s

# Clicker quiz



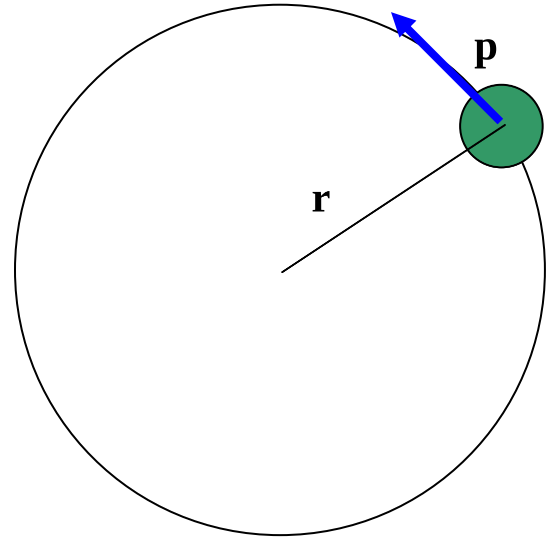
The left disk has a rope wrapped around its edge and the rope passes over a second disk. The two disks are identical and their **mass is significant**. As the system accelerates there is no slipping of the rope on either wheel; both wheels accelerate at the same rate. The tension in the rope is

a. Largest between the disks (red arrows)
b. Largest above the mass (blue arrows)
c. The same in both places.

(What's the difference with our old "massless pulleys"?)

# Angular momentum

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




Is $\vec{p}$ constant?________

Is magnitude of $\vec{p}$ constant?________

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

# Derivation of Angular Momentum

<u>Force-momentum relationship</u>

Start with Newton 2:

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

<u>Torque-ang. mom. relationship</u>

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

Define $L = I\omega$

units of $L$?

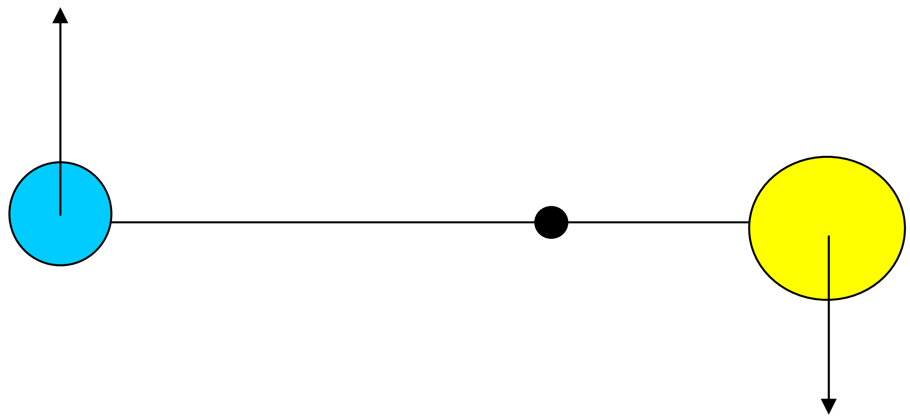
Momentum is conserved if no net external force

*Angular* momentum is conserved if no net external *torque*

# Conservation of Angular momentum blueprint

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

# Problem



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?

**Demo:** Hoberman sphere

# Clicker quiz

Is rotational kinetic energy conserved in the Hoberman sphere? The final KE is __________ as the initial KE:

a. more
b. less
c. the same

*Hint*: is there any non-conservative work done?

# From warmup

Rotating stool, student with weights. What happens to her moment of inertia as she pulls in the weights?

a. increases
b. decreases
c. remains the same

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

a. increases
b. decreases
c. remains the same

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

a. increases
b. decreases
c. remains the same

# Demo: Spinning chair

# Worked Problem

A skater has an initial $\omega$ of 2 rad/s and $I$ = 30 kg·m$^2$. When she brings in her arms, $I$ = 10 kg·m$^2$. What is her final $\omega$?

How much work did it take to do this?

Answers: 6 rad/s, 120 J

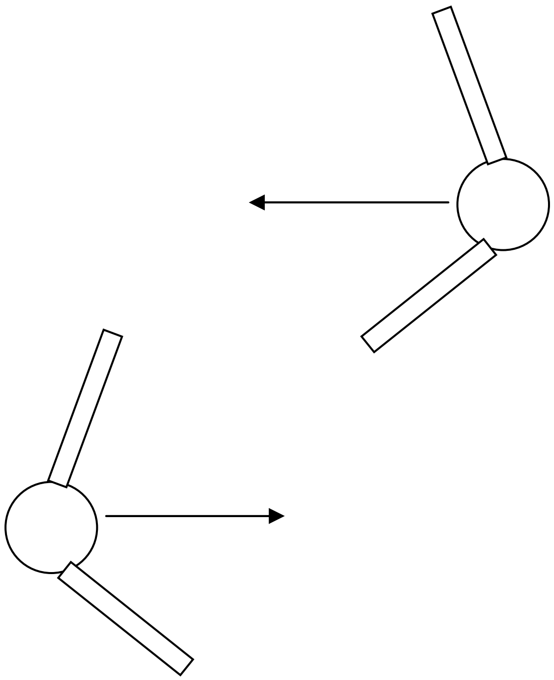
# Videos

- marbles and funnel
- train on circular track
- pocket watch

# Food for thought: two skaters joining hands

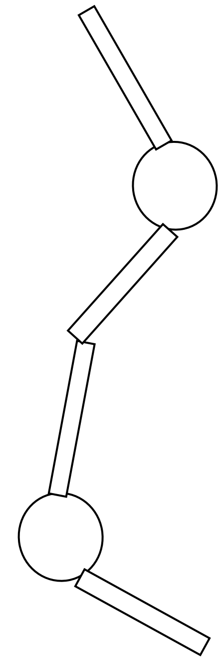
**Before**

**Any L?**



**After**

**Any L?**



**Angular momentum conserved ⇔ No external torque**
(system=both skaters)

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

a. Yes external torque/ang. mom. not conserved
b. No external torque/ang. mom. is conserved

# "Hidden" angular momentum

$$\boxed{L = r_\perp p} \quad ( \; = \; r\, p_\perp \; = \; r\, p \sin\theta)$$

Derivation:

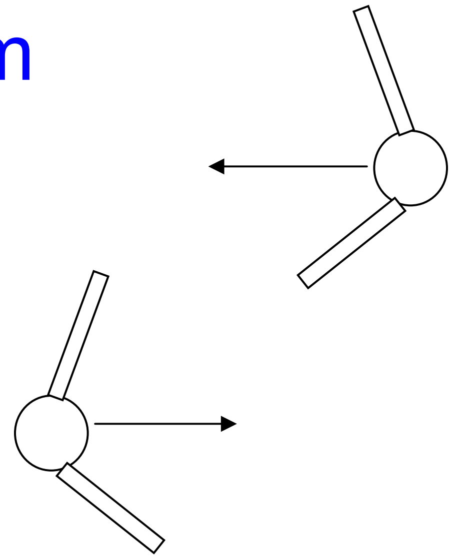
$$\tau = r_\perp F$$

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

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

But remember $\tau$ also $= \Delta L / \Delta t$ !

# Worked Problem



The skaters 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?

Answer: 5 rad/s

# *L* is a vector

With **no external torques**…

…both __________ and ____________ of L stay the same

**Demo:** gyroscope

With **external torques?**

**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?

**"Think-pair-share"**

- Think about it for a bit
- Talk to your neighbor, find out if he/she thinks the same as you
- Be prepared to share your answer with the class if called on

**Clicker:** I am now ready to share my answer if randomly selected.

a. Yes

Note: you are allowed to "pass" if you would really not answer.

# Demo

Bicycle wheel

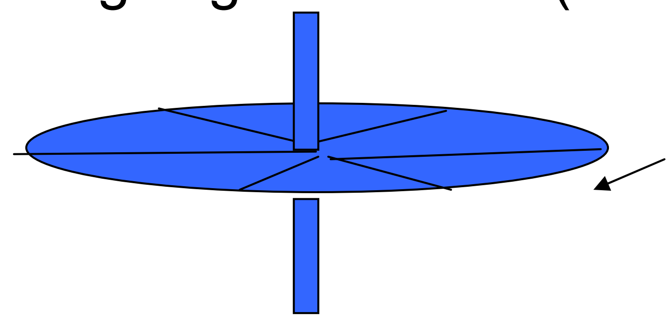
# Demo: Angular momentum with external torque
(wacky briefcase)

**Demo:** briefcase

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

# Clicker quiz

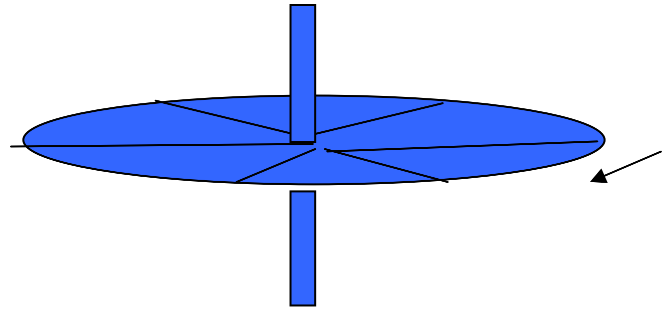
José sits still on frictionless ice, holding a bicycle wheel that's already spinning. Viewed from above it is going **clockwise** (CW).



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



José still on frictionless ice holding this spinning wheel. Viewed from above it is going **clockwise** (CW).

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

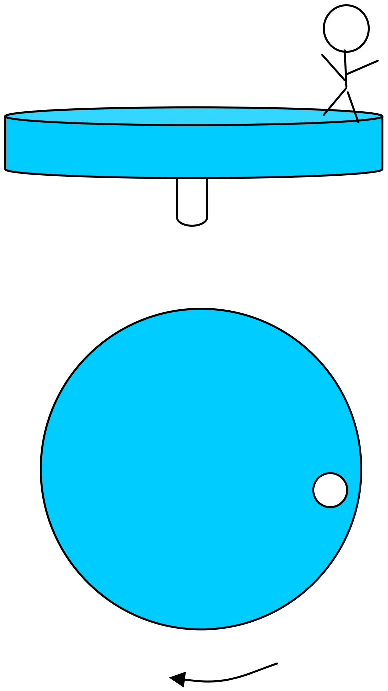
**Demos:** rotating platform, bicycle wheel
**Demo:** double bicycle wheels

# Clicker quiz

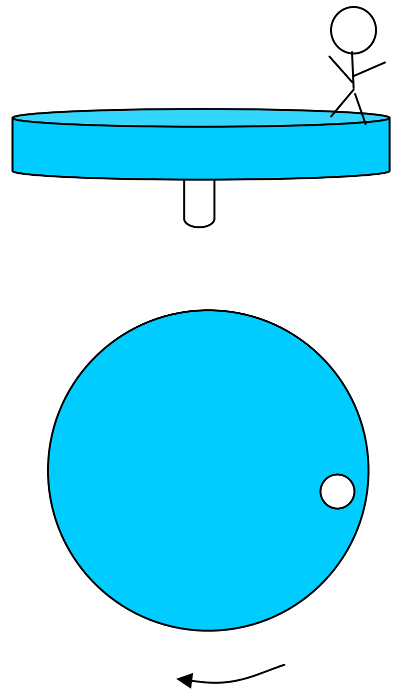
What will happen to the rotational speed $\omega$ of the merry-go-round if the girl…

…walks towards the center?

a. it slows down
b. it stays same speed
c. it speeds up



# Clicker quiz

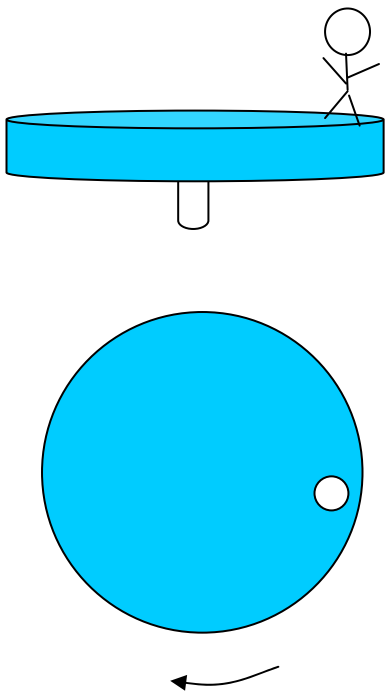


…starts running opposite to the spinning so she is at rest vs the ground?

a. it slows down
b. it stays same speed
c. it speeds up

HINT: Sometimes it's easier to think of the **forces (torques)** she puts on the merry-go-round to change, rather than conservation of L.

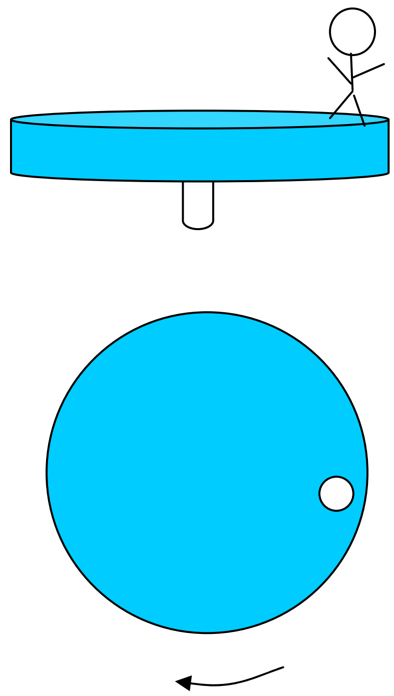
# Clicker quiz



…slips off when she steps on a frictionless icy part?

a. it slows down
b. it stays same speed
c. it speeds up

# Clicker quiz



…throws her shoe off tangentially in the direction she's moving?

a. it slows down
b. it stays same speed
c. it speeds up