

# PHY131H1F - Class 27



**Today:**

9.3 Newton's Second Law for Rotational Motion

9.4 Rotational Momentum

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Poll

## **Crazy Friday:** Let's Choose a Zoom-Filter my face today

What Studio Filter would you prefer on my face today?

A. Happy Sprout



D. Reindeer antlers



B. Pizza on Head



E. Bunny rabbit



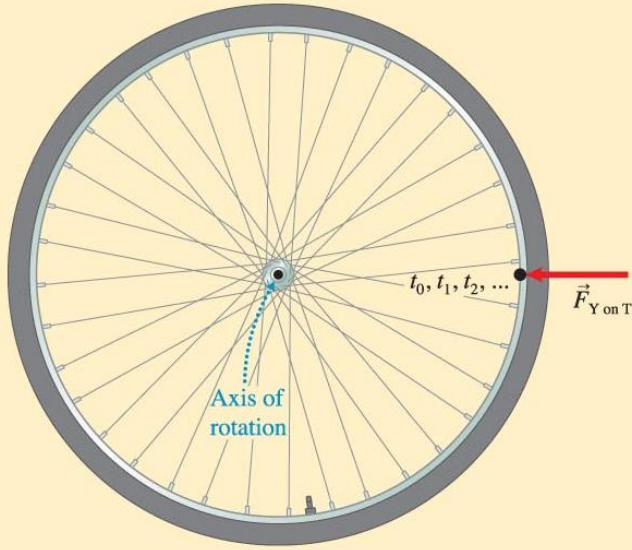
C. Shades



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## Observational Experiment #1

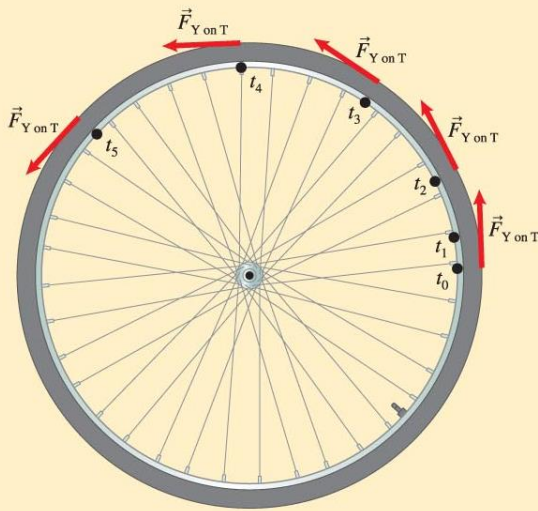
**Experiment 1:** Your bike sits upside down. You push on the front tire toward the axle. The tire does not turn.



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## Observational Experiment #2

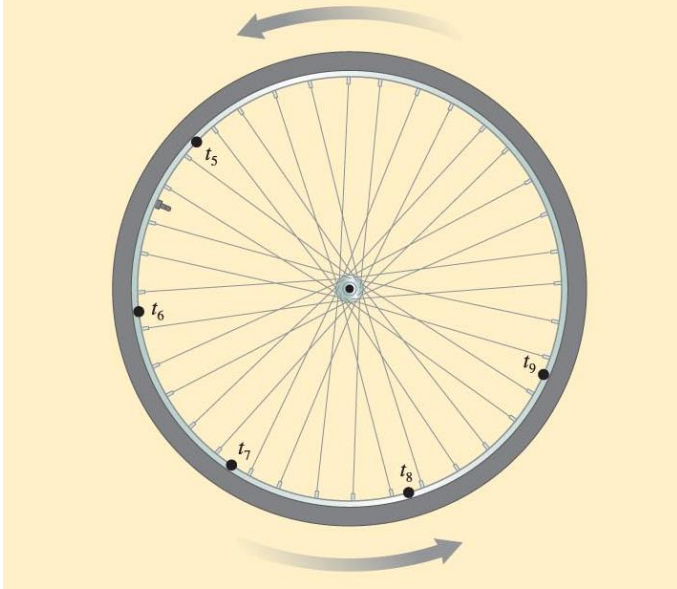
**Experiment 2:** You push lightly and continuously on the outside of the tire in a counterclockwise (ccw) direction tangent to the tire. As you continue to push, the tire rotates ccw faster and faster.



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## Observational Experiment #3

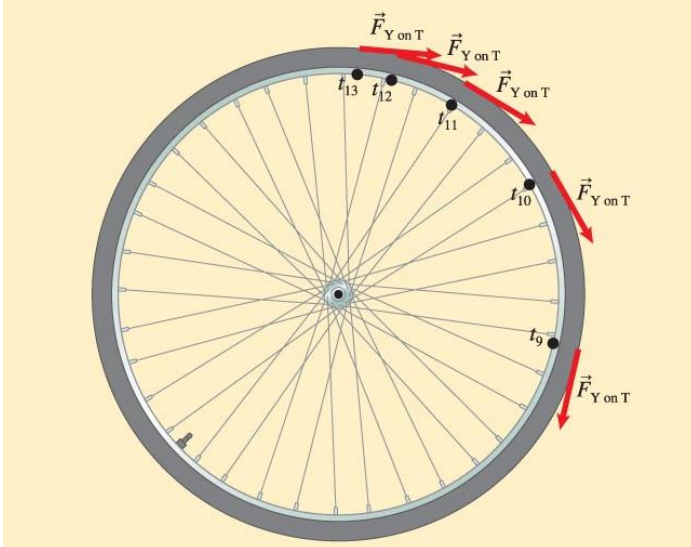
**Experiment 3:** You release the spinning tire and watch it. The tire continues rotating ccw at a constant rate.



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## Observational Experiment #4

**Experiment 4:** With the tire still rotating ccw fast, you gently and continuously push clockwise (cw) against the tire. The rotational speed decreases.



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## Rotational form of Newton's Second Law

- One or more objects exert forces on a rigid body with rotational inertia  $I$  that can rotate about some axis.
- The sum of the torques  $\Sigma\tau$  (net torque) due to these forces about that axis causes the object to have a rotational acceleration  $\alpha$ :

$$\alpha = \frac{1}{I} \Sigma\tau$$

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## Analogy chart

Linear	Rotational Analogy
• $x$	• $\theta$
• $v_x$	• $\omega$
• $a_x$	• $\alpha$

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• Force: $F_x$	• Torque: $\tau$
• Mass: $m$	• Rotational Inertia: $I$

Newton's Second Law:

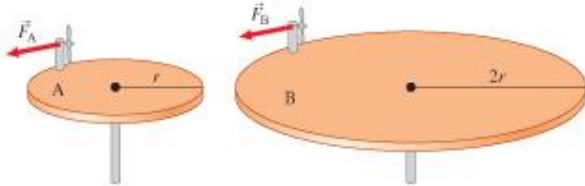
$$a_x = \frac{(F_{net})_x}{m}$$

$$\alpha = \frac{\tau_{net}}{I}$$

[Doc Cam Example]

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Two disks are cut from the same uniform board. The radius of disk B is twice the radius of the disk A. The disks can rotate around axes with negligible friction. Two very light battery-powered fans are attached to the disks, as shown. When switched on, the fans exert equal forces on the disks. What is the angular acceleration of disk A, in terms of that of disk B?



SKETCH & TRANSLATE.

SIMPLIFY & DIAGRAM

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SIMPLIFY & DIAGRAM

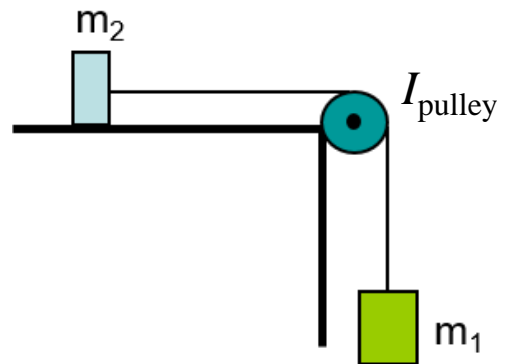
REPRESENT MATHEMATICALLY

SOLVE & EVALUATE

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# Massive Pulleys

- A real pulley has some rotational inertia,  $I_{\text{pulley}}$ .
- This means that it will require a net torque in order to cause it to have rotational acceleration.
- For an accelerating system, the tension must **change** as it goes over the pulley.



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## Crazy Friday TV Show Bracket Today: Quarterfinals

After the Team-Up Quiz we will be having four quick (15 seconds each!) polls to determine which four shows make it to the semifinals next week. Pick your favourite for each pair.

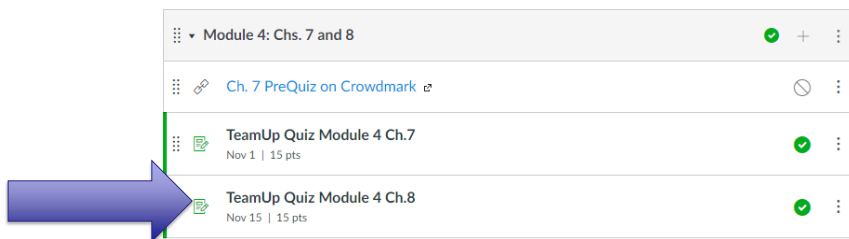
- Queen's Gambit vs
- Better Call Saul
- The Good Place vs
- BoJack Horseman
- What We Do in the Shadows vs
- Tiger King
- Schitt's Creek vs
- Parks and Recreation

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## TeamUp Time!!

- Today you will be doing three multiple choice questions, all from Chapter 9, as a team of 2-4 students in your Practicals Pod.
- Your pod-team shares the mark!
- Right now you should open Microsoft Teams and someone (most recent Facilitator) should place a **video call** to all 3 or 4 members of your Pod-Chat.



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## Now: TeamUp! You have 10 minutes

- The first step is to decide who will be the TeamUp **Driver**
- All students must log-in to Quercus [You will now have three windows open: my zoom lecture, Microsoft Teams, and Quercus]
- **Non-drivers:** Wait!
- **Driver:** Go to the TeamUp Quiz Ch.9 in Module 5, click Go to Tool, then Create a Group. Let everyone in the Breakout Room know the session ID. Then WAIT – don't drive off alone!
- **Non-drivers:** Once you get the session ID, go to the TeamUp Quiz in this module, click Go to Tool, then Join Session and type the ID you were given.
- Once everyone in your room arrives in TeamUp, start going through the questions. Please **achieve consensus** before the driver submits.
- **YOU MAY BEGIN!** I'm going to go on mute for 10 minutes. Note: if your pod-mates are available on Microsoft Teams right now, go to the PHY131 Help Centre and I'll set up breakout rooms there. Zoom Meeting ID: 938 0964 2256, Passcode: 723874

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# Crazy Friday TV Show Bracket

## Today: Quarterfinals

15 second poll. Which do you prefer?

- A. Queen's Gambit
- B. Better Call Saul

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# Crazy Friday TV Show Bracket

## Today: Quarterfinals

15 second poll. Which do you prefer?

- A. What We Do in the Shadows
- B. Tiger King

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# Crazy Friday TV Show Bracket Today: Quarterfinals

15 second poll. Which do you prefer?

- A. The Good Place
- B. BoJack Horseman

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# Crazy Friday TV Show Bracket Today: Quarterfinals

15 second poll. Which do you prefer?

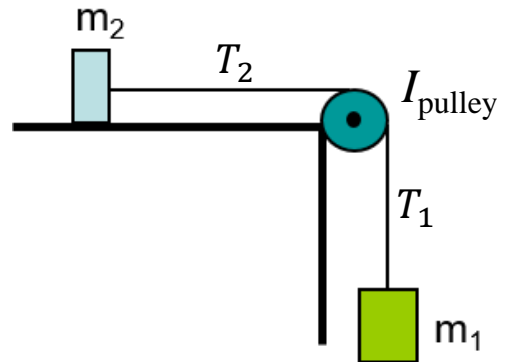
- A. Schitt's Creek
- B. Parks and Recreation

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## Question 1 Discussion

- Mass  $m_2$  is on a frictionless table. It is attached to a cord that wraps around a massive pulley of radius  $R$ , and is attached to a hanging mass  $m_1$ .
- After the system is released, how does the magnitude of the tension in the rope attached to  $m_1$  compare to the magnitude of the force of gravity,  $m_1g$ , on  $m_1$ ?

- A.  $T_1 > m_1g$
- B.  $T_1 < m_1g$
- C.  $T_1 = m_1g$
- D.  $T_1$  and  $m_1g$  cannot be compared

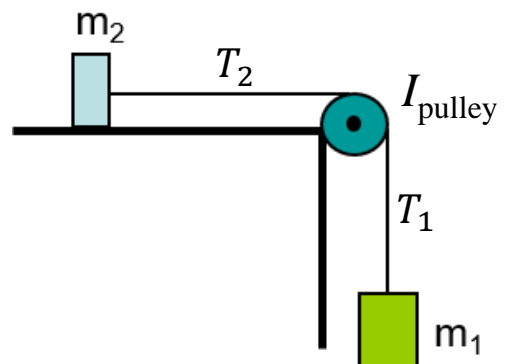


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## Question 2 Discussion

- Mass  $m_2$  is on a frictionless table. It is attached to a cord that wraps around a massive pulley of radius  $R$ , and is attached to a hanging mass  $m_1$ .
- After the system is released, how do the tensions in the two ropes compare?

- A.  $T_1 > T_2$
- B.  $T_1 < T_2$
- C.  $T_1 = T_2$
- D.  $T_1$  and  $T_2$  cannot be compared

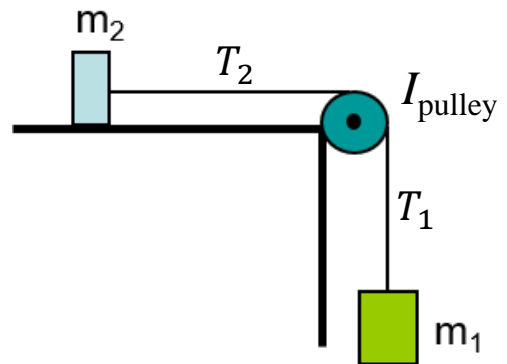


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## Question 3 Discussion

- Mass  $m_2$  is on a frictionless table. It is attached to a cord that wraps around a massive pulley of radius  $R$ , and is attached to a hanging mass  $m_1$ .
- After the system is released, what is the torque on the pulley [define counter-clockwise = positive]?

- A.  $T_1 R - T_2 R$   
 B.  $T_2 R - T_1 R$   
 C.  $T_1 R + T_2 R$   
 D.  $T_1 R$



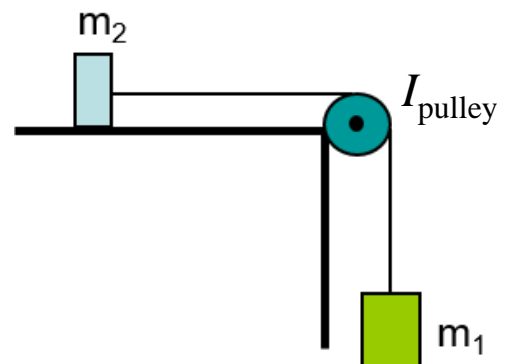
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## The Massive Pulley Constraints

When an object is attached to a pulley, the distance the object travels is equal to the change in angular position of the pulley times the radius of the pulley.

- Distance  $m_2$  and  $m_1$  move is:  $s = \theta R$ , where  $\theta$  is the angle the pulley turns through.
- Speeds of  $m_2$  and  $m_1$  are related to the angular speed of the pulley by:  $v = \omega R$
- Accelerations of  $m_2$  and  $m_1$  are related to the angular acceleration of the pulley by:

$$a = \alpha R$$



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Mass  $m_2 = 2.5$  kg is on a frictionless table. It is attached to a cord that wraps around a massive pulley of radius  $R = 0.20$  m, and rotational inertia  $I = 0.050$  kg m<sup>2</sup>. The same cord is attached to a hanging mass  $m_1 = 0.75$  kg. After the system is released, what is the acceleration of  $m_1$  as it falls?

SKETCH & TRANSLATE.

SIMPLIFY & DIAGRAM

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SIMPLIFY & DIAGRAM

REPRESENT MATHEMATICALLY

SOLVE & EVALUATE

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REPRESENT MATHEMATICALLY

SOLVE & EVALUATE

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## The Vector Description of Rotational Motion

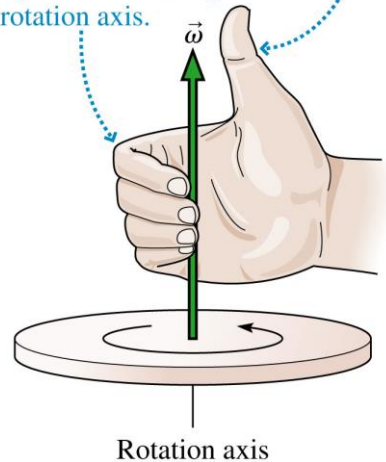
- One-dimensional motion uses a scalar velocity  $v$  and force  $F$ .
- A more general understanding of motion requires **vectors**  $\vec{v}$  and  $\vec{F}$ .
- Similarly, a more general description of rotational motion requires us to replace the scalars  $\omega$  and  $\tau$  with the vector quantities  $\vec{\omega}$  and  $\vec{\tau}$ .
- Doing so will lead us to the concept of *angular momentum*.

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# “The Right Hand Rule”

- The magnitude of the angular velocity  $\vec{\omega}$  vector is  $\omega$ .
- The angular velocity vector points along the axis of rotation in the direction given by the right-hand rule as illustrated.

1. Using your right hand, curl your fingers in the direction of rotation with your thumb along the rotation axis.
2. Your thumb is then pointing in the direction of  $\vec{\omega}$ .



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## Rotational Momentum



- Rotational momentum  
= rotational inertia  $\times$  rotational velocity

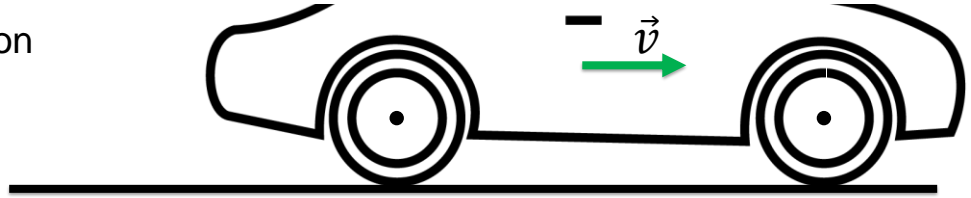
$$\vec{L} = I\vec{\omega}$$

- This is analogous to  
Linear momentum = mass  $\times$  velocity

$$\vec{p} = m\vec{v}$$

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Poll Question



You are driving your car towards the right.

What is the direction of the angular momentum,  $\vec{L}$ , of the wheels?

- A. Left
- B. Right
- C. Up
- D. Down
- E. Into the page
- F. Out of the page

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## Conservation of Angular Momentum

An isolated system that experiences no net torque has

$$\frac{d\vec{L}}{dt} = \vec{\tau}_{\text{net}} = \vec{0}$$

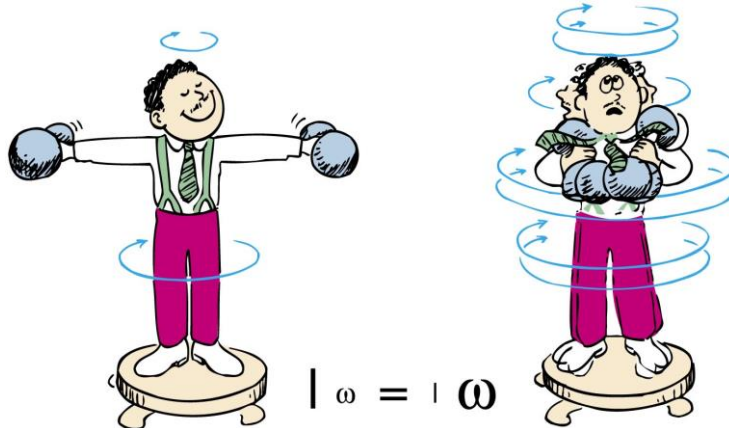
and thus the angular momentum vector  $\vec{L}$  is a constant.

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# Conservation of Angular Momentum

Example:

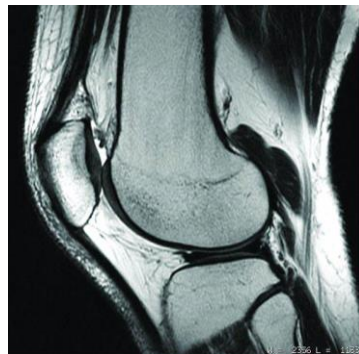
- When the professor pulls the weights inward, his rotational speed increases!



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## Nuclear Magnetic Resonance

- A proton in the nucleus of an atom is rotating like a little spinning top.
- When placed in a strong static magnetic field, the magnetic force produces a torque on the proton, which causes it to precess at a lower rate than the spin; similar to the hanging bicycle wheel demonstration.
- The precession frequency is in the radio-frequency range, which allows the proton to absorb and re-emit radio-waves.
- This allows doctors to image inside the human body using harmless radio waves.



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# Before Class 28 on Monday

- Please finish reading all of Chapter 9:
- 9.5 Rotational Kinetic Energy
- 9.6 Tides and Earth's Day
  
- Something to think about: why is there a tiny gyroscope in your phone?

