**Announcements**

1. You can pick up your exams, same spot as last time (N357, ESC)
2. Solutions will be posted same place as last time (near N361, ESC)
3. Look over your exam and the solutions, before talking to me.
   a. If you can’t figure something out after that point, I’m happy to discuss it with you.
4. We threw out exam problem 8 (gave everyone full credit). That’s the one with the weightlifter; it was a bit ambiguous that he was holding the weights at the start of the problem (weights could have been resting on scale).
5. Video: solving physics problems

**Review of Torques**

Definition of torque: (about a point)

\[ \tau = r \perp F = r F \perp = r F \sin \theta \]

Equilibrium:

\[ \sum F = 0 \quad \sum \tau = 0 \]

Positive/negative:

- Produces a clockwise rotation = negative
- Produces a counter-clockwise rotation = positive

Translation:

- if an object is not accelerating, the sum of the forces on it must be equal to zero
- if an object is not speeding up or slowing down its rotation, then the sum of the torques on it must be equal to zero

**Rotational kinetic energy**

**Demo**: Rolling object

Kinetic energy of a “point object” rotating about a center:

Write in terms of \( \omega \):

Moment of inertia:

\[ I_{pt \ mass} = mr^2 \]

Kinetic energy in terms of \( I \) and \( \omega \):

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

I for two masses on a rod?

\[ I = I_1 + I_2 + \ldots \]

**Demo**: rod with masses, different points for axis

Calculate \( I \) about axis A

Q4. Which has the largest \( I \): rotating about axis A, B or C? (C is into the page)
Extended objects

Must add up $mr^2$ for each bit of mass in the object

Which bits of mass contribute the most to $I$?

Which objects have the largest $I$?

Hoop/cylindrical shell

Solid disk/cylinder

Solid sphere

Which kind of rolling object is moving the fastest at bottom of an incline? Which got there first?

Sphere, disk or hoop, or all the same? _________

Does it depend on M, R? ____________

Demo: racing objects down incline

![Moments of Inertia for Various Rigid Objects](image)

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Worked Problem: An object with moment of inertia $I$ rolls down a height $h$ without slipping. Find the speed at bottom.

Tactic: Conservation of energy!

![Without rolling:](image)

Q5. If they continue on, which would go the farthest up a hill on the other side?

a. hoop
b. solid disk
c. solid sphere
d. all the same height at the end

Newton’s second law for rotation

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

still also have $\sum \vec{F} = m\vec{a}$

(but accel. of what?)

Example: Find downward acceleration of yo-yo as it unrolls.

Given mass $m$, radius of yo-yo $R$, different radius of rotation $r$ (where string is)

Moment of inertia, assuming cylindrical yo-yo (neglect the small gap): ____________

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Example: Falling mass and solid disc flywheel

Draw FBDs:

\[ \sum \tau = I \alpha \]

for the flywheel

\[ \sum \vec{F} = m\vec{a}_{cm} \]

for the bucket.

Find \( \alpha \) and \( a \)

Q6. 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.

Q7. As the mass falls, the disk with the largest \( \omega \) is:
   a. the large disk
   b. the small disk
   c. neither; same

Q8. The disk with the largest rotational kinetic energy is:
   a. the large disk
   b. the small disk
   c. neither; same
   (hint: look at how I and \( \omega \) may vary)

Q9. Mary and Fred are rolling a large tire down a hill. Mary says it will go faster if Fred gets inside the tire as shown and rolls down with it. Fred’s not sure. What do you think?
   a. It will go faster
   b. It will go slower
   c. It will take the same time

Q10. Did you discuss at least half of the discussion quiz questions today with a neighbor?
   a. Yes  
   b. No