Please turn in Homework 7. I will hand out solutions once everyone is here. The handout also includes HW8 and a page or two of updates to the equation sheet needed to work the HW8 questions.

Remember that I try to keep the equation sheet updated online at

http://positron.hep.upenn.edu/wja/phys008/equations.pdf

I know that Chapters 10, 11, 12 have been very difficult to absorb. Try to look over the HW8 questions over the weekend, and let me know (email or online form) if there are a couple of questions that you’d like me to sketch out in class on Monday or Wednesday.
I want to tighten a bolt to a torque of 1.0 newton-meter, but I don’t have a torque wrench. I do have an ordinary wrench, a ruler, and a 1.0 kg mass tied to a string. How can I apply the correct torque to the bolt?

(A) Orient the wrench horizontally and hang the mass at a distance 0.1 m from the axis of the bolt

(B) Orient the wrench horizontally and hang the mass at a distance 1.0 m from the axis of the bolt
If the wrench is at 45° w.r.t. horizontal, will the 1.0 kg mass suspended at a distance 0.1 m along the wrench still exert a torque of 1.0 newton-meter on the bolt?

(A) Yes. The force of gravity has not changed, and the distance has not changed.

(B) No. The torque is now smaller — about 0.71 newton-meter.

(C) No. The torque is now larger — about 1.4 newton-meter.
The angular equivalent of $F = ma$

$$\tau = I \alpha$$

Let’s try it . . .
\[ \vec{\tau} = I \dot{\vec{\alpha}} \quad \Rightarrow \quad \alpha = \frac{\vec{\tau}}{I} \]

\[ I = \sum M_i R_i^2 \]

\[ \vec{\tau} = \vec{r} \times \vec{F} \quad \Rightarrow \quad |\vec{\tau}| = rF \sin \theta_{rf} = rF \quad (r \perp F) \]

\[ \frac{d\omega}{dt} = \alpha = \frac{r \text{ (tension)}}{I} = \frac{r (mg - ma)}{I} = \frac{r \ mg}{mr^2 + I} \]

**angular acceleration:**

\[ \alpha = \frac{r_{\text{wheel}} \ mg}{mr_{\text{wheel}}^2 + \sum M_i R_i^2} \]
To tighten a bolt, I apply a force of magnitude $F$ at different positions and angles. Which torque is \textit{largest}?
To tighten a bolt, I apply a force of magnitude $F$ at different positions and angles. Which torque is smallest?
People asked about torques in architecture and (closely related) mechanical equilibrium. We will spend a big part of weeks 11–12 on this, but you’ll start to get the flavor of it in next week’s homework. For example:

15. You want to hang a 10 kg sign (shown at right) that advertises your new business. To do this, you attach a 5.0 kg beam of length ℓ to a wall at its base by a pivot P. You then attach a thin cable to the beam and to the wall in such a way that the cable and beam are perpendicular to each other. The beam makes an angle of 37° with the vertical. You hang the sign from the end of the beam to which the cable is attached. (a) What must be the minimum tensile strength of the cable (the amount of tension it can sustain) if it is not to snap? (b) Determine the horizontal and vertical components of the force the pivot exerts on the beam.
Tricky questions from HW6 (last week)?

1. The sign hanging between two buildings of unequal heights (see figure) has an unknown inertia. The tension in the cable attaching the sign to the building on the right is 80 N. (a) What is the tension in the cable attaching the sign to the building on the left? (b) What is the inertia of the sign?
2. You leave your house and walk east for 1.0 hr, northeast for 1.5 hr, south for 1.0 hr, and southwest for 2.5 hr, always moving at the same speed. Realizing it is going to get dark soon, you then head directly home. How long does it take to walk directly home if your speed stays the same as it was on every leg of the walk?
14. You have to specify the power output of a motor for a ski tow rope that will carry twenty passengers at a time, each having an average inertia of 60 kg. The grade of the ski slope is 32° above horizontal, and the average coefficient of kinetic friction between skis and snow is 0.12. You decide that 3.0 m/s is a safe speed to be towed up the slope. What must the minimum power output of the motor be?
When you are about to fall over the edge of a precipice, you instinctively wheel your fully extended arms rapidly in vertical circles. What does this accomplish?

(A) It accomplishes nothing because there is no external torque, since my arms are part of my body

(B) When I spin my arms counterclockwise (as drawn in picture), conservation of angular momentum pushes my body’s center of mass clockwise, with my feet as the pivot point, and this may help me not to fall

(C) I think argument (B) sounds good in theory, but I’m skeptical about how well it really works in practice
If you look at the face of a clock, whose hands are moving clockwise, do the rotational velocity vectors of the clock’s hands point toward you or toward the clock?

(A) Toward me
(B) Toward the clock
(C) Neither — when I curl the fingers of my right hand toward the clock, my thumb points to the left, in the 9 o’clock direction
David is twirling a rock in a sling overhead. At which point (a,b,c,d) should he release the rock, if he wants to hit Goliath? (Notice the two perpendicular axes drawn as dashed lines.)
This structure is made of 3 identical rods of uniform density. About which axis is rotational inertia *smallest*?
This structure is made of 3 identical rods of uniform density. About which axis is rotational inertia *largest*?
<table>
<thead>
<tr>
<th>Translation</th>
<th>Rotation</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \vec{p} = m\vec{v} )</td>
<td>( \vec{L} = I\vec{\omega} )</td>
<td>( \vec{L} = \vec{r} \times \vec{p} )</td>
</tr>
<tr>
<td>( \Delta \vec{p} = \sum \vec{F}_{ext} \Delta t )</td>
<td>( \Delta \vec{L} = \sum \vec{\tau}_{ext} \Delta t )</td>
<td></td>
</tr>
<tr>
<td>( \sum \vec{F}<em>{ext} = \frac{d\vec{p}}{dt} = ma</em>{cm} )</td>
<td>( \sum \vec{\tau}_{ext} = \frac{d\vec{L}}{dt} = I\vec{\alpha} )</td>
<td>( \vec{\tau} = \vec{r} \times \vec{F} )</td>
</tr>
<tr>
<td>( K_{cm} = \frac{1}{2} mv^2 )</td>
<td>( K_{rot} = \frac{1}{2} I\omega^2 )</td>
<td></td>
</tr>
<tr>
<td>( \Delta K_{cm} = (\sum \vec{F}<em>{ext}) \cdot \Delta \vec{r}</em>{cm} )</td>
<td>( \Delta K_{rot} = (\sum \vec{\tau}_{ext} \theta) \Delta \theta )</td>
<td></td>
</tr>
</tbody>
</table>
This is a demo, not a homework problem!

A bicycle wheel is set spinning as shown. A string is tied to one end of the axle, and someone is holding up the string. Use torque arguments to explain why the wheel slowly precesses horizontally around the string end of the axle when the free end of the axle is released. Why does the precession speed increase as time passes?
A bicycle wheel is set spinning as shown. A string is tied to one end of the axle, and someone is holding up the string. Use torque arguments to explain why the wheel slowly precesses horizontally around the string end of the axle when the free end of the axle is released. Why does the precession speed increase as time passes?

\[
\frac{dI}{dt} = \vec{\tau} = \vec{r} \times \vec{F}
\]

so \( \frac{dI}{dt} \) points into the page

\[
F = -mg \quad \text{(downward)}
\]
I will probably go through this problem and one or two others from HW8 in class on Monday. If there are topics/problems from HW6 or HW7 that you still find confusing even after looking at my solutions, please tell me so (either email or online form) ASAP, and I will try to cover the most popular ones on Monday.

A 215 g can of soup is 10.8 cm tall and has a radius of 3.19 cm. (a) Calculate its theoretical rotational inertia, assuming it to be a solid cylinder. (b) When it is released from rest at the top of a ramp that is 3.00 m long and makes an angle of 25° with the horizontal, it reaches the bottom in 1.40 s. What is the experimental rotational inertia? (c) Compare the experimental and theoretical rotational inertias and suggest possible sources of the difference.
5. A race car driving on a banked track that makes an angle θ with the horizontal rounds a curve for which the radius of curvature is $R$. (a) There is one speed $v_{critical}$ at which friction is not needed to keep the car on the track. What is that speed in terms of θ and $R$? (b) If the coefficient of friction between the tires and the road is $\mu_s$, what maximum speed can the car have without going into a skid when taking the curve?
Problem 5 (HW7)
(b) There is a normal force $F^N$ perpendicular to the road (pointing upward and a little bit inward), a frictional force $\mu F^N$ parallel to the road (pointing inward and a little bit downward), and a downward gravitational force $mg$. The vertical forces must sum to zero:

$$F^N \cos \theta - \mu F^N \sin \theta - mg = 0 \quad \Rightarrow \quad F^N = \frac{mg}{\cos \theta - \mu \sin \theta}$$

The horizontal forces must sum to the required centripetal force:

$$F^N \sin \theta + \mu F^N \cos \theta = \frac{mv^2}{R}$$

$$\frac{mg \left( \sin \theta + \mu \cos \theta \right)}{\cos \theta - \mu \sin \theta} = \frac{mv^2}{R} \quad \Rightarrow \quad v = \sqrt{gR \frac{\sin \theta + \mu \cos \theta}{\cos \theta - \mu \sin \theta}}$$

(a) Setting $\mu = 0$ above,

$$v = \sqrt{Rg \tan \theta}$$