Assignment VIII, PHYS 111 (General Physics I)
Fall 2016
Due 11/4/16 at start of class

As always, please put your clearly written answers on separate paper.

1. A car engine idles at about 800 rpm (rotations per minute, or – equivalently – revolutions per minute). If, after turning your car off, the engine stops running completely in 0.7 seconds, what is the rotational acceleration of the engine during the "turning-off" process? You may assume α is constant.

2. A car tire with a 28 inch diameter is rolling (without slipping), helping to support a car that is driving down the road at an initial speed of 40 miles per hour. If the car decelerates with $a = -3$ m/s^2, what is the angular deceleration of the car tire on its axis?

3. At times, massive astronomical bodies can suddenly collapse. Let's let a spinning star have initial moment of inertia $I_\circ$. If, suddenly, the star collapses in such a way that now the star has rotational inertia $\frac{I_\circ}{4}$, what is the ratio of the final rotational kinetic energy to the initial kinetic energy. (Note: $\omega_f \neq \omega_i$).

4. I once visited a data-center that used a giant flywheel to store kinetic energy that would enable the entire facility to keep running for a few seconds after a power-outage. The idea behind this is that you use a motor to get a system with a large amount of rotational inertia rotating while the power is still on and keep the thing rotating at all times when the power is on. If the power turns off, the flywheel will still keep turning for a little while and the motion of that flywheel can power your building's electricity through its motion (much like a turbine or water wheel). The details are unimportant for this problem, other than the fact that you can take the rotational kinetic energy of the flywheel and convert it back into electrical energy to power the thing you care about for a little while.

   Let's say that the building had to power 300 computers, each having requiring about 500 Watts to keep them running. You want your flywheel to power everything for 10 seconds – enough time for backup generators to kick on and start running and take over. The flywheel is constructed from a solid steel disk. (The density of the steel is 7600 kg/m^3). If the flywheel is 0.1 meters thick, and is rotated at a constant velocity of, say, 3 rotations per second about its center, what would its radius have to be in order to meet the energy requirements of keeping all the computers running for 10 seconds? (Recall that the moment of inertia of a solid disk is $\frac{1}{2}MR^2$). Assume that the energy stored in the flywheel can be completely converted back to electrical energy with perfect efficiency.

   (In case you are curious, they previously used a bank of several hundred car batteries to do this task for them. That ended up being impractical).

5. Two astronauts, each with mass M, are connected by a rope of length d having negligible mass. They are isolated in space, orbiting their center of mass with each moving at speed v. Calculate:

   a) The magnitude of the angular momentum of the system (in terms of M, v, and d). (Assume the astronauts are point particles).

   b) The rotational energy of the system (in terms of M, v, and d).

   By pulling the rope, the astronauts shorten the distance between them to $d/2$.

   c) What is the new angular momentum of the system? (again, in terms of M, v, and d).

   d) What are their new speeds?

   e) What is the new rotational energy of the system?

   f) How much work is done by the astronauts in shortening the rope?

6. A wedge of height H and wedge-angle $\theta_\circ$ has a number of different items move down it.

   a) If a solid sphere of radius R and mass M starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the sphere to reach the bottom of the wedge?

   b) If a disk of radius R and mass M starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the disk to reach the bottom of the wedge?

   c) If a hoop of radius R and mass M starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the hoop to reach the bottom of the wedge?

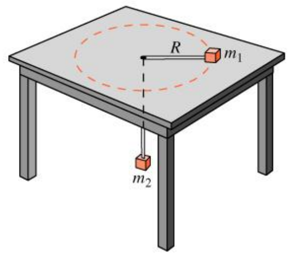
   d) If a mass (irrelevant shape) of radius R and mass M starts from rest at the top of the wedge and slides (frictionlessly) down the wedge, how long does it take the mass to reach the bottom of the wedge?

7. A cylinder with moment of inertia 4 kg m^2 about a fixed axis through its center initially rotates at 80 radians per second about this axis. A constant torque is applied to slow it down to 40 radians per second.

   a) How much kinetic energy is lost by the cylinder?

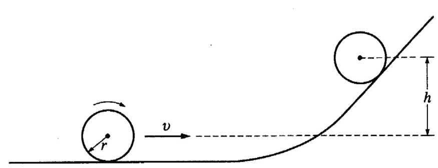
   b) If the cylinder takes 10 seconds to reach 40 radians per second, what is the magnitude of the applied torque?

8. A block of mass m_1 slides in a circular path of radius R on a frictionless table. The mass is connected via an inextensible massless string to a mass m_2 hanging below the table. What is the speed of m_1?



9. A spherical ball ($I = \frac{2}{5}mr^2$) rolls without slipping on a flat surface with its center of mass moving at initial velocity v as shown below.

   a) How high h up the incline does the ball get before momentarily stopping? Leave your answer in terms of v (the initial velocity of the center of mass of the ball), m (the mass of the ball), r (the radius of the ball), g, and/or any other fundamental constants that are necessary.
   b) Assume that, instead of rolling without slipping, the ball slides on the surface shown. (Let the surface be completely frictionless). Assume that the ball doesn't rotate at all. If the ball moves with an initial velocity v as shown (but doesn't rotate at all), then how high up the incline h does the ball get before momentarily stopping?
   c) Which is larger, your answer to part (a) or your answer to part (b)?



10. A negligible thin rod of length $2L$ runs along the x-axis from the point $-L\hat{\imath}$ to the point $L\hat{\imath}$. The ends of this rod mark the midpoints of two solid spheres, each with radius $R < L$ (so that there's a sphere of radius R centered at each of the two end points $-L\hat{\imath}$ and $L\hat{\imath}$). (This system looks like an old-school "barbell"). Let the rod have mass m and each sphere have mass M. By construction, the center of mass is at the origin no matter what m and M are. For this system:

    a) Find the moment of inertia of the whole system through the axis that goes through the origin and points in the y direction.
    b) Find the moment of inertia of the whole system through the x-axis.
    c) [Extra Credit]: Introductory texts give the following simple approximation for the nuclear radius: $R \approx (1.2 \times 10^{-15}\text{ m})A^{1/3}$ where A is the number of nucleons (protons and neutrons) in the atom. The bond-length of an N_2 molecule is approximately 145×10^{-12} m. Assuming that the bond itself has negligible mass, calculate I_y/I_x for an N_2 molecule using the basic theoretical model described above.