7^{th} Homework
Due: 29 November 2007

1. Explain how a Yo-yo works. Explain why it rolls up if you pull it vertically upwards.

2. Consider sphere of mass M and radius R. Assume that it is initially rotating around an axis parallel to the ground, and then placed on the ground. Let μ_s be the coefficient of static friction and μ_k the kinetic friction between the sphere and the ground. Initially, since it does not have any translational motion, it will be rolling with slipping. Due to friction, it will start accelerating forward until it will be doing a rolling motion without sliding. If x is the distance the sphere travels until it starts rolling without slipping, calculate x. What will be the final angular velocity? What is the amount of energy lost due to friction? Is this work equal to $W_f = F_f x$ where F_f is the frictional force and $x$is the total distance traveled until the rolling without slipping motion starts. If $W_f \neq F_f x$, why?

3. A Uniform solid sphere of mass M and radius R hangs from a string of length $R/2$. Suppose the sphere is released from an initial position making an angle of 45° with the vertical

   (a) Calculate the angular velocity of the sphere when it swings through the vertical position.

   (b) Calculate the tension in the string at this instant.

   (H. C. Ohanian, "Physics," Pg349, Q25)

4. The maximum positive acceleration an automobile can achieve on a level road depends on the maximum torque the engine can deliver to the wheels.

   (a) The engine of a Maserati sports car delivers a maximum torque of 441 Nm to the gear box. The gear box steps down the rate of revolution by a factor of 2.58; that is whenever the engine makes 2.58 revolutions, the wheels make 1 revolution. What is the torque delivered to the wheels? Ignore frictional losses in the gear box.

(b) The mass of a car (including fuel, driver, etc.) is 1770 kg and the radius of its wheels is 0.30 m. What is the maximum acceleration? Ignore the moment of inertia of the wheels and frictional losses.

(H. C. Ohanian, "Physics," Pg349, Q26)

5. Five identical books are to be stacked one on top of the other. Each book is to be shifted sideways by some variable amount, so as to form a curved leaning tower with maximum protrusion. How much must each book be shifted? What is the maximum protrusion? If you had an infinite number of books, what would be the limiting maximum protrusion? (*Hint:* Try this experimentally; start with the top book; and insert the others underneath, one by one) (H. C. Ohanian, "Physics," Pg372, Q18)

6. A power brake invented by Lord Kelvin consists of a strong flexible belt wrapped once around a spinning flywheel. One end of the belt is fixed to an overhead support; the other end carries a weight w. The coefficient of kinetic friction between the belt and the wheel is μ_k. The radius of the wheel is R and its angular velocity ω

   (a) Show that the tension in the belt is

   $$T = we^{-\mu_k \theta}$$

   as a function of the angle of contact.

   (b) Show that the net frictional torque the belt exerts on the flywheel is

   $$\tau = wR\left(1 - e^{-2\pi\mu_k}\right)$$

   (c) Show that the power dissipated by friction is

   $$P = wR\omega\left(1 - e^{-2\pi\mu_k}\right)$$

   (H. C. Ohanian, "Physics," Pg375, Q35)