9^{th} Homework
Due: December 19, 2008

1. Question

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

   (b) Many farmers have been injured when their tractors suddenly flipped over backward while pulling a heavy piece of farm equipment. Can you explain how this happens?

   (c) If you give a hard boiled egg resting on a table a twist with your fingers, it will continue to spin. If you try doing the same thing with a raw egg, it will not. Why?

   (d) Why does the front end of an automobile dip down when the automobile is breaking sharply?

   (e) Stand a pencil vertically on its point on a table and let go. The pencil will topple over.

      i. If the table is very smooth, the point of the pencil will slip in the direction opposite to that of the toppling, why?

      ii. If the table is somewhat rough, or covered with a piece of paper, the point of the pencil will jump in the direction of the toppling. Why? (*Hint:* During the early stages of the toppling, friction holds the point of the pencil fixed; thus the pencil acquires a horizontal momentum)

      iii. If the legs of a table are of exactly the same length and if the floor is exactly flat, then the weight of the table will be equally distributed over all four legs. But if there are small deviations from exactness, then the weight will not be equally distributed. Is it possible for all of the weight to rest on three legs? On two?

2. 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)

3. 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)

4. 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)

5. 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)