1995-1996 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 2: Mechanics

Due November 13^{th}*, 1995*

1. A fire broke out in your building and you are trapped on the roof. Upon looking around, you find a bungee cord and a harness for it. Being a person who likes to show off, you decided to bungee-jump off flagpole at the top of the building of this and release the harness at the bottom.

   The initial length of the bungee cord is 30 m and $k = 77$ kg/sec^2. The height of the building+flagpole is 60 m (See Figure 1).

   (a) How much bungee cord do you need if you want to have a perfect landing (i.e. $v = 0$)? Assume that you are a point particle with mass of 55 kg.

   (b) So you jumped, but it hit you that the tensile strength times the cross section of the bolt that holds the flagpole that the bungee cord is tied to is T. What's the minimum T you need in order not to be squashed on the ground?

2. Suppose you are a high school student (well, you are) who enjoys working on physics problems. One day your physics teacher asks you to try physics olympiad preparation problems. And you see the following dull questions prepared by a desperately dull guy.

   (a) A yoyo is on a level surface (Figure 2 (a)). A gentle horizontal pull is exerted on the cord so that the yoyo rolls without slipping. The yoyo will roll toward the pull. Why?

   (b) Now a yoyo is sitting on a wedge (Figure 2 (b)). Calculate the force needed on a cord to have the yoyo stationary when it is released. What is the minimum friction coefficient needed to make the yoyo stationary in this condition? Assume that the yoyo is a cylindrical object and the width of its groove is negligible.

   (The moment of inertia of a cylindrical object that has a rotational axis parallel to the axis passing through the centre of mass, which is perpendicular to the flat surface is $I_R = I_M + aM$ where a is the distance of the rotational axis from the principal axis, M is the mass of the cylinder, and I_R and I_M are the moments of inertia about the axis of rotation and about the axis passing through the centre of mass, respectively.)

3. For all your life you wanted to be a geek. Now your life long dream is about to come true. You've been noticed and invited to a prestigious geek party. But you have to answer questions correctly to be accepted as one of the geeks.

   (a) A marble is resting on the top of an overturned popcorn bowl shaped like a hemisphere (See Figure 3 (a)). The radii of the popcorn bowl and the marble are R and a, respectively. At what height, in terms of R, will the marble be airborne if the marble rolls down without slipping?

   (b) Now, the bowl is put upright (Figure 3 (b)). If you let go of the marble near the bottom of the bowl it will oscillate. Compared to a simple pendulum of length $(R - a)$, will the period of oscillation be shorter, the same, or longer? Why? A *big* brownie point will be awarded if you can give a quantitative answer.

4. You are an agent of Her Majesty's Secret Service and are being followed by goons from an organization whose plan is to conquer the world by taking control of the world's gummybear production. You decide to shake the pursuit. Your car sensor indicates that a turn with a radius 30 m lies ahead. Your car

weighs 1500 kg and its centre of mass is 40 cm above the ground. You can approximate your car to have the dimensions $500 \times 200 \times 80$ cm^3 ($length \times width \times height$).

(a) Your car is equipped with a set of SuperSticky tires[tm] (which means the friction coefficient is very, very big). But you realise that you have a cup of coffee without a lid in your cup holder and you do not want to spill the coffee on the rather expensive leather seat but you don't want to throw it away either. (The car pool department is going to raise hell if they find coffee stains on the leather seat.) How fast can you go without spilling your coffee? The coffee cup is 8 cm in diameter and 15 cm tall and 4/5 full. Assume that all four wheels of the car stay on the road without slipping.

(b) Oww, bloody hell, they start shooting at you and, to make it worse, the sensor indicates that the pavement is wet and the friction coefficient of the tire/pavement has dropped to $\mu = .23$ Good thing your car is equipped with an aerodynamic device that produces a downward force of $150 \times v$ N (v in km/h). Forget about ruining leather seats. Your life is on the line. How fast can you go without slipping (and falling from a cliff) or raising inside wheels (probably resulting in loss of control)?

5. Eeck!!! Computers at the satellite control centre are down and you are asked to transfer a $\$1.0 \times 10^9$ communication satellite from a parking orbit ($h = 200$ km) to a circular geosynchronous orbit manually. Due to engine controller malfunction you can use only two short thruster bursts. You are to use an elliptical transfer orbit whose perigee meets the lower parking orbit and apogee meets the geosynchronous orbit. Assume that the thruster expended is negligible. If you succeed, you will get your boss' eternal gratitude for saving his/her/its butt; but if you fail, you will lose your job and more.

   (a) What is the Δv required to put the satellite to a transfer orbit from the parking orbit? Also, what is the Δv needed to put the satellite from the transfer orbit to the geosynchronous orbit?

   (b) How long does the transition take?

6. Pat and Chris bought two identical pendulum clocks at X, which is on the equator. Their next destination is Y, which lies exactly on opposite side of the earth. But their travel agency screwed up and Pat has to take a westbound plane and Chris has to take an eastbound plane, where both planes' routes follow the equator. They arrive at Y exactly 12 hours later at X local time.

   (a) Do the two clocks agree with each other? (Well, obviously not.) If not, what are the effects that would make them not agree?

   (b) Find the time difference between Pat's and Chris' clocks at Y. Consider only the most important physical effect.

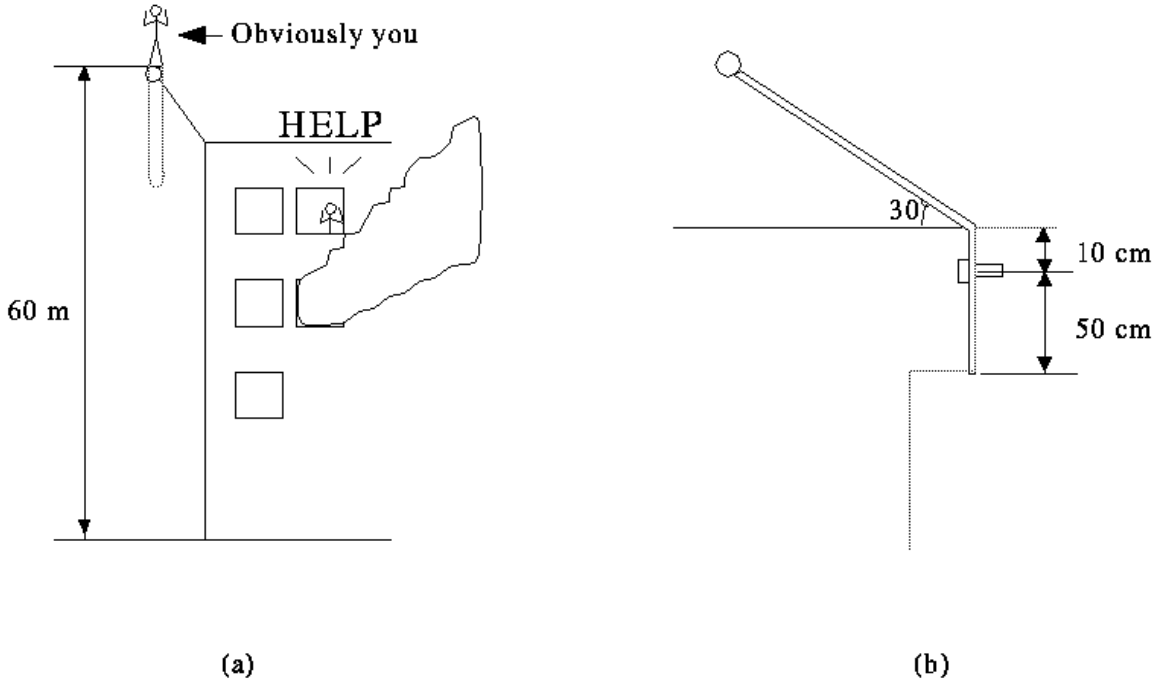

Figure 1: Figure for Problem 1.

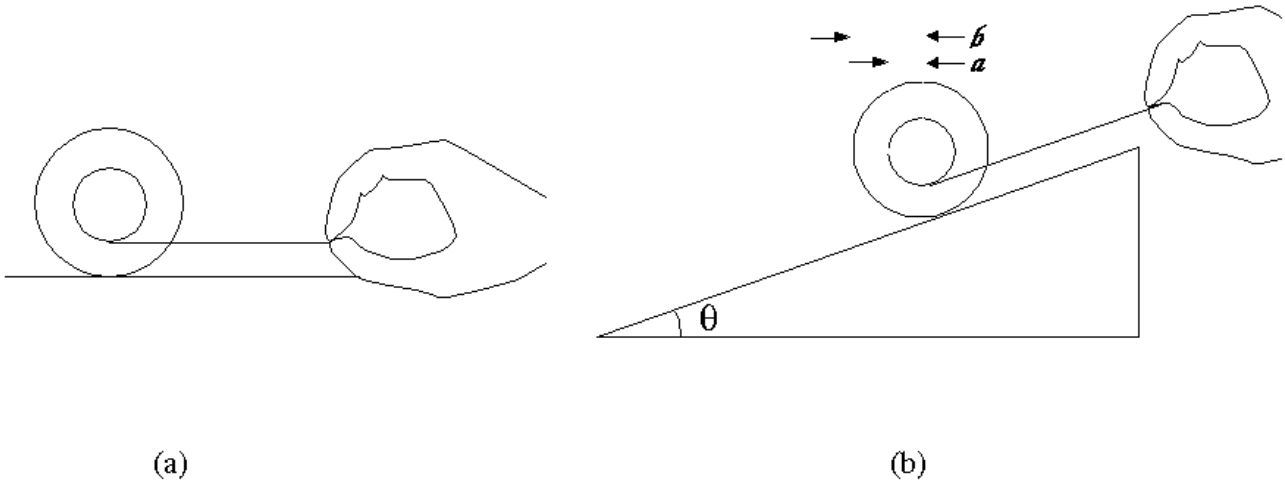

Figure 2: Figure for Problem 2.

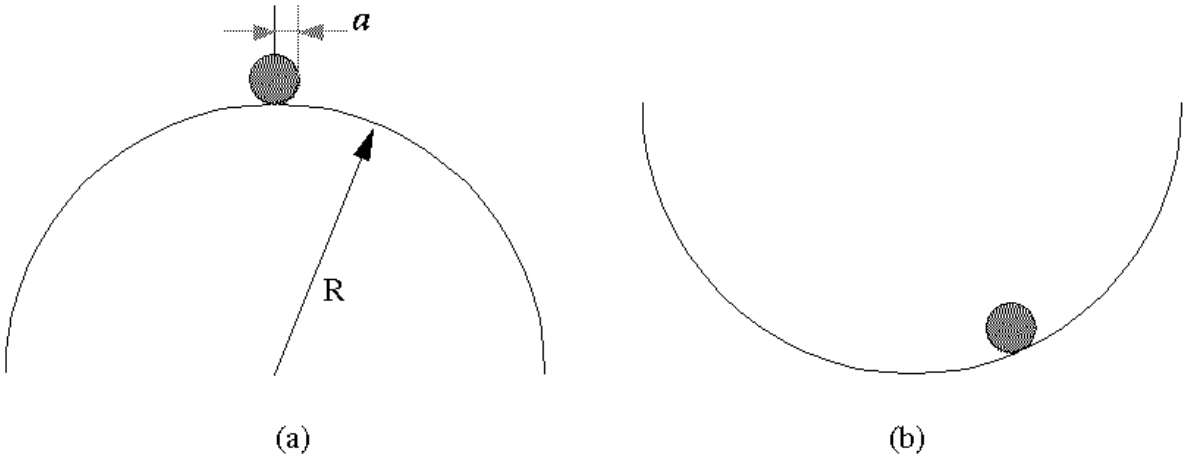

Figure 3: Figure for Problem 3.