1995-1996 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 1: General Physics

Due October 16, 1995

1. Joe "build-em tall" Girders is designing a construction crane (did you know he learned his stuff working with Tinker Toys?). He uses two beams with mass $m_1 = 9000$ kg and $m_2 = 3000$ kg with lengths $l_1 = 45$ m and $l_2 = 15$ m, attached to the vertical "trunk" of the crane and supported by cables, as shown in Fig 1.

   (a) How much mass, m_c, should there be in the counterweight located at the end of the second beam to ensure that the crane is perfectly balanced when the crane is not carrying a load.

   (b) The cable support has a height $h = 15$ m. What are the tensions on the two cables supporting the beams?

2. In the original movie *Batman*, our masked avenger has a cool get-away planned when he and Vicky Vale, the hot-shot reporter, are trying to escape the Joker after the debacle in the museum (check out the movie if you folks forget this scene). He fires up one of his awesome cables and attaches it to a girder above the street. With his super-cool winch located on his belt, he begins to lift the two of them out of harm's way. But wait! He only gets part way up. His winch appears to run out of juice. As he and Vicky twist in the wind, he ponders his potentially fatal mistake.

   (a) What is the minimum energy required to lift the two of them up 15 m, if we assume Batman tips the scale at a fit 75 kg and Vicky really does weigh 47 kg (as she claims)?

   (b) They have to be rising at least 1 m/s in order to avoid getting plastered by Joker's henchmen. What is the power required to execute this daring move?

   (c) In the movie, after Batman hooks the winch to Vicky and lets go, she is winched up the rest of the way to the girder. Can you give a plausible explanation as to what really went wrong with the winch? Did it really run out of energy?

3. Sven is tooling down Highway 11/17 with a tractor-trailer load of pulp wood to be fed into the maw of the MacBlo mill in Fort Frances. He is doing 120 km/h, easy. He comes around a corner and finds – what else? – the icon of the northern Ontario bush, a moose, standing in the middle of the road. The old pro that he is, Sven hits the brakes. He is about 150 m from the moose when his size 13 work boot hammers the brakes.

   (a) How heavily does he have to brake to avoid bagging a moose out of season (and making a mess of his front end)?

   (b) He is still in the curve when he starts braking, so his trailer filled with cord wood makes a small angle with the tractor unit. He realises as he hits the brakes that he forgot to connect his trailer brakes, so that all braking is performed by the tractor unit. It has been snowing (what else can go wrong?) so the coefficient of static friction between his wheels and the asphalt is $\mu_s = 0.2$. What is the maximum angle his trailer unit can make with the tractor unit before it starts to jacknife (the truly awesome maneuver when the trailer starts sliding and swings around)?

4. Rob Hanks was a wild and crazy man. By day he worked as an electrician for General Motors, but by night he assumed a secret identity, one that no soul knew a thing about – he became a *physics problem solver*. Now Rob often works with AWG #12 copper wire with an 80.8 mil diameter. He already knows that a 50 ft length can carry a current of 20 A, and that copper has a conductivity of $\sigma = 5.8 \times 10^7\ \Omega^{-1}\mathrm{m}^{-1}$ and an electron mobility of $\mu = 0.0032\ \mathrm{m}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$ at 20 °C. Can you help Rob calculate the electric field intensity E, the voltage drop and resistance across the 50 ft length, and the time it would take an electron to move a distance of 1 cm in the conductor?

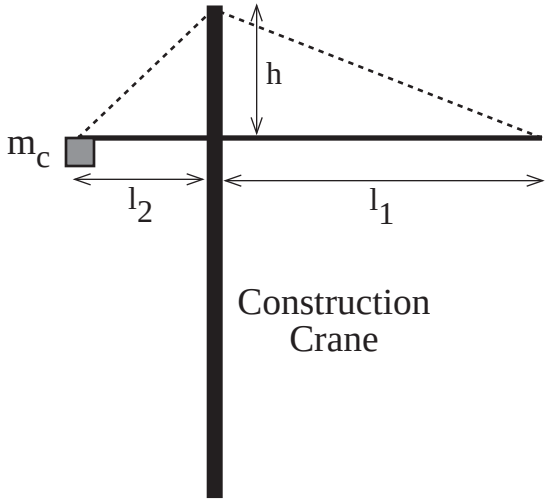

Figure 1: The construction crane in Problem 1.

5. Wanda Steerbutton was a world-class magazine photographer. She earned her living taking quality shots of supermodels, rock bands, movie stars, and politicians for the covers of those glossy magazines that people only seem to buy in airports and train stations. It was a good life, but she wanted more. Understanding the secrets of the universe sounded like a cool idea; besides, it would be a nice change from looking at people's pores through a viewfinder. So Wanda decided to take up astrophysics. Since she already owned a fancy camera, and since one of her lab courses involved photographing stars in the night sky, Wanda wondered whether she could use one of her precision engineered fixed focus lenses for the job. The lens in question had a focal length of 60 mm and was focussed for objects at a distance of 15 m. The problem was that stars are at a distance that is a little more than 15 m, like infinity maybe. Her lens did, however, have an adjustable aperture. For what aperture diameter would the diffraction blur of visible light ($\lambda = 550$ nm) be more or less the same as the defocus blur for a distant star?

6. The starship *Compromise*, the lesser known sister ship to the Federation's *Enterprise*, is to undergo an "upgrade" to its transporter control system under the supervision of your aging systems engineering professor at Starfleet Academy. She has asked you to design logic circuitry that will enable the transporter to function for the following three Away Team scenarios:

   - An android (A), the captain (C), and another senior officer (S) are all part of the Away Team;
   - An android (A), the captain (C), and another senior officer (S) are **NOT** part of the Away Team;
   - The captain (C) is a member of the Away Team.

   (a) Without thinking too deeply about the reasonableness of the above scenarios (remember, your prof is starting to lose it and ought to have retired to a quiet moon at the edge of the Alpha quadrant years ago), express the process state as a digital logic function in terms of A, C, and S. Sketch the circuit.

   (b) Algebraically simplify the circuit above so that you use a minimum number of logic devices. (Besides, if you ever were to mass produce this super intelligent control system, you'd surely want to minimize the manufacturing costs.) Sketch the simplified circuit.