Physics 103b

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Order of Magnitude Physics

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Problem Set 5

Due at *beginning* of class *11 February 1997*

Following a suggestion by Sanjoy, we would like you to *mention* the next effect you think you would have to consider in order to improve your answer to each question.

1. Relate the speed at which a pole vaulter can sprint to the height he can vault. Provide both an analytical formula and a numerical estimate in your answer.

2. Skating: the coefficient of steel sliding on ice at temperatures between -11C and -5C is about 0.005.
   a) Estimate the ratio of power a speed skater uses to overcome sliding friction compared to the power to overcome wind resistance (the world records in 5km and 10km speed skating are held by Koss, respectively $6^{\rm m}35^{\rm s}$ and $13^{\rm m}30^{\rm s}$).
   b) Estimate the forward force that must be applied by the skating strokes to maintain speed against the total drag. You should find that this is large compared to the sliding friction, but small compared to the body weight. How is speed skating possible if the forward force must be large compared to the sliding friction (banana peel effect)? Are wind resistance and sliding friction the only relevant dissipation?

3. Estimate the electrical conductivity of sea water. The mass of salt per unit mass of seawater is 0.035. Hint: think of cages of water molecules and Stokes drag on spheres.

4. Interplanetary Communication at Radio Frequencies
   a) Calculate the power p received by an earth based radio telescope of diameter D from a spacecraft at distance s that transmits power P at wavelength λ using an onboard antenna of diameter d. Provide an analytical formula and a numerical evaluation in watts for $D = 70\,\mathrm{m}$, $d = 3\,\mathrm{m}$, $s = 10\,\mathrm{AU}$, $\lambda = 4\,\mathrm{cm}$, and $P = 10\,\mathrm{watts}$.
   b) Denoting the system temperature of the earth based radio telescope by T, what is the maximum bandwidth $\Delta\nu$ at which the signal exceeds the noise? As for a), provide both an analytical formula and a numerical evaluation in Hz for $T = 20\,\mathrm{K}$.
   c) Relate $\Delta\nu$ to the bit rate at which information can be transmitted from the spacecraft to earth.

5. Interplanetary Communication at Optical Frequencies
   a) Repeat as for problem 4 except in this case the transmitter consists of a laser which emits $P = 1$ watt at $\lambda = 0.5\,\mu m$ and is located at the focus of a 10 cm diameter mirror. Assume that the signal is collected by the Hubble Space Telescope which has $D = 2.4$ m.
   b) What is the rate at which photons are received and how is that related to the bit rate at which information can be transmitted from spacecraft to earth.

6. Make up a problem of your own.