Short Problems

1. How would you expect world records for weight lifted to scale with body weight?
2. The speed of sound in liquid water H_2O at room temperature is 1,482m/s. Estimate the speed of sound in heavy water D_2O at the same temperature; be sure to state your assumptions and estimate the accuracy to which they ought to hold.
3. Estimate how fast you could walk on the moon. [useful information: the moon's radius is 1/4 that of the earth, and it's density of 3g cm^{-3} is 0.6 that of earth.]
4. What fraction of the world's river water flowing out to sea is human urine?
5. How much electrical power (in MegaWatts) could be produced by burning in a conventional powerplant all the junk mail received by everybody in the United States?
6. A California Science Fair student proposes to mount magnets (all with N pole facing out) at the front and rear of cars to prevent collisions. Estimate the size of the smallest, cubical, permanent magnet necessary to prevent collisions at 5 mph and 55 mph.

Long Problems

1. Overheated Orchestra

   During an orchestra concert, heat generated by the players and the audience causes the temperature in the auditorium to rise by 5°K. Assuming the players take no corrective action,

   a) Estimate the fractional change in frequency of notes played by the wind instruments. Do the frequencies of their notes go up or down as the temperature rises?
   b) Estimate the fractional change in frequency of notes played by the string instruments. Do the frequencies of their notes go up or down as the temperature rises? [hint: the coefficient of thermal expansion of spruce wood (used for piano and violin face and back plates) along the grain (which is parallel to the strings) is about 1/7 that of steel (used for strings).]

2. House Lights

   A 100 watt light bulb is powered by household current flowing in a pair of parallel copper wires, 1 mm in radius, separated by 2 mm, and 2 m in length.

   a) How much power is dissipated in the wires?
   b) At what velocity do the current carrying electrons drift?
   c) What is the magnetic field generated by the current 1 meter away from the wires?

3. Hot Rocks

   This problem outlines an oversimplified calculation of how the temperature varies on the surface of the moon. Starting at $t = 0$, a smooth surface paved with cold ($T \approx 0\,\mathrm{K}$) black rocks is subjected to a constant flux, F, of optical radiation. Assume that the surface absorbs all of the incident radiation and radiates like a black-body at its surface temperature, T_s.

a) What is the equilibrium value, T_{eq}, of T_s?

b) Describe the time dependence of T_s before equilibrium is reached. Hint: The heat equation reads

$$\rho c_p \frac{\partial T}{\partial t} = k\nabla^2 T.$$

You are not expected to solve this equation.

c) What is the characteristic time, t_{eq}, for the approach to equilibrium, and what is the depth, δ, of the thermal boundary layer at this time?

d) Evaluate T_{eq}, t_{eq}, and δ for $F \approx 10^6\,\mathrm{erg\,cm^{-2}\,sec^{-1}}$, a flux appropriate to solar heating of the moon.

4. Boiling Water And Whistling Tea Kettles

a) It takes about 5 minutes to boil a liter of water on a kitchen stove.

i) How much power is used to heat the water?

ii) At what rate does the boiling water evaporate?

b) Many tea kettles come with whistles. The basic whistle is a hole of radius $\approx 0.15\,\mathrm{cm}$ through which water vapor can exit the kettle.

i) At what velocity does water vapor exit the hole when water is boiling inside the kettle?

ii) What is the Reynolds number of the flow near the hole?

iii) Why does the kettle whistle and what determines its frequency?

iv) Estimate the radiated acoustic power.

5. Resting and Bouncing Balls

a) A spherical rubber ball of density, ρ, shear modulus, μ, and radius, R, is lying on a smooth, rigid floor. Estimate the radius, r, of the circular area of contact between the ball and floor.

i) Use the Buckingham Π theorem to show that $r = RF(\rho g R/\mu)$.

ii) Demonstrate that $F(x) \propto x^{1/3}$.

b) The ball described in part a) is bounced on the floor with impact velocity $v \gg (gR)^{1/2}$. Estimate the contact time, Δt, between the ball and the floor.

i) Use the Buckingham Π theorem to show that $\Delta t = (R/v)G(\rho v^2/\mu)$.

ii) Demonstrate that $G(x) \propto x^{2/5}$.

c) Numerical evaluation

i) Evaluate r in part a) for $R = 10\,\mathrm{cm}$, $\rho = 2\,\mathrm{gm\,cm^{-3}}$, and $\mu = 10^7\,\mathrm{dyne\,cm^{-2}}$.

ii) Using the same parameters as for part a) together with $v = 5\,\mathrm{m\,sec^{-1}}$, evaluate Δt and the maximum value of r in part b).