Physics 103c

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Order of Magnitude Physics

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Problem Set 1

Due at *beginning* of class *Wednesday, 12 April 1995*

Homework Problems:

1. Pencils
   a) How many atoms thick is the graphite layer left by a pencil writing on a piece of paper? [You may answer this by performing an experiment, or on a theoretical basis, or both]
   b) How many words can a standard No. 2 pencil write (assume you don't waste lead by over-sharpening)?

2. Eyes
   a) Experimentally determine the angular resolution of your eyes (in daylight, at whatever distance you have best vision, or with your usual corrective lenses in). How close are they to the diffraction limit?
   b) Use your result in (a) to estimate an upper limit to the size of the light-sensitive cells in your retina (the cones in daylight), and hence a lower limit to the total number of such cells in your eye.
   c) If you were an astronaut in space (no depth cues!) and saw a strange object floating toward you, how close would it have to get before your stereoscopic vision would allow you to estimate its distance?

3. Estimate the mass of rubber liberated from car tires each year by the cars travelling along the stretch of the 210 freeway passing through Pasadena.

4. Would the energy of all the calories you have consumed as food be enough to eject you from the solar system?

5. [Note: to answer this question, you don't have to know any thermodynamics, though you'll appreciate it more if you do. Enthalpy has units of energy.] The enthalpy per particle $h = H/N$ of a relativistic gas containing N particles in a volume V depends on:
   $s = S/N$, the entropy per particle,
   p, the pressure,
   $\hbar$, Planck's constant,
   c, the speed of light,
   m, the rest mass of the particles in the gas,
   k, Boltzmann's constant.
   [Why not temperature T, density $n = N/V$, etc. too? Because any two variables suffice to specify the thermodynamic state of a system. For use with h, s and p are the two natural variables, but (almost) any other pair would do]
   a) How many independent dimensionless quantities Π_i can be formed from these 7 variables?

b) One of these is $\Pi_1 = s/k$. Find all the others, and give an expression for H in the form $H = N v_1^{\alpha_1} v_2^{\alpha_2} \phi(\Pi_1, \Pi_2, \ldots)$, where v_1 and v_2 are two of the variables listed above. The function ϕ cannot be determined from dimensional analysis alone (and in fact also depends on the particles' dimensionless spin).

c) If the gas is nonrelativistic, the speed of light is no longer a relevant variable, so c must cancel out of the equation in (b). Give the resulting equation for H, and using the thermodynamic relation $\partial H/\partial p = V$, use that equation to prove that for any nonrelativistic gas $H = (5/2)pV$.

d) If the gas is ultrarelativistic, c will be relevant, but the rest mass of the particles shouldn't matter. Give the resulting equation for H, and prove (as in (c)) that $H = 4pV$ for any gas of ultrarelativistic particles.

6. Invent a problem of your own (you don't have to know the answer). The most interesting problems submitted will be done in class, or assigned as homework in subsequent problem sets. Your problem can be like those above, or more general.