ES265 - Problem Set 1 - Due Thurs 17th Jan

General Advice Problems are divided into S(mall), M(edium) and L(arge). Small problems shouldn't take you more than a couple of minutes. You should not need to use calculators - this is an order-of-magnitude class! Make sure you explain what you are doing - the method is much more important than the final answer. You will get bonus points if you come up with more than one solution to a problem. You're welcome to check your answers on the Internet - but do it AFTER you've done the problem! The final problem in each set (Problem 8 here) requires you to suggest (and solve) a medium-size order of magnitude question of your own. Working together is permitted, but you must each come up with a unique suggested problem.

PROBLEM 1 Is spider silk really stronger than steel? [S]

PROBLEM 2 A guy I met at a party claimed that one-third of all America's water usage went into cooling power stations. Making your assumptions clear, suggest whether you think this claim is reasonable. [M]

PROBLEM 3 Derive an order-of-magnitude expression for the maximum radius of a beetle able to walk on the surface of a pond. Assuming the surface tension of water is 0.1 N m^{-1}, calculate what this maximum radius is and comment on the result. [S]

PROBLEM 4 The maximum height of trees has been explored by many scientists. Two possible factors that limit the height of trees are mechanical strength (trees fail under their own weight) and water transport (trees can transport water only to some height due to capillary action). Estimate the height limit for trees for each of these mechanisms. [M]

PROBLEM 5 If the energies associated with the nucleus are $\sim$1 MeV, what are the characteristic size, speed, timescale and density of nuclear processes? How would the mass of a teaspoon-full of nuclear material compare with the mass of the Earth? [M]

PROBLEM 6 A naive way of determining the stress required to break a material in extension is to add up the force required to break all the bonds in 1 m^2 of material. Write down the resulting expression for stress in terms of binding energy and atomic radius, and calculate the result.

Most real materials have breaking stresses much less than this. Why? Can you suggest some materials which do approach their theoretical stress limit? [M]

PROBLEM 7 Andrade in 1934 argued that the viscosity of fluids at the melting point arose because of momentum transfer between neighbouring layers of molecules. Using the Buckingham Pi theorem (or otherwise), suggest a scaling relationship for viscosity in terms of the molecular mass m, radius a and vibration frequency ω of the molecule.

Using the results from the lecture, rewrite the viscosity in terms of the binding energy, the liquid density ρ and m. Assuming a characteristic binding energy, calculate the melting-point viscosity of the following substances and comment on your results:

Table 1:

Substance	Atomic Wt.	Melting point (K)	Density kg m^{-3}	Viscosity 10^{-4} Pa s
Potassium	39.1	336	830	5.4
Sodium	23.0	317	930	7.0
Copper	63.6	1356	8200	38
NaCl	29.2	1077	1540	16
Water	18	273	1000	18

Bonus Use a momentum transfer argument to give a physical justification for the relationship involving m,a and ω. [L]

PROBLEM 8 Suggest, and provide a solution for, a medium-size order-of-magnitude problem on a topic relating generally to materials. The question should be similar to those above, and will be graded on its originality as well as the solution approach. [L]