EPSS C113/213: Homework 1, Due January 19, 2018

1. Garrels & Lerman "reaction": In the first lecture we learned about a simplified reaction proposed by Garrels and Lerman (in 1981 and 1984 papers, available on the class website – and in the class notes) describing fluxes between chemical constituents of the solid Earth, through the ocean and atmosphere. The compound Fe_2O_3, in mineral form, is called hematite. Hematite and other iron oxide minerals tend to be red-colored, and often lend that coloration to rocks in which they occur. In the case of sediments made from sand, silt and clay, the term "red bed" describes this coloration. Looking at either the index of coal deposition in North America vs. Time in the 2nd slide from lecture 1 (and assuming that North America is more-or-less representative of the continents), or in the plot of organic carbon burial in Garrels and Lerman (1981; Fig. 6), during what time periods would you expect to see the greatest abundances of red beds? When would you expect them to be less common?

2. Nucleosynthesis
   Using the relationship $E=mc^2$, calculate the rest-mass energy of four ^1H atoms, in units of Joules. Then calculate the energy of one ^4He atom. Recall that 1 amu = $1/N_A$ (g/atom) = $0.001/N_A$ (kg/atom), where N_A is Avagadro's number = 6.022×10^{23}, and the speed of light is 2.9979×10^8 m/sec. Ignoring other energy terms and entropy, estimate the energy of the net nucleosynthesis reaction:

   $^1H + {}^1H + {}^1H + {}^1H \rightarrow {}^4He$

   In this calculation you are comparing two very similar quantities (the energies of reactants and products), so be sure to carry enough significant figures through your arithmetic to resolve the difference. A brief guide to significant figures is posted on the class website (borrowed from Alan Jircitano at Penn State; http://chemistry.bd.psu.edu/jircitano/sigfigs.html). There is also a much more detailed explanation on the Khan Academy (https://www.khanacademy.org/math/arithmetic-home/arith-review-decimals/arithmetic-significant-figures-tutorial/v/significant-figures).

   Is this reaction endothermic or exothermic?

   What is the energy released (or absorbed) per nucleon of reactant, in Joules/mole?

   Using the same relationship, calculate the energies (in Joules/mole of reactant nucleons) of the following reactions:
   $^{12}C + {}^4He \rightarrow {}^{16}O$ (this is a typical late-stage carbon-burning reaction in large stars)
   $^{52}Fe + {}^4He \rightarrow {}^{56}Ni$ (strangely, this reaction actually *makes* iron in the end, because ^{52}Fe would decay to ^{52}Cr in about a week, while ^{56}Ni decays to ^{56}Fe in a few months)
   $^{204}Hg + {}^4He \rightarrow {}^{208}Pb$

Given that a negative energy of reaction (products less massive than reactants) indicates that the products are more stable (ignoring entropy), which reactions are likely to go forward?

HINT: http://wwwndc.jaea.go.jp/CN14/index.html will help you find the input data you need. Wikipedia will also work. Just make sure to indicate where your numbers come from!

3. Thermodynamics of photosynthesis and metabolism

All forms of life require external sources of energy. A variety of energy sources are exploited by terrestrial organisms. Animals, of course, are heterotrophs – we derive energy by eating other organisms (or their products), and mixing that reduced material with atmospheric oxygen (itself mainly derived from other organisms). A way to calculate the energy available from a particular reaction is to use the Gibbs Free Energy (ΔG), defined as:

$$\Delta G = \Delta H - T\Delta S$$

where ΔH is the difference in enthalpy between products and reactants, T is the absolute temperature, and ΔS is the difference in entropy between products and reactants. A free energy less than zero indicates that the reaction could, in principle, provide energy.

Using the NIST chemistry web book (http://webbook.nist.gov/chemistry/) or any other thermodynamic database you like, calculate the Gibbs free energy (per mole of H_2 molecules) at 25ºC from combining H_2 with O_2 to make water. Assume 1 atmosphere of pressure for reactants and products, and use gas-phase data for all molecules except H_2O (where the liquid state is probably more appropriate for our purposes). Finally, convert the reaction free energy *per mole* into energy per *individual* H_2 molecule, and compare that to the energy in a single red photon with a wavelength of 7000 Å. Is there enough energy in one red photon to split a water molecule (assuming a suitable catalyst is present)? If not, how many are needed, in a hypothetical photosynthetic system with perfect efficiency?

4. (Graduate students only) Make the same comparison between the energy of a photon and the energy required to split an H_2S molecule to make H_2 and S. Make sure to use the solid-state properties of native sulfur.