APh161: Physical Biology of the Cell
Homework 3
Due Date: Tuesday, February 10, 2009

"It is the highest bliss for the thinking person to have explored what can be explored and quietly to worship what cannot." – Goethe

Reading:

Read chap. 5 of Physical Biology of the Cell (PBOC), especially section 5.5.2. Also, read chap. 8 of PBoC.

1. ATP synthesis.

Estimate the daily ATP synthesis by ATP synthases in a human. To do this estimate, imagine a typical human diet and hypothesize that roughly half of the caloric input is converted into ATPs. What is the mean rate of ATP synthesis per cell in the human body resulting from this estimate? If each ATP synthase synthesizes roughly 100 ATPs per second (see Alberts, MBoC, chap. 14), what does this imply about the number of such ATP synthases per cell? Note: the entirety of this question is to give us a feeling for the numbers and the actual numbers might be substantially different because of cell type and physiology.

2. Concentration Gradients, Free Energy and the Proton Motive Force.

In class, we discussed the role of transmembrane concentration gradients as an important source of biological free energy. In this problem you will explore the significance of these concentration gradients in several different ways, basically viewing the material in class from slightly different angles.

(a) As a warm up exercise, deduce the chemical potential for an ideal solution by filling in all of the steps between eqn. 6.78 and 6.85 of PBoC. Make sure you explain briefly in words what is going on at each step and that you are clear on how to get from 6.81 to 6.82.

(b) As mentioned several times in class, one of the consequences of the electron transfer reactions in photosynthesis is that a concentration gradient of hydrogen ions is set up across the membrane. Using your result for the chemical potential, compute $\Delta\mu$ across a pH difference of 1 across a membrane. Express your result in both eV and $k_B T$ units. More generally, find an expression for the entropic contribution to $\Delta\mu$ as a function of ΔpH.

(c) In fact, if we allow charged particles to move across a membrane across which there is an electrical potential difference, this too will contribute to the free energy change. For a transmembrane potential difference of ΔV, work out the contribution to the free energy difference across the membrane. A typical transmembrane potential is 100 mV. What is the energy associated with this transmembrane potential?

(d) Assemble your results from parts (b) and (c) to work out the so-called "proton motive force" across the membrane (i.e. the total free energy difference due to both concentration gradients and transmembrane potential difference). Write your result in terms of ΔV and ΔpH.

3. Estimates on Genome Packing in Viruses and Prokaryotes.

Write a brief (less than two pages including calculations) "Scientific American"-style essay on genome size (in bp) by referring to figures 1.13 and 8.6 of PBoC and the estimates on pgs. 291-292. What I want you to do is to explain how large the genome is in solution without the confining influences of the viral capsid or the cell and once you have this physical size, translate it into a corresponding estimate of the genome length in basepairs. How compacted is the genome in the confines of the virus capsid or the cell? Words alone will not suffice here. You need to do a simple estimate of the kind I do in class. You can use the formula for the radius of gyration as a function of number of Kuhn segments given by eqns. 8.32 or 8.33 in PBoC, but you need to explain to the reader what it means and why you are invoking it. You should have an estimate for the case of a bacterial virus (such as lambda phage) and for *E. coli*.

4. Sturtevant Experiment.

- Problem 4.4 of PBoC

5. Random Walks and Polymers.

- problem 8.4 of PBoC