BE/APh 161: Physical Biology of the Cell, Winter 2019
Homework #1

Due at the start of lecture, 2:30 PM, January 16, 2019.

Note from JB: This problem set is largely about estimation. You should be able to do these estimates on a cocktail napkin. Please try to complete this homework without the use of a calculator or computer for calculations. You may refer to any of the material in *PBoC2*, but avoid BioNumbers or *Cell Biology by the Numbers* or any other sources unless explicitly asked to. Remember that we're just estimating, so π is about 3, etc. Be sure to comment on what parts of your estimates are most suspect and why. After you come up with your estimates, you may look them up at BioNumbers or elsewhere. And of course, try to have fun!

Problem 1.1 (Exploring biology with numbers, 24 pts)**.**
Spend some time on the BioNumbers website (`http://www.bionumbers.org/`), looking at various numbers. Pick three that are particularly interesting to you, give their BNIDs, and write a few sentences about why you find each one interesting.

Problem 1.2 (Cellular eating and drinking, 24 pts)**.**
When growing up bacteria, we typically put a small number of bacterial cells in growth media, and the components of that solution are converted into more cells. (Think about that for a second. From a clear liquid solution, life makes life. After experience this profound moment of wonder, continue reading the problem statement.) *E. coli* can divide every twenty minutes under very good growth conditions.

a) Estimate the rate at which a growing *E. coli* cell drinks with a division time of twenty minutes. By "drinking" I mean estimate the number of water molecules that need to be imported into the cell per second to maintain the level of growth.

b) The growth media typically contains glucose as a carbon source. Estimate how much carbon is necessary to build the materials of a new cell (which is done in 20 minutes under very good conditions). Based on this estimate, at what rate must the bacterium "eat" glucose? It is also interesting to consider that there are about 1000 transmembrane proteins that transport suger in an *E. coli* cell. At what rate must sugar molecules come through each of these transmembrane proteins? For this estimate, we are considering only the carbon necessary to build the cellular material; we are completely neglecting the energy needed to build the cell.

Problem 1.3 (HIV estimates, problem 2.8 of *PBoC2*, 20 pts)**.**

a) Estimate the total mass of an HIV virion by comparing its volume with that of an *E. coli* cell and assuming they have the same density.

b) The HIV maturation process involves proteolytic clipping of the Gag polyprotein so that the capsid protein CA can form the shell surrounding the RNA genome and nucleocapsid NC can complex with the RNA itself. Using Figures 2.30 and 2.31 from *PBoC2* to obtain the capsid dimensions, estimate the number of CA proteins that are used to make the capsid and compare your result with the total number of Gag proteins.

Problem 1.4 (The replication paradox in *E. coli*, 12 pts).
Given that the typical rate for the motion of the replisome in *E. coli* is roughly 1000 bp/s, and that the replication of the circular bacterial chromosome is carried out by two replication forks, one heading in each direction from the origin of replication, work out how long it takes to copy the *E. coli* genome. How does this time correspond to the *E. coli* cell cycle? For rapidly dividing cells, how is this paradox resolved?

Problem 1.5 (Concentrations and spacing, 20 pts).
Use your skills of estimation to answer the following questions. Comment on the numbers you come up with.

a) Many biochemical studies in test tubes use nanomolar (nM) concentrations of purified proteins. If a protein species inside of an *E. coli* cell has concentration of 1 nM, how many total molecules of that species are there in the cell?

b) What is the typical intercell distance between *E. coli* cells in a saturated LB growth medium? *Hint*: According to BNID 104943, the saturation concentration in LB is 20.5 g/L.

c) It is estimated that there are of order 10^{30} prokaryotic cells on Earth (BNID ID 104960, see also the beautiful paper by Whitman, et al.). Roughly 10% of these are in the open ocean. Give a rough estimate for the concentration of bacteria in sea water. What is the approximate intercell spacing? *For fun*: If all the bacteria in the sea were lined up end-to-end, how long would the line be?

d) There are approximately 2 to 3 kg of bacteria in your large intestine. What is their intercell spacing?

e) Approximately how many hydronium ions are in an *E. coli* cell?