Physics of Live Processes ; Introduction to Biophysics

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Exam 28-05-2009, 13:45-16:30h

This exam consists of 6 problems (2 pages).
Note your name and student ID on every sheet.
Give sufficient motivation for your answers.
You may use books, notes and calculators

1) A model protein

Proteins are built from strings of amino acids. 20 different amino acids can be found in nature.
a) Quantify the information content of a protein made of 400 random amino acids, assuming that all amino acids are equally common?
b) How many bp of DNA are used for encoding this protein?
c) What is the information content of the gene?
d) Can you think of a reason why they are different?
e) The diffusion constant of this protein is 20 $\mu m^2/s$. What can you say about the folding of the protein? (Hint: the average diameter of an amino acid is approximately 1 nm)

2) Red blood cells

All particles in solution undergo Brownian motion. However, one needs a microscope to observe this directly. The smallest object one can see without additional optics is about 10 micrometer, the size of a red blood cell.
a) What RMS distance would such a cell move in 1 minute? (assume it is globular).
The density of a red blood cell is 1.125 kg/l.
b) How long does it take for all cells to precipitate to the bottom?
c) What acceleration would be needed to centrifuge the cells to the bottom of the tube in 10 min?
In order to study the effect of molecular polarity and size on membrane permeability, you place red blood cells into isoosmotic (= same osmotic pressure as inside cells) solutions of various alcohol solutions. If the alcohol is permeable, the alcohol molecules will diffuse through the membrane and the cell will eventually hemolyze.
d) what is hemolysis?
You put red blood cells into two iso-osmotic alcohol solutions: propyl alcohol and glycerol. Both of these molecules are about the same size, but greatly differ in their polarity, with glycerol being much more polar than propyl alcohol. Thus, any difference in observed hemolysis time must be due to differences in polarity, not size.
e) Which compound will induce hemolysis quicker? Why?
f) Given that P_s = 20 μm/s for glycerol and assume the cell to be globular, how long will it take to reduce the concentration difference by 1/e (= 0.37)?

3) Membrane potentials

Two compartments are separated by a membrane. The potential in compartment 1 equals V_1, in compartment V_2.
a) Use the Boltzmann distribution for the concentration of a charged particle to derive the Nernst relation.
b) The resting potential across a muscle cell membrane is -90 mV. The extra cellular concentration of Cl^- is 120 mM. What would be the intracellular concentration?

c) Na^+ has an intracellular concentration of 12 mM and an extracellular concentration of 145 mM, resulting in a Nernst potential of 67 mV. Is this the equilibrium distribution? If not, how can the cell achieve this situation?
d) How many ATP molecules are necessary to get one Na+ out of the cell, assuming 50% efficiency?

4) Evolution

During evolution point mutations change the amino acid composition of a protein by replacing one base pair in the DNA by another. Due to errors in replication and radiation damage on average 1 every 10^8 bp will mutate.
a) What is the probability that one mutation is inserted in a 500 bp gene ?
b) How many unique two-base mutations are possible?
When one particular guanine is replaced by an adenine this will result in a change of a serine amino acid into a phenylalanine. This may induce an advantage over the original bacterium. Suppose the protein encoded by this gene contains two serines.
c) What is the probability that both serines change into phenylanaline simultaneously?
d) Given a cell cycle of 20 min (i.e. every 20 min the cell splits into 2 daughter cells), what is the typical timescale to produce this particular double-mutation?

5) Vesicle fusion

Compare two vesicles: A has no solutes, B has twice the radius of A and contains N solutes.
a) Derive an equation for the number of solute molecules in B for which the internal pressure of both vesicles is the same (in terms of line tension Σ and radius R_A of vesicle A).
Consider $\Sigma = 1.5\ 10^{-3}$ N/m and $R_A = 1$ μm (and $N = 10^6$ if you could not answer a).
b) What is the change of entropy when the two vesicles merge? (Consider only the entropy of the solute)
c) Is this significant at room temperature?
d) What is the new pressure?
f) How much work is involved with the fusion, assuming that the total volume is constant?
e) Ignoring all other thermodynamic factors, will the fusion proceed spontaneously? Why?

6) Hair cells

Your ear transduces fluctuations in air pressure (sound) into nerve impulses. The key event involves the motion of a bundle of thin fibers (stereocilia) immersed in fluid. Let's visualize this bundle as a rod of diameter about 1 μm, vibrating at a frequency 440 s^{-1} (A tone). The amplitude of the vibration should be a few nanometers, say 2.3 nm, the displacement needed to open a tiny gate in each stereocililum.
a) The maximum speed, v_{max}, of an oscillator is 2π times the amplitude times the frequency. Compute v_{max}.
b) Suppose the fluid in the inner ear is similar to water. Decide whether viscous friction is significant for this motion and explain.