FYSA270 Biological Physics / JY

Final exam (Friday 10.06.2011, examiner: J. Akola)

Exercise 1. (3 p)
Consider a ramdom walker whose position at time t is $\vec{r}(t)$. Let us define $\vec{r}(0) = 0$. Derive the following result for the random walker, $\langle[\vec{r}(t) - \vec{r}(0)]^2\rangle \sim A\,t^x$, where the exponent $x = 1$.

The prefactor A (above) is proportional to the diffusion coefficient D. Next, assume that the random walker is an integral membrane protein which is embedded in the membrane and moves across the membrane surface. The membrane encloses a sphere-like cell with a diameter 30 μm. Estimate, how long does it take that the protein moves as a random walker around the cell by visiting the opposite side of the cell and returning back to the starting point? You may assume that the diffusion coefficient is of the order of $D = 1 \times 10^{-10}\,\text{cm}^2/\text{s}$.

Exercise 2. (12 p)
Define the following concepts and discuss their meanings. You can draw illustrating pictures.

a. Membrane potential. (1 p)
b. Chemical potential. (1 p)
c. Free energy. (1 p)
d. Adenosine triphosphate. (1 p)
e. Arrhenius rate law. (1 p)
f. Michaelis-Menten rule. (1 p)
g. pK and pH and their connection. What happens if the system's pK is smaller than pH of the surrounding liquid? Is it possible to have pK less than zero? (2 p)
h. What is the meaning of the following equation?

$$S = k_B \ln\left[\left(\frac{2\pi^{3N/2}}{(3N/2-1)!}\right)(2mE)^{3N/2}V^N\frac{1}{N!}h^{-3N}\frac{1}{2}\right] \tag{1}$$

What are the variables? (1 p)

i. Reynolds number. (1 p)
j. Hydrogen bond and its relevance to the structure of biomolecules. (2 p)

Exercise 3. (3 p)
Textbooks quote the value $\Delta G'^0 = -7.3$ kcal/mol for the hydrolysis of ATP. On the other hand, it has been observed that a certain molecular machine uses one ATP per step and does useful work equal to 14 k_BT. Reconcile these statements, using the fact that typical intracellular concentrations are [ATP]=0.01 (that is, $c_{ATP} = 10$ mM), [ADP]=0.001, and [P_i]=0.01 (the last one is an inorganic phosphate).

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Exercise 4. (6 p)
Entropy can cause an entropic force. In order to demonstrate this, consider a Gaussian chain of N monomers which are coupled together linearly. The only internal potential that acts between the monomers is the monomer-monomer coupling, which keeps the distance ℓ of two coupled monomers as a constant. Otherwise, the monomers may overlap and different segments of the chain may swing freely with respect to each other. (i) Compute the free energy for such a chain. (ii) By using the previous result, compute the force that is required to keep the distance of the polymer ends constant (for a given length). [Hint: Start from the Gaussian distribution.]

Exercise 5. (6 p)
Answer to *either* (a) *or* (b).

(a) Let us assume a liquid that is incompressible and essentially homogeneous. Furthermore, let us assume that there is a semipermeable membrane in the liquid which allows liquid molecules to flow through it but blocks solute particles, such as ions, whose number concentration is c. This will create a so-called osmotic pressure over the semipermable membrane, which follows the van 't Hoff equation $p_{\text{equil}} = c\, k_B T$ at temperature T for a system that resembles simple ideal gas. Derive this equation and discuss its meaning in biological systems.

(b) Write an essay about molecular motors and their connections to the thermal ratchet models.