FYSA270 Biological Physics / JY

Final exam (Thursday 20.05.2010, examiner: J. Akola)

Exercise 1. (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).

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

a. Membrane potential. (1 p)
b. Thermal ratchet. (1 p)
c. Entropy. (1 p)
d. Dimensional analysis. (1 p)
e. Arrhenius rate law. (1 p)
f. Bjerrum length. (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. Ideal gas; write down its equation of state also. (1 p)
i. Reynolds number. (1 p)
j. Gating mechanisms of ion channels. (2 p)

Exercise 3. (3 p)
A colloid solution is in equilibrium, and its particle density is of the form

$$c(z) = c_0 \exp(-mgz/k_BT),$$

where z is the height with respect to a reference level, m is the (effective) mass of the particles, g is the gravitational constant, and k_BT is the thermal energy. Calculate a value (expression) for c_0 by assuming that the total number of particles is N, the height of the container is h, and its cross-sectional area is A.

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.]

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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 $p_{\text{equil}} = c\,k_{\text{B}}T$ at temperature T for a system that resembles simple ideal gas. Derive this equation and discuss its meaning in biological systems.

(b) Describe the behavior of DNA upon mechanical stretching and discuss the underlying physics (biology) and simple mathematical models that have been used for modeling elongated polymers.