Tfy-0.3252 Soft Matter Physics / Pehmeän aineen fysiikka
Final exam 18.2.2014 (5 problems / 2 pages).
No auxiliary written material is allowed (tables, notes etc.) A standard calculator accepted in the Finnish matriculation examinations (yo-kirjoitukset) is allowed.
Since the language of the course was English, the exam problems are in English as well. You can write your answers either in English or Finnish.

Note: For those who took the course in fall semester 2013, please write clearly at the beginning of your exam paper whether you would like to include the project assignments in your grading or have your grade determined solely on the basis of this exam.

Problem 1. (6 points)
Define *soft matter*: What are the characteristic physical features of soft matter systems? What distinguishes soft matter from other types of condensed matter, for example, crystalline solids and standard liquids?

Give two examples of basic soft matter systems, emphasizing how they exhibit the characteristic features of soft matter mentioned above.

Problem 2. (6 points)
Provide a brief, but comprehensive explanation of the physics behind the following observations related to soft matter systems. Use simple quantitative estimates and illustrations, if possible.
a) By adding a small (characteristic size 0.5 nm) non-polar solute in water results in increase of the free energy of the system. Upon increasing the temperature of the system, the free energy change associated with adding the solute increases as well.
b) Colloidal particles carrying a negative surface charge are initially dispersed in a contained filled with water. By gradually adding salt, the particles are observed to form increasingly large aggregates. In time, the majority of the aggregates are observed to rise to the surface.

Problem 3. (6 points)
Consider two very large ("semi-infinite") parallel walls, each having the same surface charge density $\sigma_{\text{surf}} < 0$, and separated by the distance D. Let the x-axis be normal to the wall surfaces, and the midplane between the walls be located at $x = 0$. This way, the other wall fills the space $x < -D/2$ and the other one, correspondingly, fills the space $x > D/2$. The region between the walls is filled with water, and the system is at thermodynamic equilibrium at $T = 298$ K. In order to have an electroneutral system, there are also counterions of ionic valency z between the planar walls.
a) Write the Poisson-Boltzmann equation for this system.
b) Determine the counterion concentration profile $c(x)$ with respect to the ionic concentration at the midplane between the walls, $c_0 \equiv c(0)$. (Hint: start with the derivative of $c(x)$ with respect to x.)
c) Considering the case that the counterion concentration at the midplane is negligible ($c_0 \approx 0$), calculate the concentration of monovalent counterions at a wall surface with $\sigma_{\text{surf}} = -0.05$ C/m^2. Moreover, estimate the charge density due to the monovalent counterions in a thin layer of thickness δ right next to the wall surface. Interpret your result.

Turn the page.

Problem 4. (6 points)
Define the surfactant packing parameter P and explain its physical meaning. What physical or chemical factors determine the values of the different quantities in P? How could one control the value of P in the case of some given surfactant?
Finally, show that surfactants form cylindrical micelle aggregates when $\frac{1}{3} < P \leq \frac{1}{2}$.

Problem 5. (6 points)
a) Consider two flat, semi-infinite surfaces parallel to each other, and separated by a distance D in vacuum. Let the atomic densities of the surfaces be ρ_1 and ρ_2. Starting from the general expression of the van der Waals interaction between two atoms, $U_{vdw} = -C/r^6$, use the Hamaker theory to derive the interaction free energy per unit area between the surfaces.

b) Assuming a typical value for the Hamaker constant, $A = \pi^2 C \rho_1 \rho_2 \approx 10^{-19}$ J, at which distance D is the attractive force per unit area between the surfaces comparable to the atmospheric pressure (1 bar = 10^5 Pa)?

Useful constants, equations etc.
Avogadro's number $N_A = 6.0221 \times 10^{23}$ mol^{-1}
Boltzmann's constant $k_B = 1.3807 \times 10^{-23}$ J/K
Elementary charge $e = 1.60218 \times 10^{-19}$ C
Permittivity of vacuum $\varepsilon_0 = 8.85419 \times 10^{-12}$ F/m
Molar mass of water: $M_{H_2O} = 18.015$ g/mol
Chemical potential of an ideal solution: $\mu_k(x_k, p, T) = \mu_k^0(p, T) + k_B T \ln x_k$