Introduction to Biological Physics (MATR331)

University of Helsinki

Examination: October 26, 2022 (6 exercises; maximum number of points is 30)

As to background information that is allowed during the examination:

- **Calculator is ok**

Further notes such as "lunttilappu" are not allowed.

Assignment 1 [max. 3 points]
Define soft matter. Also discuss why entropy is often important in describing the properties of soft matter.

Assignment 2 [max. 7 points]
Below are statements that are either true or false. Explain why they are (or why they are not) correct.

a) Diffusion of lipids is rapid because it is fostered by ATP (adenosinetriphosphate).
b) If we had a technology to generate short pieces of dsDNA (double stranded DNA), each having a length of 10 nm, we could use these short DNA fragments to make liquid crystals.
c) Bacteria move like fish.
d) Messages in the nervous system propagate by diffusion.
e) Proteins in your cells, polyethylene, and alcohol which we can drink, are all polymers.
f) If two dipoles (comprised of two charges ($-Q$ and $+Q$) each), are separated by a distance of r, and their relative orientation is fixed, then the interaction $V(r)$ between them decays like $V(r) \sim 1/r^6$.
g) If Reynold's number (Re) for a given fluid system is much larger than 1, then the fluid system in question is characterized by formation of turbulent flows, which however become weaker as the fluid velocity increases.

Assignment 3 [max. 6 points]
Explain the following concepts, terms and phenomena. Use physical derivations, drawings, and/or essay-like descriptions to clarify the issue, when needed.

a) With biomolecules, one often talks about the so-called entropic force. What is it?
b) Mean field theory (keskikenttäteoria).
c) Differential scanning calorimetry (DSC) is a technique often used to detect phase transitions taking place in cell systems. Why?
d) In an aqueous environment, a long DNA molecule is intertwined into a ball, forming a spherical structure. Let us assume that this DNA ball would be transferred to oil. What would you expect to happen to it, and why?
e) Discuss the role of gravitation in cell motion.
f) Quite often diffusion, which describes particle motion, is called mobility. What are the differences between mobility and motility?

Assignment 4 [max. 5 points]

Consider a random walker moving along a line in one dimension. It performs jumps of distance L, each jump done with equal probability (1/2) either to the left or the right. The period between consecutive jumps is always the same, $\Delta t > 0$, and t is time. Even for a system of many random walkers moving at the same time, one can consider the diffusion coefficient D of the random walkers using the ideal gas assumptions. Under these conditions, prove that the diffusion coefficient follows the law $D \sim L^2 / t$.

Assignment 5 [max. 4 points]

The orientational properties of liquid crystal molecules (among others) are described by the order parameter

$$S = A < \cos^2 \theta > - B.$$

In two dimensions, calculate the appropriate values for the parameters A and B such that the order parameter is scaled between 0 (minimum value) and 1 (maximum value).

Assignment 6 [max. 5 points]

Suppose your body can be described with a cylinder 2 meters high and 30 cm in diameter. You are in great shape, like an Olympic athlete. When your lungs are full of air, the average density of your body is 900 kg/m^3. When your lungs are completely empty, the average density of your body is 1100 kg/m^3. You go to a lake with a water density of 1000 kg/m^3. You swim to the middle of the lake, stop in place, blow your lungs completely empty, and allow yourself to sink freely toward the bottom of the lake which is 10 meters below the surface level. What is the maximum speed V_{max} you will reach during this descent?

[Hint: keep in mind that the frictional force, slowing down the fall, has a magnitude of $6\pi\eta R_{size}v$, where η is viscosity of water, R_{size} describes your size, and v is your velocity during the fall.]

You will rise to the surface (or lifeguards will bring you back to the surface) and continue your journey into a shallow river where you can stand still so that your head is above the surface of the water. Water in the river flows past you at a speed of V_{max}. Under these circumstances, what size should you be so that the Reynolds number Re would be 1?

These might be useful:

Taylor expansion

$\sum_{n=0}^{\infty} \frac{f^{(n)}(a)}{n!}(x-a)^n$

Boltzmann constant $1.380662 \cdot 10^{-23}$ J / K

1 amu = 1.66×10^{-27} kg (atomic mass unit)

Avogadro's number $6.022 \cdot 10^{23}$ 1/mol

permittivity of vacuum $8.85 \cdot 10^{-12}$ F/m (or $coul^2/Nm^2$)

permittivity of water $\approx$ 80 times that of a vacuum

charge on a proton $1.6 \cdot 10^{-19}$ coul

viscosity of water $\eta = 10^{-3}$ kg / ms

10^{-3} kg/ms = $\frac{10^{-3} \text{ kg}}{10^{-3} \text{ s}}$

$\frac{kg}{ms} = 10^{-3}$

$\frac{kg}{10^{-3} s} = 10^{-3}$

$\frac{kg}{s} = 10^{-3} \cdot 10^{-3}$

viscosity of syrup $\approx$ 3000 times that of water

mass density of syrup $\approx$ 1.4 times that of water

$\int_{-\infty}^{\infty} e^{-ax^2} dx = \sqrt{\pi}$

$\log_a x = \frac{\log_b x}{\log_b a}$

$\frac{dy}{dt} + Ay = B$, where A, B are constants, is solved by $y = y(t_0)e^{At_0}e^{-At} - \frac{B}{A}e^{At_0}e^{-At} + \frac{B}{A}$ (t_0 = initial time)

These might be useful, too:

sin 2x = 2 sin x cos x
sin 3x = 3 sin x – 4 $\sin^3$ x
cos 2x = 1 – 2 $\sin^2$ x
cos 3x = 4 $\cos^3$ x – 3 cos x

Taylor expansion
$(1 + x)^{-1/2} \approx 1 - (1/2)x + (3/8)x^2 + O(x^3)$ for $|x| < 1$.

Poisson-Boltzmann equation in radial coordinates:

$$\frac{1}{r^2}\left[\frac{d}{dr}\left[r^2 \frac{dV}{dr}\right]\right] = \kappa^2 V$$

Boltzmann constant: 1.380662×10^{-23} J / K.

1 amu = 1.66×10^{-27} kg (atomic mass unit)