Norwegian University of
Science and Technology,
Department of Physics

Contact during the exam:
Rita de Sousa Dias
Phone 47155399

EXAM I COURSE
TFY4310, FY8911 MOLECULAR BIOPHYSICS

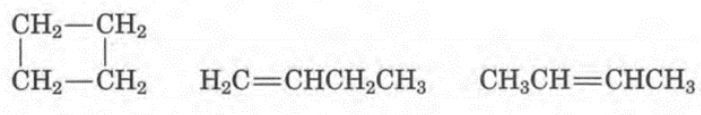
Friday, 15 December 2017
Time: kl. 09.00 - 13.00

All questions have the same weight. None of the questions require lengthy answers so answer as precisely and concisely as possible. Good luck!

Exercise 1.

Justify **six** (6) of the following (correct) sentences:

1. Contrarily to the molecular orbital theory, the valence bond theory fails to describe the delocalization of electrons in conjugated molecules.
2. Water has a tetrahedrical structure.
3. The critical micellar concentration of a cationic surfactant decreases when the hydrocarbon tail is increased.
4. If a polymer is moved from an ideal solvent to a good solvent, the overlap concentration decreases and scales with $n^{-4/5}$.
5. In transient electric birefringence, an important part of the experimental set-up consists in the application of a square electric pulse.
6. In Raman IR spectroscopy, bands corresponding to C=O stretching vibrations appear at larger wavenumbers (shorter wavelengths) than those of C–O.
7. Parts per million (ppm) in relation to a widely used reference sample (chemical shift), is a convenient way of expressing the frequency in nuclear magnetic resonance (NMR) spectra.
8. ^{1}H-NMR is a convenient method to identify and distinguish the structure of the following (isomeric) compounds of formula C_4SH_8:

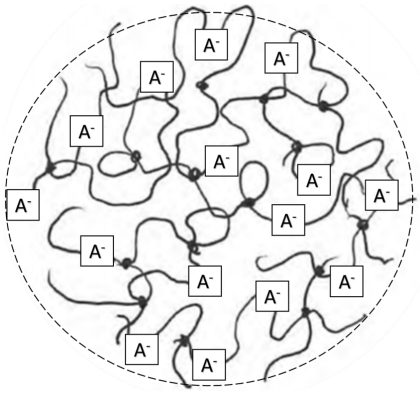


9. Small angle neutron scattering (SANS) is a powerful tool to study the structure of DNA-lipid complexes, lipoplexes, currently studied for the purpose of gene delivery to cells.

Exercise 2.

1. The figure below shows a scheme of an anionic hydrogel immersed in aqueous solution.

   Is the scheme complete? If not, identify the missing item(s). Describe qualitatively the molecular aspects of the process leading to an increase in the hydrogel swelling volume due to the anionic character of the network.



2. Does the swelling volume of the hydrogel change when the salt concentration of the aqueous solution is increased? Justify.

3. The equation

$$\Delta G = k_{\mathrm{B}}T\left[(n_1 \ln v_1 + \chi n_1 v_2) + \frac{3}{2}n\left(v_2^{-2/3} - 1 + \frac{1}{3}\ln v_2\right)\right].$$

   can be used in conjunction with the mathematical description of the swelling of hydrogels. Describe the underlying molecular mechanisms that give rise to the two terms of the equation. Can this equation be used to describe the swelling of the represented hydrogel? Justify.

Exercise 3.

1. You are given a protein solution with a known extinction coefficient (ε). While measuring the absorption of the sample, to calculate the concentration of the protein solution, you realize that the obtained value is too high and out of the so-called linear regime of the instrument.

   What is it meant with the linear regime and why is this a problem?

2. Describe two procedures to reduce the value of the measured absorption by 5?

3. The radius of gyration can be easily calculated using molecular simulations but it is also possible to determine it experimentally. Describe an experimental procedure to measure the radius of gyration of the protein. Mention the used technique and any approximation that may be needed.

4. Describe the Metropolis algorithm, very commonly used in Monte Carlo simulations.

Exercise 4.

T4 is a large virus with an approximately spherical capsid which contains DNA. These spherical particles have the following characteristics: $s = 1025$ S ($1\ \text{S} = 10^{-13}$ s), and partial specific volume $\overline{V}_1^{(S)} = 0.605\ \text{cm}^3/\text{g}$. Dynamic light scattering experiments were performed of the virus in water at 20 °C, using light with a wavelength of 500 nm and a scattering angle of 40°. Plotting the results as $\ln[g^{(2)}(q,\tau) - 1]$ as a function of τ gives a straight line with a slope equal to $-532.00\ \text{s}^{-1}$.

1. Calculate the translational diffusion coefficient of the capsid.
2. Calculate the frictional coefficient of the capsid.
3. What is the molecular weight of the capsid?
4. Calculate the volume of the non-hydrated capsid.
5. Calculate the hydrodynamic volume of the capsid.
6. What is the hydration fraction of the virus capsid (g of water per g of virus)?
7. The shell of the virus (capsid) is composed of proteins that possess positively charged aminoacids towards the interior of the virus, and non-polar aminoacids on the edges of the proteins that face the other proteins in the capsid. Knowing that the proteins of the capsid do not assemble in the absence of the DNA, discuss the main intermolecular interactions that contribute to the assembly of the virus.

The following formulas and data may or may not be of use in answering the preceding questions. You do not need to derive any of the formulas but all parameters must be defined, if used.

Electron charge: $e = 1.602 \times 10^{-19}$ C

Avogadro constant: $N_{\text{Av}} = 6.022 \times 10^{23}\ \text{mol}^{-1}$

Boltzmann constant: $k_{\text{B}} = 1.380 \times 10^{-23}\ \text{m}^2\ \text{kg}\ \text{s}^{-2}\ \text{K}^{-1}$, $\text{J}\ \text{K}^{-1}$

Permittivity in vacuum: $\varepsilon_0 = 8.854 \times 10^{-12}\ \text{C}^2\ \text{J}^{-1}\ \text{m}^{-1}$

Properties of water at 20 °C:
$\varepsilon = 78.4$; $\eta = 0.01\ \text{g cm}^{-1}\text{s}^{-1}$; $\rho = 1.02\ \text{g/cm}^3$

Temperature: [K] = [°C] + 273.15

Atomic orbitals: H: $1s^1$; C: [He]$2s^2 2p_x^1 2p_y^1$; N: [He]$2s^2 2p_x^1 2p_y^1 2p_z^1$; O: [He]$2s^2 2p_x^2 2p_y^1 2p_z^1$

Atomic weights: $\mathrm{A}_r(\mathrm{H}) = 1.0$; $\mathrm{A}_r(\mathrm{C}) = 12.0$

Thermodynamics $G = H - TS \qquad A = U - TS \qquad \vec{F} = -\vec{\nabla} A$

$S = k_\mathrm{B} \ln W$

Coulomb potential $V(r) = \dfrac{z_1 z_2\, e^2}{4\pi\epsilon_0 \epsilon r}$

Screened Coulomb potential

$$V(r) = \frac{z_1 z_2\, e^2}{4\pi\epsilon_0 \epsilon r} \exp\left(-\frac{r}{\lambda_\mathrm{D}}\right)$$

Debye screening length $\lambda_\mathrm{D}^2 = \dfrac{\epsilon k_\mathrm{B} T}{\sum_i (eZ_i)^2\, n_{i\infty}}$

Density of ions at a charged surface $\rho_\mathrm{s} = \rho_0 + \dfrac{\sigma^2}{2\epsilon\epsilon_0 k_\mathrm{B} T}$

Statistical chain molecules $\left\langle R_\mathrm{ee}^2 \right\rangle = C_n Q^2 n$

$$C_n = 1 \; ; \; C_n = \frac{1-\cos\theta}{1+\cos\theta} \; ; \; C_n = \frac{1-\cos\theta}{1+\cos\theta}\frac{1+\langle\cos\phi\rangle}{1-\langle\cos\phi\rangle}$$

Scaling $\left\langle R_\mathrm{ee}^2 \right\rangle^{1/2} \sim Q n^\alpha \; ; \; \alpha = 1/2 \; ; \; \alpha = 3/5$

For ideal chains $\left\langle R_\mathrm{ee}^2 \right\rangle = 6 \left\langle R_G^2 \right\rangle$

Radius of gyration of a sphere $R_{G,\mathrm{sph}} = \sqrt{3/5} R_{sph}$

Critical packing parameter

$$\mathrm{CPP} = v/a_0 l_c$$

Overlap concentration (in molar concentration of monomers)

$$C^\star = \frac{3N_p}{4\pi N_\mathrm{Av}} \frac{10^{-3}}{R_G^3}$$

Friction coefficients $\vec{F} = -f\vec{v}, \qquad \vec{M} = -\xi\vec{\omega}$

Stokes formula $f = 6\pi\eta R_h, \qquad \xi = 8\pi\eta R_h^3$

Hydrodynamic volume $v_{\mathrm{h},1} = \left(\overline{V}_1^{(S)} + \delta\overline{V}_0^{(S)}\right) \dfrac{M_1}{N_\mathrm{Av}}$

Specific volume (per mass) $\overline{V}_1^{(S)} = v_1 \left(\dfrac{N_\mathrm{Av}}{M_1}\right)$

Fick's laws $$\frac{\partial c}{\partial t} = -\vec{\nabla} \cdot \vec{J}, \qquad \vec{J} = -D_{\mathrm{T}} \vec{\nabla} c, \qquad \frac{\partial c}{\partial t} = D_{\mathrm{T}} \frac{\partial^2 c}{\partial x^2}$$

Nernst-Einstein relations $$f D_{\mathrm{T}} = k_{\mathrm{B}} T, \qquad \xi D_{\mathrm{R}} = k_{\mathrm{B}} T$$

Lamm-equation $$\frac{\partial c(r,t)}{\partial t} = D_{\mathrm{T}} \left(\frac{\partial^2 c(r,t)}{\partial r^2} + \frac{1}{r} \frac{\partial c(r,t)}{\partial r} \right) - s\omega^2 \left(r \frac{\partial c(r,t)}{\partial r} + 2c(r,t) \right)$$

Svedberg equation $$s = \left(1 - \overline{V}_1^{(S)} \rho \right) \frac{M_1}{N_{\mathrm{Av}} f}$$

Equilibrium centrifugation: $$m_1(r) = m_1(r_{\mathrm{m}}) \exp \left\{ \frac{M_1 (1 - \overline{V}_1^{(\mathrm{S})} \rho) \omega^2 (r^2 - r_{\mathrm{m}}^2)}{2RT} \right\}$$

Planck's law $$E = h\nu = \frac{hc}{\lambda} = hc\tilde{\nu}$$

Beer-Lambert law $$A(\lambda) = \varepsilon(\lambda) c l$$

Electrically-induce birefringence $$I(t) = \frac{I_0}{4} \delta_0^2 \exp(-12 D_R t)$$

Raman spectroscopy $$P = \alpha_0 E_0 \cos 2\pi\nu_0 t + \frac{1}{2} \left(\frac{\partial \alpha}{\partial q_i} \right)_0 q_{i0} \left[\cos(2\pi(\nu_0 + \nu_m)t) + \cos(2\pi(\nu_0 - \nu_m)t) \right]$$

Nuclear spin $$\vec{m} = \gamma \vec{L}, \qquad (\vec{m})^2 = \gamma^2 \hbar^2 \ell(\ell+1), \qquad m_{\mathrm{z}} = m_\ell \, \gamma \, \hbar$$

Gyromagnetic ratio

Nucleus	^{1}H	^{2}H	^{13}C	^{14}N	^{19}F	^{31}P
$\gamma \left(10^7 \frac{\mathrm{rad/s}}{\mathrm{T}} \right)$	26.753	4.107	6.728	1.934	25.179	10.840

Larmor frequency $$\nu = \frac{\gamma}{2\pi} B_0$$

Small-angle scattering $$q = \frac{4\pi}{\lambda} \sin \left(\frac{\theta}{2} \right)$$

Guinier approximation $$I_s(q) = I_0 \exp \left(-\frac{1}{3} q^2 R_G^2 \right)$$

Discrete identical homogeneous particles $$\langle I_s(q) \rangle = N b^2(0) P(q) S(q)$$

Static light scattering Rayleigh regime $$\frac{\langle I_{\mathrm{S}}(q) \rangle}{I_0} R^2 = cM\kappa,$$

Large systems

$$\frac{\kappa c}{R_\theta} = \frac{1}{M}\left[1 + \frac{16\pi^2}{3\lambda^2} R_{\mathrm{G}}^2 \sin^2\frac{\theta}{2}\right] \cdot [1 + 2B_2 c],$$

For y-polarized light

$$\kappa = \frac{1}{N_{\mathrm{Av}}} \frac{4\pi^2 n_0^2}{\lambda_0^4} \left(\frac{\mathrm{d}n_0}{\mathrm{d}c}\right)^2,$$

$$R_\theta = \frac{\langle I_{\mathrm{S}}(q)\rangle}{I_0} R^2,$$

Dynamic light scattering
Siegert relation

$$g^{(2)}(q,\tau) = 1 + [g^{(1)}(q,\tau)]^2$$

$$g^{(1)}(q,\tau) = \exp(-q^2 D_T \tau)$$

Scattering length density

Substance	H_2O	D_2O	proteins	nucleic acids	lipids
ρ (10^{-4} nm^{-2})	-0.55	6.36	3.11	4.44	-0.01