Final exam

Name: _____

Student number ("Matrikelnummer"): _____

- Please write your name on the exam and keep an ID card ready.
- You may use a **calculator** (but no computer or smart phone) and a **dictionary**.
- The exam is closed book, i.e. you are not allowed to consult books, notes, or other references.
- You have 90 min for the exam.
- Please only write on the handed out exam sheet. You may use both sides of the pages.
- Good luck!

Problem	Your points	Maximal points
1		11
2		5
3		9
4		10
5		9
6		10
7		8
8		7
9		9
10		7
11		8
Σ		93

Some useful constants
Atomic mass unit: $u = 1.66 \cdot 10^{-27}$ kg
Permittivity of free space (electric constant): $\epsilon_0 = 8.85 \cdot 10^{-12}$ $C^2/N/m^2$
Elementary charge unit: $e = 1.6 \cdot 10^{-19}$ C

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Aufgabe 1

Central Dogma and nucleic acids.

a) State the central dogma of molecular biology.

b) Briefly describe three molecular mechanisms that go beyond the "traditional" central dogma?

c) Give one reason why RNA is considered one of the most ancient molecules of life?

d) Describe the two differences between RNA and DNA.

e) Give two element configurations that form hydrogen bonds. Sketch their geometry.

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Aufgabe 2

Time scales. Give the (approximate) time scales for the following processes:

a) Time for *E. coli* to divide under optimal environmental conditions.

b) Rotation of a water molecule.

c) Lifetime of the excited state of a fluorescence molecule.

d) Time for a nucleotide to be copied by a DNA polymerase.

e) Time for an amino acid to be incorporated by the ribosome.

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Aufgabe 3

λ-phage DNA. The λ-phage (which is essentially a virus that preys on *E. coli*) has a 48.5 kbp double-stranded DNA genome. Purified λ-phage DNA ("λ-DNA") is frequently used in biophysical experiments. Let us consider some properties of λ-DNA in aqueous solution at (roughly) physiological salt concentration ($\approx$ 150 mM monovalent salt) and pH. You can consider λ-DNA to be well approximated by the FJC model in this problem.

a) What is the contour length of λ-DNA?

b) What is the average root-mean-squared end-to-end distance of λ-DNA?

c) What is the average radius of gyration R_g of λ-DNA?

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Aufgabe 4

Electrostatics for folded RNAs and proteins. Electrostatics typically play a much more important role for folded RNA molecules than for folded proteins. Here, we will derive simple estimates of the electrostatic energies involved. Let us consider a hypothetical folded RNA of 100 nucleotides and a equally hypothetical folded protein consisting of 100 amino acids. Let us further assume that they both have approximately spherical and close-packed shapes and that they consist of exactly equal amounts of all canonical nucleotides or amino acids, respectively.

a) Estimate the sizes (i.e. radii) of the spherically-folded RNA and protein. You can assume that they both have a density of 1.35 g/ml. The molecular weight of an amino acid is on average 110 Da, that of a nucleotide 330 Da.

b) What is the total charge of the hypothetical protein and RNA, if we assume that all nucleotides and amino acids are in their standard charge state at physiological conditions?

c) Assume that the charges calculated in part b) are uniformly distributed over the spheres with radii computed in part a). What is the electrostatic energy of the two uniformly charged spheres in vacuum? In water?.

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Aufgabe 5

Reaction kinetics. Consider the reaction

$$A + B + C \underset{k_{off}}{\overset{k_{on}}{\rightleftharpoons}} ABC \tag{1}$$

The on-rate k_{on} describes the reaction speed towards the complex ABC whereas k_{off} describes the decay of the complex.

a) What are the units of the rate constants k_{on} and k_{off}?

b) Please write down the differential equations that govern the reaction kinetics.

c) Consider the steady state where the concentration do not change over time. Derive an expression for the steady state concentrations. What is the name of this relation?

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Aufgabe 6

Brownian particle in a gradient. A molecule is moved by a gradient force. The drift velocity is given by $v = -k\nabla A$ where k is a proportionality constant and A the quantity from which the gradient force is derived (for example temperature or electrical potential).

a) Derive an expression for the molecule flux density j for the particle movement due to the gradient force.

b) Add to the above flux density a flux due to the diffusion term with diffusion coefficient D, i.e. consider the fact that the particle movement is balanced by diffusion, given by Fick's law. If you are not sure about the sign, consider that the gradient force is moving away from positions of large A if k is positive.

c) Assume now that the particle movement in the gradient is balanced by diffusion, i.e. that the total flux is zero. Integrate the steady state $j = 0$ to derive a molecule concentration depending on the gradient force field $c(A)$. [Hint: $\nabla \ln c = c^{-1}(\nabla c)$].

d) How is the diffusion coefficient determined from the viscosity and the hydrodynamic radius of the particle (assumed to be spherical)?

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Aufgabe 7

Persistence length

a) Give the mathematical definition of the persistence length.

b) Give an estimate of the persistence length of double-stranded DNA, double-stranded RNA, single-stranded DNA and single-stranded RNA.

c) How does the persistence length relate to the elastic modulus for bending (i.e. the bending stiffness)?

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Aufgabe 8

Amino acids and proteins.

a) Write down the chemical formula of amino acids (use R for the side chain).

b) State three contributions to the free energy of protein folding.

c) Give three methods with which you can experimentally follow the folding transition of a protein.

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Aufgabe 9

Filaments.

a) Describe the internal structure of actinfilaments (also known as microfilaments) and of microtubuli.

b) What is their typical role inside a cell?

c) Which one of the two is more stiff? Why?

d) Describe the treadmilling process in actin.

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Aufgabe 10

Living at the small scale.

a) What did Dean Astumian mean by "walking in hurricane"?

b) Can you estimate the length a protein with Diffusion coefficient $D = 100\ \mu\text{m}^2/\text{s}$ covers on average by Brownian motion within one second? Within one hour?

c) Describe two strategies how micrometer-sized animals can swim around.

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Aufgabe 11

Michaelis-Menten for survival. Two bacterial strains, A and B, use sucrose (table sugar) as a sole carbon source (i.e. "food"). The first step in the process of sucrose utilization is the passage of sucrose through a sucrose transporter protein in the membrane. The two strains have different transport proteins; both transporters follow Michaelis-Menten kinetics for their transport and both strains have the same (copy) number of transporters. The Michaelis-Menten parameters for the respective transporters have been measured experimentally:

Strain	A	B
K_M	1000 mM	10 mM
V_{max}	1000 mmol/min	100 mmol/min

a) Assuming that the rate of sucrose uptake is the rate limiting step in growth, which strain will grow faster if the concentration of sucrose is: 10 mM? 100 mM? 1000 mM?

b) Schematically draw the transport rate as a function of sucrose concentration for the two strains.

c) One strain was isolated from the soil and the other from the floor of the "Der verrückte Eismacher" ice cream shop. Which was likely to be which? Why?