Student name:
Student number:

Materials and Molecules

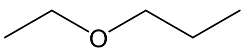
Mock exam 2023

The exam may appear long, but all questions can be answered very concisely. Work fast. Hint: when you cannot answer a question immediately, do not keep on thinking for a long time, but move on to the next question. Then, come back to the skipped and unanswered question(s) later when you still have time.

General and organic chemistry

Question 1 (12 points)

The molecular formula $C_5H_{12}O$ belongs to a certain group of organic compounds. Two structural isomers of molecules that are described by this molecular formula are given below.



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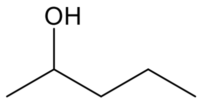

2

a) Give the names of **1** and **2** according to the IUPAC naming rules. (2 p)

b) Are **1** and **2** chiral? Why (not)? (2 p)

c) Some of the physical properties of **1** and **2** are listed in the table below. Explain the differences in boiling point and solubility (in water). If you have a mixture of both, how could you separate them? (4 p)

Compound	**1**	**2**
T_m (°C)	-172	-73
T_b (°C)	62	119
Density (g ml^{-1})	0.739	0.812
Solubility in H_2O (g L^{-1})	< 1	45

d) Another compound with the same molecular formula would be 3-methylbutan-2-ol. Draw its structure using the bond-line method. Indicate its chiral center(s). (2 p)

e) Give the structures of two more constitutional isomers. (2 p)

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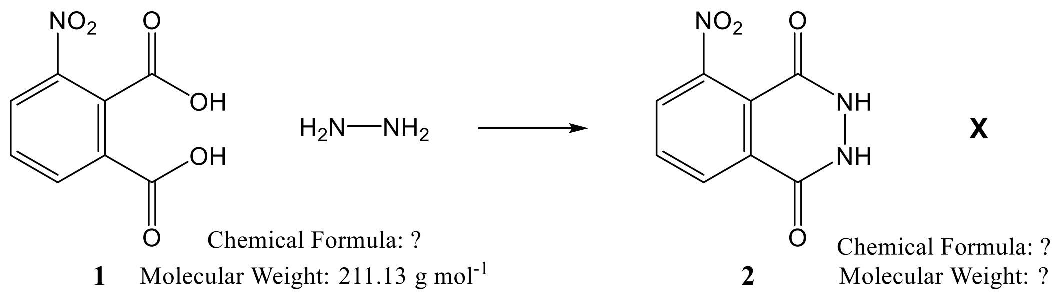
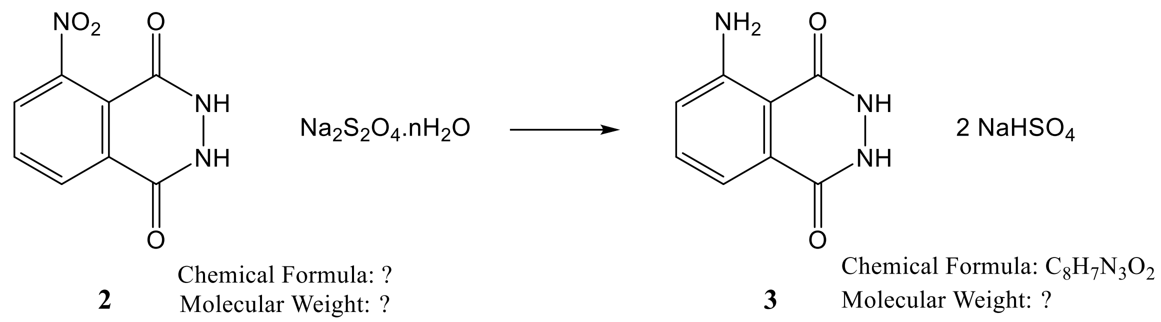
Question 2 (12 points)

Luminol is a chemiluminescent compound, meaning that it emits blue light when undergoing a specific chemical reaction, in this case an oxidation. You may have encountered it in crime series, where the investigator sprays a solution of both luminol and oxidant in the area of interest. The iron that is present in blood catalyzes the oxidation. Luminol (compound **3**) can be synthesized via a two-step reaction, starting from 3-nitrophthalic acid (compound **1**). The product of reaction I (compound **2**) is subsequently treated with sodium dithionite ($Na_2S_2O_4$) to finally give luminol. For some of these compounds the molecular weights and/or chemical formulas are already given.

I)



II)



a) For reaction I, give the atomic composition of compound "**X**" (2 p)

b) In reaction II, sodium dithionite ($Na_2S_2O_4$) is used as a so-called hydrate, meaning that the salt contains *n* molecules of water. Determine the value of "*n*". (2 p)

c) Starting with 5.62 g of 3-nitrophthalic acid (**1**), how much luminol (**3**) (in g) can be obtained at 100% conversion? (4 p)

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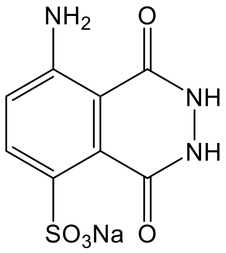
It turns out that reaction II is incomplete (starting from 7.30 g of **2**), and furthermore, an undesired side-product is formed (compound **4**). The reaction mixture consists of 1.23 g **2**, 3.50 g **3** and 2.67 g **4**.



4

Chemical Formula: $C_8H_6N_3NaO_5S$
Molecular Weight: 279.20 g mol^{-1}

d) Calculate the conversion of **2**. (4 p)

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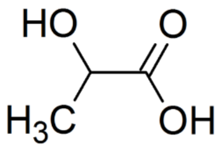
Polymer science

Question 3 (8 points)



Polylactic acid is made by polymerizing the monomer lactic acid. During this reaction a carboxylic acid group reacts with an alcohol group.

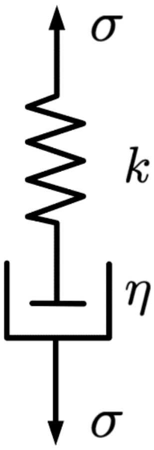
a) What is the name of the bond that is formed upon reaction of a carboxylic acid and an alcohol? (2 p)

b) Draw the general structure of this bond. (2 p)

c) Which class of polymerizations does this polymerization fall into? (2 p)

d) Draw the molecular structure of polylactic acid. (2 p)

Question 4 (8 points)



Viscoelasticity of polymers can be modelled with springs and dashpots. In this question we assume the polymer to behave according to the model shown on the right; a purely viscous damper (with viscosity η) and a purely elastic spring (with spring constant k) connected in series. At t = 0 we apply a constant stress (σ) to the polymer. This stress is removed at t = 100 s.

a) Draw the stress as a function of time from t = 0 till t = 100 s. (4 p)

b) Draw the strain as a function of time from t = 0 till t = 100 s. (4 p)

Question 5 (8 points)

You are given two plastic cups and asked to hit them with a hammer.

a) Which one is more likely to shatter, a cup made from polystyrene or polypropylene? Explain why. (4 p)

b) Draw the molecular structures of polystyrene and polypropylene. (4 p)

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Biomolecules

Question 6 (8 points)

This question consists of 6 multiple choice questions. Grading of these questions: 1 or 2 correct = 0; 3 = 2; 4 = 4; 5 = 6; 6 = 8 points. Please encircle the correct answer as follows:

A. Xxx
B. Yyyy
C. Zzzz
D. Www

1. There are five types of nitrogenous bases, four of which are found in the DNA molecule. These are:

A. Adenine, thymine, guanine, uracil
B. Adenine, uracil, guanine, cytosine
C. Adenine, thymine, cytosine, guanine
D. Adenine, uracil, phosphate, ribose

2. How many carbons are present in the diterpene farnasene?

A. 10
B. 5
C. 15
D. 12

3. The alpha-helical structure of a protein is stabilized mainly by …?

A. Hydrogen bonds
B. Disulphide bonds
C. Glycosidic bonds
D. None of these

4. A membrane lipid contains … fatty acid side chains.

A. 1
B. 2
C. 3
D. None

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5. The melting point of a fat with many unsaturated fatty acids is … than/to a fat with only saturated fatty acids.

A. Higher
B. Lower
C. Equal
D. Similar

6. What is the correct order, going from high to low bond strength?

A. C-C covalent bond > hydrogen bond > ionic interaction
B. Ionic interaction > C-C covalent bond > hydrogen bond
C. Ionic interaction > hydrogen bond > C-C covalent bond
D. Hydrogen bond > Ionic interaction > C-C covalent bond

Question 7 (8 points)

a) Please draw the Fisher structure of the L-isomer of a C5 aldehyde sugar. (6 p)

b) Draw the C3 epimer of the same sugar. (2 p)

Question 8 (4 points)

Please draw the structure of the tripeptide of the amino acid alanine (methyl side chain functional group).

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Materials science

Question 9: Mechanical properties (10 points)

A specimen of pure copper has a yield strength of 110 MPa and of pure nickel 200 MPa. The yield strength is the stress level that marks the transition from elastic to plastic deformation.

a) What happens on the atomic/microscopic scale in metals like copper and nickel when they start to deform plastically? (Can be answered in 1 or 2 sentences) (3 p)

b) The nickel is alloyed with 5 atomic percent copper. Compared to pure nickel, is the yield strength decreasing, staying the same or increasing? Motivate your answer in 1 or 2 sentences. (4 p)

c) Why are windows (next to the passenger seats) in an airplane round and not rectangular? (Can be answered in 1 or 2 sentences.) (3 p)

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Question 10: Electrical properties (10 points)

We have p-doped silicon.

a) Which atoms (at least mention three elements that) can be used for this type of doping? Hint: Look at the Periodic Table of the Elements at the end of the exam. (3 p)

b) Schematically draw how (for a standard doping level) the conductivity of this material (y-axis) depends on the temperature (x-axis). Note that you must start from zero Kelvin! (Hint: The answer is in the equations at the end of this exam.) (4 p)

c) How is it possible that the resistivity of a semiconductor like intrinsic silicon reduces when we shine visible light on it? (Can be answered in 1 or 2 sentences) (3 p)

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Question 11: Materials Selection and Design (5 points)

When designing with materials, we want to use shapes that produce maximum performance for the least amount of material used. Draw schematically what the optimum shape is of the cross-section of a long beam when it is loaded by (1) bending and (2) torsion. Note that the shapes are different for these two different modes of loading! So, draw two different (cross section) shapes and motivate (in about one sentence) for each shape why it is the optimum one for the given mode of loading.

(Note that this optimization problem relates to maximizing the integral $\int y^2 dA$ in case of bending and $\int r^2 dA$ in case of torsion with *y* the distance to the bending axis in the cross-section, with *r* the distance to the rotation point in the cross-section and *dA* infinitesimal pieces of area of the cross-section. The integration is of course taken over the entire cross-sectional area containing the material.)

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Appendices

1) Periodic table

Key: 29 ← Atomic number; Cu ← Symbol; 63.55 ← Atomic weight

Metal

Nonmetal

Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.33	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.2	76 Os 190.23	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.19	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)								

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

2) Equations Materials Science

Mechanical properties:

$$\sigma = \frac{F}{A_0}, \quad \varepsilon = \frac{l - l_0}{l_0}$$ (stress σ is force F divided by area A, strain ε is relative length change.) normal stress (σ) $F \perp A$, shear stress (τ) $F // A$

$$\varepsilon_{//} = \frac{\sigma}{E}, \quad \varepsilon_{\perp} = -\nu \frac{\sigma}{E},$$

E: Young's modulus (*elasticity modulus*),
ν: Poisson's ratio (*lateral contraction*)

Work/Energy U: (toughness)

$$U = \int F ds = V_0 \int \sigma d\varepsilon$$

Area below stress-strain curve = energy uptake in the material per unit volume V_0

elastic: $U_e = \frac{V_0}{2} \sigma\varepsilon = \frac{V_0}{2} \frac{\sigma^2}{E}$

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Electrical properties:

Ohm's Law: $V = IR$ (voltage = current times resistance)

Resistivity: $\rho = \dfrac{RA}{l}$ (with A cross-section area and l length of wire); Conductivity: $\sigma = \dfrac{1}{\rho}$

Electron conductance: $\sigma = n|e|\mu_e$

with n number of free (conduction) electrons per unit volume, $|e|$ the absolute charge of an electron and μ_e the electron mobility

Resistivity of metals:

$$\rho_{Total} = \rho_{Thermal} + \rho_{\mathrm{Im}\,purity} + \rho_{Deformation}$$

$$\rho_{Thermal} \approx aT + b$$

with a and b constants. For pure undeformed metals: $b \approx 0$.

Semiconductors:

An electron that can escape from the valence band to the conduction band leaves a hole behind in the valence band. For the conduction it holds:

$$\sigma = n|e|\mu_e + p|e|\mu_h$$

with p the number of holes and μ_h the mobility of the holes ($\mu_h < \mu_e$)

Intrinsic semiconductor: n = p

$$\sigma \approx C_1 n = C_1 p = C_2 \exp\left(-\frac{E_g}{2kT}\right)$$ with E_g the bandgap energy

Extrinsic semiconductor: doping with foreign atom in intrinsic semiconductor

n-type: n >> p by doping with +1 element, whereby +1 element acts as electron donor to conduction band:

$$\sigma \approx C_a n = C_b \exp\left(-\frac{E_g - E_d}{kT}\right)$$ with E_d the energy of the donor level in the bandgap.

p-type: p >> n by doping with -1 element, whereby -1 element acts as electron acceptor from valence band:

$$\sigma \approx C_c p = C_d \exp\left(-\frac{E_a}{kT}\right)$$ with E_a the energy of the acceptor level in the bandgap.