Final Exam 2024 – Chemistry

(FrJ, HaH, HoJ)

Exam duration: 4 hours

Permitted examination aids:
- Chemistry part from «Formulae, Tables and Concepts»
- Periodic Table of the Elements
- Redox Table
- Acid and Base Table

General Information
- Use the technical terms to answer the questions.
- Write all your answers directly onto the exam sheets.
- Use separate solution sheets if there is insufficient space on the exam sheet. Use one sheet per question. State your name and class on each of your solution sheets.

Grading scale:
You do not need all points to reach grade 6.0.

Maximum Points: 87

We wish you a successful exam!

Name

Exercise 1: Atomic Structure (6 P)

a) Complete the table on the structure of atoms. (4) each entry 0.5P

	Protons	**Neutrons**	**Electrons**
Na			
	83		
Al^{3+}	13		

b) Firework rockets contain a mixture of metal salts to produce colourful displays. The metal salts evaporate during the rocket's explosion, releasing free metal atoms into the gas phase. Sodium salts are responsible for the release of yellow effects.
Explain the phenomenon of colour emission using the example of sodium with the help of Bohr's model. Add an explanatory sketch to your answer. (2)

Exercise 2: Concentration Analysis (6 P)

Pharmacokinetics describes the fate of a drug in the human body from absorption through excretion.

The concentration of a drug's active substance in urine and blood after administering a specific dose is determined to examine its distribution in the body.

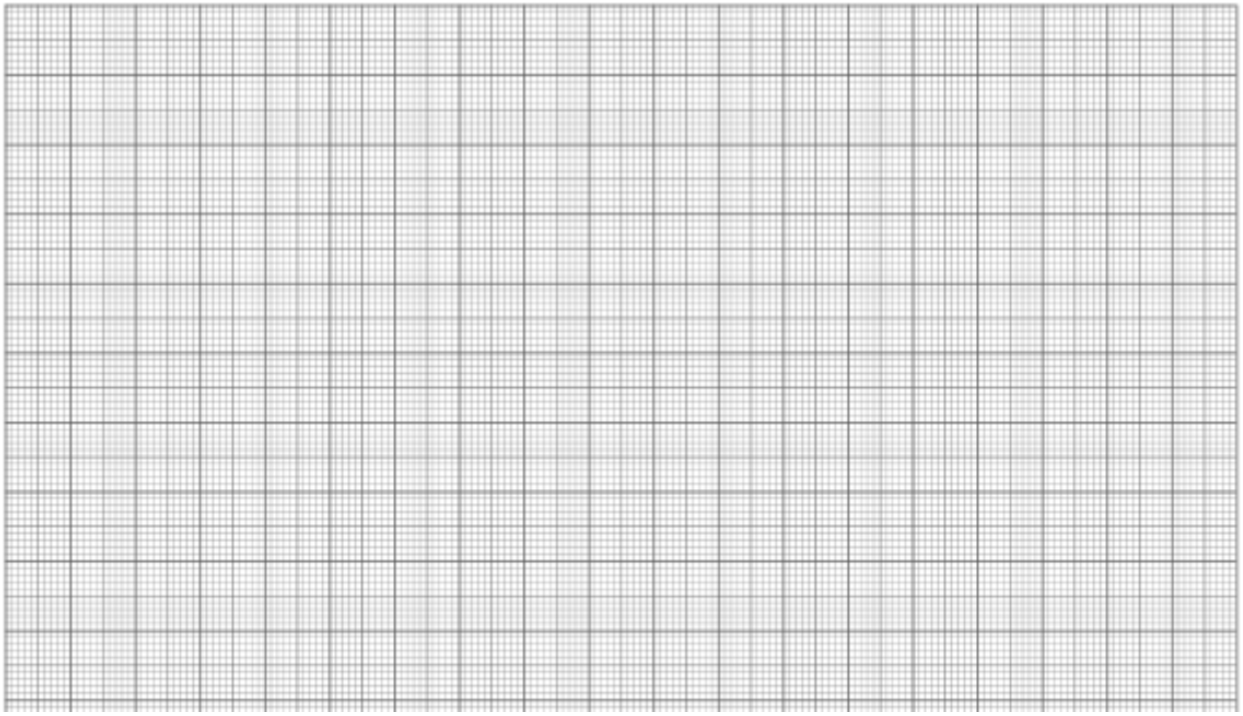
During a study on the pharmacokinetics of the painkiller Paracetamol, mice were administered 20 mg of Paracetamol. Blood samples were drawn, processed, and photospectrometrically investigated to measure the Paracetamol concentration in the mice's blood plasma.

0.1 mℓ mouse blood is centrifuged to remove its solid components, obtaining 0.05 mℓ plasma. The blood plasma is transferred into a volumetric flask and diluted to 2 mℓ with a buffer solution.

The diluted plasma samples' absorption at 243 nm is measured. Five standard solutions with a known paracetamol concentration are also measured at 243 nm. The results of all measurements are compiled in the table below.

Sample	**Concentration Paracetamol (mg/ℓ)**	**Absorption at 243 nm**
Standard 1	0.01	0.024
Standard 2	0.02	0.050
Standard 3	0.04	0.094
Standard 4	0.06	0.146
Standard 5	0.08	0.190
Plasma Sample		0.126

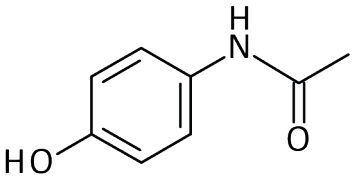
a) Use the information above to create a labelled standard curve on the graph below. Use the space meaningfully. (2)



b) Use your graph to determine the concentration of Paracetamol in the diluted sample. (1)
Calculate the concentration of Paracetamol in the mouse blood. Show your calculations. (1.5)

c) Use the concentration from concentration b) to calculate the molar concentration c of Paracetamol in mouse blood. (1.5)

(If you could not solve b), use a concentration of 0.08 mg/ℓ)



Structure of Paracetamol

Exercise 3: Stoichiometry (5 P)

Ion-selective electrodes measure the concentration of individual ions in solution in environmental and medicinal analyses. Their working principle corresponds to that of pH electrodes.

The concentration of lead ions (Pb^{2+}) should be measured in sewage samples with the help of an ion-selective electrode. First, the electrode must be calibrated using different standard solutions. These solutions are produced by diluting a stock solution.

To produce the stock solution, 41.4 g of highly soluble lead nitrate $Pb(NO_3)_2$ is added to a 250 mℓ volumetric flask. The flask is filled up to the graduation mark with deionised water.

Exercise c) can be solved independently from a) and b). Show all your calculations.

a) Calculate the molar and mass concentration of the stock solution. (2)

b) Use the stock solution to produce 50 mℓ standard solution with a concentration of 0.22 mol/ℓ. Explain your procedure and show your calculations. (2)

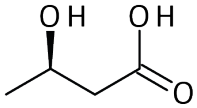
c) How many lead ions are in the calibration solution in part b)? Calculate both the number of particles and the amount of substance. (1)

Exercise 4: 3-Hydroxybutanoic acid (10.5 P)

3-Hydroxybutanoic acid is an important starting material for biologically degradable polymers. Both the reactant and the polymer product show some interesting properties.

All questions can be solved independently.

a) The enantiomer of 3-Hydroxybutanoic acid shown below occurs naturally. Determine the chiral centre and give its absolute configuration (R or S). (0.5P)
Draw its enantiomer, a non-chiral constitutional isomer, and a chiral constitutional isomer. (3)



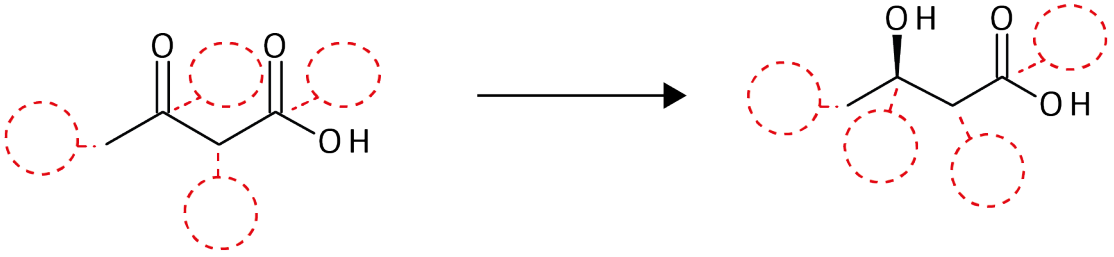
Natural 3-Hydroxybutanoic acid

Its enantiomer | A non-chiral isomer | A chiral constiturional isomer

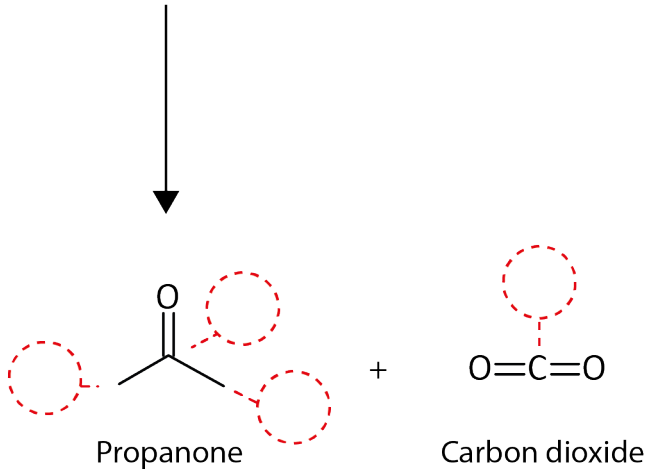
b) Draw the natural enantiomer of 3-Hydroxybutanoic acid in the Fisher projection. Specify its configuration (D or L) (1)

c) 3-Hydroxybutanoic acid can react to form the polymer PHP (= polyhydroxybutanoic acid). It is a biologically degradable plastic.
Draw an excerpt of this polymer that contains two monomer units. (2)

d) In the human body, 3-oxo butanoic acid may react to form 3-Hydroxybutanoic acid or propanone and carbon dioxide.
Add the oxidation numbers of the carbon atoms into the corresponding circles. (3)



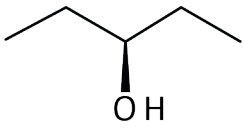
3-Oxobutanoic acid 3-Hydroxybutanoic acid



Propanone Carbon dioxide

e) Explain whether the reaction of 3-Oxobutanoic acid to propanone and carbon dioxide is a redox, an acid-base, or a different type of reaction. Explain your answer. (1)

Exercise 5: Organic Substances (6.5 P)



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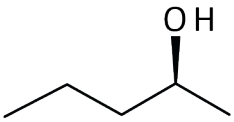

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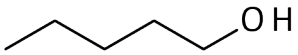

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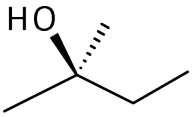

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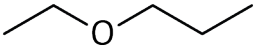

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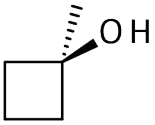


6

A chemist has synthesised substance **A** but is unsure which of the possible substances 1-6 he produced. She asks a colleague from the neighbouring lab to help her interpret the results.

a) Substance A reacts with a glowing oxidised copper coin. After the reaction, the copper coin shone rosily.
b) Heating substance **A** with an appropriate catalyst eliminates water. A product X is formed during this process, which decolourises bromine water. The boiling temperature of **X** is lower than that of **A**.
c) An investigation of **X** proves that it is a mixture of several isomers.
d) Substance **A** combusts, forming carbon dioxide and water.
e) Substance **A** is chiral.

Questions:

i. Which of the substances 1-6 is substance **A**?
Name substance **A** and explain how you identified it. (2)

ii. Give the reaction equation of Experiment a). Name the organic reaction product. (1.5 P)

iii. Give two structures that might be present in **X** and name them. (2)

iv. Give the reaction equation of experiment d). (1)

Exercise 6: Organic Substances II (9 P)

Give the structures and names of substances that fulfil the conditions below.

- All substances contain exactly five carbon atoms. All other atom types may be added as needed to fulfil the conditions.
- Use each structure only once.

Property	Structure	Name	Additional Question
The substance is flammable.			Give the reaction products.
The substance is water soluble.			
The substance is chiral.			Give the absolute configuration (R or S).
Reacts with ethanoic acid to form an ester.			Draw the resulting ester.
The molar mass is larger than 100 u.			
The substance spontaneously reacts with bromine.			Draw a possible reaction product.
The aqueous solution of the substance has a pH < 7.			

Exercise 7: Different Substances (4.5 P)

Decide whether the substances below are electrically conductive in the given states.

	It is conductive in the **solid** state.	It is conductive in the **liquid** state.	Is conducive to the **gaseous** state	It is conductive when **Dissolved in water**.	It is conductive when **Dissolved in ethanol.**
Ammonia	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
1,2-Cyclohexandiol	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
Ethanoic acid	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
Magnesium	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]		
Magnesium acetate	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
Methanol	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
Sodium chloride	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]
Mercury	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]		
Hydrogen	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]	Yes [ ] No [ ]

Exercise 8: The Fischer-Tropsch Synthesis (7 P)

Hydrogen and carbon monoxide react according to the Fischer-Tropsch synthesis to form methanol.

$$2\ H_2 + CO \rightleftharpoons CH_3OH \qquad \Delta H = -91\ kJ/mol$$

a) Name three specific measures to increase the yield of methanol. Explain your choices with the help of Le Chatelier's principle. (3)

b) The Fischer-Tropsch synthesis is performed at 500 K using a suitable catalyst in industrial processes. Explain the importance of the catalyst in this process. (1)

c) At 500 K, the equilibrium constant amounts to K = 9.5 (ℓ^2/mol^2). In a reaction vessel with a volume of 1 ℓ, the following amounts of substances are found:

$n(H_2)$ = 2 mol
$n(CO)$ = 2 mol
$n(CH_3OH)$ = 0.5 mol

Has this reaction already reached its equilibrium? If not, how will the concentration of methanol change until the equilibrium is reached? Explain your answer using the law of mass action. (3)

Exercise 9: Synthesis of Elementary Sodium (8 P)

The elementary pure substance sodium is produced via fused-salt electrolysis of sodium chloride.

a) Sketch the setup of this electrolysis. Label the cathode and anode, the locations of the oxidation and reduction, and the positive and negative poles. Specify the substances produced at the electrodes. (3)

b) Give the partial reaction of the anode and cathode. Specify the oxidation and reduction reaction. (2)

c) Give the minimum voltage needed to decompose sodium chloride at standard conditions. (2)

d) Instead of melting the sodium chloride, electrolysis in an aqueous sodium chloride solution is suggested. Explain whether this process would work. (1)

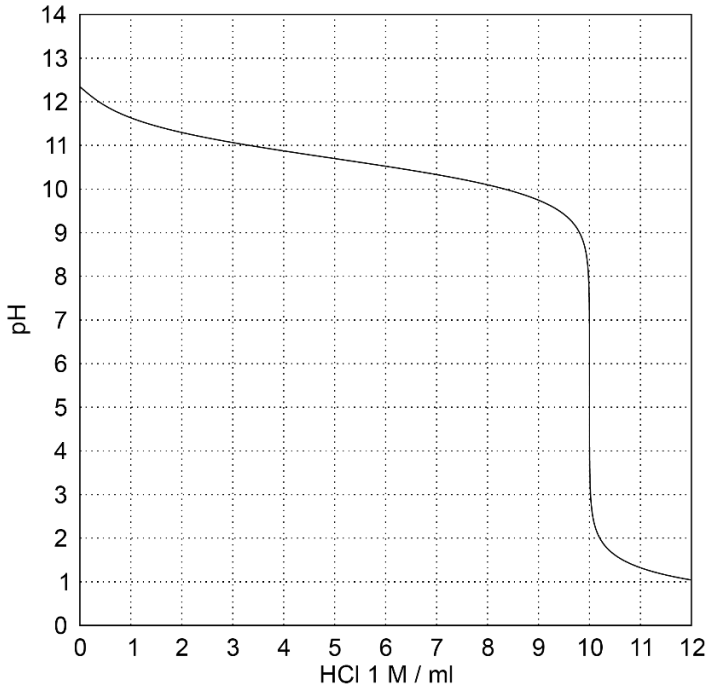
Exercise 10: Acid and Base Reactions (8 P)

Exercises a.) to f.) can be solved independently.

a) Acetic acid (CH_3COOH) is dissolved in water. Give the reaction equation between acetic acid and water. Identify the acid and base in this reaction. (2)

b) Butylamine ($C_4H_9NH_2$) is dissolved in water. Give the reaction equation between water and butylamine. Identify the acid and the base in this reaction. (2)

50 mℓ of an unknown substance gets dissolved in water. We titrate the solution using a hydrochloric acid solution of the concentration c = 1 mol/ℓ. The following questions refer to the titration curve below.



c) Mark the half-equivalence and the equivalence point in the titration curve. (1)

d) Give the pK_A-value of the titrated substance. Explain how you found this value. (1)

e) Calculate the concentration of the titrated substance. (1)

f) Which of the following substances was titrated? Explain your choice. (1)

i.) NaOH ii.) H_2SO_4 iii.) C_4H_9COOH iv.) $C_4H_9NH_2$

Exercise 11: Confusion with an Order (7 P)

You have ordered the following chemicals at an online shop:

A: Potassium acetate solution, 0.4 mol/ℓ
B: Calcium hydroxide solution, 0.5 mol/ℓ
C: Acetic acid solution, 0.2 mol/ℓ
D: Hydrochloric acid solution, 0.4 mol/ℓ
E: Sodium chloride solution, 0.2 mol/ℓ

Unfortunately, the bottles' labels came off during transportation. After profoundly considering this problem, you decided to identify the solutions with a pH meter.

Exercises a.) and b.) can be solved independently.

a) Calculate the pH value of all solutions. (5)

b) You mix 0.5 ℓ of solutions A and C. Explain the unique properties of the resulting mixture with respect to the addition of a strong acid, respectively, a strong base. Calculate the pH value of this solution. (2)

Exercise 12: Peptides I (5 P)

The tripeptide Lys-Glu-Ala is a building block of bacterial cell walls.

a) Draw the skeletal formula of this tripeptide. Make sure to get the spatial arrangement of the side chains correct. (2.5 P)

Hint: Start drawing the N-terminus on the left and end with the C-terminus on the right.

b) Give the charge of this tripeptide at pH= 2, pH= 7, and pH = 10 (1.5 P)

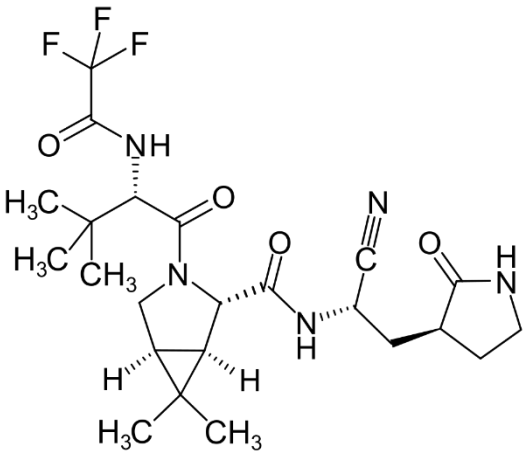
pH	Charge
2	
7	
10	

c) Explain whether the isomeric tripeptide Ala-Glu-Lys is an enantiomer, a constitutional isomer or a diastereomer. (1 P)

Exercise 13: Peptides II (4.5 P)

In the USA, Nirmatrelvir is an approved drug to treat COVID-19.

All questions can be solved independently.



Structure of Nirmatrelvir

a) Nirmatrelvir contains chiral centres. Label them with an asterisk and count them. (1.5)

The structure of Nirmaltrevir contains _____ chiral centres.

b) Nirmatrelvir contains several amide groups that can be hydrolysed. When we hydrolyse all amide groups, we obtain four organic compounds. Draw two of them (2) and name one of them according to the IUPAC rules. (1).

Structure of product 1 Structure of product 2

The name of one of the products is: _____