

DUTCH NATIONAL CHEMISTRY OLYMPIAD

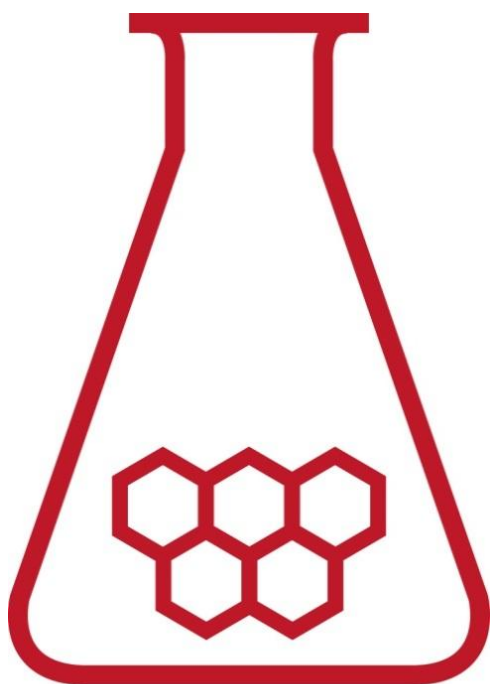
2026

Assignments and Marking schemes

Preliminary round 1

Preliminary round 2

Final round



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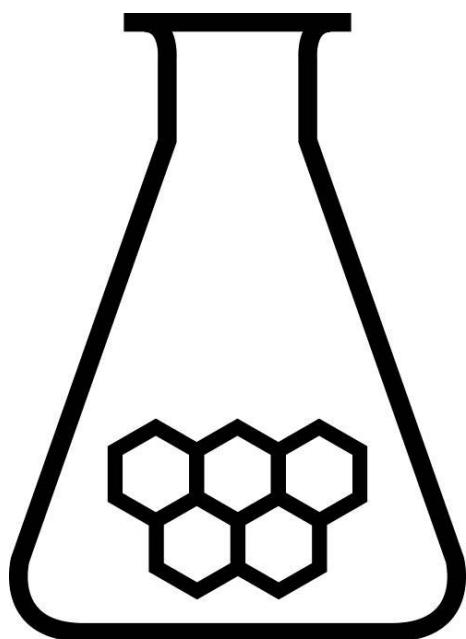
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NATIONAL CHEMISTRY OLYMPIAD 2026

ASSIGNMENTS PRELIMINARY ROUND 1

To be held between 12th and 30th January 2026



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- This preliminary round consists of 25 multiple choice questions divided over 9 topics, and 2 problems with a total of 8 open questions, in addition to an answer sheet for the multiple choice questions.
- Use the answer sheet to answer the multiple choice questions.
- For the open questions, use a separate answer sheet for each of the two problems. Remember to include your name on each sheet.
- The maximum score for this paper is 73 points.
- The preliminary round lasts two hours in total.
- Required materials: (graphic) calculator and BINAS 7th edition, ScienceData 1st edition or BINAS 5th edition, English version. “Green chemistry” table is included.
- The total number of points available for each question is stated.
- Unless otherwise stated, standard conditions apply: $T = 298\text{ K}$ and $p = p_0$.

This test was made possible with the support of the following people:

Olav Altenburg
Kees Beers
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The final editing was done by:
Martin Groeneveld, Piet Mellema and Pia Scheffer

The test was translated into English by:
Lilian Buuron
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Jan Rombach
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Problem 1 Multiple choice questions

total 50 points

For each question, write your answer (letter) on the answer sheet. The answer sheet can be found at the end of this examination booklet.

Marks: 2 points for each correct answer.

Carbon chemistry

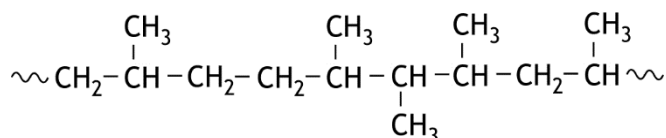
- 1 How many monobromosubstitution products are formed when methylbutane reacts with bromine under the influence of UV light?
Take stereoisomerism into account.

A 3
B 4
C 5
D 6

- 2 How many noncyclic isomers exist with the molecular formula C_3H_6S ?
Take stereoisomerism into account.

A 4
B 5
C 6
D 7
E 8

- 3 Below is a fragment from the middle of a polymer molecule.

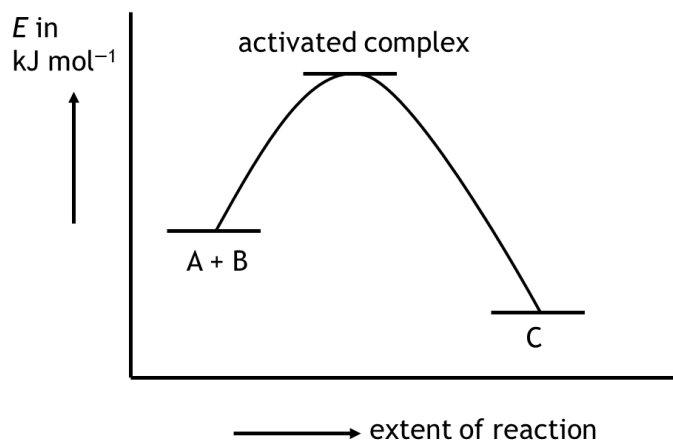


From which monomer / monomers could this polymer be formed?

- A only propene
B ethene and but-2-ene
C ethene and propene
D propene and but-2-ene
- 4 Amylose is a carbohydrate formed by the polymerization of glucose molecules. What is the average degree of polymerization of amylose when the average molar mass is $3.29 \cdot 10^5 \text{ g mol}^{-1}$?
- A $5.07 \cdot 10^2$
B $1.83 \cdot 10^3$
C $1.85 \cdot 10^3$
D $2.03 \cdot 10^3$

Thermochemistry

- 5 The energy diagram for the reaction $A + B \rightarrow C$ is shown below:



Which of the following statements is true?

- I The reaction is endothermic.
- II Addition of a catalyst increases the energy level of reactants A and B.

- A none
- B only I
- C only II
- D both

Reaction rate and equilibrium

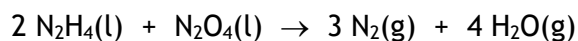
- 6 The following equilibria are given:

- I $2 \text{NO}_2(\text{g}) \rightleftharpoons \text{N}_2\text{O}_4(\text{g})$
- II $3 \text{O}_2(\text{g}) \rightleftharpoons 2 \text{O}_3(\text{g})$

Which equilibrium shifts to the right with increasing temperature?

- A none
- B only I
- C only II
- D both

- 7 In the reaction



the rate at which N_2H_4 reacts is $3.5 \cdot 10^{-4} \text{ mol s}^{-1}$.

What is the rate in mol s^{-1} at which nitrogen is formed?

- A $2.3 \cdot 10^{-4}$
- B $3.5 \cdot 10^{-4}$
- C $5.3 \cdot 10^{-4}$
- D $1.1 \cdot 10^{-3}$

- 8 In a closed vessel the following equilibrium is established:



At some point the equilibrium is disturbed because the volume of the vessel is increased while the temperature remains constant.

Which reaction is temporarily favoured immediately after this disturbance?

After some time, a new equilibrium is established.

After the equilibrium is re-established, will the CO_2 concentration have decreased, remained the same, or increased compared to the concentration before the disturbance?

- | | temporarily favoured | concentration of CO_2 |
|---|-----------------------|--------------------------------|
| A | reaction to the left | decreased |
| B | reaction to the left | remained the same |
| C | reaction to the left | increased |
| D | reaction to the right | decreased |
| E | reaction to the right | remained the same |
| F | reaction to the right | increased |

Structures and formulae

- 9 A double salt contains sodium ions, magnesium ions and sulfate ions. The formula for a double salt is $\text{Na}_x\text{Mg}_y(\text{SO}_4)_z$.

What are the values for x , y , and z in the double salt if the molar ratio of the sodium ions and magnesium ions is 1 : 1?

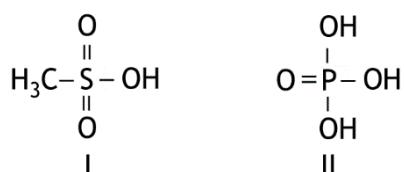
- | | x | y | z |
|---|-----|-----|-----|
| A | 1 | 1 | 2 |
| B | 1 | 2 | 3 |
| C | 2 | 1 | 2 |
| D | 2 | 2 | 3 |
| E | 3 | 3 | 3 |

- 10 How many lone pairs should be drawn in the Lewis structure of nitromethane, CH_3NO_2 ? Assume that the C, N, and O atoms obey the octet rule.

- A 3
B 4
C 5
D 6
E 7

- 11 The acidity of an acid depends, among other things, on the number of resonance structures of its conjugate base.

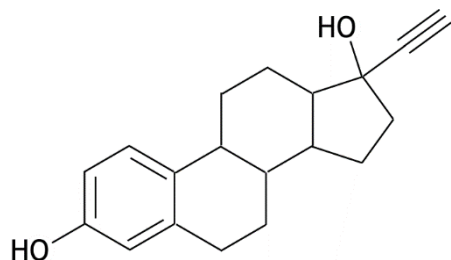
The structural formulas of two acids are shown below.



How many resonance structures can be drawn for the conjugate base of each of the above acids in which both the S and P atoms have no formal charge?

	number of resonance structures of the conjugate base of I	number of resonance structures of the conjugate base of II
A	2	2
B	2	3
C	2	4
D	3	2
E	3	3
F	3	4
G	4	2
H	4	3
I	4	4

- 12 Ethinylestradiol is a substance used in contraceptives. Its structural formula is shown below.



How many carbon atoms have a coordination number of 2 and how many carbon atoms have a coordination number of 3 in a molecule of ethinylestradiol?

	number of C atoms with a coordination number of 2	number of C atoms with a coordination number of 3
A	2	5
B	2	6
C	2	11
D	2	12
E	8	5
F	8	6
G	8	11

pH and acid-base

- 13 How many grams of HClO ($M = 52.46 \text{ g mol}^{-1}$) and how many grams of NaClO ($M = 74.44 \text{ g mol}^{-1}$) can be dissolved in 1.00 L of water to prepare a buffer solution with a pH of 7.83?
- | | HClO | NaClO |
|---|-------|-------|
| A | 1.0 g | 3.8 g |
| B | 1.0 g | 1.9 g |
| C | 1.9 g | 1.0 g |
| D | 3.8 g | 1.0 g |
- 14 Four different solutions with a volume of 1.0 L, each containing a different acid, all have a pH of 2.5.
In which solution is the smallest number of moles of acid dissolved?
- A CH_3COOH
B HF
C HIO_3
D HNO_2
- 15 In a 0.1200 M solution of a monoprotic weak acid, 2.3% of the acid is ionised.
What is the value of K_a for this acid?
- A $2.4 \cdot 10^{-2}$
B $5.4 \cdot 10^{-2}$
C $5.4 \cdot 10^{-4}$
D $6.3 \cdot 10^{-5}$
E $6.5 \cdot 10^{-5}$

Redox and Electrochemistry

- 16 Copper reacts with a solution of nitric acid according to the following unbalanced chemical reaction equation:
- $$\text{Cu} + \text{H}^+ + \text{NO}_3^- \rightarrow \text{Cu}^{2+} + \text{NO} + \text{H}_2\text{O}$$
- What is the coefficient of H^+ in the balanced reaction equation?
- A 2
B 4
C 6
D 8

- 17 How long should a 3.5 A current be applied to a solution containing Zn^{2+} ions to obtain 5.0 g of zinc?

Given: $1 \text{ A} = 1 \text{ C s}^{-1}$ and the charge of one mole of electrons is 96 485 C.

- A $1.1 \cdot 10^3 \text{ s}$
- B $2.1 \cdot 10^3 \text{ s}$
- C $4.2 \cdot 10^3 \text{ s}$
- D $1.5 \cdot 10^4 \text{ s}$

Analysis

- 18 A barium nitrate solution is added to:

I a sodium sulfite solution

II a potassium ethanoate solution

Which addition produces a cloudy mixture?

- A neither addition
- B only the addition to the sodium sulfite solution
- C only the addition to the potassium ethanoate solution
- D both additions

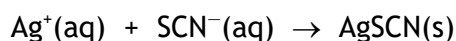
- 19 Natural bromine consists of the isotopes Br–79 and Br–81.

These isotopes occur in a percentage ratio of 50.7 : 49.3.

How many peaks appear in the mass spectrum of natural bromine?

- A 2
- B 3
- C 4
- D 5
- E 6

- 20 The mass percentage of theobromine ($\text{C}_7\text{H}_8\text{N}_4\text{O}_2$; $M = 180.2 \text{ g mol}^{-1}$) in cocoa beans is determined as follows. A 2.95 g sample of cocoa beans is treated with 25.00 mL of a 0.0100 M AgNO_3 solution. All of the theobromine is converted into solid $\text{AgC}_7\text{H}_7\text{N}_4\text{O}_2$. After filtration, the filtrate is titrated with a 0.0108 M KSCN solution. The reaction that occurs during the titration is:



The endpoint of the titration is reached after 7.69 mL has been added.

What is the mass percentage of theobromine in the cocoa beans?

- A 0.507%
- B 1.02%
- C 1.53%
- D 9.81%

Calculations

- 21 Complete combustion of an amount of a hydrocarbon produces 8.0 dm^3 of $\text{CO}_2(\text{g})$ and 12.0 dm^3 of $\text{H}_2\text{O}(\text{g})$.
What could be the molecular formula of this hydrocarbon?
- A C_2H_6
B C_3H_4
C C_3H_6
D C_4H_6
E C_8H_{12}
- 22 The only source of copper in a copper ore is the mineral malachite, $\text{Cu}_2\text{CO}_3(\text{OH})_2$ ($M = 221.1 \text{ g mol}^{-1}$).
From a 1.00 kg sample of this ore, 47.0 g of metallic copper is obtained.
What mass percentage of the ore consists of malachite, assuming all the copper present in the sample is recovered?
- A 8.18%
B 16.4%
C 28.7%
D 32.7%
E 57.5%
- 23 How many millilitres of a 0.327 M CuSO_4 solution must be diluted with water to a total volume of 1.00 L to obtain a 0.100 M CuSO_4 solution?
- A 3.27 mL
B 30.6 mL
C 32.7 mL
D 306 mL
- 24 How many nitrogen atoms are present in 486 g of N_2O_5 ?
- A $1.35 \cdot 10^{24}$
B $2.71 \cdot 10^{24}$
C $5.42 \cdot 10^{24}$
D $1.90 \cdot 10^{25}$

Green chemistry

- 25 Which combination of atom economy and yield results in the lowest E -factor?
- | | atom economy | yield |
|---|--------------|-------|
| A | low | low |
| B | low | high |
| C | high | low |
| D | high | high |

Open questions

total 23 points

Problem 2 Pilsner

9 points

Pilsner is a type of beer that is widely consumed in the Netherlands. Pilsner has a pH between 4.1 and 4.9 and is therefore moderately acidic. This low pH is caused by the presence of several acids.

A particular pilsner was analysed for the presence of a number of common organic acids found in beer. The molar concentrations of these organic acids in the analysed pilsner are listed in Table 1, which also gives the number of acidic groups (COOH groups) per molecule.

Table 1

Acid name	Molar concentration in the pilsner (mmol L ⁻¹)	Number of COOH groups per molecule
malic acid	0.433	2
pyruvic acid	0.545	1
lactic acid	1.099	1
acetic acid	0.466	1
citric acid	0.562	3
succinic acid	0.415	2
fumaric acid	0.362	2
<i>total</i>	<i>3.882</i>	

In addition to the organic acids listed in Table 1, a number of unknown organic acids are also present in the pilsner. In this problem it is assumed that all acidic groups in these unknown organic acids are also COOH groups. To determine the amount of COOH groups present in these unknown organic acids in the analysed pilsner, a titration with a sodium hydroxide solution can be performed. During the titration, the pH of the solution is monitored, and the titration is stopped once the pH reaches 8.2. At this pH, it may be assumed that all COOH groups of all organic acids present have reacted.

Before the titration can begin, the CO₂ present in the pilsner must be removed, because otherwise the result of the titration will not give an accurate picture of the total amount of organic acids in the pilsner.

- 1 Explain whether the presence of CO₂ in the pilsner during the titration would result in a value for the total amount of organic acids that is too high or too low.

2

The CO₂ is removed from the pilsner. Assume that neither the volume nor the rest of its composition changes in the process. The CO₂-free pilsner is then titrated with a sodium hydroxide solution, where the OH⁻ ions react with all COOH groups.

When the analysed pilsner contains only the organic acids listed in Table 1, it can be calculated that an average of 1.601 mol of COOH groups are present per mole of organic acid.

- 2 Show this calculation.

2

The analysed pilsner contains, in addition to the COOH groups from the acids listed in Table 1, COOH groups from other organic acids as well. These COOH groups are referred to below as the extra COOH groups.

To determine the total number of COOH groups in the analysed pilsner, the contents of one bottle of pilsner were made CO₂-free. From the CO₂-free pilsner, 25.00 mL was pipetted into an Erlenmeyer flask. The titration was carried out with a 0.0560 M sodium hydroxide solution. A volume of 3.14 mL was required to bring the pH of the solution in the Erlenmeyer to 8.2.

- 3 Calculate the number of mmol of extra COOH groups per bottle of the analysed pilsner. One bottle contains 330 mL of pilsner.

5

■ Problem 3 Disaster in Beirut

14 points

On the 4th of August 2020 a large explosion occurred in the harbour of Beirut, the capital of Lebanon.

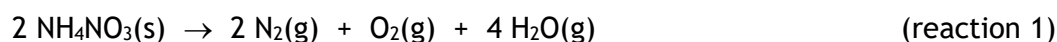
The cause of the explosion was linked to a large illegal storage of ammonium nitrate (NH_4NO_3) in a warehouse in the port of Beirut. A fire broke out in a neighbouring warehouse, which then spread to the one containing 2750 tons of ammonium nitrate, after which the explosion occurred.

Ammonium nitrate is produced through an acid-base reaction of ammonia with a nitric acid solution. After the reaction, a separation technique is applied.

- 4 Carry out the following assignments:
- Give the equation of the acid-base reaction that occurs when ammonia is added to a nitric acid solution.
 - Give the name of the separation technique that can be used to obtain solid ammonium nitrate from the resulting mixture.
- 2

- 5 Give the name of the two types of bonds that are present in solid ammonium nitrate.
- 2

At high temperatures, a decomposition reaction occurs:



Large amounts of gas are formed during this decomposition reaction.

- 6 Calculate how many m^3 of gas are formed if 2750 tons of ammonium nitrate decompose according to the above reaction equation at a temperature of 1000 K. Give your answer to the correct number of significant figures. Use the following data:
- 1 ton = 1000 kg;
 - the volume of 1 mol of gas at 1000 K is 82.1 dm^3 .
- 4

The decomposition reaction of ammonium nitrate is exothermic. The energy that is released during the explosion causes the products of the reaction to heat up and contributes to the expansion of volume.

- 7 Calculate, using the enthalpies of formation from your data booklet, the reaction enthalpy of reaction 1 in J per mole of ammonium nitrate.
- 3

An explosion of ammonium nitrate can also occur if it is mixed with petrol (C_7H_{16}).

- 8 Give the reaction equation for the reaction that occurs during this explosion. In this reaction, nitrogen, water vapour and carbon dioxide are formed.
- 3

Green Chemistry

The twelve principles of green chemistry are:

1. *Prevention* Preventing waste is better than treating or cleaning up waste after it is created.
2. *Atom economy* Synthetic methods should try to maximize the incorporation of all materials used in the process into the final product. This means that less waste will be generated as a result.
3. *Less hazardous chemical syntheses* Synthetic methods should avoid using or generating substances toxic to humans and/or the environment.
4. *Designing safer chemicals* Chemical products should be designed to achieve their desired function while being as non-toxic as possible.
5. *Safer solvents and auxiliaries* Auxiliary substances should be avoided wherever possible, and as non-hazardous as possible when they must be used.
6. *Design for energy efficiency* Energy requirements should be minimized, and processes should be conducted at ambient temperature and pressure whenever possible.
7. *Use of renewable feedstocks* Whenever it is practical to do so, renewable feedstocks or raw materials are preferable to non-renewable ones.
8. *Reduce derivatives* Unnecessary generation of derivatives—such as the use of protecting groups—should be minimized or avoided if possible; such steps require additional reagents and may generate additional waste.
9. *Catalysis* Catalytic reagents that can be used in small quantities to repeat a reaction are superior to stoichiometric reagents (ones that are consumed in a reaction).
10. *Design for degradation* Chemical products should be designed so that they do not pollute the environment; when their function is complete, they should break down into non-harmful products.
11. *Real-time analysis for pollution prevention* Analytical methodologies need to be further developed to permit real-time, in-process monitoring and control *before* hazardous substances form.
12. *Inherently safer chemistry for accident prevention* Whenever possible, the substances in a process, and the forms of those substances, should be chosen to minimize risks such as explosions, fires, and accidental releases.

$$\text{atom economy} = \frac{\text{mass of desired product}}{\text{total mass of all reactants}} \times 100\%$$

$$\text{percentage yield} = \frac{\text{experimental yield}}{\text{theoretical yield}} \times 100\%$$

$$E\text{-factor} = \frac{\text{total mass of all reactants} - \text{mass of desired product}}{\text{mass of desired product}}$$

47th National Chemistry Olympiad 2026 preliminary round 1
Answer sheet: Multiple Choice Questions

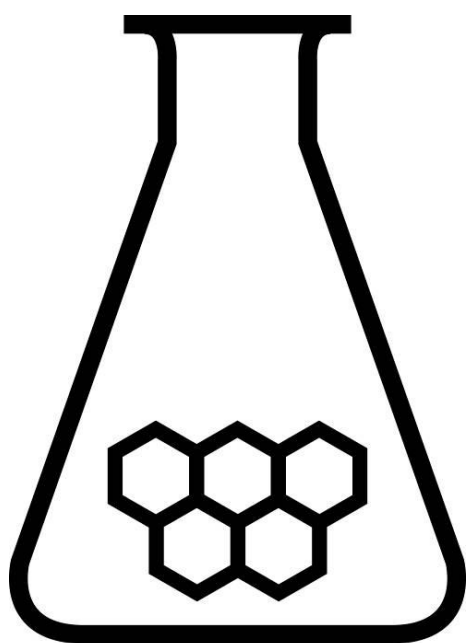
no.	Answer letter	(score)
1		
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22		
23		
24		
25		
Total		

Name:	
Teacher:	
School:	

NATIONAL CHEMISTRY OLYMPIAD 2026

ASSIGNMENTS PRELIMINARY ROUND 2

To be held between 16th and 23rd March 2026



**SCHEIKUNDE
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**Universiteit
Utrecht**

- This preliminary round consists of 20 multiple choice questions divided over 8 topics, and 3 problems with a total of 13 open questions, in addition to an answer sheet for the multiple choice questions.
- Use the answer sheet to answer the multiple choice questions.
- For the open questions, use a separate answer sheet for each of the three problems. Remember to include your name on each sheet.
- The maximum score for this paper is 94 points.
- The preliminary round lasts three hours in total.
- Required materials: (graphic) calculator and BINAS 7th edition or ScienceData 1st edition or BINAS 5th edition, English version. "Green chemistry" table is included.
- The total number of points available for each question is stated.
- Unless otherwise stated, standard conditions apply: $T = 298 \text{ K}$ and $p = p_0$.

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Problem 1 Multiple choice questions

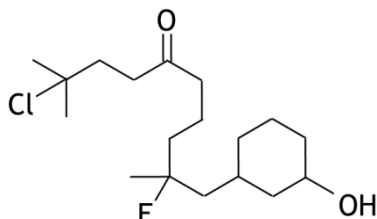
total 40 points

For each question, write your answer (letter) on the answer sheet. The answer sheet can be found at the end of this examination booklet.

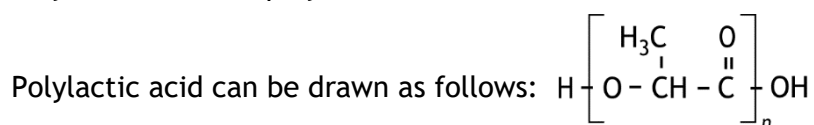
Marks: 2 points for each correct answer.

Carbon chemistry

- 1 How many stereoisomers does the following compound have?



- A 2
B 3
C 4
D 8
E 16
- 2 Polylactic acid is a polymer formed from lactic acid.



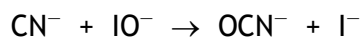
The ester bonds in polylactic acid can be broken through a reaction with water under acidic conditions.

What is the minimum amount of H_2O , in mmol, which must react in order to break all of the ester linkages in 500 mg polylactic acid with $n = 12$?

- A 6.23
B 6.36
C 6.80
D 6.94

Reaction rate and equilibrium

- 3 Cyanide (CN^-) can be converted into cyanate (OCN^-) using hypiodite (IO^-) in an alkaline solution:

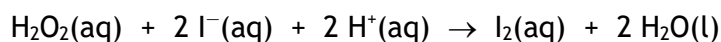


This conversion occurs according to the following mechanism:



What is the rate equation?

- A $\text{rate} = k [\text{CN}^-][\text{IO}^-][\text{OH}^-]^2$
 B $\text{rate} = k [\text{CN}^-][\text{IO}^-][\text{OH}^-]$
 C $\text{rate} = k [\text{CN}^-][\text{IO}^-]$
 D $\text{rate} = k \frac{[\text{CN}^-][\text{IO}^-]}{[\text{OH}^-]}$
 E $\text{rate} = k \frac{[\text{CN}^-][\text{IO}^-]}{[\text{OH}^-]^2}$
- 4 The reaction rate of the conversion of iodide to iodine by hydrogen peroxide in hydrochloric acid is studied by allowing the following reaction to take place:



The initial rate rate_0 of this reaction is measured in different experiments.

The following data was obtained using solutions prepared with the volumes of the various solutions shown below.

experiment	H_2O_2 solution (mL)	KI solution (mL)	hydrochloric acid (mL)	water (mL)	rate_0 ($\text{mol L}^{-1} \text{s}^{-1}$)
1	2.0	2.0	2.0	4.0	$1.00 \cdot 10^{-4}$
2	2.0	2.0	4.0	2.0	$1.02 \cdot 10^{-4}$
3	2.0	4.0	2.0	2.0	$2.05 \cdot 10^{-4}$
4	4.0	2.0	2.0	2.0	$2.07 \cdot 10^{-4}$

The rate equation is given as $\text{rate} = k [\text{H}_2\text{O}_2]^a [\text{I}^-]^b [\text{H}^+]^c$.

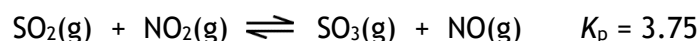
What are the values of a , b and c ?

- | | | | |
|---|-----|-----|-----|
| | a | b | c |
| A | 0 | 1 | 0 |
| B | 0 | 1 | 1 |
| C | 1 | 1 | 0 |
| D | 1 | 1 | 1 |
| E | 1 | 2 | 0 |
| F | 1 | 2 | 1 |

- 5 The reaction rate at 100 °C for a certain reaction is four times faster than the reaction rate at 50 °C, measured with the same initial concentrations.
What is the activation energy of this reaction?

A $1.52 \cdot 10^3 \text{ J mol}^{-1}$
 B $1.21 \cdot 10^4 \text{ J mol}^{-1}$
 C $2.78 \cdot 10^4 \text{ J mol}^{-1}$
 D $5.40 \cdot 10^4 \text{ J mol}^{-1}$
 E $8.01 \cdot 10^4 \text{ J mol}^{-1}$

- 6 The following reaction equation is given:



All four gases are added together in a reaction vessel and each gas has an initial partial pressure of 0.60 bar.

What is the partial pressure of $\text{SO}_2(\text{g})$ when equilibrium has been reached?

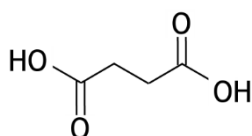
A 0.19 bar
 B 0.25 bar
 C 0.35 bar
 D 0.41 bar

Structures and formulas

- 7 How many electrons with quantum number $m_l = 1$ are present in an As atom in its ground state?

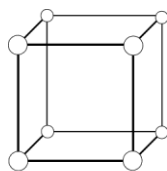
A 5
 B 7
 C 15
 D 18

- 8 How many π bonds and how many σ bonds are present in a molecule of succinic acid, as shown below?

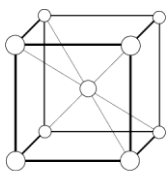


	number of π bonds	number of σ bonds
A	2	5
B	2	7
C	2	9
D	2	13
E	4	5
F	4	7
G	4	9
H	4	13

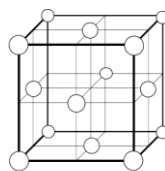
- 9 Gold has a density of $19.3 \cdot 10^3 \text{ kg m}^{-3}$. The unit cell of gold's crystal lattice is a cube with edges of $4.08 \cdot 10^{-10} \text{ m}$.
How many atoms are present in the unit cell of gold, and in which of the following types of unit cell is gold crystallised: simple cubic (cubic-P), body-centred cubic (bcc) or face-centred cubic (fcc)?



cubic-P



bcc



fcc

	number of atoms	type of unit cell
A	1	cubic-P
B	8	cubic-P
C	2	bcc
D	4	bcc
E	4	fcc
F	8	fcc

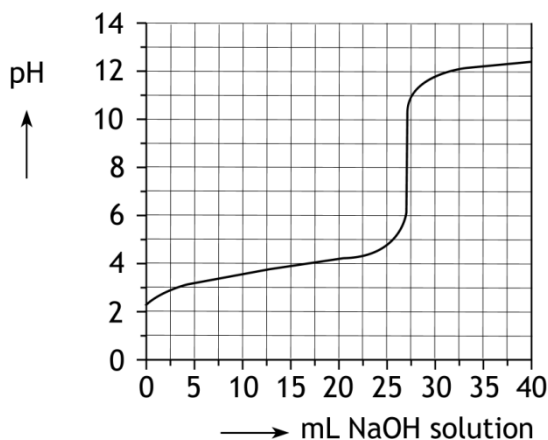
pH / acid-base

- 10 A solution of allylamine, $\text{C}_3\text{H}_5\text{NH}_2$, has a pH of 11.12.
In this solution 3.61% of the allylamine is converted into its conjugate acid.
What is the $\text{p}K_{\text{a}}$ of the conjugate acid of allylamine?

- A 1.44
- B 3.77
- C 4.31
- D 9.69
- E 10.23
- F 12.56

- 11 A solution of formic acid, HCOOH , is titrated with a 0.1000 M sodium hydroxide solution.

The change in pH during titration is shown below.

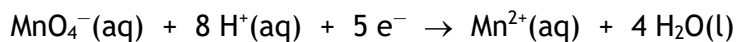


What are the relative concentrations of HCOOH , HCOO^- and Na^+ when 15.0 ml of the 0.1000 M sodium hydroxide solution is added?

- A $[\text{HCOO}^-] = [\text{Na}^+] > [\text{HCOOH}]$
- B $[\text{HCOO}^-] > [\text{HCOOH}] = [\text{Na}^+]$
- C $[\text{HCOOH}] = [\text{Na}^+] > [\text{HCOO}^-]$
- D $[\text{HCOOH}] > [\text{HCOO}^-] = [\text{Na}^+]$

Redox and electrochemistry

- 12 The standard electrode potential of the half-equation below is +1.51 V.



What is the value of the electrode potential of the half-reaction above at 298 K and $[\text{MnO}_4^-] = 0.0100 \text{ M}$, $[\text{H}^+] = 0.200 \text{ M}$ and $[\text{Mn}^{2+}] = 0.0200 \text{ M}$?

- A +1.16 V
- B +1.44 V
- C +1.50 V
- D +1.58 V

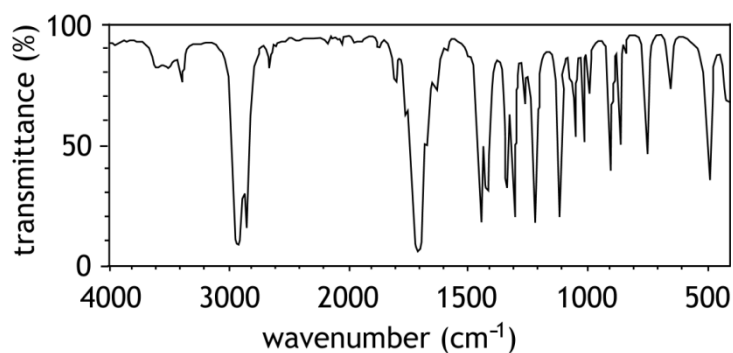
- 13 When charging a lead-acid battery, the following reaction occurs:
$$2 \text{PbSO}_4(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{Pb}(\text{s}) + \text{PbO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + 2 \text{SO}_4^{2-}(\text{aq})$$

Below are two statements about the lead-acid battery:
I During charging, $\text{PbO}_2(\text{s})$ is formed at the negative electrode.
II During charging, the same amount of $\text{SO}_4^{2-}(\text{aq})$ is produced at both electrodes.
Which of the above statements is/are correct?
- A neither
B only I
C only II
D both
- 14 Bronze statues turn slightly green over time. Copper, one of the metals in the bronze alloy, reacts in various ways with oxygen, water, sulfur trioxide, and carbon dioxide, among others, to form copper compounds with various colours. Four of these reactions are shown below.
Reaction 1: $4 \text{Cu} + \text{O}_2 \rightarrow 2 \text{Cu}_2\text{O}$
Reaction 2: $2 \text{Cu}_2\text{O} + \text{O}_2 \rightarrow 4 \text{CuO}$
Reaction 3: $4 \text{CuO} + \text{SO}_3 + 3 \text{H}_2\text{O} \rightarrow \text{Cu}_4\text{SO}_4(\text{OH})_6$
Reaction 4: $2 \text{CuO} + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Cu}_2\text{CO}_3(\text{OH})_2$
Reaction 1 is a redox reaction.
Which of the other reactions is a / are redox reaction(s)?
- A none of them
B only reaction 2
C only reaction 3
D only reaction 4
E reactions 2 and 3
F reactions 2 and 4
G reactions 3 and 4
H all reactions

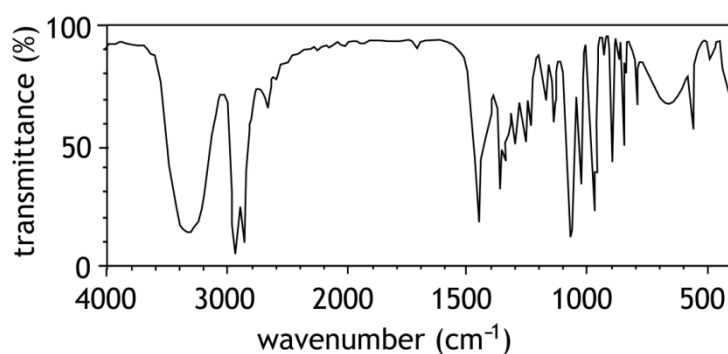
Analysis

15 Two IR spectra are shown below.

spectrum 1



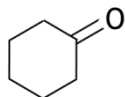
spectrum 2



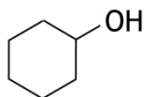
Each spectrum corresponds to one of the substances below.



I



II



III

Which spectrum corresponds to which substance?

	spectrum 1	spectrum 2
A	I	II
B	I	III
C	II	I
D	II	III
E	III	I
F	III	II

Calculations

- 16 A white, crystalline solid contains only the atoms C, H, N, and O. Complete combustion of 1.000 g of this substance produces 1.831 g of CO_2 and 0.750 g of H_2O .
Which of the molecular formulas below could this substance have?
- A $\text{C}_3\text{H}_6\text{NO}_2$
B $\text{C}_4\text{H}_4\text{NO}_2$
C $\text{C}_6\text{H}_{12}\text{N}_2\text{O}_2$
D $\text{C}_8\text{H}_8\text{N}_2\text{O}_4$
- 17 A gas mixture of 10.0 dm^3 consists of methane (CH_4) and propane (C_3H_8). For the complete combustion of this gas mixture, 38.0 dm^3 of oxygen gas is required.
What is the volume percentage of propane in the original gas mixture?
- A 30.0%
B 40.0%
C 50.0%
D 60.0%
E 70.0%

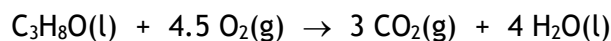
Thermochemistry

- 18 For the reaction:
- $$\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$$
- the following applies at 450 K:

	$\Delta_f H^\circ (\text{J mol}^{-1})$	$S^\circ (\text{J mol}^{-1} \text{K}^{-1})$
$\text{Cl}_2(\text{g})$	0	223.1
$\text{PCl}_3(\text{g})$	$-2.870 \cdot 10^5$	311.8
$\text{PCl}_5(\text{g})$	$-3.749 \cdot 10^5$	364.4

- What is the value of the equilibrium constant K_p of the above equilibrium reaction at 450 K?
- A 19.8
B $2.02 \cdot 10^4$
C $3.17 \cdot 10^6$
D $1.60 \cdot 10^{10}$

- 19 Standard reaction enthalpies of three reactions are given below.
- $3 \text{ C(s)} + 4 \text{ H}_2\text{(g)} + 0.5 \text{ O}_2\text{(g)} \rightarrow \text{C}_3\text{H}_8\text{O(l)}$ $\Delta_r H_1^0 = -3.18 \cdot 10^5 \text{ J mol}^{-1}$
 $\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$ $\Delta_r H_2^0 = -3.94 \cdot 10^5 \text{ J mol}^{-1}$
 $\text{H}_2\text{(g)} + 0.5 \text{ O}_2\text{(g)} \rightarrow \text{H}_2\text{O(l)}$ $\Delta_r H_3^0 = -2.86 \cdot 10^5 \text{ J mol}^{-1}$
- What is the standard enthalpy of reaction for the combustion reaction shown below?



- A $-3.62 \cdot 10^5 \text{ J mol}^{-1}$
B $-9.98 \cdot 10^5 \text{ J mol}^{-1}$
C $-20.08 \cdot 10^5 \text{ J mol}^{-1}$
D $-21.16 \cdot 10^5 \text{ J mol}^{-1}$
E $-40.16 \cdot 10^5 \text{ J mol}^{-1}$
- 20 For a particular reaction, $\Delta H^0 = -3.83 \cdot 10^4 \text{ J mol}^{-1}$ and $\Delta S^0 = -113 \text{ J mol}^{-1} \text{ K}^{-1}$. For this question, assume that ΔH^0 and ΔS^0 are independent of temperature.
- Which of the following statements is correct?
- A The reaction occurs at all temperatures.
B The reaction only occurs at temperatures below 66 °C.
C The reaction only occurs at temperatures above 66 °C.
D The reaction does not occur at any temperature.

Open questions

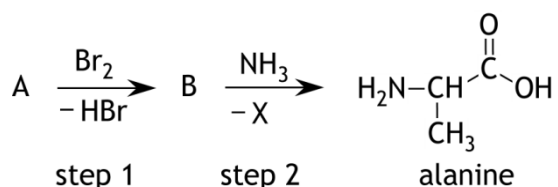
total 54 points

■ Problem 2 Carboxylic acid

16 points

Carboxylic acids are produced industrially on a large scale, for example for the synthesis of amino acids.

To synthesize alanine, a certain carboxylic acid reacts with Br_2 and then with NH_3 according to the synthesis scheme below:

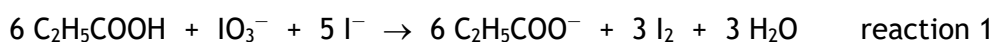


- 1 Complete the following assignments:
- Draw the structural formulas of A and B.
 - Give the molecular formula of X.
 - Give the name of the type of reaction that occurs in step 2 of the synthesis scheme above. Choose from: *addition reaction*, *elimination reaction*, and *substitution reaction*.
 - Besides alanine, another amino acid is also formed. Draw the structural formula of this other amino acid.

5

E280 is a preservative whose main component is a carboxylic acid with the molecular formula $\text{C}_2\text{H}_5\text{COOH}$. Use of a preservative requires high purity. The $\text{C}_2\text{H}_5\text{COOH}$ content in a sample of E280 can be determined by iodometric titration.

200 mg of a sample of E280 is transferred to a conical flask and dissolved in water. Excess iodide ions and excess iodate ions are added to the solution. The equation for the reaction that occurs is:



- 2 Write the equation for the half-reaction for conversion of IO_3^- to I_2 . In this half-reaction, include only the particles IO_3^- , I_2 , $\text{C}_2\text{H}_5\text{COOH}$, $\text{C}_2\text{H}_5\text{COO}^-$, H_2O and e^- .

4

35.0 mL of 0.100 M sodium thiosulfate solution is then added to the solution.

The equation for the reaction that occurs is:



The resulting mixture is titrated with a 0.0500 M solution of I_2 . 9.75 mL of this I_2 solution was needed to react with the remaining thiosulfate.

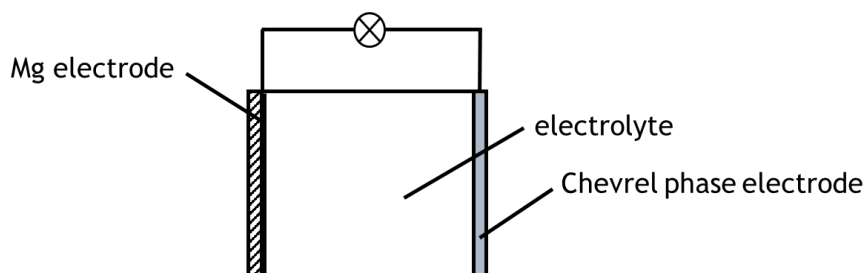
- 3 Calculate the mass percentage of $\text{C}_2\text{H}_5\text{COOH}$ in the examined sample E280.

7

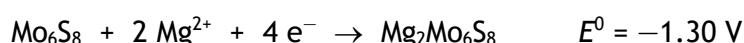
Problem 3 A promising home battery

12 points

To make the energy transition a success, affordable rechargeable home batteries are needed. Li-ion batteries are currently used for this purpose. To avoid being solely dependent on lithium, alternatives are actively being researched. A promising alternative is the Mg-ion home battery. A schematic diagram of the Mg-ion home battery is shown below.



During discharge of the Mg-ion home battery the following reactions occur:



- 4 Calculate the Gibbs energy for the formation of $\text{Mg}_2\text{Mo}_6\text{S}_8$ in the Mg-ion home battery, under standard conditions. Use $\Delta G^0 = -nF\Delta E^0$. Give your answer in $\text{J mol}^{-1} \text{Mg}_2\text{Mo}_6\text{S}_8$. 3

The Chevrel phase electrode consists of a stack of Mo_6S_8 units. These units contain voids. The Mg^{2+} ions generated at the Mg electrode during discharging migrate to the Chevrel phase electrode and are absorbed into these voids.

The resulting $\text{Mg}_2\text{Mo}_6\text{S}_8$ units consist of a Mo_6^{12+} cluster surrounded by eight S^{2-} ions and two Mg^{2+} ions contained in the voids. The Mo_6^{12+} cluster can be viewed as an octahedron of 6 Mo^{2+} ions. This Mo_6^{12+} cluster contains 24 4d-electrons.

In a positively charged Mo_6 cluster, each Mo ion can be connected to four other Mo ions through covalent bonds. These covalent bonds are formed by the 4d-electrons from the Mo ions. These covalent bonds stabilize a positively charged Mo_6 cluster.

- 5 Based on the information above, explain in which substance the positively charged Mo_6 cluster is more stable: in $\text{Mg}_2\text{Mo}_6\text{S}_8$ or in Mo_6S_8 . 4

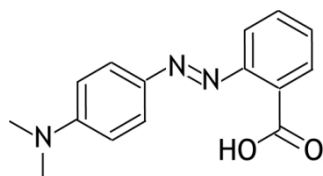
The thickness of the Mg electrode for a fully charged Mg-ion home battery is $10.0 \mu\text{m}$. The thickness of the Mg electrode varies during use of the Mg-ion home battery, and the Mg electrode is thinnest after a complete discharge of the Mg-ion home battery.

- 6 Calculate the thickness (in μm) of the Mg electrode after complete discharge of the Mg-ion home battery. Assume that:
- the Chevrel phase electrode consisting of $2.5 \text{ g Mo}_6\text{S}_8$ has completely reacted;
 - both electrodes have a surface area of 100 cm^2 ;
 - the Mg has reacted evenly over the electrode surface.
- 5

Problem 4 Synthesis and function of methyl red

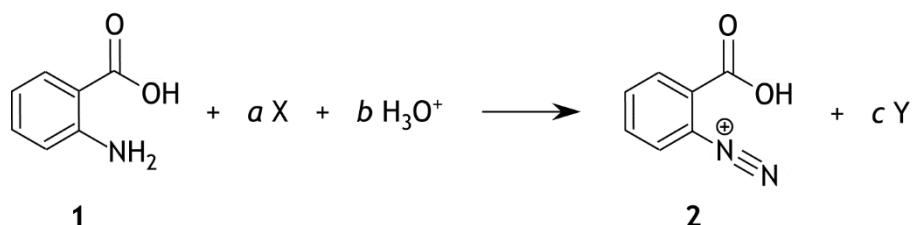
26 points

Methyl red is a substance used as an indicator in acid-base and redox titrations. The structural formula of methyl red is shown below.



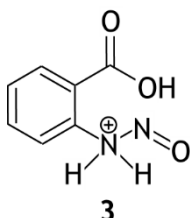
- 7 Explain whether optical isomers and/or *cis-trans* isomers of methyl red can exist. 3

Methyl red can be produced through two reactions. In the first reaction, the amino group of anthranilic acid (substance 1) is converted into a diazonium group using sodium nitrite solution and hydrochloric acid via a process called diazotization. The incomplete equation for this reaction is shown below.



- 8 Give the formula for substance X and substance Y and the coefficients a , b and c to obtain a balanced equation for the reaction. 3

The mechanism of this reaction consists of several steps. In one of these steps, intermediate 3, shown below, is formed.



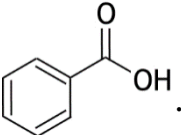
Reactant 1 is converted into intermediate 3 by a reaction with a positively charged ion.

- 9 Draw the Lewis structure of the charged ion that reacts with reactant 1. In this Lewis structure, place the formal charge in the correct place. 3

The mechanism of the conversion of intermediate **3** to ion **2** is described step-by-step below.

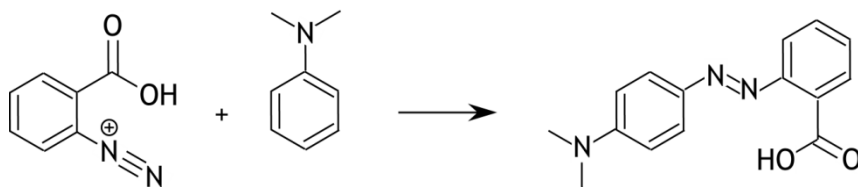
- Step 1: A bonding pair of electrons between the O atom and the N atom in intermediate **3** binds an H atom from the adjacent N atom. A double bond between the N atoms is created through bond rearrangement.
- Step 2: A proton is transferred from the N atom to a water molecule.
- Step 3: One of the non-bonding electron pairs on the O atom of the OH group created in step 1 binds a proton from an H_3O^+ ion.
- Step 4: By displacement of bonding and non-bonding electron pairs, H_2O leaves the molecule and ion **2** is formed.

- 10 Represent steps 1 to 4 of the mechanism using structural formulas. Use the information below.

- Use the notation **R** for the side group: .
- Draw all bonding and non-bonding electron pairs.
- Indicate with curly arrows () how electron pairs move.
- Place all formal charges in the correct place.

8

In a second reaction, a diazonium coupling occurs between ion **2** and N,N-dimethylaniline according to the incomplete reaction equation below.



In this incomplete reaction equation, one particle is missing.

- 11 Give the formula for the missing particle in the incomplete reaction equation above and indicate whether it should be placed before or after the arrow.

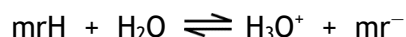
1

This reaction can occur because N,N-dimethylaniline has resonance structures where positions with a 1– charge exist in the benzene ring. This delocalization also involves the N atom. One of these resonance structures results in the formation of a methyl red molecule.

- 12 Draw this resonance structure. Give your answer as Lewis structure including all formal charges in the correct place.

2

Methyl red is a weak acid. When methyl red is added to a colourless solution, the resulting colour depends on the pH of the solution. The following equilibrium plays a role:



where mr^- is the conjugate base of methyl red (mrH). The pK_a of methyl red is 5.00.

At high pH, mr^- absorbs maximum light at a wavelength of 429 nm, and at low pH, mrH absorbs maximum light at a wavelength of 520 nm. By measuring the absorbance at 429 nm (A_{429}) and at 520 nm (A_{520}), the concentrations of mrH and mr^- can be determined using the Lambert-Beer law. From this, the pH of the solution can then be calculated.

The table below gives the molar extinction coefficients of mrH and mr^- at two wavelengths.

	$\mathcal{E}_{429 \text{ nm}}$ ($\text{L mol}^{-1} \text{ cm}^{-1}$)	$\mathcal{E}_{520 \text{ nm}}$ ($\text{L mol}^{-1} \text{ cm}^{-1}$)
mr^-	$1.25 \cdot 10^4$	$1.33 \cdot 10^3$
mrH	$3.86 \cdot 10^3$	$2.15 \cdot 10^4$

A small amount of methyl red was added to a colourless solution and the following absorbances were measured: $A_{429} = 0.108$ and $A_{520} = 0.219$.

A cuvette with a path length of 1.00 cm was used for the measurements.

- 13 Calculate the pH of the solution.

6

Green Chemistry

The twelve principles of green chemistry are:

1. *Prevention*. Preventing waste is better than treating or cleaning up waste after it is created.
2. *Atom economy*. Synthetic methods should try to maximize the incorporation of all materials used in the process into the final product. This means that less waste will be generated as a result.
3. *Less hazardous chemical syntheses*. Synthetic methods should avoid using or generating substances toxic to humans and/or the environment.
4. *Designing safer chemicals*. Chemical products should be designed to achieve their desired function while being as non-toxic as possible.
5. *Safer solvents and auxiliaries*. Auxiliary substances should be avoided wherever possible, and as non-hazardous as possible when they must be used.
6. *Design for energy efficiency*. Energy requirements should be minimized, and processes should be conducted at ambient temperature and pressure whenever possible.
7. *Use of renewable feedstocks*. Whenever it is practical to do so, renewable feedstocks or raw materials are preferable to non-renewable ones.
8. *Reduce derivatives*. Unnecessary generation of derivatives – such as the use of protecting groups – should be minimized or avoided if possible; such steps require additional reagents and may generate additional waste.
9. *Catalysis*. Catalytic reagents that can be used in small quantities to repeat a reaction are superior to stoichiometric reagents (ones that are consumed in a reaction).
10. *Design for degradation*. Chemical products should be designed so that they do not pollute the environment; when their function is complete, they should break down into non-harmful products.
11. *Real-time analysis for pollution prevention*. Analytical methodologies need to be further developed to permit real-time, in-process monitoring and control *before* hazardous substances form.
12. *Inherently safer chemistry for accident prevention*. Whenever possible, the substances in a process, and the forms of those substances, should be chosen to minimize risks such as explosions, fires, and accidental releases.

$$\text{atom economy} \quad \frac{\text{mass of desired product}}{\text{total mass of all reactants}} \times 100\%$$

$$\text{percentage yield} \quad \frac{\text{experimental yield}}{\text{theoretical yield}} \times 100\%$$

$$E - \text{factor} \quad \frac{\text{total mass of all reactants} - \text{mass of desired product}}{\text{mass of desired product}}$$

47th National Chemistry Olympiad 2026 preliminary round 2
Answer sheet: multiple choice questions

no.	answer (letter)	(score)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
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17		
18		
19		
20		
Total		

Name:	
Teacher:	
School:	

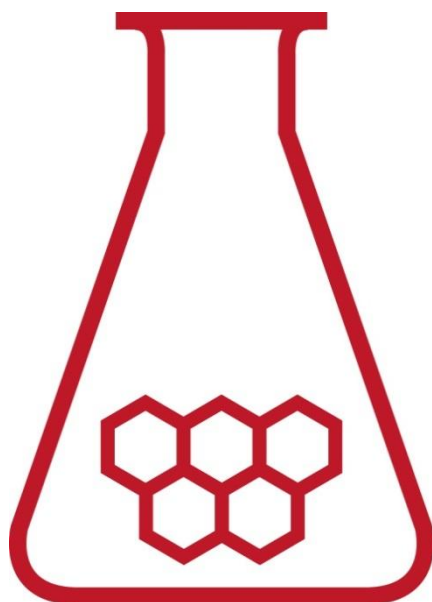
47th National Chemistry Olympiad

Utrecht University

THEORY TEST

Question booklet

Monday 8th June 2026



**SCHEIKUNDE
OLYMPIADE**



**Universiteit
Utrecht**



- This test consists of 7 problems with 35 open questions.
- Use a separate answer sheet for each problem, making sure to write your name on each sheet. Maintain a 2 cm margin on all sides of the page.
- The maximum score for this test is 120 points.
- The test will last a maximum of 4 hours.
- Required resources: (graphic) calculator and Binas 7th edition or BINAS 5th edition, English version or ScienceData 1st edition.
- The number of points available for each question is given.
- Unless otherwise stated, standard conditions apply: $T = 298\text{ K}$ and $p = p_0$.

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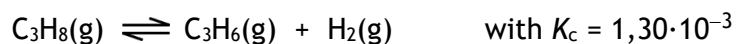
The NSO committee

Marijn Jonker and Emiel de Kleijn

■ Problem 1 Trouble in a cylinder

10 points

A cylinder sealed by a movable piston contains a quantity of propane. The cylinder is heated to 527 °C. The following equilibrium is established:



When equilibrium has been reached, the volume percentage of propane is equal to 80%.

- 1 Calculate $[\text{C}_3\text{H}_8]$, $[\text{C}_3\text{H}_6]$, $[\text{H}_2]$, all in mol dm^{-3} , and the total pressure, in Pa, in the cylinder when equilibrium has been reached. 7

Next, the piston is pushed in until the volume is reduced by half while maintaining a constant temperature.

- 2 Once equilibrium has been re-established, will the pressure in the cylinder be twice as high, more than twice as high, or less than twice as high? Explain your answer. 3

Problem 2 Malaprade

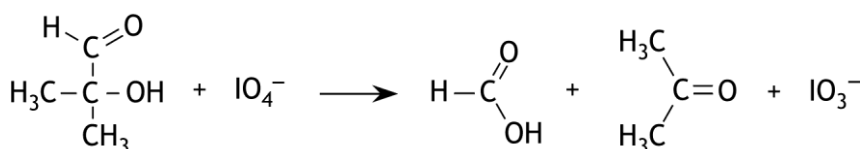
19 points

Organic compounds with certain functional groups in the molecule that are bonded to neighboring (vicinal) carbon atoms can react with sodium periodate (NaIO_4). In this reaction, the bond between the carbon atoms to which the functional groups are attached is broken, while the groups bound to those carbon atoms are also transformed. The following rules apply:

- When the functional group is a hydroxyl group, it is converted into a carbonyl group.
- When the functional group is a carbonyl group, it is converted into a carboxyl group.
- When the functional group is a carboxyl group, it is converted into carbon dioxide.

This reaction may be referred to as the Malaprade reaction. The Malaprade reaction is a redox reaction.

For example: 2-hydroxy-2-methylpropanal is converted by periodate into methanoic acid and propanone in a molar ratio 1 : 1; the periodate is converted into iodate (IO_3^-):

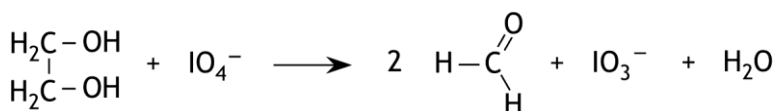


- 3 Give the structural formula of the compound that yields ethanoic acid as the sole product in the Malaprade reaction.

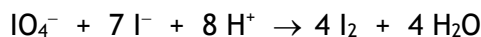
2

The Malaprade reaction can be used, among others, to determine the concentration of glycol (ethane-1,2-diol) in solution. A glycol solution is commonly used as antifreeze.

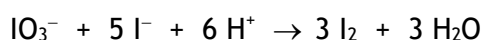
In such a determination, 150 mg of antifreeze was added to a 25.0 mL solution of sodium periodate (in excess). The following reaction occurred:



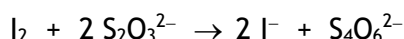
After the reaction was complete, the solution was acidified and an excess amount of iodide was added. Both the IO_4^- and the formed IO_3^- reacted with iodide to form I_2 :



and



Finally, the formed iodine was titrated with a 0.502 M solution of sodium thiosulfate. The following reaction occurred:



The titration required 19.6 mL of the sodium thiosulfate solution.

Next, a blank determination was performed, as described above, but without adding the antifreeze. For this blank determination, 23.9 mL of the sodium thiosulfate solution was required to titrate the formed iodine.

- 4 Calculate the mass percentage of glycol in the antifreeze sample.

8

The Malaprade reaction can also be used to distinguish between certain sugars. For example the Malaprade reaction can be used to determine whether a sugar is glucose or fructose.

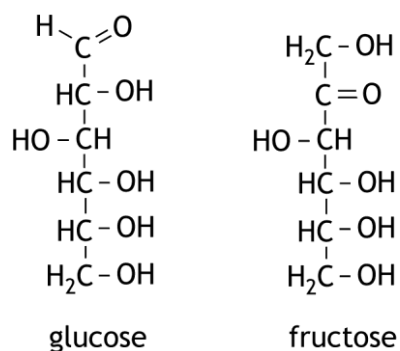
During the Malaprade reaction with glucose and fructose, all C – C bonds in the molecules are broken. The following substances can then be formed: methanal, methanoic acid and carbon dioxide.

- 5 Answer the following questions:

9

- Which substances are finally formed in the Malaprade reaction of glucose, and in what molar ratio are these substances formed?
- Which substances are finally formed in the Malaprade reaction of fructose, and in what molar ratio are these substances formed?
- How could you determine whether a sugar is glucose or fructose: by determining the molar ratio in which glucose and fructose react with periodate, or by titrating the reaction products of the Malaprade reaction with sodium hydroxide? Explain your answer.

Use the information provided at the beginning of this problem and the open-chain structures of glucose and fructose:



Problem 3 Electrochemical conversion of CO₂

23 points

The electrochemical conversion of CO₂ is seen as a promising and technically feasible method for mitigating the negative effects of rising CO₂ levels in the atmosphere. Using renewable energy, CO₂ can be converted into various platform chemicals. To ensure that the formation of desired products during electrolysis proceeds at a practically feasible rate, research is conducted into the use of electrocatalysts. A new concept in the field of such catalysts is based on the use of electrodes coated in a foam-like material.

This foam-like material has a large surface area that is readily accessible to reactants (e.g. H₂O, H₂ en CO₂).

Copper-based materials are the only known metallic electrocatalysts capable of producing hydrocarbons and alcohols in significant quantities through the electrolysis of CO₂.

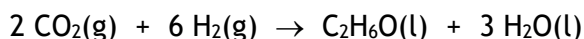
During a specific electrolysis in an acidic medium, CO₂ is converted at the negative electrode into ethanol and propan-1-ol. In these conversions, 6 moles of electrons react per mole of converted CO₂.

- 6 Provide the equation of the half-reaction for the conversion of CO₂ to propan-1-ol in an acidic medium.

3

The standard electrode potential for the conversion of CO₂ to ethanol can be calculated by considering a galvanic cell consisting of a standard CO₂/ethanol half-cell and a standard H₂/H⁺ half-cell.

The reaction occurring in this galvanic cell can be represented by the following reaction equation:



- 7 Calculate the standard electrode potential for the conversion of CO₂ to ethanol. Use data from the information booklet and the formula $\Delta_r G = -n \times F \times \Delta E$.

5

A representative example of the formation of electrode material with a copper-based metallic foam layer is described below:

Electrolysis is carried out in an acidic solution containing both copper(II) ions and silver ions. A copper plate with a surface area of 1.0 cm² serves as the negative electrode, while platinum foil acts as the positive electrode. During electrolysis, a layer of porous, foam-like Cu-Ag bimetal deposits on the negative electrode. This porous structure of the bimetal forms because tiny hydrogen bubbles evolve within the bimetal during the metal deposition. The bimetal is, so to speak, slightly inflated.

A layer of foam containing 5.4 mg of Cu-Ag bimetal forms on the copper plate.

This bimetal contains 90% Cu by mass and 10% Ag.

During this electrolysis 60 C cm⁻² of charge was used.

- 8 Calculate the Faraday efficiency (FE in %) of this metal deposition.

FE is defined as $\frac{Q_{\text{product}}}{Q_{\text{total}}} \times 100\%$. Q represents the amount of electric charge.

4

The Cu-Ag bimetallic foam catalyst (90 wt% Cu; 10 wt% Ag) is used in a CO₂ electrolysis experiment:

35 mL of 0.5 M KHCO₃ electrolyte solution saturated with CO₂ is electrolyzed.

The negative copper electrode is coated with the Cu-Ag bimetallic foam catalyst and the positive electrode is made of platinum. The CO₂ electrolysis is carried out at a constant current density of $J = 30 \text{ mA cm}^{-2}$ for 1.0 hour (Note: the current density is normalized to a surface area of 1.0 cm²).

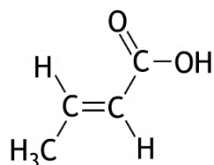
An analysis of the product after the electrolysis yields mass concentrations of 41.3 mg L⁻¹ ethanol and 7.4 mg L⁻¹ propan-1-ol. Both alcohols are liquid reaction products and accumulate in the electrolyte during the electrolysis. It may be assumed that only hydrogen gas (H₂) is formed as a byproduct at the negative electrode.

- 9 Provide the equation for the half-reaction that occurs at the positive electrode. 2
- In the electrolysis described above, 33.6 percent of the current is used for the production of ethanol and 6.9 percent for the production of propan-1-ol.
- 10 Calculate how many cm³ H₂ (at p_0 and 298 K) is formed at the negative electrode. 5
- 11 Calculate how many mg of CO₂ are converted in the electrolysis described above. Assume that the total volume of the electrolyte, ethanol, and propan-1-ol remains 35 mL. 4

Problem 4 Crotonic acid

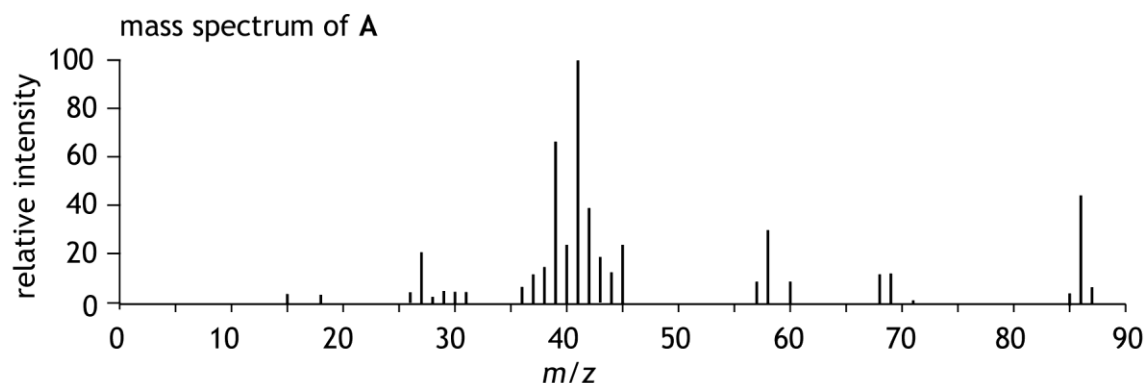
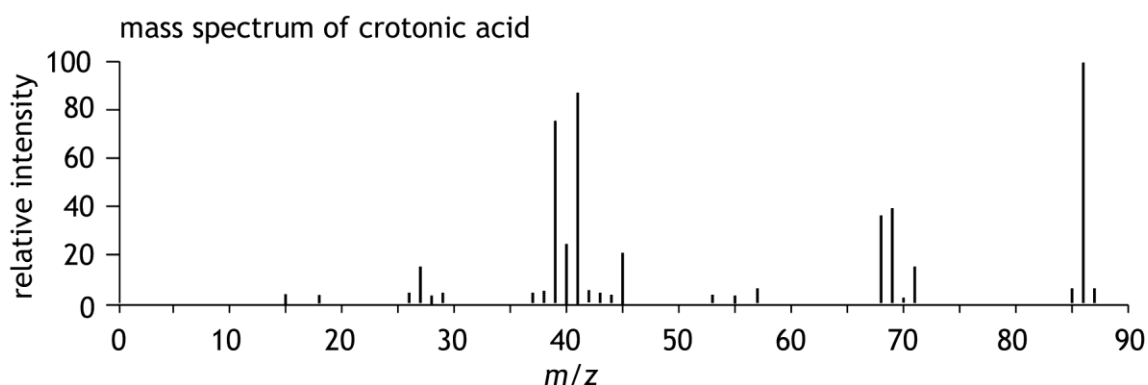
17 points

Crotonic acid has the following chemical structure:



- 12 Copy this structural formula onto your answer sheet and write the type of hybridization for each carbon atom. 2

There are various synthetic routes for the production of crotonic acid. The byproducts often include the stereoisomer and a specific structural isomer **A** of crotonic acid. The mass spectra of crotonic acid and of this structural isomer **A** are shown below.



- 13 Perform the following tasks:
- Explain, based on these mass spectra, that **A** is a structural isomer of crotonic acid.
 - Explain that it can be deduced from these mass spectra that **A**, like crotonic acid, is also a carboxylic acid.
- 3

Crotonic acid can be obtained by the thermolysis of the biopolymer *poly*(3-hydroxybutanoic acid). This polymer can be produced by certain bacteria.

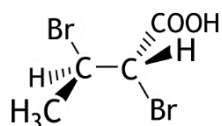
- 14 Provide the structural formula of a fragment from the middle of a molecule of this polymer. This fragment must consist of three monomer units. 3
- 15 Provide the reaction equation in molecular formulas for the thermolysis of *poly*(3-hydroxybutanoic acid) to crotonic acid. 2

Crotonic acid is used as a starting material in organic synthesis.

A specific synthetic route starts with the electrophilic addition of bromine to crotonic acid. This reaction yields 2,3-dibromobutanoic acid.

This addition reaction proceeds via a so-called *anti*-mechanism:

A bromine molecule reacts with a crotonic acid molecule. This produces a so-called bromonium ion and a bromide ion. In the bromonium ion, Br is located at the bottom or at the top of the ion. The bromide ion then reacts from the opposite side (*anti*), forming the product. This can result in the following product:



- 16 Explain whether carbon atom 2 has the *R* or the *S* configuration. Include a drawing in your explanation. 3

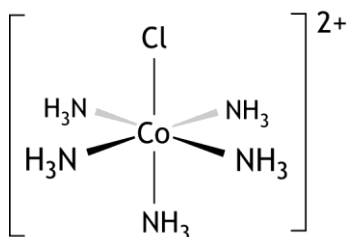
In the structural formula shown for 2,3-dibromobutanoic acid, various stereoisomers are possible. However, not all of these are formed during the electrophilic addition of bromine to crotonic acid.

- 17 Explain how many stereoisomers of 2,3-dibromobutanoic acid are possible in total, in principle. 2
- 18 Explain how many stereoisomers of 2,3-dibromobutanoic acid are formed during the electrophilic addition of bromine to crotonic acid. 2

Problem 5 CoFe

17 points

The structure of the chloropentaamminecobalt(III) complex, $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$, is shown below.

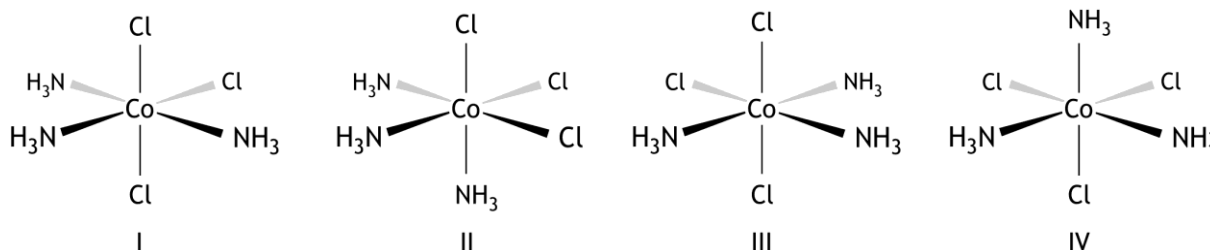


These complexes occur in a solution of chloropentaamminecobalt(III) chloride. An excess of a silver nitrate solution is added to 10.00 mL of a 0.0500 M solution of chloropentaamminecobalt(III) chloride. This produces a precipitate.

- 19 Calculate how many g of precipitate are formed.

3

$\text{Co}(\text{Cl})_3(\text{NH}_3)_3$ complexes also exist. Four structures with this formula are shown below:



- 20 Which of these structures are identical?

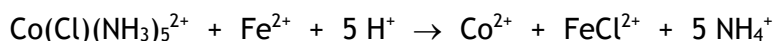
2

A solution that contains complex ions $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$ is red in colour. The transmittance, T , of a solution with $[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}] = 0.0200 \text{ mol L}^{-1}$ is measured at 520 nm in a cuvette with a path length of 1.00 cm. The transmittance is 7.50%.

- 21 Calculate the molar extinction coefficient ϵ of $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$. Assume that in this solution, only $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$ absorbs light.

3

When an acidified solution of iron(II) chloride is added to a solution containing $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$, the following reaction takes place:



The speed of this reaction is given by $r = k[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}][\text{Fe}^{2+}]$.

To determine the rate constant k of this reaction, an experiment is carried out in which 10.00 mL of a 0.300 M solution of iron(II) chloride is added to 10.00 mL of a solution containing $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$. Care is taken to ensure that the initial concentration of Fe^{2+} is many times greater than the concentration of $\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}$.

During the reaction, the absorbance A of the solution is measured at 520 nm at various points in time. The following observations are obtained:

t (min)	10	20	40	60	∞
A	1.15	0.875	0.558	0.410	0.283

The absorbance at $t = \infty$ is the absorbance measured once the reaction has finished.

For the calculation of k , you can assume that $[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}]_t$ is proportional to $(E_t - E_\infty)$.

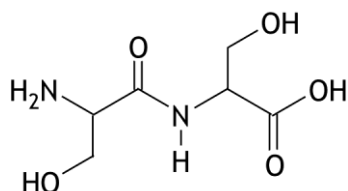
- 22 Give a possible explanation for the fact that E_∞ does not equal zero. 1
- 23 Explain why $[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}]_t$ is proportional to $(E_t - E_\infty)$. 2
- 24 Calculate k in the correct SI unit. 6

Problem 6 Dipeptide

14 points

Dipeptides are an important source of nitrogen and free amino acids within the cell. It turns out that transport of dipeptides across the cell membrane via specialised transport proteins is faster and, moreover, more energy-efficient than the transport of free amino acids. As a result, the cell efficiently takes in twice the amount of building blocks.

The dipeptide Ser – Ser dissolves easily in water; the structural formula for Ser – Ser can be represented as follows:



In a neutral solution, Ser – Ser is rarely found in the form shown in the structural formula above.

- 25 Show, using a structural formula, how the dipeptide Ser – Ser mainly exists in a solution with a pH of 7.0. 1

A Ser – Ser molecule contains what is known as an amide group. The bond between the carbon atom and the nitrogen atom in this group behaves partly like a double bond.

- 26 Explain this using electron configurations (resonance structures) of the amide group. 3

This also means that the bonds around the nitrogen atom lie in one plane and that Ser – Ser has *E/Z* isomers. It turns out that one of the *E/Z* isomers of Ser – Ser occurs much more frequently than the other one.

- 27 Carry out the following tasks:
- Explain that Ser – Ser has *E/Z* isomers.
 - Draw a three-dimensional structure of the *E/Z* isomer of Ser – Ser that occurs most frequently and explain why it occurs most frequently.
- 3

The formation of the dipeptide Ser – Ser is an equilibrium reaction:



For equilibrium 1, $\Delta G_1^0 = +1.7 \cdot 10^4 \text{ J mol}^{-1}$.

In biological systems, the formation of dipeptides is linked to the hydrolysis of adenosine triphosphate (ATP), which produces adenosine diphosphate (ADP) and a phosphate group (P_i):

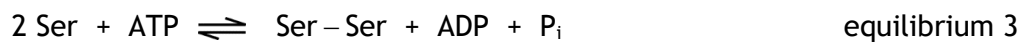


Possible formulas for P_i are H_3PO_4 , H_2PO_4^- , HPO_4^{2-} and PO_4^{3-} .

- 28 Which two of the options for P_i mentioned above are most common in a solution with a pH of 7.0? 2

For equilibrium 2, $\Delta G_2^0 = -2.8 \cdot 10^4 \text{ J mol}^{-1}$.

Coupling equilibrium 2 with equilibrium 1 creates a new equilibrium:



□29 Carry out the following tasks:

- Calculate the equilibrium constant $K_{c,1}$ for equilibrium 1.
- Calculate the equilibrium constant $K_{c,3}$ for equilibrium 3.
- Explain how the coupling of the two equilibria affects the yield of the dipeptide.

5

Problem 7 Hydrogen storage

20 points

The alloy with the formula LaNi_5 is very suitable for the storage and transport of hydrogen.

The alloy can be prepared by allowing lanthanum(III) oxide and nickel(II) oxide to react in the correct ratio in the presence of an excess of calcium hydride. This also produces calcium hydroxide. Approximately twice as much calcium hydride is used as is theoretically required.

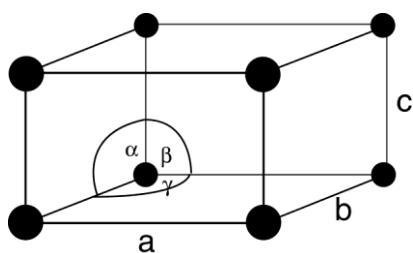
- 30 Calculate the mass ratio in which lanthanum(III) oxide and nickel(II) oxide must react. Write your answer as lanthanum(III) oxide : nickel(II) oxide = ... : 1.0. 3

- 31 Calculate how many grams of calcium hydride are used to synthesise 1.0 g of LaNi_5 if a twofold excess of calcium hydride is applied. 4

Once the reaction is complete, a mixture of the solids LaNi_5 , calcium hydroxide and calcium hydride is obtained. The calcium hydroxide and calcium hydride have to be removed from this mixture.

- 32 Explain how you could do this. 2

The unit cell of LaNi_5 has the following shape:



Here, the angles α and β equal 90° and the angle γ equals 120° , whilst the edges are given by $a = b = 511 \text{ pm}$ and $c = 397 \text{ pm}$.

The formula of the unit cell is LaNi_5 . The lanthanum atoms (the black dots) are located at the corners. In the full drawing of the unit cell of LaNi_5 , 9 nickel atoms still have to be drawn.

- 33 Explain where the nickel atoms can be located within the unit cell. 3

- 34 Calculate the density of LaNi_5 in kg m^{-3} . For this calculation, you will need the volume of the unit cell; if you are unable to calculate this, assume $V_{\text{cel}} = 1.2 \cdot 10^{-28} \text{ m}^3$; this is not the correct volume. 3

Hydrogen atoms can occupy the spaces between the atoms in the LaNi_5 lattice. When all these spaces are filled with hydrogen atoms, the LaNi_5 alloy can hold 1 244 times as many hydrogen atoms per cm^3 as are present in one cm^3 of gaseous hydrogen at 273 K and $p = p_0$.

- 35 Calculate the maximum number of hydrogen atoms that can be stored in one unit cell. For this calculation, you will need the volume of the unit cell; if you are unable to calculate this, assume $V_{\text{cel}} = 1.2 \cdot 10^{-28} \text{ m}^3$; this is not the correct volume. 5

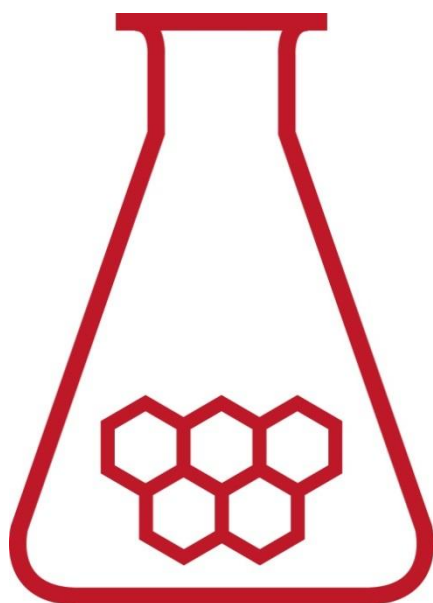
47th National Chemistry Olympiad

Utrecht University

PRACTICAL TEST

Exam booklet

Tuesday 9th June 2026



**SCHEIKUNDE
OLYMPIADE**



**Universiteit
Utrecht**



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Instructions/Resources

- This practical exam consists of two parts:
 - The synthesis of the ester 1-pentyl propanoate
 - The determination of the acetic acid content in vinegar using a titration curve
- The practical exam ends after four hours. Within this time:
 - the attached answer sheets must be completed
 - all questions must be answered
- After the practical exam, once you have handed in all materials, the glassware must be cleaned and placed in the bins for used glassware.
- The maximum score for the practical exam is **80 points**.
- The score is determined by:
 - practical skills, neatness, and safety maximum 20 points
 - results of the determinations and answers to the questions maximum 60 points
- Required tools: a (graphical) calculator, ruler/protractor triangle and Binas or ScienceData.
- First, read the introduction and all assignments, and only then begin carrying them out.
- Write your answers to the questions in the boxes on the answer sheets. If you do not have enough space, you may ask for extra paper.

Additional Information:

- This is an examination; consultation with other participants is not permitted.
- If you have a question, you may ask a supervisor.
- If there is a problem with your glassware or equipment, report it to the supervisor as soon as you discover it. Do not borrow equipment from another participant.

Order of the Experiments

This exam consists of two experiments.

Start with **Experiment 1** (the synthesis of an ester).

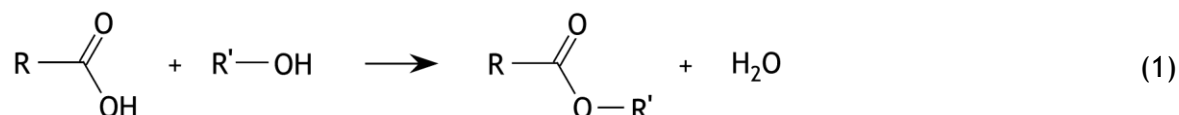
During this experiment, the reaction mixture must be heated under reflux for 1.5 hours. Use this time to carry out **Experiment 2** (determining the acetic acid content in vinegar) and answer the associated questions.

Experiment 1 The synthesis of the ester 1-pentyl propanoate

40 points

Introduction

Esters are organic compounds whose molecules contain a $\text{—}\overset{\text{O}}{\parallel}{\text{C}}\text{—O—}$ group. Esters can be regarded as the product of a reaction between a carboxylic acid and an alcohol:

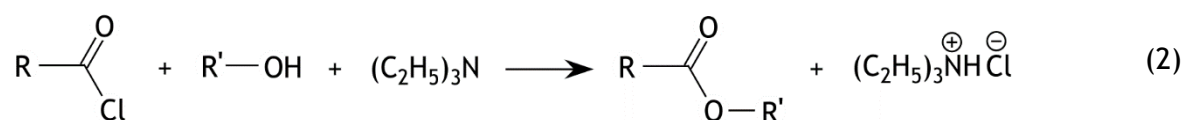


In everyday life, we come across both natural and synthetic esters everywhere. For example, esters are responsible for the scent of fruits and flowers, fats and oils are esters of glycerol and fatty acids, and ester compounds are commonly found in medicines.

So, esters can be synthesised by a reaction between a carboxylic acid and an alcohol (1). However, these reactions are inefficient and have a low yield. A more efficient way to make esters is by a reaction of an alcohol with an acid chloride, which is much more reactive than a carboxylic acid. When doing this, care must be taken to ensure that the acid chloride does not come into contact with water prior to the reaction, as it will then immediately undergo a violent reaction, forming the corresponding carboxylic acid and hydrogen chloride.

In this type of esterification, an organic base such as triethylamine is often used. This acts as a catalyst, but it also serves to bind the H^+ released during the reaction.

Triethylammonium chloride is then produced, which precipitates as a solid from the reaction mixture:



In this experiment, you will use this reaction to synthesise 1-pentyl propanoate. You'll start with a smelly mixture containing triethylamine and end up with a nice fruity ester!

The reactants for the synthesis are pentan-1-ol, propanoyl chloride and triethylamine. A slight excess of each of the latter two substances is used.

Chemicals

- triethylamine
- diethyl ether (hereafter referred to as ether for convenience)
- pentan-1-ol
- propanoyl chloride
- demineralised water
- 2 M sulphuric acid
- 1 M Na_2CO_3 solution
- MgSO_4 powder
- CaCl_2 granules

Safety information and data about the chemicals

- wear safety goggles
- if your skin comes into contact with any of the chemicals, rinse it off immediately

<u>Triethylamine</u>  ▪ Formula: $\text{C}_6\text{H}_{15}\text{N}$ ▪ $M = 101.191 \text{ g mol}^{-1}$ ▪ $\rho = 0.726 \text{ g mL}^{-1}$ ▪ H301+H311+H331 H314, H335. ▪ P280, P303+P361+P353, P304+P340+P310 P305+P351+P338.	<u>Diethyl ether (Ethoxy ethane)</u>  ▪ Formula: $\text{C}_4\text{H}_{10}\text{O}$ ▪ $M = 74.12 \text{ g mol}^{-1}$ ▪ $\rho = 0.713 \text{ g mL}^{-1}$ ▪ H224, H336 ▪ P210, P243, P261 ▪ P303+P361+P353 P304+P340 P312
<u>Sulphuric acid solution 2 M</u>  ▪ Formula: H_2SO_4 solution ▪ H290, H314 ▪ P280, P301+P330+P331+P310 P303+P361+P353, P310, P305+P351+P338.	<u>Calcium chloride granules</u>  ▪ Formula: CaCl_2 ▪ $M = 111 \text{ g mol}^{-1}$ ▪ H319 ▪ P280 P305+P351+P338 P337+P313

<u>Propanoyl chloride</u>  - Formula: $\text{C}_3\text{H}_5\text{ClO}$ $M = 92.53 \text{ g mol}^{-1}$ $\rho = 1.06 \text{ g mL}^{-1}$ - H331, H314, H302, H225 - P305+P351+P338 - P303+P361+P353 - P280, P210	<u>Pentan-1-ol</u>  - Formula: $\text{C}_5\text{H}_{12}\text{O}$ $M = 88.15 \text{ g mol}^{-1}$ $\rho = 0.814 \text{ g mL}^{-1}$ - H226, H315, H332, H335 - P210, P260 - P302+P352, P312
<u>1-Pentyl propanoate</u>  - Formula: $\text{C}_8\text{H}_{16}\text{O}_2$ $M = 144.2 \text{ g mol}^{-1}$ $\rho = 0.873 \text{ g mL}^{-1}$ - H226 - P210, - P370+P378	

Materials

You'll find the materials you need in the box with clean glassware in your own aisle. Other materials can be found along the edges of the lab.

Protocol

Read the full protocol before you start!

1. Set up a dry reflux apparatus. This is a reflux apparatus with a calcium chloride tube placed on top of the bulb condenser. We have already filled the calcium chloride tube for you. Use a 250 mL three-necked flask.
2. Place a dropping funnel on one of the “side necks” of the three-neck flask. Make sure the tap is closed.
3. Use a measuring cylinder (and a funnel if you want) to measure out approximately 21.7 mL of pentan-1-ol and approximately 33.7 mL of triethylamine. Write down the measured volumes to the correct number of decimal places.
4. Transfer the alcohol and the triethylamine into the three-neck flask of your reflux set-up. Rinse the measuring cylinder used to measure out the alcohol with two 5 mL portions of diethyl ether (hereafter referred to simply as ether).
5. Add approximately 25 mL of anhydrous ether and a stir bar.
6. Use a pan filled with ice and a small amount of water to cool the reaction mixture.
7. Switch on the stirring motor.
8. Let a supervisor check your set-up.
9. Use a clean, dry measuring cylinder to measure out approximately 19.2 mL of the acid chloride. Write down the measured volume to the correct number of decimal places.
10. Transfer the acid chloride into the dropping funnel. Make sure that the acid chloride cannot accidentally end up in the reaction mixture.
11. Add the acid chloride slowly, drop by drop, to the reaction mixture. Ensure that the reaction stays under control.
12. Once all acid chloride is added, the ice bath can be removed.
13. Place a heating mantle under the setup, switch on the heater and allow the reaction mixture to reflux for 1.5 hours. (It can sometimes be difficult to tell if it is boiling, but that is not a problem.)

Now carry out **Experiment 2**.

After having carried out **Experiment 2**, carry out the rest of **Experiment 1**.

14. After 1.5 hours of refluxing, switch off the heat, lower the lab lift with the heating mantle and allow the flask containing the reaction mixture to cool for about 10 minutes.
15. Add about 40 mL demineralised water to the reaction mixture.
16. Make sure that as much of the material as possible is dissolved. If necessary, swirl gently.
17. Transfer the reaction mixture into a separatory funnel.
18. Remove the aqueous layer.
19. Wash the ether layer by adding 15 mL of 2 M sulphuric acid to the ether layer, shake the mixture (remember to release the gas), and then remove the aqueous layer.
20. Wash the ether layer by adding 10 mL water to the ether layer, shake the mixture (remember to release the gas), and then remove the aqueous layer.
21. Wash the ether layer by adding 15 mL 1 M Na_2CO_3 solution to the ether layer, shake the mixture (remember to release the gas, this is particularly important in this step!), and then remove the aqueous layer.
22. Wash the ether layer by adding 10 mL water to the ether layer, shake the mixture

- (remember to release the gas), and then remove the aqueous layer.
23. Transfer the ether layer into an Erlenmeyer flask
 24. Add a few small scoops of dry MgSO_4 until you see a fine powder when you swirl the Erlenmeyer flask.
 25. Weigh a 100 mL round-bottom flask. Write down the mass.
 26. Place some cotton wool at the top of a funnel and filter the mixture through it. Collect the filtrate in the weighed round-bottomed flask.
 27. Use a rotavap to evaporate the ether. Keep the water bath at $\leq 20^\circ\text{C}$.
 28. Weigh the flask with your ester. Write down the mass.
 29. Using a Pasteur pipette, transfer 1 drop of your ester into an NMR tube. Seal the NMR tube with a cap and use a “little flag” to mark the tube.
 30. Hand in the labelled NMR tube. After the practical test, this will be used to record an NMR spectrum to determine the purity of your product. You do not need to wait for the result.
 31. Transfer the rest of your ester into a 20 mL counting vial. Close the vial and write your fume hood number on the vial using a waterproof pen.
 32. Hand in the counting vial.

Questions - write the answers on the answer sheets

- | | | |
|---|---|---|
| 1 | Give the name(s) of the substance(s) that are removed from the reaction mixture when water is added (step 15). | 3 |
| 2 | What is the purpose of washing with sulphuric acid (step 19)? | 1 |
| 3 | What is the purpose of adding magnesium sulphate (step 24)? | 1 |
| 4 | Write down: <ul style="list-style-type: none">– the number of mL of alcohol you have used– the number of mL of triethylamine you have used– the number of mL of acid chloride you have used | 2 |
| 5 | Calculate the maximum number of grams of ester that can be produced during the synthesis at 100% conversion. | 4 |
| 6 | Write down: <ul style="list-style-type: none">– the mass of the empty round-bottom flask– the mass of the round-bottom flask with your ester | 3 |
| 7 | Calculate the yield of the ester synthesis. Express your answer both in grams and as a percentage of the maximum yield at 100% conversion. | 2 |

The triethylamine used in the reaction acts as a catalyst, but also as a base to bind the H^+ that is split off. For this reason, triethylamine is not used in a catalytic amount.

- 8 Give a possible mechanism for the action of the triethylamine.

Write the acid chloride as $R-\overset{\overset{O}{\parallel}}{C}-Cl$, the alcohol as $R'-OH$ and the triethylamine as

$N(C_2H_5)_3$. Draw the non-bonding electron pairs in this and use curly arrows () to show how electron pairs move.

Experiment 2 The determination of the acetic acid content in vinegar, using a titration curve.

40 points

Introduction

During an acid-base titration, the pH of the solution being titrated changes. If a (weak) acid is titrated with caustic soda (a solution of sodium hydroxide), the pH rises slowly at first, then strongly and finally slowly again. The pH gradient during a titration can be measured with a pH meter and plotted in a diagram. In this way, a titration curve is obtained.

In this experiment, the titration curve for the titration of a solution of acetic acid is determined, and on this basis, it can be determined if the vinegar used meets the requirements of the Commodities Act.

Chemicals

- vinegar; density $1,005 \text{ g mL}^{-1}$
- demineralised water
- 0.1 M caustic soda (the exact molarity is given)

Safety

- Wear safety glasses
- If your skin comes into contact with any of the chemicals, rinse it off immediately

<u>Caustic soda 0.1 M</u>	<u>Acetic acid solution <10%</u>
	
▪ Formula: NaOH solution ▪ H290 ▪ P234, P390	▪ Formula: $\text{C}_2\text{H}_4\text{O}_2$ ▪ H226, H314, H318

Materials

You'll find the materials you need in the box with clean glassware in your own aisle. Other materials can be found along the edges of the lab.

Protocol

Read the full protocol before you start!

1. Pipette 5.00 mL of vinegar into a beaker.
2. Add 20.00 mL of water with a volumetric pipette.
3. Use a stirring bean to gently stir the mixture during the titration.
4. Remove the cap from the pH electrode. Note: handle it carefully, the electrode is a fragile instrument.
5. Gently rinse the electrode over a large beaker of demineralised water and dab the electrode with a soft tissue to remove the water. Do not touch the electrode with your fingers!
6. Insert the electrode into the solution and press the "read" button to measure the pH. Make sure that the stirring bean does not touch the electrode!
7. When the pH level is stable and no longer blinks, write it down on the answer sheet. Remove the electrode from the solution.
8. Titrate the vinegar solution by adding a little caustic soda at a time, measuring the pH after each addition and writing it on the answer sheet. Also write down how much caustic soda you have added. Rinse and dab the electrode between each measurement. Make sure you have enough measuring points to be able to construct the entire titration curve. Stop when the pH of the solution is about 12.5. Near the equivalence point, the pH changes very quickly!
9. Repeat steps 1 to 8. Use your experience from the first measurements to choose smart step sizes for adding caustic soda, so that you get a good picture of the interesting pH ranges, but don't take unnecessary measurements in the less interesting pH ranges.

Questions: Write down the answers on the answer sheets.

- 9 Write down the exact molarity of the caustic soda you used. 2
- 10 Write down all the pH levels in the tables on your answer sheet and the corresponding amount of caustic soda added. You don't have to use all the rows in the tables. 2
- 11 Plot the measurement results of both determinations on graph paper to obtain a titration curve of acetic acid for each determination. 10
- 12 Check whether the acetic acid content in the vinegar used meets the requirement of the Commodities Act (at least 4 per cent by mass). Use the titration curve of your most reliable determination for this. 10
- 13 In point 2, you added 20.00 mL of water with a volumetric pipette. Could you have used a graduated cylinder for this? Explain your answer. 2
- You can also calculate the pH course of an acid-base titration. For example for the titration of 10 mL of 0.10 M acetic acid with 0.10 M caustic soda.
- 14 For this titration, calculate the pH at the following moments: 6
- when 5.0 mL of caustic soda is added
 - at the equivalence point

Name: _____

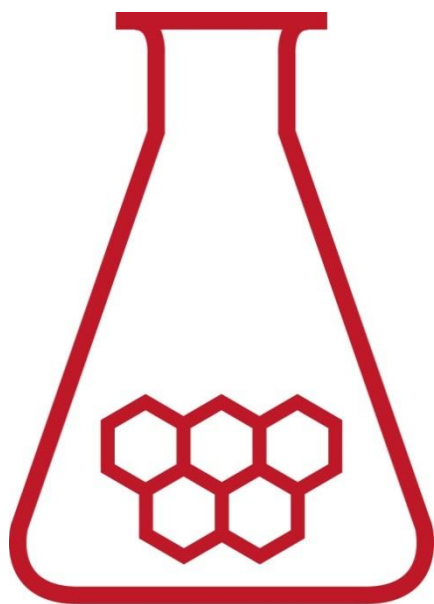
47th National Chemistry Olympiad

Utrecht University

PRACTICAL EXAM

Answer sheets

Tuesday 9th June 2026



**SCHEIKUNDE
OLYMPIADE**



**Universiteit
Utrecht**



58th International
Chemistry Olympiad
Uzbekistan 2026

Name: _____

Answer sheets for the practical exam

Experiment 1

Question 1

Question 2

Question 3

Question 4

number of mL of alcohol

number of mL of triethylamine

number of mL of acid chloride

Name: _____

Question 5

Question 6

mass of the empty round-bottom flask

mass of the round-bottom flask with ester

Question 7

Name: _____

Question 8

Experiment 2

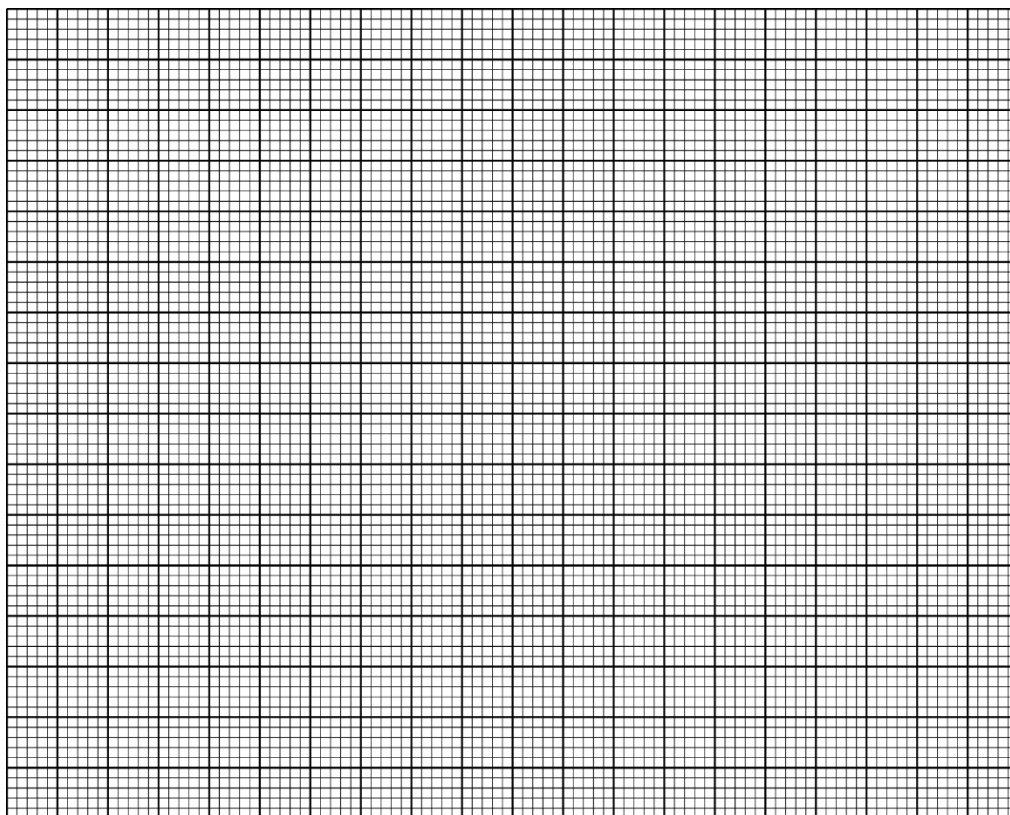
caustic soda molarity:

[illegible]

Name: _____

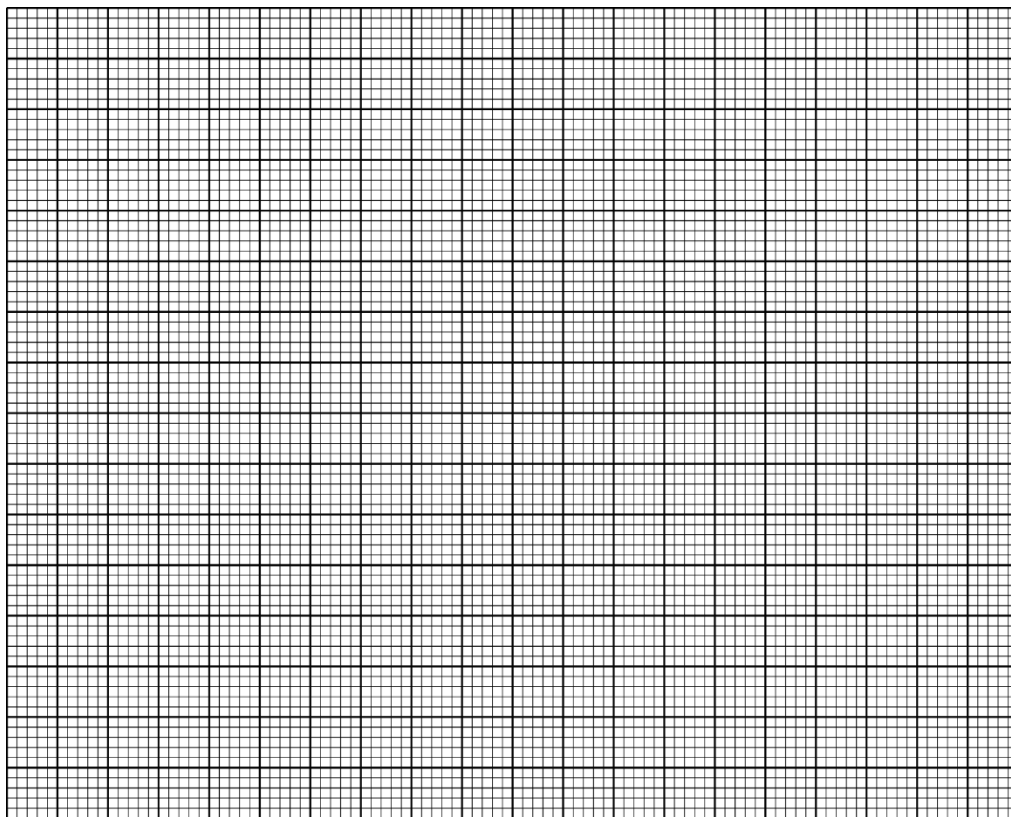
Question 11

first titration



Name: _____

second titration



Name:

Question 12

Question 13

Name: _____

Question 14

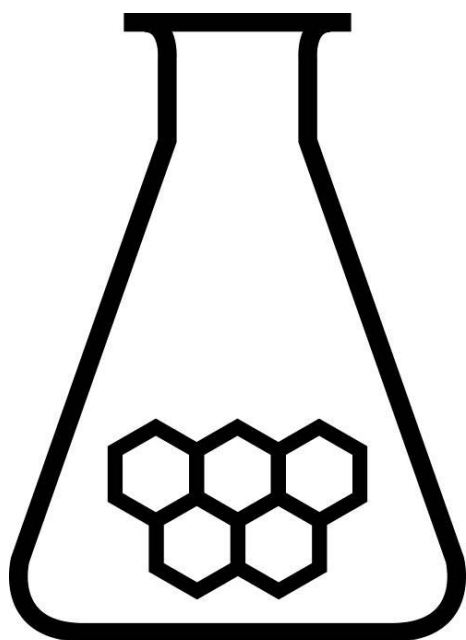
calculation of the pH after adding 5.0 mL caustic soda

calculation of pH at equivalence point

NATIONAL CHEMISTRY OLYMPIAD 2026

MARKING SCHEME PRELIMINARY ROUND 1

To be held between 12th and 30th January 2026



SCHEIKUNDE OLYMPIADE



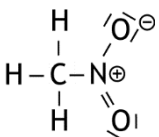
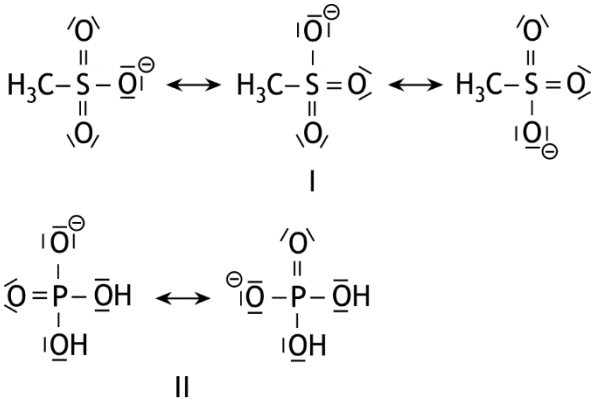
Universiteit Utrecht

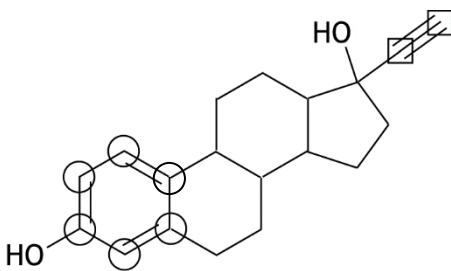
- This preliminary round consists of 25 multiple choice questions divided over 9 topics, and 2 problems with a total of 8 open questions, in addition to an answer sheet for the multiple choice questions.
- Use the answer sheet to answer the multiple choice questions.
- For the open questions, use a separate answer sheet for each of the two problems. Remember to include your name on each sheet.
- The maximum score for this paper is 73 points.
- The preliminary round lasts two hours in total.
- Required materials: (graphic) calculator and BINAS 7th edition, ScienceData 1st edition or BINAS 5th edition, English version. “Green chemistry” table is included.
- The total number of points available for each question is stated.
- Unless otherwise stated, standard conditions apply: $T = 298 \text{ K}$ and $p = p_0$.

Problem 1 Multiple choice questions**total 50 points****For every correct answer: 2 points****Brief summary**

nr.	answer
1	D
2	D
3	D
4	D
5	A
6	C
7	C
8	E
9	D
10	C
11	D
12	B
13	A
14	C
15	E
16	D
17	C
18	B
19	D
20	B
21	A
22	A
23	D
24	C
25	D

		Carbon Chemistry
1	D	All products are shown below. The C atoms indicated with * are asymmetrical. These compounds have two stereo isomers. $\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_2-\text{CH}^*- \text{CH}_2-\text{CH}_3 \\ \\ \text{Br} \end{array}$ $\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3-\text{C}-\text{CH}_2-\text{CH}_3 \\ \\ \text{Br} \end{array}$ $\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3-\text{CH}-\text{CH}^*-\text{CH}_3 \\ \\ \text{Br} \end{array}$ $\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_2 \\ \\ \text{Br} \end{array}$
2	D	$\begin{array}{c} \text{H}_3\text{C} \quad \text{H} \\ \diagdown \quad \diagup \\ \text{C}=\text{C} \\ \diagup \quad \diagdown \\ \text{H} \quad \text{SH} \end{array}$ <i>cis and trans</i> $\begin{array}{c} \text{H} \quad \text{H} \\ \diagdown \quad \diagup \\ \text{C}=\text{C} \\ \diagup \quad \diagdown \\ \text{H} \quad \text{CH}_2-\text{SH} \end{array}$ $\begin{array}{c} \text{H}_2\text{C} \quad \text{CH}_3 \\ \diagdown \quad \diagup \\ \text{C}=\text{C} \\ \\ \text{SH} \end{array}$ $\begin{array}{c} \text{S} \\ \\ \text{CH}_3-\text{CH}_2-\text{C} \\ \\ \text{H} \end{array}$ $\begin{array}{c} \text{H}_3\text{C} \quad \text{CH}_3 \\ \diagdown \quad \diagup \\ \text{C} \\ \\ \text{S} \end{array}$ $\begin{array}{c} \text{H} \quad \text{H} \\ \diagdown \quad \diagup \\ \text{C}=\text{C} \\ \diagup \quad \diagdown \\ \text{H} \quad \text{S}-\text{CH}_3 \end{array}$
3	D	See below. $\begin{array}{ccccccc} & \text{CH}_3 & & \text{CH}_3 & & \text{CH}_3 & & \text{CH}_3 \\ & & & & & & & \\ \sim \text{CH}_2 & -\text{CH}- & \text{CH}_2- & \text{CH}_2-\text{CH}- & \text{CH}-\text{CH}- & \text{CH}_2-\text{CH}- & \sim \\ & & & & & & \\ & & & & \text{CH}_3 & & \\ & \text{CH}_3 & & \text{CH}_3 & & \text{CH}_3 & & \text{CH}_3 \\ & & & & & & & \\ & \text{CH}=\text{CH}_2 & & \text{CH}_2=\text{CH} & & \text{CH}=\text{CH} & & \text{CH}_2=\text{CH} \\ & & & & & & \\ & & & & \text{CH}_3 & & \end{array}$ propene propene but-2-ene propene
4	D	The repeating unit is $\text{C}_6\text{H}_{10}\text{O}_5$ with a molar mass of $162.14 \text{ g mol}^{-1}$. degree of polymerization = $\frac{3.29 \cdot 10^5 - 18.015}{162.14} = 2.03 \cdot 10^3$
		Thermochemistry
5	A	The energy level of the product is lower than that of the reactants. The reaction is therefore exothermic. A catalyst only lowers the energy level of the activated state.

		Reaction rate and equilibrium
6	C	For the reaction to the right, the heat of reaction is: I: $(2 \times -0.332 \cdot 10^5) + 0.111 \cdot 10^5 = -0.553 \cdot 10^5$ J per 2 mol NO₂ II: $0 + (2 \times 1.43 \cdot 10^5) = 2.86 \cdot 10^5$ J per 3 mol O₂ With an increase in temperature the endothermic reaction is temporarily favoured. Reaction I shifts to the left and reaction II shifts to the right.
7	C	$3.5 \cdot 10^{-4} \times \frac{3}{2} = 5.3 \cdot 10^{-4} \text{ mol s}^{-1}$
8	E	When the volume increases, the reaction shifts toward the side with the most gas particles. In this case, that is to the right. For this equilibrium, $[\text{CO}_2] = K$ applies. Therefore the concentration of CO₂ remains constant.
		Structures and formulae
9	D	The ions present are Na ⁺ , Mg ²⁺ and SO ₄ ²⁻ . With the molar ratio 2 : 2 : 3 of these ions, the total charge is zero and the molar ratio Na ⁺ : Mg ²⁺ is equal to 1 : 1.
10	C	 Can also be calculated: $4 + 3 \times 1 + 5 + 2 \times 6 = 24$ valence electrons, therefore 12 electron pairs. $\frac{4 \times 8 + 3 \times 2 - 24}{2} = 7$ bonding electron pairs. So $12 - 7 = 5$ lone pairs.
11	D	 II

12	B	 coordination number 2: ☐ coordination number 3: ☐																
		pH and acid-base																
13	A	$\text{HClO} + \text{H}_2\text{O} \rightleftharpoons \text{ClO}^- + \text{H}_3\text{O}^+$ $[\text{H}_3\text{O}^+] = K_a \times \frac{\text{number of moles of HClO}}{\text{number of moles of ClO}^-} = K_a \times \frac{\text{number of moles of HClO}}{\text{number of moles of NaClO}}$ $10^{-7.83} = 10^{-7.40} \times \frac{\text{number of moles of HClO}}{\text{number of moles of NaClO}}$ $\frac{\text{number of moles of HClO}}{\text{number of moles of NaClO}} = \frac{10^{-7.83}}{10^{-7.40}}$ $\frac{\text{number of grams of HClO}}{\text{number of grams of NaClO}} = \frac{10^{-7.83} \times 52.46}{10^{-7.40} \times 74.44} = \frac{1.0}{3.8}$																
14	C	The formation of H_3O^+ causes the pH to decrease. They are all weak acids, and HIO_3 has the highest K_a value. HIO_3 is the strongest weak acid, and the smallest number of moles of this acid is needed to achieve a pH of 2.5.																
15	E	$\text{HZ} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{Z}^-$ If in a 0.1200 M HZ solution 2.3% of the acid is ionized, then $[\text{Z}^-]_{\text{equilibrium}} = 0.023 \times 0.1200 = 0.00276 \text{ M}$. <table><tr><td></td><td>[HZ]</td><td>[Z⁻]</td><td>[H₃O⁺]</td></tr><tr><td>initial</td><td>0.1200</td><td>0</td><td>0</td></tr><tr><td>change</td><td>− 0.00276</td><td>+ 0.00276</td><td>+ 0.00276</td></tr><tr><td>equilibrium</td><td>0.1172</td><td>0.00276</td><td>0.00276</td></tr></table> $K_a = \frac{0.00276 \times 0.00276}{0.1172} = 6.5 \cdot 10^{-5}$		[HZ]	[Z ⁻]	[H ₃ O ⁺]	initial	0.1200	0	0	change	− 0.00276	+ 0.00276	+ 0.00276	equilibrium	0.1172	0.00276	0.00276
	[HZ]	[Z ⁻]	[H ₃ O ⁺]															
initial	0.1200	0	0															
change	− 0.00276	+ 0.00276	+ 0.00276															
equilibrium	0.1172	0.00276	0.00276															
		Redox and electrochemistry																
16	D	$\begin{array}{lcl} \text{NO}_3^- + 4 \text{H}^+ + 3 \text{e}^- & \rightarrow & \text{NO} + 2 \text{H}_2\text{O} & (\times 2) \\ \text{Cu} & \rightarrow & \text{Cu}^{2+} + 2 \text{e}^- & (\times 3) + \\ \hline 3 \text{Cu} + 8 \text{H}^+ + 2 \text{NO}_3^- & \rightarrow & 3 \text{Cu}^{2+} + 2 \text{NO} + 4 \text{H}_2\text{O} & \end{array}$																

17	C	$\text{Zn}^{2+} + 2 \text{e}^{-} \rightarrow \text{Zn}$ $\frac{5.0}{65.38} = 0.0765 \text{ mol Zn}$ $2 \times 0.0765 = 0.153 \text{ mol e}^{-}$ $0.153 \times 96485 = 14758 \text{ C}$ $\frac{14758}{3.5} = 4.2 \cdot 10^3 \text{ s}$
		Analysis
18	B	When a barium nitrate solution is added to a sodium sulfite solution, a cloudy mixture forms because barium sulfite is a poorly soluble salt. When a barium nitrate solution is added to a potassium ethanoate solution, a clear mixture is formed.
19	D	Fragmentation of the Br_2 molecules produces Br^{+} ions with $m/z = 79$ and $m/z = 81$. There are also three molecular ion peaks with $m/z = 158$, $m/z = 160$ and $m/z = 162$.
20	B	$25.00 \times 0.100 = 0.250 \text{ mmol Ag}^{+}$ is added. Of this, $0.250 - 7.69 \times 0.0108 = 0.167 \text{ mmol}$ has reacted, with an equal amount of theobromine. Therefore, the mass percentage of theobromine is: $\frac{0.167 \cdot 10^{-3} \times 180.2}{2.95} \times 100\% = 1.02\% .$
		Calculations
21	A	CO_2 and H_2O both have the same molar volume, so the molar ratio $\text{CO}_2 : \text{H}_2\text{O}$ is equal to the volume ratio and is therefore 8 : 12. The ratio C : H is then $8 : 24 = 1 : 3$ as in C_2H_6.
22	A	$\frac{47.0}{63.55} = 0.7396 \text{ mol Cu}$ That comes from $\frac{0.7396}{2} = 0.3698 \text{ mol malachite}$. That is $0.3698 \times 221.1 = 81.76 \text{ g malachite}$. The mass percentage malachite in the ore sample is $\frac{81.76}{1000} \times 100 \% = 8.18 \% .$
23	D	1.00 L 0.100 M CuSO_4 solution contains 0.100 mol CuSO_4. $\frac{0.100}{0.327} \times 1000 = 306 \text{ mL}$
24	C	$\frac{486}{108.02} = 4.50 \text{ mol N}_2\text{O}_5.$ That is equal to $4.50 \times 2 \times 6.02 \cdot 10^{23} = 5.42 \cdot 10^{24}$ nitrogen atoms.

		Green chemistry
25	D	For the <i>E</i>-factor the following applies: $E\text{-factor} = \frac{m_{\text{reactants}} - m_{\text{actual yield product}}}{m_{\text{actual yield product}}}$ With a higher yield, the $m_{\text{actual yield product}}$ is higher, and with a higher atom economy, the $m_{\text{actual yield product}}$ is also higher. Both result in a lower <i>E</i>-factor.

Open questions

total 23 points

Problem 2 Pilsner

9 points

□1 **Maximum score 2**

CO₂ in solution is acidic / forms H₂CO₃. This acid causes the amount of sodium hydroxide / base needed to reach the endpoint to be higher. This leads to the conclusion that the amount of acid is greater than it actually is, and therefore to a value that is too high for the total amount of organic acids present.

- CO₂ / H₂CO₃ reacts with OH⁻ 1
- consistent conclusion 1

□2 **Maximum score 2**

An example of a correct calculation is:

$$\frac{0.433 \times 2 + 0.545 + 1.099 + 0.466 + 0.562 \times 3 + 0.415 \times 2 + 0.362 \times 2}{3.882} = 1.601$$

- correct processing of the number of acidic groups per molecule 1
- remainder of the derivation 1

□3 **Maximum score 5**

An example of a correct calculation is:

$$3.14 \times 0.0560 \times \frac{330}{25.00} - 3.882 \times 1.601 \times \frac{330}{1000} = 0.27 \text{ (mmol)}$$

or in steps:

3.14 mL 0.056 M caustic soda contains $3.14 \times 0.0560 = 0.176$ mmol OH⁻.

This reacts with 0.176 mmol COOH groups in 25.00 mL CO₂-free pilsner.

A bottle of pilsner contains a total of $3.14 \times 0.0560 \times \frac{330}{25.00} = 2.32$ mmol COOH groups.

Per litre of pilsner 3.882 mmol of the organic acids listed in Table 1 are present.

These react with $3.882 \times 1.601 = 6.215$ mmol OH⁻.

This means that per litre pilsner 6.215 mmol COOH groups originate from the organic acids listed in Table 1.

A bottle of pilsner contains $3.882 \times 1.601 \times \frac{330}{1000} = 2.05$ mmol COOH groups originating from

the organic acids listed in Table 1.

The number of extra COOH groups per bottle of the examined pilsner is

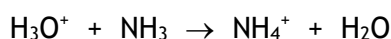
$$3.14 \times 0.0560 \times \frac{330}{25.00} - 3.882 \times 1.601 \times \frac{330}{1000} = 0.27 \text{ mmol.}$$

- calculation of the number of (m)moles of used OH⁻ 1
- conversion to the total number of (m)moles of COOH groups per bottle of the pilsner examined 1
- calculation of the number of (m)moles of COOH groups originating from the organic acids listed in Table 1 per litre of the pilsner examined 1
- conversion to the number of (m)moles of COOH groups originating from the organic acids listed in Table 1 in the examined bottle of pilsner 1
- calculation of the number of extra mmoles of COOH groups per bottle of the examined pilsner 1

Problem 3 Disaster in Beirut

14 points

□4 Maximum score 2



To obtain ammonium nitrate, the water can be removed by evaporation.

- acid-base reaction
- evaporation

1
1

Notes

- If the acid-base reaction $\text{H}^+ + \text{NH}_3 \rightarrow \text{NH}_4^+$ is given, award full marks.
- If distillation or crystallisation is given as the separation technique, award full marks.

□5 Maximum score 2

Ionic bonds (between the NH_4^+ and NO_3^- ions) and covalent bonds (between the atoms within the ions).

- ionic bonds
- covalent bonds

1
1

□6 Maximum score 4

An example of a correct calculation is:

$$2750 \text{ tonnes } \text{NH}_4\text{NO}_3 \text{ would correspond to } \frac{2750 \cdot 10^6}{80.043} = 3.436 \cdot 10^7 \text{ mol } \text{NH}_4\text{NO}_3.$$

$$\text{This produces } \frac{3.436 \cdot 10^7 \times 7}{2} = 1.202 \cdot 10^8 \text{ mol gas.}$$

$$\text{This has a volume of } \frac{1.202 \cdot 10^8 \times 82.1}{1000} = 9.87 \cdot 10^6 \text{ m}^3.$$

- calculation of the number of moles of NH_4NO_3
- calculation of the number of moles of gas
- conversion to the number of m^3 of gas
- significant figures

1
1
1
1

□7 Maximum score 3

An example of a correct calculation is:

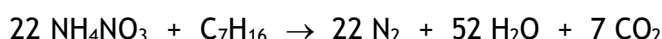
$$\Delta E = 4 \times E_{\text{V}}(\text{H}_2\text{O}(\text{g})) - 2 \times E_{\text{V}}(\text{NH}_4\text{NO}_3) = 4 \times -2.42 \cdot 10^5 - 2 \times (-3.66 \cdot 10^5) = -2.36 \cdot 10^5 \text{ J per 2 mol } \text{NH}_4\text{NO}_3$$

$$\text{This corresponds to } \frac{-2.36 \cdot 10^5}{2} = -1.18 \cdot 10^5 \text{ J mol}^{-1}.$$

- absolute values of the enthalpies of formation of all substances
- use of coefficients
- remainder of the calculation

1
1
1

□8 Maximum score 3

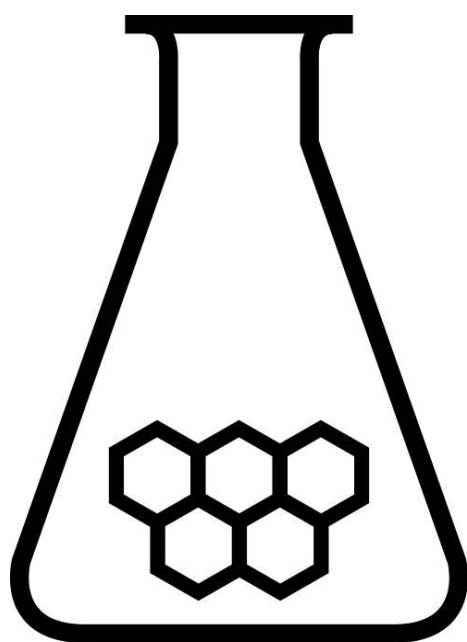


- correct substances before and after the arrow
- H and N correctly balanced using only correct formulas before and after the arrow
- C and O correctly balanced using only correct formulas before and after the arrow

1
1
1

NATIONAL CHEMISTRY OLYMPIAD 2026

MARKING SCHEME PRELIMINARY ROUND 2
To be held between 16th and 23rd March 2026



**SCHEIKUNDE
OLYMPIADE**



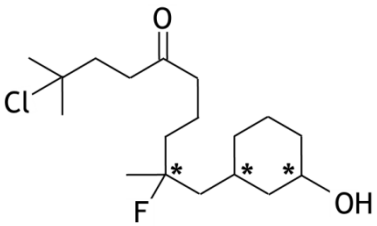
**Universiteit
Utrecht**

- This preliminary round consists of 20 multiple choice questions divided over 8 topics, and 3 problems with a total of 13 open questions.
- The maximum score for this paper is 94 points.
- Required materials: (graphic) calculator and BINAS 7th edition or ScienceData 1st edition or BINAS 5th edition, English version.
- The total number of points available for each question is stated.
- The attached marking scheme must be used when grading the work. In addition, the general rules for the Dutch Central Exams apply.

■ Problem 1 Multiple choice questions**total 40 points****For every correct answer: 2 points****Brief summary**

no.	answer
1	D
2	A
3	D
4	C
5	C
6	D
7	B
8	D
9	E
10	D
11	A
12	B
13	C
14	B
15	D
16	C
17	D
18	A
19	C
20	B

Carbon chemistry

1	D	 The molecule has three asymmetric carbon atoms. There are therefore $2^3 = 8$ stereoisomers.
2	A	500 mg polylactic acid with $n = 12$ is $\frac{500}{12 \times 72.06 + 18.02} = 0.566$ mmol. In one molecule of polylactic acid with $n = 12$ there are 11 ester bonds, so in 0.566 mmol of polylactic acid with $n = 12$ there are $11 \times 0.566 = 6.23$ mmol ester bonds. To break these, 6.23 mmol of H_2O is required.

Reaction rate and equilibrium

3	D	The rate of reaction is determined by the slowest reaction: $rate = k' [ICN][OH^-]$ The equilibrium conditions of the two equilibria above are: $K_1 = \frac{[HIO][OH^-]}{[IO^-]}$ and $K_2 = \frac{[ICN][OH^-]}{[CN^-][HIO]}$ Rearranging gives: $K_2[CN^-][HIO] = [ICN][OH^-]$ and $\frac{[IO^-]}{[OH^-]} K_1 = [HIO]$ This leads to: $rate = k' K_2 [CN^-][HIO] = k' K_1 K_2 [CN^-] \frac{[IO^-]}{[OH^-]} = k \frac{[CN^-][IO^-]}{[OH^-]}$
4	C	A comparison of experiments 1 and 4 shows that doubling the amount of H_2O_2 leads to doubling the rate. Therefore, $a = 1$. A comparison of experiments 1 and 3 shows that doubling the amount of I^- leads to a doubling of the rate. Therefore, $b = 1$. A comparison of experiments 1 and 2 shows that the amount of hydrochloric acid has no influence on the reaction rate. Therefore, $c = 0$.
5	C	$k_{373} = 4 \times k_{323}$ $E_a = R \times \frac{T_1 \times T_2}{T_1 - T_2} \ln \frac{k_{T_1}}{k_{T_2}} = 8.314 \times \frac{373 \times 323}{373 - 323} \ln 4 = 2.78 \cdot 10^4 \text{ J mol}^{-1}$

6	D	(bar) SO₂(g) + NO₂(g) $\rightleftharpoons$ SO₃(g) + NO(g) p_{initial} 0.60 0.60 0.60 0.60 change – x – x + x + x $p_{\text{equilibrium}}$ 0.60 – x 0.60 – x 0.60 + x 0.60 + x $K_p = \frac{[0.60 + x]^2}{[0.60 - x]^2} = 3.75$. From this follows that x = 0.19 bar. Therefore $p_{\text{equilibrium}}(\text{SO}_2) = 0.60 - 0.19 = 0.41$ bar.
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Structures and formulas

7	B	The electron configuration of As with atomic number 33 is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$ An s orbital has no electrons with $m_l = 1$. Filled p orbitals contain 2 electrons with a quantum number $m_l = 1$. Filled d orbitals contain 2 electrons with a quantum number $m_l = 1$. The 4p orbitals contain 3 electrons and, according to Hund's rule, these are evenly distributed over the three 4p orbitals and therefore contain 1 electron with a quantum number $m_l = 1$. In total, an As atom therefore contains 7 electrons with a quantum number $m_l = 1$.
8	D	All bonds between atoms contain one σ bond. Double bonds also contain one π bond. There are thirteen bonds in total, two of which are double bonds. Therefore, there are thirteen σ bonds and two π bonds.
9	E	The volume of the unit cell is $(4.08 \cdot 10^{-10})^3 \text{ m}^3$. If n is the number of gold atoms in the unit cell, then the mass of the unit cell is $n \times 197.0 \times 1.66 \cdot 10^{-27} \text{ kg}$. The density is therefore $\rho = \frac{n \times 197.0 \times 1.66 \cdot 10^{-27}}{(4.08 \cdot 10^{-10})^3} = 19.3 \cdot 10^3 \text{ kg m}^{-3}$, which gives $n = 4$, and this corresponds to a face-centred cubic unit cell.

pH / acid-base

10	D	$\text{C}_3\text{H}_5\text{NH}_3^+ + \text{H}_2\text{O} \rightleftharpoons \text{C}_3\text{H}_5\text{NH}_2 + \text{H}_3\text{O}^+$ 3.61 % 96.39 % $K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_3\text{H}_5\text{NH}_2]}{[\text{C}_3\text{H}_5\text{NH}_3^+]} = \frac{10^{-11.12} \times 96.39}{3.61} = 2.03 \cdot 10^{-10}$ $\text{p}K_a = 9.69$.
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11	A	As long as HCOOH is present, it holds that $[Na^+] = [HCOO^-]$, since for every Na^+ ion that is added, one HCOOH molecule is converted into $HCOO^-$ through reaction with OH^- . The equivalence point is reached after the addition of 27 mL of sodium hydroxide solution, which means that after 15.0 mL more than half of the HCOOH has been converted into $HCOO^-$.
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Redox and electrochemistry

12	B	The Nernst equation for the Mn^{2+}/MnO_4^- , H^+ redox couple is: $E = E^0 + \frac{0.059}{5} \log \frac{[MnO_4^-] \times [H^+]^8}{[Mn^{2+}]} = 1.51 + \frac{0.059}{5} \log \frac{0.0100 \times (0.200)^8}{0.0200} = 1.44 \text{ V}$
13	C	The half-equations during the charging of the lead-acid battery are: Negative electrode: $PbSO_4(s) + 2 e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$ Positive electrode: $PbSO_4(s) + 2 H_2O(l) \rightarrow PbO_2(s) + 4 H^+(aq) + SO_4^{2-}(aq) + 2 e^-$
14	B	The charge of Cu changes from 1+ to 2+ in reaction 2. The charge on Cu remains 2+ in reaction 3. The charge on Cu remains 2+ in reaction 4.

Analysis

15	D	In spectrum 1, a strong C=O stretching vibration of a ketone is visible at 1715 cm^{-1} , which corresponds to substance II. In spectrum 2, a strong and broad O – H stretching vibration is visible at $3200 - 3500 \text{ cm}^{-1}$, which corresponds to substance III.
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Calculations

16	C	1.831 g CO_2 is equal to $\frac{1.831}{44.01} = 4.160 \cdot 10^{-2} \text{ mol } CO_2$ and therefore $4.160 \cdot 10^{-2} \text{ mol C}$. 0.750 g H_2O is equal to $\frac{0.750}{18.02} = 4.16 \cdot 10^{-2} \text{ mol } H_2O$ and therefore $8.32 \cdot 10^{-2} \text{ mol H}$. The mole ratio C : H = 1 : 2. Thus answer A or C. 1.000 g $C_3H_6NO_2$ is equal to $\frac{1.000}{88.09} = 1.135 \cdot 10^{-2} \text{ mol } C_3H_6NO_2$ and therefore $3.406 \cdot 10^{-2} \text{ mol C}$. 1.000 g $C_6H_{12}N_2O_2$ is equal to $\frac{1.000}{144.17} = 6.936 \cdot 10^{-3} \text{ mol } C_6H_{12}N_2O_2$ and therefore $4.162 \cdot 10^{-2} \text{ mol C}$. The correct molecular formula is therefore $C_6H_{12}N_2O_2$.
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17	D	The combustion reactions are: $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \quad \text{and}$ $\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g})$ All substances are in the gaseous state, so volume ratios are equal to mole ratios. Let the volume of propane be $y \text{ dm}^3$ and the volume of methane be $(10.0 - y) \text{ dm}^3$. Then: $2 \times (10.0 - y) + 5 y = 38.0$ From this follows that $y = 6.00$ and the volume percentage of propane is 60.0 %.
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Thermochemistry

18	A	$\Delta_r H = \Delta_f H_{\text{PCl}_5} - \Delta_f H_{\text{PCl}_3} = -3.749 \cdot 10^5 - (-2.870 \cdot 10^5) = -0.879 \cdot 10^5 \text{ J mol}^{-1}.$ $\Delta_r S = S_{\text{PCl}_5} - S_{\text{PCl}_3} - S_{\text{Cl}_2} = 364.4 - 311.8 - 223.1 = -170.5 \text{ J mol}^{-1} \text{ K}^{-1}.$ Thus, at a temperature of 450 K, it holds that $\Delta_r G = \Delta_r H - T \Delta_r S = -0.879 \cdot 10^5 - 450 \times (-170.5) = -1.118 \cdot 10^4 \text{ J mol}^{-1}.$ $K_p = e^{\frac{-\Delta_r G}{RT}} = e^{\frac{1.118 \cdot 10^4}{8.314 \times 450}} = e^{2.99} = 19.8$
19	C	The three given reactions must be added together as follows: $\begin{array}{ll} \text{C}_3\text{H}_8\text{O}(\text{l}) \rightarrow 3 \text{C}(\text{s}) + 4 \text{H}_2(\text{g}) + 0.5 \text{O}_2(\text{g}) & -1 \times -3.18 \cdot 10^5 \text{ J} \\ 3 \text{C}(\text{s}) + 3 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) & 3 \times -3.94 \cdot 10^5 \text{ J} \\ 4 \text{H}_2(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow 4 \text{H}_2\text{O}(\text{l}) & 4 \times -2.86 \cdot 10^5 \text{ J} \end{array}$ $\Delta_r H^0 = -1 \times (-3.18 \cdot 10^5) + 3 \times (-3.94 \cdot 10^5) + 4 \times (-2.86 \cdot 10^5) = -20.08 \cdot 10^5 \text{ J mol}^{-1}.$
20	B	The reaction proceeds spontaneously if $\Delta G^0 = \Delta H^0 - T \Delta S^0 < 0$. Therefore, $T < \frac{\Delta H^0}{\Delta S^0} = \frac{3.83 \cdot 10^4}{113} = 339 \text{ K} = 66^\circ \text{C}$

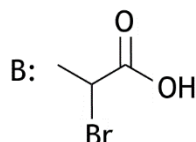
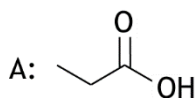
Open questions

total 54 points

■ Problem 2 Carboxylic acid

16 points

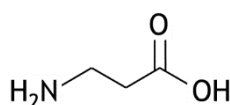
□1 Maximum score 5



X: HBr

In the second reaction of the synthesis scheme, a Br atom is replaced by an NH₂ group, and this is a substitution reaction.

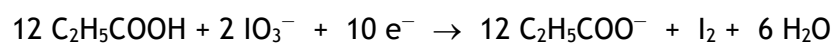
other carboxylic acid:



- A correct 1
- B correct 1
- X correct 1
- substitution reaction 1
- other product correct 1

□2 Maximum score 4

A correct answer could look as follows:



- C₂H₅COOH before the arrow and C₂H₅COO⁻ after the arrow, and C balance correct 1
- IO₃⁻ before the arrow and I₂ after the arrow and I balance correct 1
- H₂O after the arrow and H and O balance correct 1
- only when the correct formulas and correct element balance before and after the arrow are given, the correct charge balance 1

□3 Maximum score 7

An example of a correct calculation is:

During the titration $9.75 \times 0.0500 = 0.4875$ mmol I_2 was added.

That reacted with $0.4875 \times 2 = 0.9750$ mmol $S_2O_3^{2-}$.

In total $35.0 \times 0.100 = 3.50$ mmol $S_2O_3^{2-}$ was added.

This means that $3.50 - 0.975 = 2.525$ mmol $S_2O_3^{2-}$ reacted with the I_2 formed in reaction 1.

This corresponds to 2.525 mmol C_2H_5COOH .

The molar mass of C_2H_5COOH is 74.08 g mol^{-1} .

$2.525 \times 74.08 = 0.187$ g C_2H_5COOH reacted.

The percentage by mass of C_2H_5COOH in the examined sample E280 is

$$\frac{0.187}{0.200} \times 100\% = 93.5\%$$

- | | |
|---|---|
| · calculation of the number of mmoles of I_2 added during the titration | 1 |
| · calculation of the number of mmoles of $S_2O_3^{2-}$ that reacted during the titration | 1 |
| · calculation of the number of mmoles of $S_2O_3^{2-}$ that was added in total | 1 |
| · calculation of the number of mmoles of $S_2O_3^{2-}$ that reacted with the I_2 formed in reaction 1 | 1 |
| · calculation of the number of mmoles of C_2H_5COOH | 1 |
| · correct molar mass of C_2H_5COOH | 1 |
| · calculation of the percentage by mass of C_2H_5COOH in the examined sample E280 | 1 |

■ Problem 3 A promising home battery

12 points

□4 Maximum score 3

An example of a correct calculation is:

$$\Delta E^0_{\text{red}} = -1.30 - (-2.37) = +1.07 \text{ V}$$

$$\Delta G^0 = -nF\Delta E^0 = -4 \times 96485 \times 1.07 = -4.13 \cdot 10^5 \text{ J (mol}^{-1} \text{ Mg}_2\text{Mo}_6\text{S}_8\text{)}$$

- calculation of ΔE^0 1
- the notion that $n = 4 \text{ mol e}^-$ per mol $\text{Mg}_2\text{Mo}_6\text{S}_8$ 1
- remainder of the calculation is correct 1

□5 Maximum score 4

An example of a correct answer is:

When all six Mo ions in the positively charged Mo_6 cluster form four covalent bonds, a total of $\frac{6 \times 4}{2} = 12$ covalent bonds are required with a total of $2 \times 12 = 24$ 4d-electrons.

In Mo_6S_8 the charge of the Mo_6 cluster is $16+$.

In the Mo_6^{16+} cluster of Mo_6S_8 a total of $24 - 4 = 20$ 4d-electrons are present / four 4d-electrons less.

This means that in $\text{Mg}_2\text{Mo}_6\text{S}_8$ all covalent bonds can be formed whereas in Mo_6S_8 not enough 4d-electrons are present.

The positively charged Mo_6 cluster in $\text{Mg}_2\text{Mo}_6\text{S}_8$ is therefore more stable than in Mo_6S_8 .

- calculation of the number of covalent bonds in the positively charged Mo_6 cluster when all Mo ions have formed four covalent bonds 1
- calculation of the number of 4d-electrons needed to form all covalent bonds 1
- determination of the $16+$ charge of the positively charged Mo_6 cluster in Mo_6S_8 1
- remainder of the explanation and a consistent conclusion 1

□6 Maximum score 5

An example of a correct calculation is:

The molar mass of Mo_6S_8 is $832.12 \text{ g mol}^{-1}$.

2.5 g Mo_6S_8 would correspond to $\frac{2.5}{832.12} = 0.0030 \text{ mol Mo}_6\text{S}_8$.

That reacts with $\frac{2.5}{832.12} \times 2 \times 24.31 = 0.15 \text{ g Mg}$.

That corresponds to $\frac{\frac{2.5}{832.12} \times 2 \times 24.31}{1.74} = 0.084 \text{ cm}^3 \text{ Mg}$.

The decrease in the thickness of the Mg electrode is

$\frac{\frac{2.5}{832.12} \times 2 \times 24.31}{1.74 \times 100} = 8.4 \cdot 10^{-4} \text{ cm} = 8.4 \text{ } \mu\text{m}$.

The thickness of the Mg electrode after complete discharge is $10.0 - 8.4 = 1.6 \text{ } \mu\text{m}$.

- | | |
|--|---|
| · calculation of the number of moles of Mo_6S_8 in 2.5 g | 1 |
| · calculation of the number of grams of Mg | 1 |
| · conversion to the number of cm^3 of Mg | 1 |
| · calculation of the decrease in the thickness of the Mg electrode | 1 |
| · calculation of the thickness of the Mg electrode after complete discharge in μm | 1 |

Problem 4 Synthesis and function of methyl red

26 points

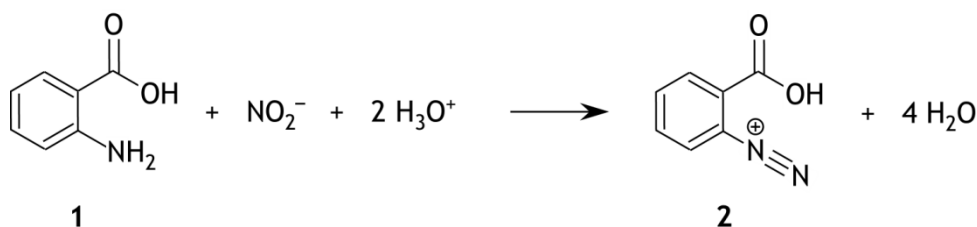
□7 Maximum score 3

A correct answer might look like this:

The structural formula of methyl red does not contain a chiral (carbon) atom. There are no optical isomers of methyl red. A double bond/rigid bond exists between the N atoms, and both N atoms have a non-bonding electron pair and an atomic group/two different groups. Therefore, *cis-trans* isomers of methyl red exist.

- correct explanation that there are no mirror-image isomers of methyl red 1
- state that there is a double bond / rigid bond between the N atoms and that both N atoms have a non-bonding electron pair and an atomic group / two different groups 1
- consistent conclusion 1

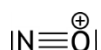
□8 Maximum score 3



This means that $a = 1$, $b = 2$, $c = 4$, X is NO_2^- and Y is H_2O .

- correct formula X and Y 1
- correct value for a 1
- correct value for b and c 1

□9 Maximum score 3



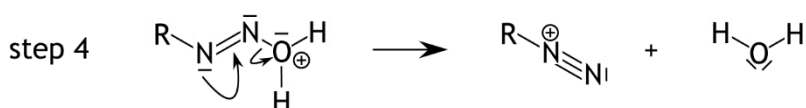
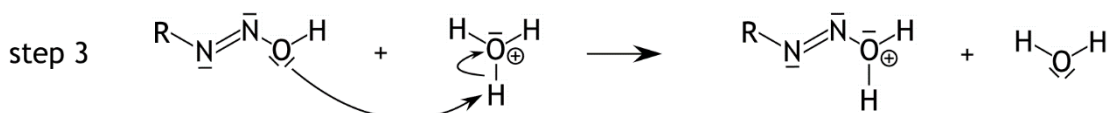
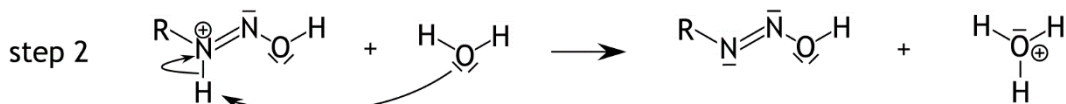
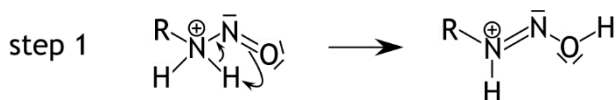
- particle consists of one N atom and one O atom 1
- bonding electron pairs and non-bonding electron pairs correct 1
- formal charge correct and in the right place 1

If the answer given is:

NO^+ or ON^+ 1

□10 Maximum score 8

An example of a correct answer is:



- in step 1 the arrows are drawn correctly 1
- in step 1 the Lewis structures and formal charges are correct 1
- in step 2 the arrows are drawn correctly 1
- correct Lewis structures and formal charges after step 2 1
- in step 3 the arrows are drawn correctly 1
- correct Lewis structures and formal charges after step 3 1
- in step 4 the arrows are drawn correctly 1
- correct Lewis structures and formal charges after step 4 1

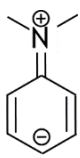
Note

If in step 2 H₃O⁺ is not written on the right side of the arrow and/or in steps 3 and 4 H₂O is not written on the right side of the arrow, this should not be penalized.

□11 Maximum score 1

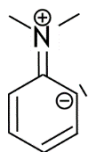
An H⁺ must be added after the arrow. 1

□12 Maximum score 2



- all bonding and non-bonding electron pairs correctly shown 1
- the formal charges correctly shown 1

If the following answer is given: 1



□13 Maximum score 6

$$A_{429} = 1.25 \cdot 10^4 \times [\text{mr}^-] \times 1.00 + 3.86 \cdot 10^3 \times [\text{mrH}] \times 1.00 = 0.108.$$

$$A_{520} = 1.33 \cdot 10^3 \times [\text{mr}^-] \times 1.00 + 2.15 \cdot 10^4 \times [\text{mrH}] \times 1.00 = 0.219.$$

From this, it can be calculated that $[\text{mr}^-] = 5.60 \cdot 10^{-6} \text{ M}$ and $[\text{mrH}] = 9.84 \cdot 10^{-6} \text{ M}$.

$$\text{It follows that: } [\text{H}_3\text{O}^+] = K_a \times \frac{[\text{mrH}]}{[\text{mr}^-]} \text{ and } \text{pH} = \text{p}K_a - \log \frac{[\text{mrH}]}{[\text{mr}^-]}.$$

$$\text{The pH of the solution is } 5.00 - \log \frac{9.84 \times 10^{-6}}{5.60 \times 10^{-6}} = 5.00 - 0.24 = 4.76.$$

- formulating the correct equation for A_{429} 1
- formulating the correct equation for A_{520} 1
- calculation of $[\text{mr}^-]$ 1
- calculation of $[\text{mrH}]$ 1
- correct equilibrium constant expression, possibly partially filled in 1
- calculation of the pH of the solution 1

If the calculation was carried out as follows:

$$A_{429} = 1.25 \cdot 10^4 \times [\text{mr}^-] \times 1.00 = 0.108 \text{ and } A_{520} = 2.15 \cdot 10^4 \times [\text{mrH}] \times 1.00 = 0.219.$$

This results in $[\text{mr}^-] = 8.64 \cdot 10^{-6} \text{ M}$ and $[\text{mrH}] = 1.02 \cdot 10^{-5} \text{ M}$ and $\text{pH} = 4.93$ 3

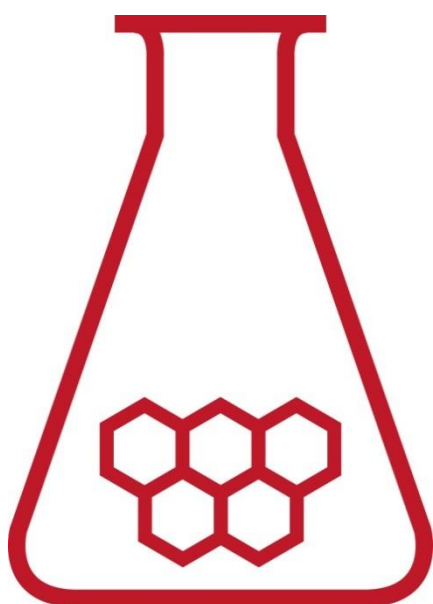
47th National Chemistry Olympiad

Utrecht University

THEORY TEST

Marking scheme

Monday 8th June 2026



**SCHEIKUNDE
OLYMPIADE**



**Universiteit
Utrecht**



- This test consists of 7 problems with 35 open questions.
- The maximum score for this test is 120 points.
- The test will last a maximum of 4 hours.
- Required resources: (graphic) calculator and Binas 7th edition or BINAS 5th edition, English version or ScienceData 1st edition.
- The number of points available for each question is given.

Problem 1 Trouble in a cylinder

10 points

□1 Maximum score 7

Examples of a correct calculation are:

Let $[C_3H_8] = x \text{ mol L}^{-1}$, then $[C_3H_6] = [H_2] = \frac{x}{8} \text{ mol L}^{-1}$ applies.

Substituting into K_c yields: $\frac{\frac{x}{8} \times \frac{x}{8}}{x} = 1.30 \cdot 10^{-3}$ and this gives $x = 0.0832 \text{ mol L}^{-1}$.

So $[C_3H_8] = 0.0832 \text{ mol L}^{-1}$ and $[C_3H_6] = [H_2] = \frac{0.0832}{8} = 0.0104 \text{ mol L}^{-1}$.

The total number of moles per dm^3 is therefore $0.0832 + 2 \times 0.0104$.

The total pressure in the cylinder is therefore

$$p_{\text{total}} = n_{\text{total}} \frac{RT}{V} = (0.0832 + 2 \times 0.0104) \frac{8.314 \times (527 + 273)}{10^{-3}} = 6.91 \cdot 10^5 \text{ Pa.}$$

and

The volume percentages C_3H_6 and H_2 are both 10%.

Let the volume of the gas mixture be $V \text{ dm}^3$ and the molar volume under the conditions of the experiment be $V_m \text{ dm}^3 \text{ mol}^{-1}$.

$$\text{Then } [C_3H_8] = \frac{\frac{0.80 \times V}{V_m}}{V} = \frac{0.80}{V_m} \text{ mol dm}^{-3} \text{ and } [C_3H_6] = [H_2] = \frac{\frac{0.10 \times V}{V_m}}{V} = \frac{0.10}{V_m} \text{ mol dm}^{-3}.$$

The equilibrium expression is $\frac{[C_3H_6][H_2]}{[C_3H_8]} = K_c$.

$$\text{So } \frac{\left(\frac{0.10}{V_m}\right)^2}{\left(\frac{0.80}{V_m}\right)} = 1.30 \cdot 10^{-3}; \text{ this gives } V_m = 9.6 \text{ dm}^3 \text{ mol}^{-1}.$$

$$\text{So } [C_3H_8] = \frac{0.80}{9.6} = 0.083 \text{ mol dm}^{-3} \text{ and } [C_3H_6] = [H_2] = \frac{0.10}{9.6} = 0.010 \text{ mol dm}^{-3}.$$

The total number of moles per dm^3 is therefore $0.083 + 2 \times 0.010$.

The total pressure in the cylinder is therefore

$$p_{\text{total}} = n_{\text{total}} \frac{RT}{V} = (0.083 + 2 \times 0.010) \frac{8.314 \times (527 + 273)}{10^{-3}} = 6.85 \cdot 10^5 \text{ Pa.}$$

- notion that concentrations of C_3H_6 and H_2 are equal to each other 1
- (assuming that $[C_3H_8] = x \text{ mol L}^{-1}$) $[C_3H_6] = [H_2] = \frac{x}{8} \text{ mol L}^{-1}$ 1
- correct equilibrium expression (possibly already partially filled in) 1
- calculation of $[C_3H_8]$, $[C_3H_6]$ and $[H_2]$ 1
- calculation of the total number of moles per dm^3 in the gas mixture 1
- conversion of temperature from $^{\circ}\text{C}$ to K and from dm^3 to m^3 1
- rest of the calculation 1

or

- notion that the volume percentages and the concentrations of C_3H_6 and H_2 are equal to each other 1
- (when stating that the molar volume V_m is) demonstrate that $[C_3H_8] = \frac{0.80}{V_m} \text{ mol dm}^{-3}$ and
that $[C_3H_6] = [H_2] = \frac{0.10}{V_m} \text{ mol dm}^{-3}$ 1
- correct equilibrium expression (possibly already partially filled in) 1
- calculation of V_m 1
- calculation of $[C_3H_8]$, $[C_3H_6]$ and $[H_2]$ 1
- calculation of the total number of moles per dm^3 in the gas mixture 1
- conversion of temperature from $^{\circ}\text{C}$ to K and from dm^3 to m^3 and the rest of the calculation 1

□2 Maximum score 3

An example of a correct answer is:

When the volume is halved, the pressure becomes twice as large. However, as the volume decreases, the position of the equilibrium shifts towards the side with the lowest number of gas molecules in the reaction equation, which in this case is to the left. Therefore, the total number of molecules in the cylinder decreases, and consequently, the pressure decreases as well. In the new equilibrium, the pressure is less than twice as large.

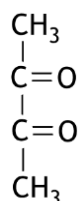
- notion that without an equilibrium shift the pressure becomes twice as large (possibly implicit) 1
- correct explanation regarding the shift in the position of equilibrium 1
- conclusion 1

Problem 2 Malaprade

19 points

□3 Maximum score 2

A correct answer might look like this:



- a structure with two double-bonded oxygen atoms to adjacent carbon atoms 1
- rest of the formula is correct 1

□4 Maximum score 8

An example of a correct calculation is:

From the blank determination it follows that the 25.0 mL sodium periodate solution

contained $\frac{1}{4} \times \frac{1}{2} \times 23.9 \times 0.502 = 1.50$ mmol IO_4^- . Suppose that the 150 mg antifreeze

contained x mmol glycol, then x mmol IO_3^- was formed in the malaprade reaction with $(1.50 - x)$ mmol IO_4^- remaining.

From x mmol IO_3^- , $3x$ mmol I_2 is formed in the reaction with iodide, and from $(1.50 - x)$ mmol IO_4^- , $4 \times (1.50 - x)$ mmol I_2 is formed in the reaction with iodide.

So a total of $3x + 4 \times (1.50 - x)$ mmol I_2 is formed.

For the titration of this amount of I_2 , 19.6 mL of sodium thiosulfate solution was required,

so $\frac{1}{2} \times 19.6 \times 0.502 = 3x + 4 \times (1.50 - x)$.

This leads to $x = 1.08$.

Therefore, 150 mg of antifreeze contained 1.08×62.07 mg glycol, and that is

$\frac{1.08 \times 62.07}{150} \times 100 = 44.7$ mass percent.

- calculation of the number of mmol $\text{S}_2\text{O}_3^{2-}$ in both titrations 1
- calculation of the number of mmol I_2 that reacted in both titrations 1
- calculation of the number of mmol IO_4^- in the 25.0 mL sodium periodate solution 1
- (setting the number of mmol glycol equal to x) calculation of the number of mmol IO_3^- formed in the malaprade reaction 1
- calculation of the number of mmol IO_4^- remaining after the malaprade reaction 1
- calculation of the total number of mmol I_2 formed after the reactions with iodide 1
- calculation of x 1
- calculation of the mass percentage 1

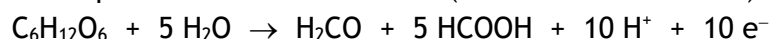
□5 Maximum score 9

An example of a correct answer is:

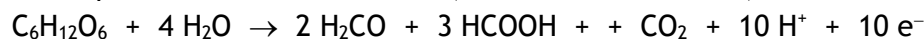
In the malaprade reaction of glucose, methanal and methanoic acid are formed in the molar ratio methanal : methanoic acid = 1 : 5.

In the malaprade reaction of fructose, methanal, methanoic acid, and carbon dioxide are formed in the molar ratio methanal : methanoic acid : carbon dioxide = 2 : 3 : 1.

The equation of the half-reaction (in molecular formulas) for the conversion of glucose is:



The equation of the half-reaction (in molecular formulas) for the conversion of fructose is:



Therefore, 10 moles of electrons are released per mole of sugar in both cases, which means that the number of moles of oxidizing agent (IO_4^-) that reacts per mole of sugar is the same.

Therefore, with iodate, you cannot distinguish between glucose and fructose.

The number of moles of methanoic acid formed per mole of sugar are different, so you can distinguish between them by means of titration with sodium hydroxide.

- with glucose, methanal and methanoic acid are formed 1
- correct molar ratio in which methanal and methanoic acid are formed 1
- with fructose, methanal, methanoic acid and carbon dioxide are formed 1
- correct molar ratio in which methanal, methanoic acid and carbon dioxide are formed 1
- correct equation for the half-reaction of glucose 1
- correct equation for the half-reaction of fructose 1
- conclusion regarding the use of iodate 1
- notion that the amounts of acid formed in both reactions are different 1
- conclusion regarding the use of sodium hydroxide 1

Problem 3 Electrochemical conversion of CO₂

23 points

□6 Maximum score 3



- CO₂ before the arrow and C₃H₈O plus H₂O after the arrow 1
- H⁺ and e⁻ before the arrow 1
- atoms and charge balanced correctly 1

□7 Maximum score 5

An example of a correct calculation is:

$$\Delta_r H = -2.78 \cdot 10^5 + 3 \times (-2.86 \cdot 10^5) - 2 \times (-3.935 \cdot 10^5) = -3.49 \cdot 10^5 \text{ J mol}^{-1}$$

$$\Delta_r S = 161 + 3 \times 70 - 2 \times 214 - 6 \times 131 = -843 \text{ J K mol}^{-1}$$

$$\Delta_r G = \Delta_r H - T \times \Delta_r S = -3.49 \cdot 10^5 - 298 \times (-843) = -0.978 \cdot 10^5 \text{ J mol}^{-1}$$

$$-0.978 \cdot 10^5 = -12 \times 9.649 \cdot 10^4 \times \Delta E^0$$

$$\Delta E^0 = \frac{-0.978 \cdot 10^5}{-12 \times 9.649 \cdot 10^4} = 0.0845 \text{ V}$$

$$\Delta E^0 = E^0_{\text{CO}_2/\text{propan-1-ol}} - E^0_{\text{H}_2/\text{H}^+}$$

$$E^0_{\text{CO}_2/\text{propan-1-ol}} = \Delta E^0 + E^0_{\text{H}_2/\text{H}^+} = 0.0845 + 0.00 = +0.0845 \text{ V}$$

- calculation of $\Delta_r H$ 1
- calculation of $\Delta_r S$ 1
- calculation of $\Delta_r G$ 1
- calculation of $\Delta_r E$ 1
- rest of the calculation 1

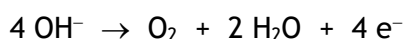
□8 Maximum score 4

An example of a correct calculation is:

$$\frac{\left(\frac{0.0054 \times 0.90}{63.55} \times 2 + \frac{0.0054 \times 0.10}{107.9} \right) \times 9.649 \cdot 10^4}{60} \times 10^2 = 25\%$$

- calculation of the number of moles of Cu and the number of moles of Ag 1
- calculation of the number of moles of electrons 1
- conversion to C 1
- rest of the calculation 1

□9 Maximum score 2



If $2 \text{ H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{ H}^+ + 4 \text{ e}^-$ is given 1

□10 Maximum score 5

An example of a correct calculation is:

$$\frac{[1.00 - (0.336 + 0.069)] \times 60 \times 60 \times 0.030}{9.649 \cdot 10^4} \times \frac{1}{2} \times 24.5 \cdot 10^3 = 8.2 \text{ cm}^3$$

- calculation of the total charge in C 1
- calculation of the number of C used for the formation of H₂ 1
- conversion to the number of moles of electrons used for the formation of H₂ 1
- calculation of the number of moles of H₂ 1
- conversion to the number of cm³ 1

□11 Maximum score 4

An example of a correct calculation is:

$$\left[\left(\frac{0.035 \times 0.0413}{46.07} \right) \times 2 + \left(\frac{0.035 \times 0.0074}{60.09} \right) \times 3 \right] \times 44.01 \cdot 10^3 = 3.3 \text{ mg}$$

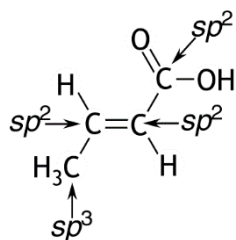
- calculation of the masses of ethanol and propan-1-ol 1
- conversion of the masses of ethanol and propan-1-ol to mol 1
- calculation of the number of moles of CO₂ that reacted 1
- conversion of the number of moles of CO₂ to mg 1

Problem 4 Crotonic acid

17 points

□12 Maximum score 2

A correct answer can be shown as follows:



If the correct hybridization is shown for three C atoms

1

If the correct hybridization is shown for two or fewer C atoms

0

□13 Maximum score 3

A correct answer can be formulated as follows:

In both mass spectra, the molecular ion peak occurs at $m/z = 86$, so the molecular formula is the same. The peak patterns/peaks in the mass spectra are different, so the molecules have a different structure (structural formula).

In the mass spectrum of A (as with crotonic acid), a peak of the COOH group occurs at $m/z = 45$.

· in both mass spectra the molecular ion peak occurs with $m/z = 86$, so the molecular formula is the same

1

· the peak patterns/peaks in the mass spectra are different, so the molecules have a different structure (structural formula)

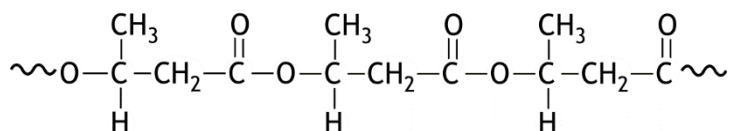
1

· in the mass spectrum of A, a peak occurs at $m/z = 45$ of the COOH group

1

□14 Maximum score 3

A correct answer can be shown as follows:



· two ester groups correctly shown

1

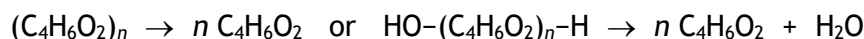
· ends correctly shown

1

· rest of the structural formula correctly shown

1

□15 Maximum score 2



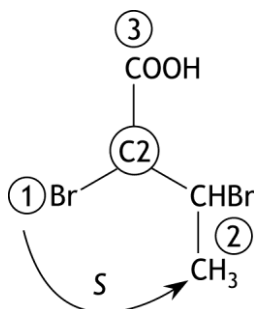
· $(C_4H_6O_2)_n$ or $HO-(C_4H_6O_2)_n-H$ before the arrow

1

· $n C_4H_6O_2$ or $n C_4H_6O_2 + H_2O$ after the arrow

1

- 16 Maximum score 3
An example of a correct answer is:



- a correct diagram 1
 - the correct prioritization 1
 - correct designation of the configuration 1
- 17 Maximum score 2
A correct answer can be formulated as follows:
2,3-dibromobutanoic acid has two asymmetrical carbon atoms,
so there are ($2^2 =$) 4 possible stereoisomers.
- there are 4 possible stereoisomers 1
 - correct explanation 1
- 18 Maximum score 2
A correct answer can be formulated as follows:
Two stereoisomers are formed. In addition to the shown stereoisomer, the mirror image is also produced.
- two stereoisomers are formed 1
 - in addition to the shown stereo isomer, the mirror image is also formed 1

Problem 5 CoFe

17 points

□19 Maximum score 3

An example of a correct calculation is:

10.00 mL of 0.0500 M chloropentaamminecobalt(III) chloride solution contains

10.00×0.0500 mmol of chloropentaamminecobalt(III) chloride and therefore

$2 \times 10.00 \times 0.0500$ mmol Cl^- .

That reacts with $2 \times 10.00 \times 0.0500$ mmol Ag^+ to form $2 \times 10.00 \times 0.0500$ mmol AgCl .

That is $2 \times 10.00 \times 0.0500 \times 143.32 \times 10^{-3} = 0.14$ g AgCl .

- calculation of the number of mmol Cl^- that can react 1
- calculation of the number of mmol AgCl that can be formed 1
- rest of the calculation 1

□20 Maximum score 2

- I and III are identical 1
- II and IV are identical 1

□21 Maximum score 3

An example of a correct calculation is:

$$E = -\log T = -\log 0.075 = \varepsilon \times 0.0200 \times 1.00$$

$$\text{So } \varepsilon = \frac{-\log 0.075}{0.0200 \times 1.00} = 56 \text{ L mol}^{-1} \text{ cm}^{-1}.$$

- $T = 0.075$ 1
- rest of the calculation 1
- correct unit 1

□22 Maximum score 1

An example of a correct answer is:

Apparently, the unreacted Fe^{2+} (and the formed Co^{2+} and FeCl^{2+}) also absorb light at 520 nm.

□23 Maximum score 2

An example of a correct answer is:

Because the Fe^{2+} has been added in large excess, the extinction of the Fe^{2+} can be considered constant (and the extinctions of the small amounts of Co^{2+} and FeCl^{2+} are negligible).

The total extinction of the solution at time t is then $E_{\text{total},t} = E_{\text{cobalt complex},t} + E_{\infty}$,

$$\text{so } E_{\text{cobalt complex},t} = E_{\text{total},t} - E_{\infty}, \text{ or } \varepsilon \times [\text{Co}(\text{Cl})(\text{NH}_3)_5]_t \times 1.00 = E_{\text{total},t} - E_{\infty} \text{ or}$$

$$[\text{Co}(\text{Cl})(\text{NH}_3)_5]_t = \frac{E_{\text{total},t} - E_{\infty}}{\varepsilon \times 1.00}.$$

- explanation that the sum of the extinctions of the unreacted Fe^{2+} (and the formed Co^{2+} and FeCl^{2+}) during the reaction is constant 1
- rest of the explanation 1

□24 Maximum score 6

An example of a correct calculation is:

With a large excess of Fe^{2+} , $[\text{Fe}^{2+}]$ is constant during the reaction. The reaction rate is then given by $s = k[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}][\text{Fe}^{2+}] = k'[\text{Co}(\text{Cl})(\text{NH}_3)_5^{2+}]$, with $k' = k[\text{Fe}^{2+}]$. This is the equation of a (pseudo-)first-order reaction.

This applies to $\ln \frac{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_0}{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_t} = k't$, or $k' = \frac{\ln \frac{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_0}{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_t}}{t}$.

Enter the data for the interval 10–20 minutes, for example:

$$k' = \frac{\ln \frac{1.15 - 0.283}{0.875 - 0.283}}{10} \text{ min}^{-1} \text{ or } k' = \frac{\ln \frac{1.15 - 0.283}{0.875 - 0.283}}{10 \times 60} = 6.36 \cdot 10^{-4} \text{ s}^{-1}.$$

During the reaction, the $[\text{Fe}^{2+}] = \frac{0.300}{2} = 0.150 \text{ mol L}^{-1}$,

$$\text{so } k = \frac{6.36 \cdot 10^{-4}}{0.150} = 4.2 \cdot 10^{-3} \text{ L mol}^{-1} \text{ s}^{-1}.$$

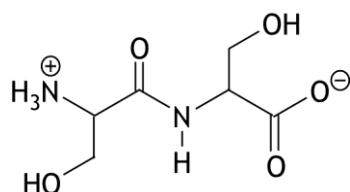
- notion that the reaction is a (pseudo-)first-order reaction 1
- use of $k' = \frac{\ln \frac{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_0}{[\text{Co}(\text{Cl})(\text{NH}_3)_5]_t}}{t}$, possibly already partially filled in 1
- calculation of k' 1
- calculation of $[\text{Fe}^{2+}]$ 1
- calculation of k 1
- correct unit 1

Problem 6 Dipeptide

14 points

□25 Maximum score 1

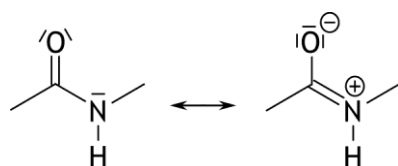
An example of a correct answer is:



□26 Maximum score 3

An example of a correct answer is:

Two Lewis structures can be drawn for the amide group, one of which has a double bond between the carbon atom and the nitrogen atom:



- in both resonance structures all bonding and non-bonding electron pairs correctly drawn 1
- in the right resonance structure the charges correctly indicated 1
- in the right resonance structure a double bond between C and N is drawn 1

□27 Maximum score 3

An example of a correct answer is:

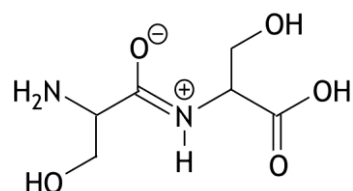
E/Z stereoisomerism occurs, because the double bond character prevents free rotation around the C – N bond.

The structure: occurs most often, because in the other stereoisomer steric hindrance occurs.

- there is no free rotation around the C – N bond 1
- correct diagram 1
- steric hindrance occurs in the other isomer 1

Note:

Do not penalize when the following structure is drawn:



□28 Maximum score 2

H_2PO_4^- and HPO_4^{2-} occur most frequently.

· H_2PO_4^-

1

· HPO_4^{2-}

1

□29

M

Maximum score 5

An example of a correct answer is:

$$K_{c,1} = e^{-\frac{\Delta_r G}{RT}} = e^{-\frac{-1.7 \cdot 10^4}{8.314 \times 298}} = e^{-6.84} = 1.0 \cdot 10^{-3}$$

For equilibrium 3, the following applies:

$$\Delta G_3^0 = \Delta G_1^0 + \Delta G_2^0 = +1.7 \cdot 10^4 + (-2.8 \cdot 10^4) = -1.1 \cdot 10^4 \text{ J mol}^{-1}.$$

$$\text{So } K_{c,3} = e^{-\frac{\Delta G^0}{RT}} = e^{-\frac{-1.1 \cdot 10^4}{8.314 \times 298}} = e^{4.4} = 85.$$

The equilibrium constant of equilibrium 3 is therefore much larger than that of equilibrium 1, so equilibrium 3 lies further to the right than equilibrium 1 and the yield of the dipeptide is greater in equilibrium 3.

· calculation of $K_{c,1}$

1

· calculation of ΔG_3^0

1

· calculation of $K_{c,3}$

1

· explanation that equilibrium 3 lies further to the right than equilibrium 1

1

· conclusion regarding the yield of dipeptide

1

Problem 7 Hydrogen storage

20 points

□30 Maximum score 3

An example of a correct calculation is:

La_2O_3 and NiO must be combined in the molar ratio 1 : 10, so in a mass ratio of $325.8 : (10 \times 74.69) = 0.44 : 1.0$.

- correct mole ratio 1
- correct molar masses 1
- rest of the calculation 1

□31 Maximum score 4

An example of a correct calculation is:

The reaction equation is: $2 \text{La}_2\text{O}_3 + 20 \text{NiO} + 13 \text{CaH}_2 \rightarrow 4 \text{LaNi}_5 + 13 \text{Ca(OH)}_2$.

for every 4 mol of LaNi_5 , 26 mol of CaH_2 is required for a twofold excess.

So for every $4 \times 432.4 \text{ g LaNi}_5$ you need 26×42.096 , that is per 1.0 g LaNi_5

$$\frac{26 \times 42.096}{4 \times 432.4} = 0.63 \text{ g Ca(OH)}_2.$$

- correct reaction equation (possibly already given in the previous question) 1
- correct processing of double excess 1
- correct molar mass of LaNi_5 1
- rest of the calculation 1

□32 Maximum score 2

An example of a correct answer is:

You can perform an extraction with water. Calcium hydroxide dissolves and calcium hydride reacts with it, but the alloy does not. Then filter (and dry).

- calcium hydroxide and calcium hydride dissolve in water / react with water 1
- so add water and then filter 1

□33 Maximum score 3

An example of a correct answer is:

There can be one nickel atom in the cell; it counts fully.

And there can be eight nickel atoms on the faces (for example, two on the top face, two on the bottom face, and one nickel atom on the side faces), which count for half. (There are no nickel atoms on the edges.)

- correct number inside the cell 1
- correct number on the faces 1
- correct explanation 1

□34 Maximum score 3

An example of a correct calculation is:

The volume of the unit cell is $397 \times 511 \times 511 \times \frac{1}{2} \times \sqrt{3} \times 10^{-36} \text{ m}^3$.

The mass of the unit cell is $432.4 \times 1.66 \cdot 10^{-27} \text{ kg}$.

So the density is $\frac{432.4 \times 1.66 \cdot 10^{-27}}{397 \times 511 \times 511 \times \frac{1}{2} \times \sqrt{3} \times 10^{-36}} = 8.00 \cdot 10^3 \text{ kg m}^{-3}$.

- | | |
|--|---|
| · correct calculation of the volume of a unit cell | 1 |
| · correct calculation of the mass of a unit cell | 1 |
| · rest of the calculation | 1 |

Note:

If the same incorrect molar mass for LaNi_5 is used in the answer of question 34 as in question 31, do not penalize again.

□35 Maximum score 5

Examples of a correct calculation are:

The density of hydrogen at 273 K and $p = p_0$ is 0.090 kg m^{-3} . A cm^3 is therefore $0.090 \cdot 10^{-3} \text{ g}$, and it contains $\frac{0.090 \cdot 10^{-3}}{1.008}$ moles of H atoms, which are $\frac{0.090 \cdot 10^{-3}}{1.008} \times 6.02 \cdot 10^{23}$ H atoms.

Therefore, there are $\frac{0.090 \cdot 10^{-3}}{1.008} \times 6.02 \cdot 10^{23} \times 1244 = 6.69 \cdot 10^{22}$ H atoms in a cm^3 of LaNi_5 .

The volume of the unit cell is $8.98 \cdot 10^{-23} \text{ cm}^3$ (follows from the previous question), so there are $\frac{1}{8.98 \cdot 10^{-23}} = 1.11 \cdot 10^{22}$ unit cells in a cm^3 .

$\frac{6.69 \cdot 10^{22}}{1.11 \cdot 10^{22}} = 6$ H atoms can be stored in a unit cell.

And

At 273 K and $p = p_0$, $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$.

Therefore, in a cm^3 there are $\frac{1}{22.4} \times 10^{-3}$ moles of H_2 or $2 \times \frac{1}{22.4} \times 10^{-3}$ moles of

H atoms, which are $2 \times \frac{1}{22.4} \times 10^{-3} \times 6.02 \cdot 10^{23} = 5.38 \cdot 10^{19}$ H atoms. Therefore, in a

$\text{cm}^3 \text{ LaNi}_5$ there are $1244 \times 2 \times \frac{1}{22.4} \times 10^{-3} \times 6.02 \cdot 10^{23} = 6.69 \cdot 10^{22}$ H atoms.

In one $\text{cm}^3 \text{ LaNi}_5$, $\frac{1}{8.98 \cdot 10^{-23}} = 1.11 \cdot 10^{22}$ unit cells are present.

So $\frac{6.69 \cdot 10^{22}}{1.11 \cdot 10^{22}} = 6$ H atoms can be stored in a unit cell.

- | | |
|---|---|
| · calculation of the number of moles of H atoms in a cm^3 of hydrogen at 273 K and $p = p_0$ | 1 |
| · calculation of the number of H atoms in a cm^3 of hydrogen at 273 K and $p = p_0$ | 1 |
| · calculation of the number of H atoms in a $\text{cm}^3 \text{ LaNi}_5$ | 1 |
| · calculation of the number of unit cells in a $\text{cm}^3 \text{ LaNi}_5$ | 1 |
| · calculation of the number of H atoms that can be stored in a unit cell | 1 |

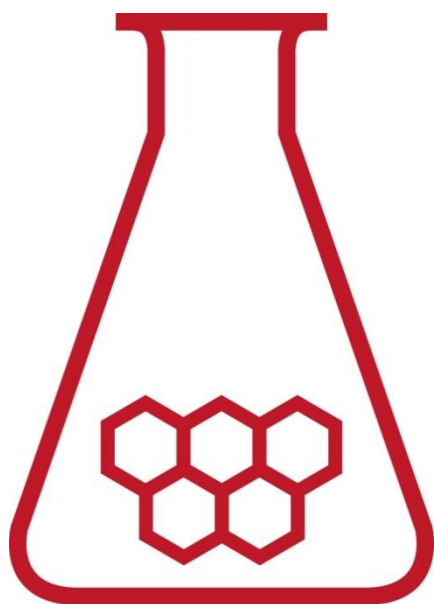
47th National Chemistry Olympiad

Utrecht University

PRACTICAL TEST

Marking Scheme

Tuesday 9th June 2026



**SCHEIKUNDE
OLYMPIADE**



**Universiteit
Utrecht**



58th International
Chemistry Olympiad
Uzbekistan 2026

Experiment 1 The synthesis of the ester 1-pentylpropanoate

40 points

Maximum score 10

The following practical skills are assessed:

- safety, neatness and independent working
- handling of glassware

Maximum score 5

Assessment of 1-pentylpropanoate yield:

The score for yield is determined by comparing the yield (calculated by the organization) with the yield of an experiment carried out by the organization.

Maximum score 5

Assessment of 1-pentylpropanoate purity:

The purity of the product is determined by using an NMR spectrum.

The score is determined by comparing the measured purity with a completely pure sample.

Optionally, an IR spectrum is also recorded.

□1 Maximum score 3

- propanoyl chloride

2

- triethylammonium chloride

1

Note:

If the answer „propanoic acid, hydrogen chloride and triethylammonium chloride” is given, count this as correct.

□2 Maximum score 1

Sulphuric acid reacts with the excess triethylamine (to triethylammonium chloride, which is thus removed from the reaction mixture)

□3 Maximum score 1

Magnesium sulphate is a desiccant, and that ensures that the last bit of water is removed.

□4 Maximum score 2

- number of mL stated

1

- correct accuracy

1

□5 Maximum score 4

- calculation of the number of grams of alcohol and acid chloride

1

- calculation of the number of moles of alcohol and acid chloride

1

- determining the maximum number of moles of ester that can be formed

1

- calculation of the maximum number of grams of ester that can be formed

1

□6 Maximum score 3

- masses noted

1

- correct units

1

- correct accuracy

1

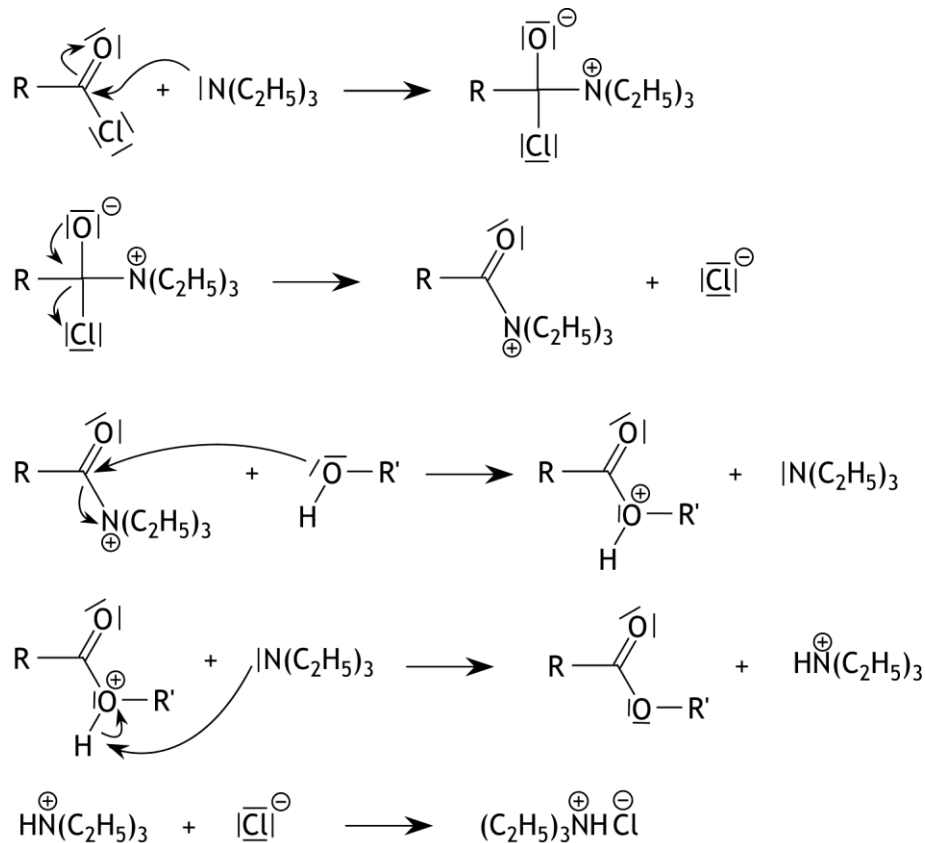
□7 Maximum score 2

- yield calculated in grams
- percentage yield calculated

1
1

□8 Maximum score 4

An example of a correct answer is:



- a plausible mechanism drawn
- in each step all non-bonding electron pairs drawn
- in every step the charges in the correct place
- in every step all curly arrows drawn correctly

1
1
1
1

Note:

If the last step is not listed, do not penalize.

■ Experiment 2 The determination of the acetic acid content in vinegar using a titration curve. 40 points

Maximum score 10

The following practical skills are assessed:

- safety, neatness and independent working
- handling of the glassware

□9 Maximum score 0

correct molarity stated

□10 Maximum score 7

- total number of mL sodium hydroxide correctly recorded 1
- corresponding pH values 1
- the second titration performed more efficiently than the first 5

□11 Maximum score 5

- grid optimally used 1
- title vertical axis 1
- title horizontal axis 1
- points displayed correctly 1
- smooth line drawn 1

Note:

If one or more of the above sub-scores are not met in the titration curve for the first titration, do not penalize this.

□12 Maximum score 10

- equivalence point correctly determined 1
- calculation of the number of mmol sodium hydroxide and the number of mmol acetic acid in 5.00 mL vinegar 1
- calculation of the number of mg of acetic acid in 5.00 mL of vinegar 1
- calculation of the mass of 5.00 mL vinegar 1
- calculation of the mass percentage and conclusion 1
- result 5

□13 Maximum score 2

Examples of a correct answer are:

The use of a volumetric pipette is not necessary, because the 20 mL of water play no role in the calculation.

And

The use of a volumetric pipette is not necessary, because only the amount of acetic acid in the 5.00 mL of vinegar is important.

- correct explanation 1
- corresponding conclusion 1

□14 Maximum score 6

An example of a correct answer is:

After adding 5.0 mL of sodium hydroxide, half the number of moles of acetic acid is converted to acetate. Then a buffer solution is formed in which $[\text{HAc}] = [\text{Ac}^-]$, so

$$\text{pH} = \text{p}K_{\text{a}} + \log \frac{[\text{Ac}^-]}{[\text{HAc}]} = 4.76.$$

At the equivalence point, a 0.050 M solution of sodium acetate was formed. In this

$$K_{\text{b}} = \frac{[\text{HAc}][\text{OH}^-]}{[\text{Ac}^-]} = \frac{[\text{OH}^-]^2}{0.050 - [\text{OH}^-]} = 5.8 \cdot 10^{-10}. \text{ This gives } [\text{OH}^-] = 5.4 \cdot 10^{-6} \text{ mol L}^{-1},$$

$$\text{so pH} = 14.00 - (-\log 5.4 \cdot 10^{-6}) = 8.73.$$

- after adding 5.0 mL of sodium hydroxide solution, $[\text{HAc}] = [\text{Ac}^-]$ 1
- calculation of the pH of the solution after adding 5.0 mL sodium hydroxide 1
- at the equivalence point a 0.050 M solution of sodium acetate was formed 1
- notion that $[\text{HAc}] = [\text{OH}^-]$ and $[\text{Ac}^-] = 0.050 - [\text{OH}^-]$ 1
- calculation of the $[\text{OH}^-]$ in the solution formed at the equivalence point 1
- calculation of the pH in the solution formed at the equivalence point 1

Note:

If $[\text{OH}^-]$ is neglected compared to 0.050 in the calculation of the pH of the solution formed at the equivalence point, count this as correct.