NATIONAL CHEMISTRY OLYMPIAD 2025

ASSIGNMENTS PRELIMINARY ROUND 1

To be held between 13th and 31st January 2025

SCHEIKUNDE OLYMPIADE

Symeres
Making Molecules Matter. Together.

- **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 76 points.**
- **The preliminary round lasts two hours in total.**
- **Required materials: (graphic) calculator and BINAS 6th or 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 K and $p = p_0$.**

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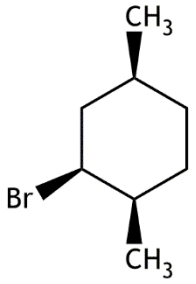
Problem 1 Multiple choice questions (total 50 points)

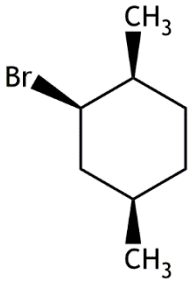
For each question, write your answer (letter) on the answer sheet. The answer sheet can be found at the end of this examination booklet.
Marks: 2 points for each correct answer.

Carbon chemistry

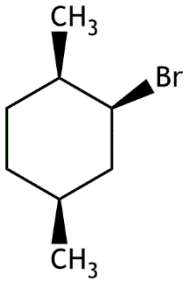
1 Which of the substances, I and II, shown below is a stereoisomer / are stereoisomers of substance X?



X



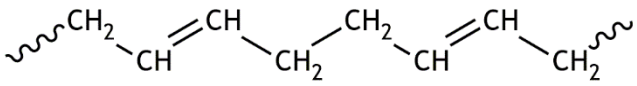
I



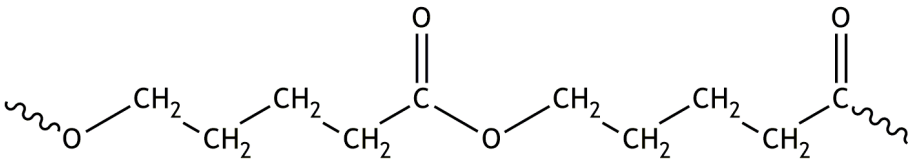
II

A none
B only I
C only II
D both

2 Fragments of two polymer chains are shown below.



polymer I



polymer II

What are the molecular formulas of the monomers from which the above polymer chains could have been formed?

	polymer I	polymer II
A	C_2H_4	$C_5H_{10}O_2$
B	C_2H_4	$C_5H_{10}O_3$
C	C_4H_6	$C_5H_{10}O_2$
D	C_4H_6	$C_5H_{10}O_3$
E	C_4H_8	$C_5H_{10}O_2$
F	C_4H_8	$C_5H_{10}O_3$

3 How many alcohols with the molecular formula $C_5H_{12}O$ are there? Take stereoisomerism into account.

A 6
B 7
C 8
D 9
E 10
F 11
G 12

Thermochemistry

4 Sodium perchlorate, $NaClO_4$, is a solid at room temperature. When heated, it melts and thermolysis occurs:

$NaClO_4(l) \rightarrow NaCl(s) + 2\ O_2(g)$ (reaction 1)

What is the reaction enthalpy of reaction 1?

Use, among others, the following thermodynamic data for sodium perchlorate :

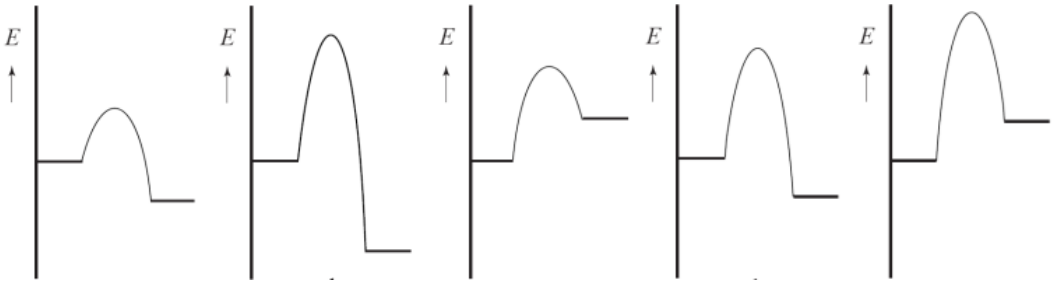
- The enthalpy of formation of $NaClO_4$ (s) is -382.75 kJ mol^{-1}.
- The amount of energy required to melt 1 mole of $NaClO_4$(s) is 14.7 kJ.
- Assume that data valid at 298 K is also valid under the conditions of reaction 1.

A -809 kJ mol^{-1}
B -779 kJ mol^{-1}
C -43 kJ mol^{-1}
D -13 kJ mol^{-1}
E $+13$ kJ mol^{-1}
F $+43$ kJ mol^{-1}
G $+779$ kJ mol^{-1}
H $+809$ kJ mol^{-1}

5 Electrolysis of water produces hydrogen and oxygen:

$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$ (reaction 1)

Five energy diagrams (I, II, III, IV and V) are shown below. In these diagrams, the left level corresponds to the energy level of the reactants and the right level to the energy level of the products. One of the diagrams shows the course of reaction 1 without a catalyst and one of the other diagrams shows the course of reaction 1 with a catalyst. In all diagrams, the vertical axis has the same scale.



I II III IV V

Which of the diagrams above shows the progress of reaction 1 without a catalyst and which of the diagrams shows the progress of reaction 1 with a catalyst?

	without catalyst	with catalyst
A	I	IV
B	I	II
C	II	I
D	II	IV
E	III	V
F	IV	I
G	IV	II
H	V	III

Reaction rate and equilibrium

6 10 mL of 0.50 M potassium sulfate solution and 10 mL of 0.50 M silver nitrate solution are combined.

A heterogeneous mixture is formed and equilibrium is achieved.

What is the correct order of the concentrations of the ions in this mixture?

A $[K^+] = [NO_3^-] > [Ag^+] > [SO_4^{2-}]$

B $[K^+] = [NO_3^-] > [SO_4^{2-}] > [Ag^+]$

C $[K^+] > [NO_3^-] > [Ag^+] > [SO_4^{2-}]$

D $[K^+] > [NO_3^-] > [SO_4^{2-}] > [Ag^+]$

E $[K^+] > [NO_3^-] > [SO_4^{2-}] = [Ag^+]$

F $[K^+] > [NO_3^-] = [SO_4^{2-}] = [Ag^+]$

7 Consider the following equilibrium:

$2\ NO_2(g) \rightleftharpoons N_2O_4(g)$ with equilibrium constant K.

Extra NO_2 is added. The new equilibrium is reached. During the addition of the NO_2 and the reaching of the equilibrium, the volume and temperature are kept constant.

After reaching equilibrium, did the value of K decrease, remain the same, or increase?

After reaching equilibrium, did the rate of reaction to the left decrease, remain the same, or increase?

	value of K	reaction rate to the left
A	decreased	decreased
B	decreased	remained the same
C	decreased	increased
D	remained the same	decreased
E	remained the same	remained the same
F	remained the same	increased
G	increased	decreased
H	increased	remained the same
I	increased	increased

8 In a closed space of 250 cm^3 2.50 g of calcium carbonate is heated to a constant temperature. The following equilibrium results:

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

When equilibrium is reached, 1.70 g of $CaCO_3$ is still present.

What is the value of the equilibrium constant, K_c, of this equilibrium at this temperature?

A 0.0080
B 0.015
C 0.032
D 0.068
E 31
F 66
G $1.3 \cdot 10^2$

9 Consider the following equilibrium:

$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$

For the reaction to the right, $\Delta H = -196$ kJ mol^{-1}.

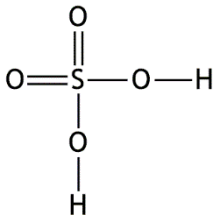
Under constant temperature, how should the pressure be changed to favour the reaction to the right?

Under constant pressure, how should the temperature be changed to favour the reaction to the right?

	pressure (under constant T)	temperature (under constant p)
A	decrease	decrease
B	decrease	increase
C	increase	decrease
D	increase	increase

Structures and formulas

10 The structural formula for sulfuric acid is:



What are the partial charges of the atoms in this molecule?

	H atom	S atom	double-bonded O atoms (O═)	O atoms in O—H groups
A	δ^+	δ^+	δ^-	δ^+
B	δ^+	δ^+	δ^-	δ^-
C	δ^+	δ^-	δ^-	δ^+
D	δ^+	δ^-	δ^-	δ^-
E	δ^-	δ^+	δ^+	δ^+
F	δ^-	δ^+	δ^+	δ^-
G	δ^-	δ^-	δ^+	δ^+
H	δ^-	δ^-	δ^+	δ^-

11 An atom of ^{232}Th is transformed into an atom of ^{208}Pb after emitting a number of alpha particles. An alpha particle is the nucleus of a He-4 atom. During this transformation, a number of neutrons in the atomic nucleus are also converted into protons. Electrons are not considered during this process.

How many alpha particles are emitted during this transformation?

How many neutrons are converted into protons?

	number of emitted alpha particles	number of neutrons converted into protons
A	4	4
B	4	8
C	6	4
D	6	12
E	8	8
F	8	12

12 How many valence electrons does a ClO_3^- particle contain?

A 24
B 25
C 26
D 31
E 32
F 33

13 How many resonance structures can be drawn for the oxalate ion ($C_2O_4^{2-}$)? Assume that all atoms follow the octet rule.

A 1
B 2
C 3
D 4
E 5
F 6

pH and acid-base

14 0.320 mol of the monoprotic weak acid HA is dissolved in water and diluted with water to a volume of 1.00 L.

In this solution, 10.2% of the acid is ionized.

What is the K_a of HA?

A $3.33 \cdot 10^{-3}$
B $3.71 \cdot 10^{-3}$
C $1.16 \cdot 10^{-2}$
D $3.26 \cdot 10^{-2}$

15 A 100 mL solution of sodium hydroxide (NaOH) has a pH of 9.20.

How many mL of 0.10 M HCl solution must be added to reduce the pH to 8.20?

A 0.00014 mL
B 0.0016 mL
C 0.014 mL
D 0.016 mL
E 0.10 mL

16 Four solutions are made by dissolving 0.1 mol of the following substances in water: K_2CO_3, K_2O, NaOH, Na_2SO_4. The final volume of each solution was 1 L.

Which of these solutions has the highest pH?

A the solution with 0.1 mol of K_2CO_3
B the solution with 0.1 mol of K_2O
C the solution with 0.1 mol of NaOH
D the solution with 0.1 mol of Na_2SO_4

Redox and electrochemistry

17 To launch space shuttles into space, two 'solid rocket boosters' were used. These worked based on a redox reaction between ammonium perchlorate and aluminium.

The incomplete reaction equation, where only the coefficients are missing, is shown below.

$NH_4ClO_4 + Al \rightarrow Al_2O_3 + NO + HCl + H_2O$

What is the ratio between the coefficients of Al and HCl in the balanced equation for this reaction?

	Al	:	HCl
A	8	:	3
B	2	:	1
C	1	:	1
D	1	:	2
E	2	:	3

18 In an electrochemical cell, one of the half-cells contains a 1 M solution of lead(II) nitrate and an electrode.

The half reaction that occurs in this half-cell during current flow is:

$Pb^{2+} + 2e^- \rightarrow Pb$

What material could be used for the electrode?

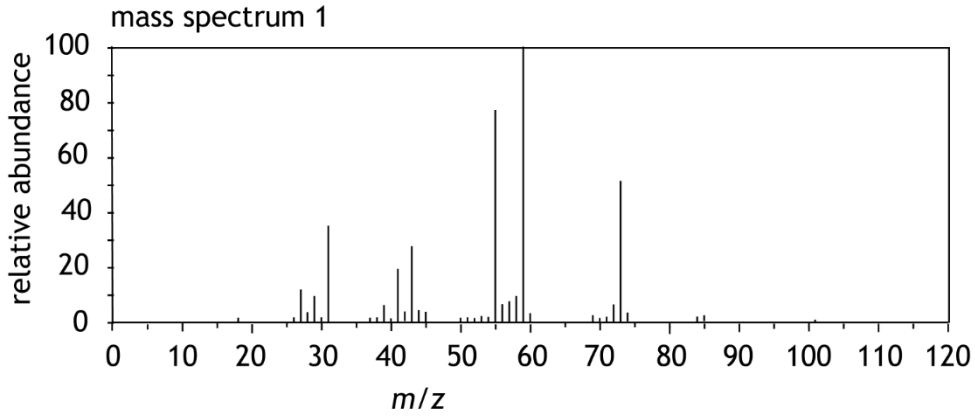
Would this be the positive or negative electrode during discharging?

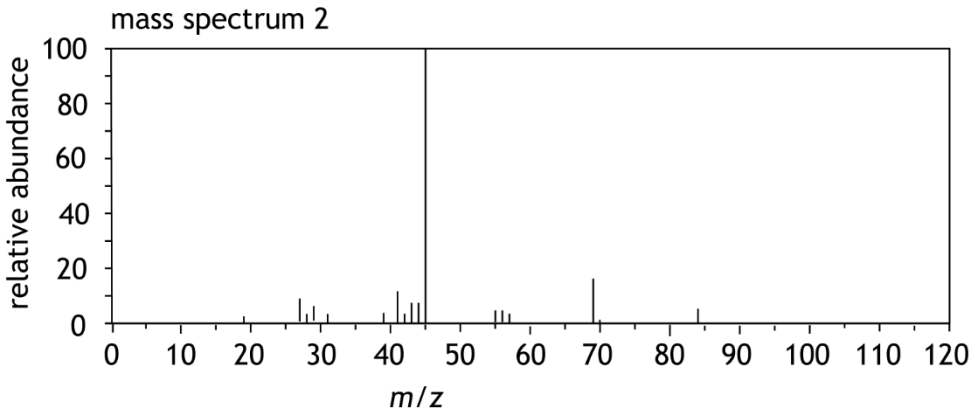
	material	electrode is
A	copper	positive
B	copper	negative
C	zinc	positive
D	zinc	negative

Analysis

19 There are three isomeric unbranched hexanols: hexan-1-ol, hexan-2-ol and hexan-3-ol.

The mass spectra of two of these structural isomers are shown below.





It is known that in alcohols, a C — C bond adjacent to the alcohol group can be broken. One of these two C atoms is attached to the O atom of the alcohol group.

In the mass spectra above, in both cases, the peak with the highest abundance can be attributed to a fragment that is formed when a C — C bond adjacent to an alcohol group is broken.

To which substance does mass spectra 1 belong and to which substance does mass spectra 2 belong?

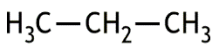
	mass spectrum 1	mass spectrum 2
A	hexan-1-ol	hexan-2-ol
B	hexan-1-ol	hexan-3-ol
C	hexan-2-ol	hexan-1-ol
D	hexan-2-ol	hexan-3-ol
E	hexan-3-ol	hexan-1-ol
F	hexan-3-ol	hexan-2-ol

20 Which salt below is sparingly soluble in water, but gives a clear solution in a solution containing sufficient hydrogen iodide?

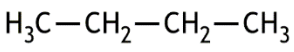
A lead(II) chloride
B lead(II) oxide
C magnesium chloride
D magnesium oxide

21 In gas chromatography, a mixture of the following substances I, II and III is separated in a non-polar column.

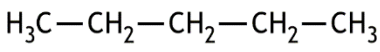
Which substance has the shortest retention time and which has the longest?



I



II



III

	shortest retention time	longest retention time
A	I	II
B	I	III
C	II	I
D	II	III
E	III	I
F	III	II

Chemical calculations

22 Sodium cyanide (NaCN) is used to extract gold from ore according to the reaction equation below.

$4\ Au(s) + 8\ CN^-(aq) + O_2(g) + 2\ H_2O(l) \rightarrow 4\ Au(CN)_2^-(aq) + 4\ OH^-(aq)$

How many litres of a 0.0100 M sodium cyanide solution are needed to completely convert 11.8 g of gold according to the above reaction equation?

A 0.749 L
B 1.50 L
C 2.99 L
D 5.99 L
E 12.0 L

23 Ethanol (C_2H_5OH) is converted by dichromate in an acidic environment to ethanal (CH_3CHO) according to the reaction equation below.

$3\ C_2H_5OH(aq) + Cr_2O_7^{2-}(aq) + 8\ H^+(aq) \rightarrow 3\ CH_3CHO(aq) + 2\ Cr^{3+}(aq) + 7\ H_2O(l)$

At what rate does the $[CH_3CHO]$ change if the $[Cr^{3+}]$ increases by 0.18 mol $L^{-1}\ s^{-1}$ according to the above reaction equation?

A the $[CH_3CHO]$ decreases by 0.12 mol $L^{-1}\ s^{-1}$
B the $[CH_3CHO]$ decreases by 0.27 mol $L^{-1}\ s^{-1}$
C the $[CH_3CHO]$ increases by 0.12 mol $L^{-1}\ s^{-1}$
D the $[CH_3CHO]$ increases by 0.27 mol $L^{-1}\ s^{-1}$

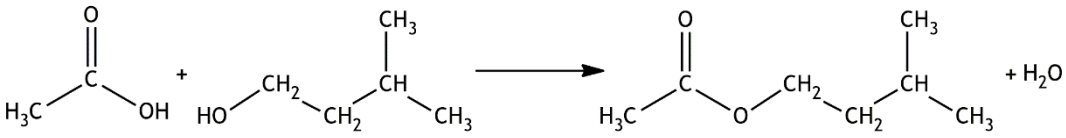
24 A spoon is coated with silver by electrolysis of a 1.0 M solution of silver nitrate at a current of 0.10 A.

How many minutes of electrolysis are required to ensure that 0.10 g of silver is coated on the spoon?
1 A is 1 C s^{-1} and the charge on 1 mole of electrons is $9.65 \cdot 10^4$ C.

A 1.5 min
B 5.0 min
C 10 min
D 15 min
E 30 min

Green chemistry

25 The following reaction occurs in the production of the banana-scented ester:



The water produced in this reaction is considered waste.

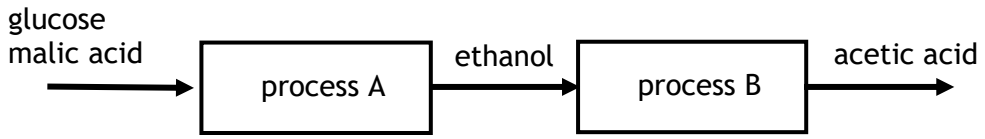
What is the percentage yield of this process if the *E*-factor is 0.34?

A 34%
B 66%
C 75%
D 85%

Open questions (total 26 points)

Problem 2 Apple cider vinegar (12 points)

Apple cider vinegar is used as a salad dressing and as a food preservative. Apple cider vinegar is made from apple juice by performing two processes. This is shown in simplified form in the block diagram below.



apple juice *apple cider vinegar*

In process A, glucose and malic acid (2-hydroxybutanedioic acid, $C_4H_6O_5$) from apple juice are converted to ethanol. The reaction equations of the two reactions that take place in process A are shown below.

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$ (reaction 1)

$C_4H_6O_5 \rightarrow C_2H_5OH + 2\ CO_2$ (reaction 2)

In process B, ethanol is converted with oxygen from the air to, among others, acetic acid (ethanoic acid).

The resulting solution is apple cider vinegar.

▫1 Draw the structural formula of malic acid. 2

▫2 Give the equation for the reaction that takes place in process B. Use molecular formulas. 2

The dissolved malic acid content of apple juice from which apple cider vinegar is produced was determined by an acid-base titration. For this purpose, 10.00 mL of apple juice was titrated with 0.1000 M sodium hydroxide solution and phenolphthalein as an indicator. The malic acid content was determined as 7.382 g L^{-1}.

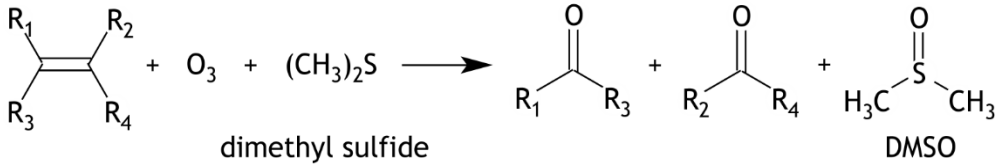
▫3 Calculate how many mL of 0.1000 M sodium hydroxide solution were needed for this titration. 4

The acetic acid content of the produced apple cider vinegar was 1.086 mol L^{-1}.

▫4 Calculate the glucose content in the apple juice in g L^{-1}.
Assume the following:
- The volume of the solution does not change during processes A and B.
- The percentage yield of processes A and B is 100%. 4

Problem 3 Ozonolysis (14 points)

Ozonolysis is a chemical reaction in which an alkene reacts with ozone. In this reaction, the C = C bond is broken to form carbonyl groups. When an alkene reacts with ozone and then with dimethyl sulfide, aldehydes and/or ketones and DMSO are formed. These reactions can be represented in one equation (reaction 1):



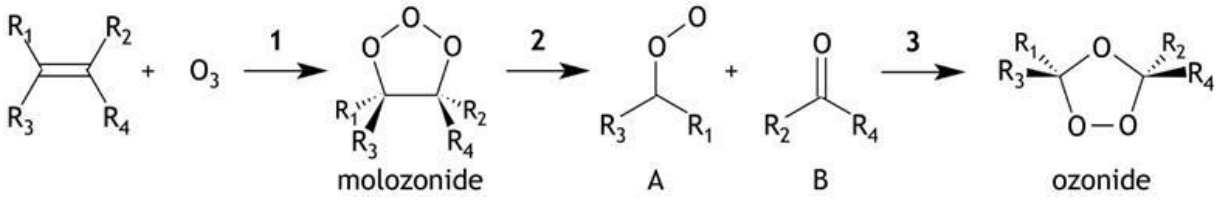
(reaction 1)

Here, R1 up to R4 represent hydrocarbon groups and/or H atoms.

▫5 Give the structural formulas of the two carbonyl compounds formed when 2-methylhex-2-ene reacts according to reaction 1. 2

In ozonolysis, the alkene first reacts with ozone to form a so-called ozonide. This reaction proceeds in three steps via a number of intermediate products. These steps are shown in figure 1. The structural formula of A is not complete in this figure.

figure 1



In step 1, an alkene molecule reacts with an ozone molecule to form a molozonide molecule. In step 2, electron pairs in the molozonide molecule are shifted to form A and B. One covalent bond is missing from the structural formula of A. Both oxygen atoms in molecule A have a formal charge. All atoms in molecule A follow the octet rule .

▫6 Complete the following assignments:

- Copy the incomplete structural formula of A from figure 1 and draw the missing covalent bond and complete the Lewis structure of A. Also indicate the formal charges.
- Copy the structural formula of the molozonide from figure 1 and draw the lone pairs in it.
- Use curly arrows to show how electron pairs in a molozonide molecule moved to create A and B. 4

Finally, in step 3, the ozonide molecule is formed.

Dimethyl sulfide is then added to the formed ozonide to convert the ozonide to carbonyl compounds. This is a redox reaction.

▫7 Complete the following assignments:

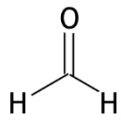
- Give the equation of the half-reaction for the conversion of ozonide shown above. Use the formula $C_2H_4O_3$ for ozonide . Here R_1 to R_4 are H atoms.
  This conversion produces only one carbonyl compound. H_2O and H^+ are also present in this equation.
- Using this equation, explain whether dimethyl sulfide is acting as an oxidizing agent or as a reducing agent. 3

Unsaturated compounds containing more than one C = C bond per molecule can also be ozonolyzed. Such ozonolysis occurs in the same way as described above: each individual C = C bond reacts in the way described.

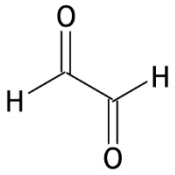
Ozonolysis was formerly used in the structural analysis of organic compounds. An example of such an analysis is the following:

A given amount of hydrocarbon X, containing more than one C = C bond per molecule, undergoes complete ozonolysis.

The only carbonyl compounds formed in this process are formaldehyde and glyoxal.



formaldehyde



glyoxal

Complete ozonolysis of a given amount of substance X produces 4.8 mg of formaldehyde and 14 mg of glyoxal.

▫8 Determine the structural formula of X, showing your calculation 5

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.

atom economy	$\frac{\text{mass of desired product}}{\text{total mass of all reactants}} \times 100\%$
percentage yield	$\frac{\text{experimental yield}}{\text{theoretical yield}} \times 100\%$
E-factor	$\frac{\text{total mass of all reactants} - \text{mass of desired product}}{\text{mass of desired product}}$

46th National Chemistry Olympiad 2025 preliminary round 1

Answer sheet: multiple choice questions

name:

no.	Answer letter	(score)
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