NATIONAL CHEMISTRY OLYMPIAD 2026

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

SCHEIKUNDE OLYMPIADE

Universiteit Utrecht

- This preliminary round consists of 20 multiple choices 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 K and p = p_0.

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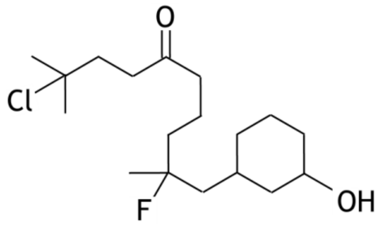
Problem 1 Multiple choice questions total 40 points

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.

Polylactic acid can be drawn as follows: $H \left[O-\overset{H_3C}{\overset{|}{C}H}-\overset{O}{\overset{\|}{C}} \right]_n OH$

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 to cyanate (OCN^-) using hypoiodite (IO^-) in an alkaline solution:

$$CN^- + IO^- \rightarrow OCN^- + I^-$$

This conversion occurs according to the following mechanism:

$IO^- + H_2O \rightleftharpoons HIO + OH^-$	fast
$CN^- + HIO \rightleftharpoons ICN + OH^-$	fast
$ICN + OH^- \rightarrow HOCN + I^-$	slow
$HOCN + OH^- \rightarrow OCN^- + H_2O$	fast

What is the rate equation?

A $rate = k\,[CN^-][IO^-][OH^-]^2$

B $rate = k\,[CN^-][IO^-][OH^-]$

C $rate = k\,[CN^-][IO^-]$

D $rate = k\,\dfrac{[CN^-][IO^-]}{[OH^-]}$

E $rate = k\,\dfrac{[CN^-][IO^-]}{[OH^-]^2}$

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:

$$H_2O_2(aq) + 2\,I^-(aq) + 2\,H^+(aq) \rightarrow I_2(aq) + 2\,H_2O(l)$$

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)	$rate_0$ (mol L^{-1} 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 $rate = k\,[H_2O_2]^a[I^-]^b[H^+]^c$.

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

6 The following reaction equation is given:

$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g) \qquad K_p = 3.75$$

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 SO_2(g) when equilibrium has been reached?

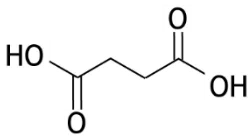
A 0.19 bar
B 0.25 bar
C 0.35 bar
D 0.41 bar

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

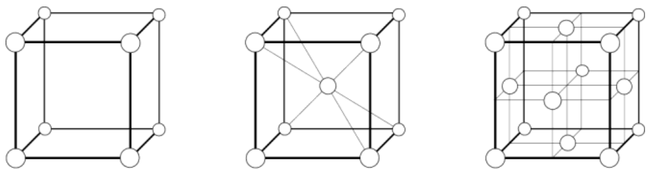
8 How many π bonds and how many σ bonds are present in a molecule of succinic acid, as shown below?



	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 $19.3 \cdot 10^3$ kg m^{-3}. The unit cell of gold's crystal lattice is a cube with edges of $4.08 \cdot 10^{-10}$ 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)?



	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

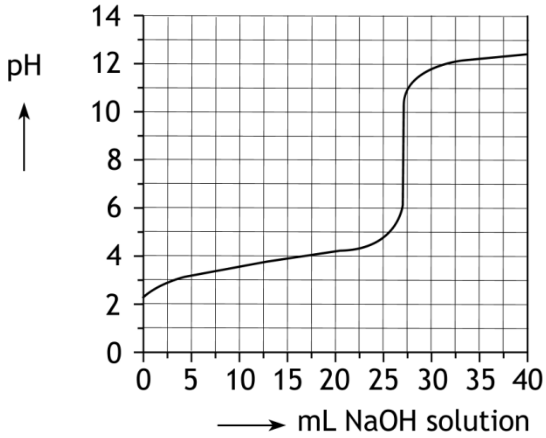
10 A solution of allylamine, $C_3H_5NH_2$, has a pH of 11.12.
In this solution 3.61% of the allylamine is converted to its conjugate acid.

What is the pK_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 $[HCOO^-] = [Na^+] > [HCOOH]$
B $[HCOO^-] > [HCOOH] = [Na^+]$
C $[HCOOH] = [Na^+] > [HCOO^-]$
D $[HCOOH] > [HCOO^-] = [Na^+]$

Redox and electrochemistry

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

$$MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^- \rightarrow Mn^{2+}(aq) + 4\,H_2O(l)$$

What is the value of the electrode potential of the half-reaction above at 298 K and $[MnO_4^-]$ = 0.0100 M, $[H^+]$ = 0.200 M and $[Mn^{2+}]$ = 0.0200 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:

$2\ PbSO_4(s) + 2\ H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 4\ H^+(aq) + 2\ SO_4^{2-}(aq)$

Below are two statements about the lead-acid battery:

I During charging, $PbO_2(s)$ is formed at the negative electrode.

II During charging, the same amount of $SO_4^{2-}(aq)$ 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: $4\ Cu + O_2 \rightarrow 2\ Cu_2O$
Reaction 2: $2\ Cu_2O + O_2 \rightarrow 4\ CuO$
Reaction 3: $4\ CuO + SO_3 + 3\ H_2O \rightarrow Cu_4SO_4(OH)_6$
Reaction 4: $2\ CuO + CO_2 + H_2O \rightarrow Cu_2CO_3(OH)_2$

Reaction 1 is a redox reaction.

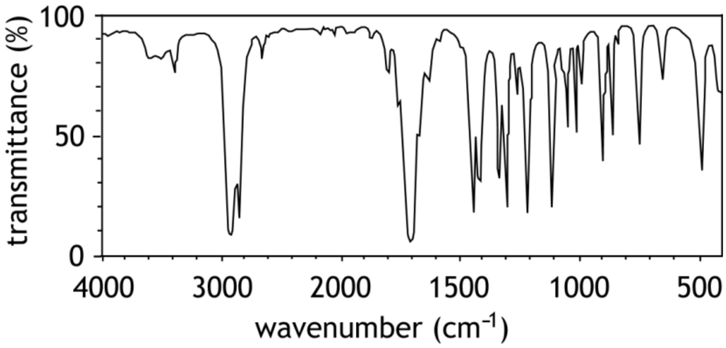
Which of the other reactions is a / are redox reaction(s)?

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

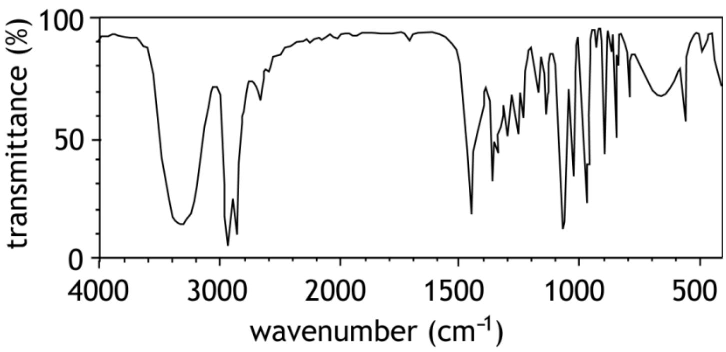
Analysis

15 Two IR spectra are shown below.

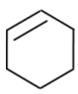
spectrum 1



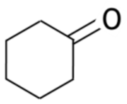
spectrum 2



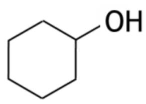
Each spectrum corresponds to one of the substances below.



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 $C_3H_6NO_2$
B $C_4H_4NO_2$
C $C_6H_{12}N_2O_2$
D $C_8H_8N_2O_4$

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:

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$$

the following applies at 450 K:

	$\Delta_f H^0$ (J mol^{-1})	S^0 (J mol^{-1} K^{-1})
$Cl_2(g)$	0	223.1
$PCl_3(g)$	$-2.870 \cdot 10^5$	311.8
$PCl_5(g)$	$-3.749 \cdot 10^5$	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.

$3\ C(s) + 4\ H_2(g) + 0.5\ O_2(g) \rightarrow C_3H_8O(l)$ $\Delta_r H^0{}_1 = -3.18 \cdot 10^5\ J\ mol^{-1}$

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta_r H^0{}_2 = -3.94 \cdot 10^5\ J\ mol^{-1}$

$H_2(g) + 0.5\ O_2(g) \rightarrow H_2O(l)$ $\Delta_r H^0{}_3 = -2.86 \cdot 10^5\ J\ mol^{-1}$

What is the standard enthalpy of reaction for the combustion reaction shown below?

$C_3H_8O(l) + 4.5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(l)$

A $-3.62 \cdot 10^5\ J\ mol^{-1}$

B $-9.98 \cdot 10^5\ J\ mol^{-1}$

C $-20.08 \cdot 10^5\ J\ mol^{-1}$

D $-21.16 \cdot 10^5\ J\ mol^{-1}$

E $-40.16 \cdot 10^5\ J\ mol^{-1}$

20 For a particular reaction, $\Delta H^0 = -3.83 \cdot 10^4\ J\ mol^{-1}$ and $\Delta S^0 = -113\ J\ mol^{-1}\ K^{-1}$. 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.

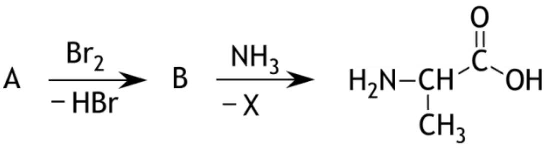
D The reaction does not occur at any temperature.

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:



step 1 step 2 alanine

□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 C_2H_5COOH. Use of a preservative requires high purity. The C_2H_5COOH 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:

$$6\ C_2H_5COOH\ +\ IO_3^-\ +\ 5\ I^-\ \rightarrow\ 6\ C_2H_5COO^-\ +\ 3\ I_2\ +\ 3\ H_2O \qquad \text{reaction 1}$$

□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, C_2H_5COOH, $C_2H_5COO^-$, 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:

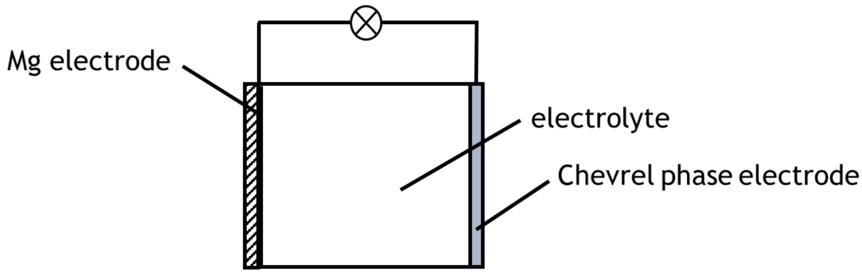
$$I_2\ +\ 2\ S_2O_3^{2-}\ \rightarrow\ 2\ I^-\ +\ S_4O_6^{2-} \qquad \text{reaction 2}$$

The resulting mixture is titrated with a 0.0500 mL 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 C_2H_5COOH 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:

$Mg \rightarrow Mg^{2+} + 2\ e^-$ $E^0 = -2.37$ V

$Mo_6S_8 + 2\ Mg^{2+} + 4\ e^- \rightarrow Mg_2Mo_6S_8$ $E^0 = -1.30$ V

□4 Calculate the Gibbs energy for the formation of $Mg_2Mo_6S_8$ in the Mg-ion home battery, under standard conditions. Use $\Delta G^0 = -nF\Delta E^0$. Give your answer in $J\ mol^{-1}$ $Mg_2Mo_6S_8$. 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 $Mg_2Mo_6S_8$ 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 4*d*-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 4*d*-electrons from the Mo ions. These covalent bonds stabilize a positively charged Mo_6 cluster.

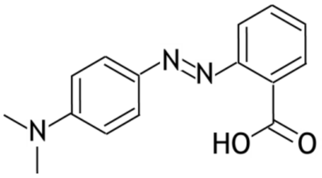
□5 Based on the information above, explain in which substance the positively charged Mo_6 cluster is more stable: in $Mg_2Mo_6S_8$ or in Mo_6S_8. 4

The thickness of the Mg electrode for a fully charged Mg-ion home battery is 10.0 μm. 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 g Mo_6S_8 has completely reacted;
- both electrodes have a surface area of 100 cm^2;
- the Mg has reacted evenly over the electrode surface. 5

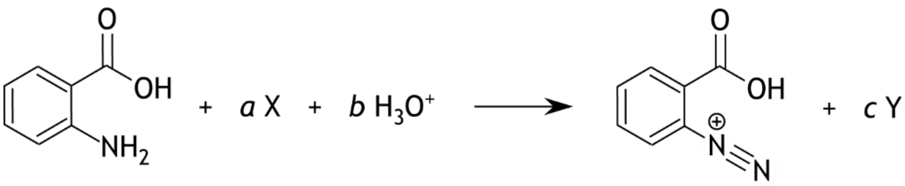
Problem 4 Synthesis and function of methyl red (26 points)

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

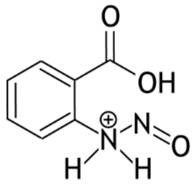
Methyl red can be produced through two reactions. In the first reaction, the amino group of anthranilic acid (substance **1**) is converted to a diazonium group using sodium nitrite solution and hydrochloric acid via a process called diazotization. The incomplete equation for this reaction is shown below.



1 **2**

□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.



3

Reactant **1** is converted to 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.

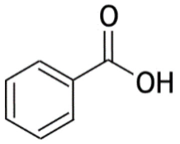
Step 1: A bonding pair of electrons between the O atom and the N atom in intermediate **3** binds an H atom from the adjacent N atom. A double bond between the N atoms is created through bond rearrangement.

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.

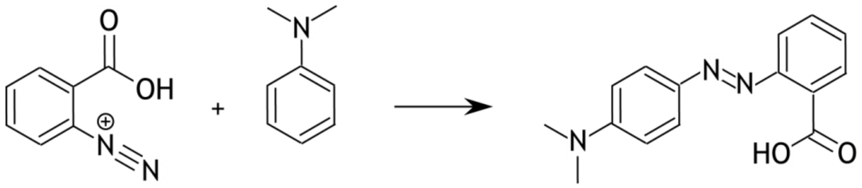
Step 4: By displacement of bonding and non-bonding electron pairs, H_2O leaves the molecule and ion **2** is formed.

▫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:

$$mrH + H_2O \rightleftharpoons H_3O^+ + mr^-$$

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.

	$\varepsilon_{429\ nm}$ ($L\ mol^{-1}\ cm^{-1}$)	$\varepsilon_{520\ nm}$ ($L\ mol^{-1}\ cm^{-1}$)
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.

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

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

no.	answer (letter)	(score)
1		
2		
3		
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20		
Total		

Name:	
Teacher:	
School:	