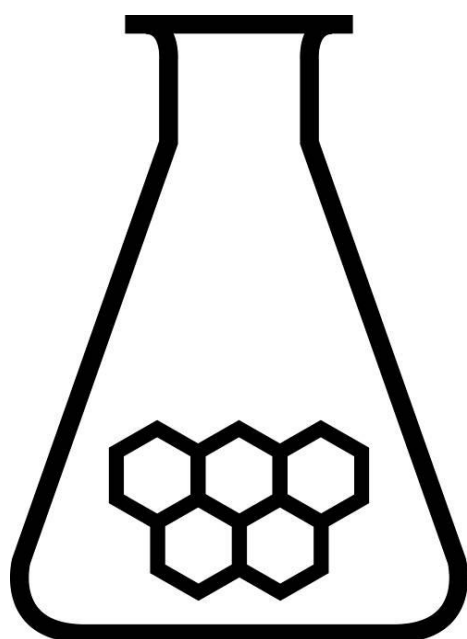


NATIONAL CHEMISTRY OLYMPIAD 2026

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



SCHEIKUNDE OLYMPIADE



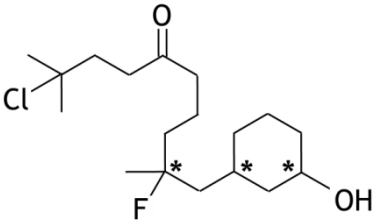
Universiteit
Utrecht

- 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	 <p>The molecule has three asymmetric carbon atoms. There are therefore $2^3 = 8$ stereoisomers.</p>
2	A	<p>500 mg polylactic acid with $n = 12$ is $\frac{500}{12 \times 72.06 + 18.02} = 0.566$ mmol.</p> <p>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.</p>

Reaction rate and equilibrium

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

6	D	(bar)	SO ₂ (g)	+	NO ₂ (g)	⇌	SO ₃ (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.

Structures and formulas

7	B	<p>The electron configuration of As with atomic number 33 is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$</p> <p>An s orbital has no electrons with $m_l = 1$.</p> <p>Filled p orbitals contain 2 electrons with a quantum number $m_l = 1$.</p> <p>Filled d orbitals contain 2 electrons with a quantum number $m_l = 1$.</p> <p>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 $m_l = 1$.</p> <p>In total, an As atom therefore contains 7 electrons with a quantum number $m_l = 1$.</p>
8	D	<p>All bonds between atoms contain one σ bond. Double bonds also contain one π bond.</p> <p>There are thirteen bonds in total, two of which are double bonds. Therefore, there are thirteen σ bonds and two π bonds.</p>
9	E	<p>The volume of the unit cell is $(4.08 \cdot 10^{-10})^3 \text{ m}^3$.</p> <p>If n is the number of gold atoms in the unit cell, then the mass of the unit cell is $n \times 197.0 \times 1.66 \cdot 10^{-27} \text{ kg}$.</p> <p>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.</p>

pH / acid-base

10	D	<p> $\text{C}_3\text{H}_5\text{NH}_3^+ + \text{H}_2\text{O} \rightleftharpoons \text{C}_3\text{H}_5\text{NH}_2 + \text{H}_3\text{O}^+$ </p> <p> $\frac{3.61\%}{[\text{C}_3\text{H}_5\text{NH}_3^+]} = \frac{96.39\%}{[\text{C}_3\text{H}_5\text{NH}_2]}$ </p> <p> $K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_3\text{H}_5\text{NH}_2]}{[\text{C}_3\text{H}_5\text{NH}_3^+]} = \frac{10^{-11.12} \times 96.39}{3.61} = 2.03 \cdot 10^{-10}$ </p> <p>$\text{p}K_a = 9.69$.</p>
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11	A	As long as HCOOH is present, it holds that $[\text{Na}^+] = [\text{HCOO}^-]$, 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 $\text{Mn}^{2+}/\text{MnO}_4^-$, H^+ redox couple is: $E = E^0 + \frac{0.059}{5} \log \frac{[\text{MnO}_4^-] \times [\text{H}^+]^8}{[\text{Mn}^{2+}]} = 1.51 + \frac{0.059}{5} \log \frac{0.0100 \times (0.200)^8}{0.0200} = 1.44 \text{ V}$
13	C	The half-equations during the charging of the lead-acid battery are: Negative electrode: $\text{PbSO}_4(\text{s}) + 2 \text{e}^- \rightarrow \text{Pb}(\text{s}) + \text{SO}_4^{2-}(\text{aq})$ Positive electrode: $\text{PbSO}_4(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{PbO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2 \text{e}^-$
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 $\frac{0.750}{18.02} = 4.16 \cdot 10^{-2} \text{ mol H}_2\text{O}$ 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 $\text{C}_3\text{H}_6\text{NO}_2$ is equal to $\frac{1.000}{88.09} = 1.135 \cdot 10^{-2} \text{ mol C}_3\text{H}_6\text{NO}_2$ and therefore $3.406 \cdot 10^{-2} \text{ mol C}$. 1.000 g $\text{C}_6\text{H}_{12}\text{N}_2\text{O}_2$ is equal to $\frac{1.000}{144.17} = 6.936 \cdot 10^{-3} \text{ mol C}_6\text{H}_{12}\text{N}_2\text{O}_2$ and therefore $4.162 \cdot 10^{-2} \text{ mol C}$. The correct molecular formula is therefore $\text{C}_6\text{H}_{12}\text{N}_2\text{O}_2$.
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17	D	<p>The combustion reactions are:</p> $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \quad \text{and}$ $\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g})$ <p>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:</p> $2 \times (10.0 - y) + 5y = 38.0$ <p>From this follows that $y = 6.00$ and the volume percentage of propane is 60.0 %.</p>
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Thermochemistry

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

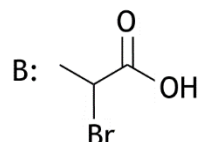
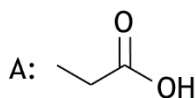
Open questions

total 54 points

■ Problem 2 Carboxylic acid

(16 points)

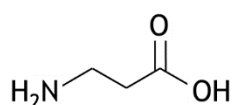
□1 Maximum score 5



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.

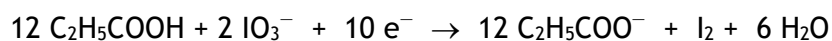
other carboxylic acid:



- 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)

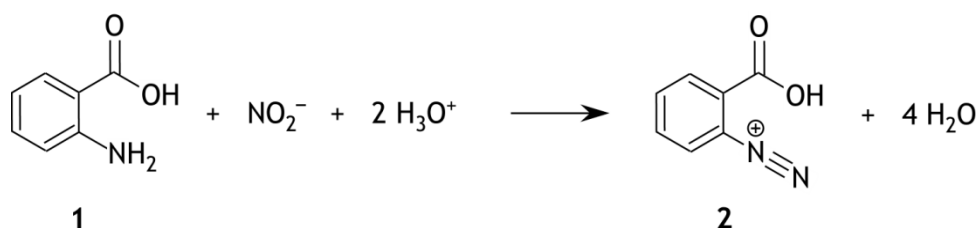
□7 Maximum score 3

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

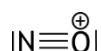
□8 Maximum score 3



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



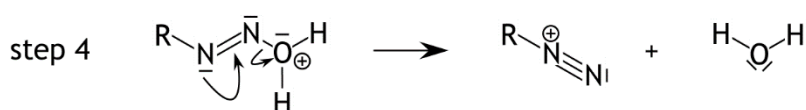
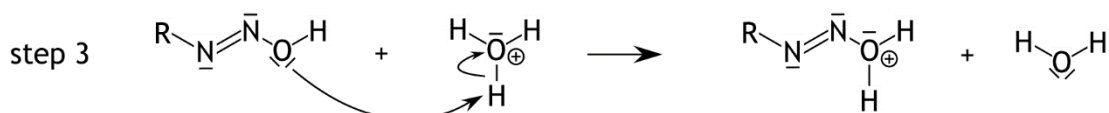
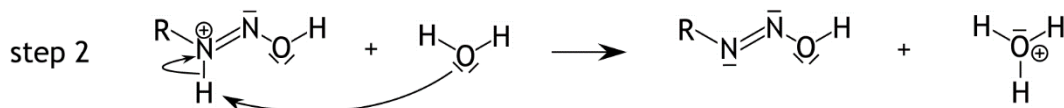
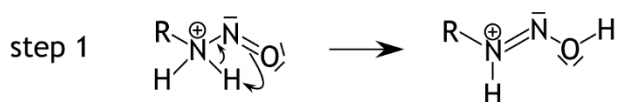
- particle consists of one N atom and one O atom 1
- bonding electron pairs and non-bonding electron pairs correct 1
- formal charge correct and in the right place 1

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

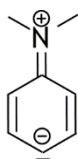
Note

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

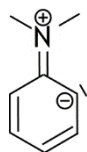
An H⁺ must be added after the arrow. 1

□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 $[\text{mrH}] = 9.84 \cdot 10^{-6} \text{ M}$.

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