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All Examiners are instructed that alternative correct answers and unexpected approaches in candidates’ scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the Report on the Examination.

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<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a)</td>
<td><strong>FIRST, CHECK THE ANSWER ON ANSWER LINE</strong></td>
<td></td>
<td><strong>ALLOW</strong> 1 mark for $8.3 \times 10^4$ with no working (power of 10 is error)</td>
</tr>
<tr>
<td></td>
<td>IF answer = $8.3 \times 10^4$ <strong>OR</strong> 83333 award 2 marks THEN IF units are dm$^6$ mol$^{-2}$ s$^{-1}$, award 1 further mark</td>
<td></td>
<td><strong>ALLOW</strong> 2 SF up to calculator value of $8.3333333 \times 10^4$ correctly rounded</td>
</tr>
<tr>
<td></td>
<td>$k = \frac{\text{rate}}{[H_2(g)] [\text{NO(g)}]^2}$ <strong>OR</strong> $\frac{3.6 \times 10^{-2}}{(1.2 \times 10^{-3}) \times (6.0 \times 10^{-3})^2}$ ✓</td>
<td></td>
<td><strong>ALLOW</strong> ECF for calculated answer from incorrectly rearranged $k$ expression but <strong>not</strong> for units</td>
</tr>
<tr>
<td></td>
<td>= $8.3 \times 10^4$ <strong>OR</strong> 83000 <strong>OR</strong> 83333 ✓</td>
<td></td>
<td>(Marked independently see below)</td>
</tr>
<tr>
<td></td>
<td><strong>ALLOW</strong> dm$^6$, mol$^{-2}$ and s$^{-1}$ in any order, <strong>eg</strong> mol$^{-2}$ dm$^6$ s$^{-1}$</td>
<td></td>
<td><strong>DO NOT ALLOW</strong> other units</td>
</tr>
<tr>
<td></td>
<td>(Rate equation supplied on paper – <strong>not</strong> derived from data)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (b)</td>
<td>(i) effect on rate $\times 2$ ✓</td>
<td>1</td>
<td><strong>ALLOW</strong> ‘doubles’ <strong>OR</strong> rate $= 7.2 \times 10^{-2}$ (mol dm$^{-3}$ s$^{-1}$)</td>
</tr>
<tr>
<td>(ii)</td>
<td>effect on rate $\times \frac{1}{4}$ <strong>OR</strong> $\times 0.25$ ✓</td>
<td>1</td>
<td><strong>ALLOW</strong> ‘a quarter’ <strong>OR</strong> decrease by $\frac{1}{4}$ <strong>OR</strong> decrease by 0.25</td>
</tr>
<tr>
<td></td>
<td><strong>OR</strong> rate decreases by 4 <strong>OR</strong> decrease by 75%</td>
<td></td>
<td><strong>OR</strong> rate $= 0.9 \times 10^{-2}$ (mol dm$^{-3}$ s$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td><strong>DO NOT ALLOW</strong> just $0.5^2$ of rate <strong>OR</strong> rate decreases by $2^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (iii)</td>
<td>effect on rate $\times 64$ ✓</td>
<td>1</td>
<td><strong>ALLOW</strong> rate $= 2.3(04)$ (mol dm$^{-3}$ s$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td><strong>DO NOT ALLOW</strong> just ‘increases by 4 and then by 16 / $4^2$ <strong>OR</strong> increases by $4^3$</td>
<td></td>
<td></td>
</tr>
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<tr>
<td>1 (c) (i)</td>
<td>(initial) rate increases AND more frequent collisions OR more collisions per second/time ✓</td>
<td>1</td>
<td>BOTH points required for mark ALLOW rate increases AND concentration increases For concentration increases, ALLOW particles closer together OR less space between particles DO NOT ALLOW just more collisions OR collisions more likely</td>
</tr>
<tr>
<td>(ii)</td>
<td>rate constant does not change ✓</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>step 1: $H_2(g) + 2 \text{NO}(g) \rightarrow N_2O(g) + H_2O(g)$ LHS of step one ✓ step 2: $H_2(g) + N_2O(g) \rightarrow N_2(g) + H_2O(g)$ rest of equations for step 1 AND step 2 ✓</td>
<td>2</td>
<td>State symbols NOT required For ‘rest of equations’, This mark can only be awarded if 1st mark can be awarded ALLOW other combinations of two steps that together give the overall equation (shown above part in scoris window), eg step 1: $\rightarrow N_2(g) + \frac{1}{2} \text{O}_2(g) + H_2\text{O}(g)$ step 2: $H_2(g) + \frac{1}{2} \text{O}_2(g) \rightarrow H_2\text{O}(g)$ step 1: $\rightarrow H_2\text{O}_2(g) + N_2(g)$ step 2: $H_2(g) + H_2\text{O}_2(g) \rightarrow 2H_2\text{O}(l)$ There may be others with species, such as $H_2N_2\text{O}_2$ and $H\text{NO}$. Provided the two steps add up to give the overall equation AND charges balance, the 2nd mark can be awarded</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>10</td>
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| 2 (a)    | Fe: $\text{Fe}^2+: (1s^22s^22p^6)3s^23p^63d^6$ ✓  
          | Fe$^2+$: $(1s^22s^22p^6)3s^23p^63d^6$ ✓  | 2     | ALLOW 4$s$ before 3$d$, i.e. $(1s^22s^22p^6)3s^23p^64s^23d^6$ ✓  
          | ALLOW 4$s^6$ ✓  
          | ALLOW subscripts ✓  
          | IGNORE 1s$^2$2s$^2$2p$^6$ is written out a second time ✓  |
| (b)      | coloured (compound/complex/precipitate/ions) ✓  
          | OR catalyst ✓  | 1     | IGNORE 'variable oxidation states' ✓  
          | .... but ALLOW the idea that Fe$^{2+}$ can react to form an ion with ✓  
          | a different charge/oxidation state. ✓  
          | 'ion' is essential: 'atom' or 'metal' is not sufficient ✓  
          | IGNORE partially filled d sub-shell/d orbital ✓  
          | (question refers to property of Fe$^{2+}$) ✓  |
| (c)      | Fe oxidised from +2 to +3 ✓  
          | Cr reduced from +6 to +3 ✓  | 2     | CHECK and credit oxidation numbers on equation ✓  
          | ALLOW Fe$^{2+}$ oxidised to Fe$^{3+}$ ✓  
          | ALLOW Cr$^{6+}$ reduced to Cr$^{3+}$ ✓  
          | ALLOW + sign after number in oxidation number, ie 2+, etc ✓  
          | ALLOW 1 mark only if oxidation numbers given with no ✓  
          | identification of which species has been oxidised or reduced, ie ✓  
          | Fe goes from +2 to +3 AND Cr goes from +6 to +3 ✓  
          | Fe reduced from +2 to +3 AND Cr oxidised from +6 to +3 ✓  
          | (oxidation and reduction the wrong way around) ✓  
          | DO NOT ALLOW just 'Fe is oxidised and Cr reduced' ✓  
          | IGNORE other oxidations numbers (even if wrong) ✓  
<pre><code>      | IGNORE any references to electrons ✓  |
</code></pre>
<table>
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| 2 (d)  | \( K_{\text{stab}} = \frac{[\text{Fe(NH}_3\text{)}_6]^{2+}}{[\text{Fe(H}_2\text{O)}_6]^{2+} \cdot [\text{NH}_3]^6} \)  

On top, ONLY \([\text{Fe(NH}_3\text{)}_6]^{2+}\) shown  
AND  
on bottom, \([\text{Fe(H}_2\text{O)}_6]^{2+}\) AND \([\text{NH}_3]^6\) shown ✓  
correct use of square brackets and double square brackets in expression ✓  | 2 | IGNORE state symbols  
ALLOW 1 mark if complete expression with correct use of double brackets is shown but upside down  

DO NOT ALLOW round brackets for concentrations and complex ions  
ALLOW for 1 mark \( K_{\text{stab}} = \frac{[\text{Fe(NH}_3\text{)}_6]^{2+} \cdot [\text{H}_2\text{O}]^6}{[\text{Fe(H}_2\text{O)}_6]^{2+} \cdot [\text{NH}_3]^6} \)  |
| (e) (i)  | \( \text{O}_2/\text{oxygen bonds to Fe}^{2+}/\text{Fe(II)/Fe} ✓ \)  

When required, \( \text{O}_2 \) substituted OR \( \text{O}_2 \) released ✓  | 2 | ANNOTATE WITH TICKS AND CROSSES, etc  
ALLOW \( \text{O}_2 \) binds to Fe\(^{2+}\) OR \( \text{O}_2 \) donates electron pair to Fe\(^{2+}\)  
ALLOW \( \text{O}_2 \) bonds to metal ion/metal  
DO NOT ALLOW just \( \text{O}_2 \) bonds to haemoglobin  
OR \( \text{O}_2 \) bonds to complex  
ALLOW bond breaks between \( \text{O}_2 \) and Fe\(^{2+}\) when \( \text{O}_2 \) required  
OR \( \text{O}_2 \) replaces \( \text{H}_2\text{O} \) OR vice versa  
ALLOW \( \text{O}_2 \) replaces CO\(_2\) OR vice versa  
ALLOW \( \text{O}_2 \) replaces a ligand OR vice versa  
IGNORE just ‘by ligand substitution’ (in the question) |
<table>
<thead>
<tr>
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<th>Answer</th>
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</tr>
</thead>
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| 2 (e) (ii) | (For complex) with CO, stability constant is greater (than with complex in O₂) OR with CO, stability constant is high ✓ | 2 | ANNOTATE WITH TICKS AND CROSSES, etc
Comparison of CO and O₂ is NOT required ALLOW stability constant with/of CO is greater IGNORE (complex with) CO is more stable ALLOW bond with CO is less likely to break OR bond with CO more likely to form OR ‘CO cannot be removed’ OR idea that attachment of CO is irreversible OR CO is a stronger ligand (than O₂) OR CO has greater affinity for ion/metal/haemoglobin (than O₂) IGNORE CO bonds more easily |
<p>| 2 (f) (i) | Pt²⁺/Pt is +2/2⁺, 2 x Cl⁻ –2 ✓ | 1 | DO NOT ALLOW response in terms of Cl₂ rather than Cl⁻ DO NOT ALLOW ‘charges cancel’ without the charges involved being stated |</p>
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<thead>
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<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
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| 2 (f) (ii) | ![Structures](image) | 3 | **Ignore** any charge, ie Pt\(^{2+}\) **or** Cl\(^{-}\), even if wrong  
**Ignore** any angle, even if wrong  
**Accept** bonds to H\(_3\)N (does not need to go to ‘N’)  
Assume that a solid line is in plane of paper  
Each structure must contain 2 'out wedges' **AND** 2 'in wedges'  
**Or** 4 solid lines at right angles (all in plane of paper)  
**Do not allow** any structure that cannot be in one plane  
**Do not allow** any structure with Cl\(_2\) as a ligand  
**Do not apply** ECF from one structure to the other  
**Allow** coordinate bonds shown on diagrams provide that they start from a lone pair  
**Allow** 'dative covalent bond' or 'dative bond' as alternative for 'coordinate bond  
**Ignore** *cis* and *trans* labels (even if incorrect)  
**Ignore** incorrect connectivity to H\(_3\)N, ie **allow** H\(_3\)N— |
| (iii) | platin binds to DNA (of cancer cells)  
**Or** platin stops (cancer) cells dividing/replicating | 1 |  **Ignore** *cis* and *trans* labels (even if incorrect)  
**Ignore** incorrect connectivity to H\(_3\)N, ie **allow** H\(_3\)N— |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
</table>
| 2 (g)    | 1,1-cyclobutanedicarboxylate ion | 2   | Must show cyclobutane ring with both COO\(^{-}\) groups bonded to same carbon  
ALLOW COO\(^{-}\) OR CO\(_2\)^{-} for each carboxylate ion  
ALLOW structures showing CH\(_2\) or C atoms provided it is clear that C skeleton is shown,  
Note: H atoms are not required if C atoms shown, \(ie\)  
DO NOT ALLOW circle inside cyclobutane ring  
Two bonds from Pt to O atoms  
Any bonds from ligand MUST come from O OR from atom with lone pair  
IGNORE any charge shown  
Note: H atoms are not required if C atoms shown, (see ion in 1st structure)  
ALLOW ECF from 1st structure provided that the attached atoms are capable of forming coordinate bonds  
(\(ie\) they contain a lone pair of electrons)  
**Example** if 1st structure is as below, then ALLOW 1 mark ECF  |
|          | carboplatin (cis isomer shown below) |     |          |

Correct charge required  
(could also be 2– outside square brackets)
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
</table>
| 3 (a) (i) | HOCH$_2$COOH + NaOH $\rightarrow$ HOCH$_2$COONa + H$_2$O ✓ | 1 | ALLOW: HOCH$_2$COOH + OH$^-$ $\rightarrow$ HOCH$_2$COO$^-$ + H$_2$O
ALLOW: H$^+$ + OH$^-$ $\rightarrow$ H$_2$O
DO NOT ALLOW molecular formulae (cannot see which OH has reacted) |
| (ii) | FIRST, CHECK THE ANSWER ON ANSWER LINE
IF answer = 0.142 (mol dm$^{-3}$), award 2 marks
amount of HOCH$_2$COOH = 0.125 × $\frac{25.0}{1000}$ = 0.003125 (mol) ✓
concentration NaOH = 0.003125 × $\frac{1000}{22.00}$ = 0.142 (mol dm$^{-3}$) ✓ | 2 | IF there is an alternative answer, check to see if there is any ECF credit possible using working below
ANNOTATE WITH TICKS AND CROSSES, etc
ALLOW 3.125 × 10$^{-3}$ mol
ALLOW ECF: answer above × $\frac{1000}{22.00}$
ALLOW 2 SF: 0.14 to calculator value: 0.142045454
If candidate has written in (a)(i): HOCH$_2$COOH + 2NaOH, mark by ECF:
concentration NaOH = 2 × 0.003125 × $\frac{1000}{22.00}$ = 0.284 (mol dm$^{-3}$) |
| (iii) | Vertical section matches the (pH) range (of the indicator)
OR colour change (of the indicator)
OR end point (of the indicator) ✓ | 1 | ALLOW stated pH range for vertical section at about 7–10, 6–10, etc
ie ALLOW ‘pH range must be about 7–10’
ALLOW ‘pH changes rapidly’ for vertical section
ALLOW ‘equivalence point’ for vertical section,
ie ALLOW equivalence point matches the (pH) range, etc
DO NOT ALLOW just ‘end point matches (pH) range’
DO NOT ALLOW just ‘indicator matches vertical section’
Response must link either the pH range or colour change or end point with the vertical section / pH range ~ 7–10 |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
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</tr>
</thead>
<tbody>
<tr>
<td>3 (b) (i)</td>
<td>(K_a = \frac{[H^+] [\text{HOCH}_2\text{COO}^-]}{[\text{HOCH}_2\text{COOH}]})</td>
<td>1</td>
<td><strong>Ignore</strong> state symbols <strong>Ignore</strong> (\frac{[H^+]^2}{[\text{HOCH}_2\text{COOH}]}) in (i) but <strong>Allow</strong> in (ii)</td>
</tr>
</tbody>
</table>
| (ii) | **FIRST, CHECK THE ANSWER ON ANSWER LINE**  
**IF** answer = \(1.46 \times 10^{-4}\), award 2 marks  
**THEN IF** units are mol dm\(^{-3}\), award 1 further mark | 2 | **IF** there is an alternative answer, check to see if there is any ECF credit possible using working below  
**UNITS** can be credited with no numerical answer  
**ANNOTATE WITH TICKS AND CROSSES, etc**  
**Allow** \(4.27 \times 10^{-3}\) (mol)  
**Allow** 2 SF: 0.0043 up to 0.004265795188 (calc value)  
**If** candidate has rounded to 0.00427 (mol dm\(^{-3}\)) in 1st response, credit  
**Either**  
2 SF: 1.5 \times 10^{-4} up to 1.458632 \times 10^{-4} (from 0.00427)  
**OR**  
2 SF: 1.5 \times 10^{-4} up to 1.455760687 \times 10^{-4} (from unrounded calculator value of 0.004265795188)  
**Allow** calculation based on equilibrium conc of glycolic acid as 0.125 – \([H^+]\):  
Using \([H^+] = 0.00427, K_a = \frac{0.00427^2}{0.125-0.00427} = 1.51 \times 10^{-4}\)  
**For UNITS** this is the **ONLY** correct answer |
| (iii) | \% dissociation = \(\frac{0.00427}{0.125} \times 100 = 3.4\%\) | 1 | **Allow** ECF using calculated \([H^+]\) from b(ii),  
**Allow** 2 SF: 3.4 \% up to calculator value  
**Note:** \([H^+]\) from b(ii) displayed at top of answer window  
**DO NOT MARK THIS TWICE!** |
<table>
<thead>
<tr>
<th>Question</th>
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</table>
| 3 (c)    | ONE mark for equilibrium expression  
equilibrium: HOCH₂COOH ⇌ H⁺ + HOCH₂COO⁻  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- | 1    | **ANNOTATE WITH TICKS AND CROSSES, etc**  
DO NOT ALLOW H⁺, A⁻ and HA  
ALLOW < -> as alternative for equilibrium sign  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- |
|          | Four marks for action of buffer                                                                                                                                                                       |      | **ALLOW response in terms of H⁺, A⁻ and HA**  
Equilibrium responses **must** refer back to a written equilibrium:  
IF more than one equilibrium shown, assume correct one  
**ALLOW** weak acid reacts with added alkali  
DO NOT ALLOW acid reacts with added alkali  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- |
|          | HOCH₂COOH reacts with added alkali  
OR HOCH₂COOH + OH⁻ →  
OR added alkali reacts with H⁺  
OR H⁺ + OH⁻ → √  
→ HOCH₂COO⁻  
OR Equilibrium → right √  
HOCH₂COO⁻ reacts with added acid √  
→ HOCH₂COOH  
OR Equilibrium → left √   | 4    | **ALLOW** conjugate base reacts with added acid  
DO NOT ALLOW salt/base reacts with added acid  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- |
|          | Two marks for preparation of buffer  
Ammonia reacted with an **excess** of glycolic acid  
OR some glycolic acid remains √  
HOCH₂COOH + NH₃ → HOCH₂COONH₄ √  | 2    | **ALLOW** as products HOCH₂COO⁻ + NH₄⁺  
**ALLOW** = sign instead of →  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- |
| (d)      | Base 1 + Acid 2 = Acid 1 + Base 2  
1st mark for identifying acids and bases. √  
2nd mark for correct pairing (ie numbers) √  | 2    | **ALLOW**: Base 2 + Acid 1 = Acid 2 + Base 1  
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------- |
<table>
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<tbody>
<tr>
<td>3 (e)</td>
<td>$2\text{HSCH}_2\text{COO}^- + R-\text{S}-\text{S}-R$ $\rightarrow$ $\text{OOCCH}_2\text{S}-\text{SCH}_2\text{COO}^- + 2\text{R}-\text{SH}$ ✓</td>
<td>2</td>
<td>ALLOW ($\text{SCH}_2\text{COO}^-$)$_2$</td>
</tr>
<tr>
<td></td>
<td>$2\text{R}-\text{SH} + \text{H}_2\text{O}_2$ $\rightarrow$ $\text{R-S-S-R} + 2\text{H}_2\text{O}$ ✓</td>
<td></td>
<td>ALLOW equation with ammonium salt, ie:</td>
</tr>
<tr>
<td></td>
<td>$2\text{HSCH}_2\text{COONH}_4 + \ldots \ldots$ $\rightarrow$ $\text{H}_4\text{NOOCCH}_2\text{S}-\text{SCH}_2\text{COONH}_4 + \ldots \ldots$</td>
<td></td>
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**Total** 20
<table>
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<tr>
<th>Question</th>
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<th>Guidance</th>
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<tbody>
<tr>
<td>4 (a) (i)</td>
<td>Complete circuit with electrodes to voltmeter <strong>AND</strong> salt bridge between solutions ✓</td>
<td>3</td>
<td>ANNOTATE WITH TICKS AND CROSSES, etc circuit shown must be complete, <em>ie</em> must be capable of working; salt bridge must be labelled and must dip into both solutions. ALLOW concentration label of ‘equimolar’ or similar wording for Sn⁴⁺/Sn²⁺ half cell. ALLOW any strong acid. IF both half cells are correct with no concentrations, ALLOW 1 out of the 2 marks available for the 2 half cells. IGNORE any stated temperature or pressure, even if wrong.</td>
</tr>
<tr>
<td></td>
<td>Sn⁴⁺/Sn²⁺ half cell with Pt electrode <strong>AND</strong> both solutions labelled as 1 mol dm⁻³ / 1M ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H⁺/H₂ half cell with Pt electrode <strong>AND</strong> H⁺ solution labelled as 1 mol dm⁻³ / 1M ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>ANNOTE WITH TICK</strong> circuit shown must be complete, <em>ie</em> must be capable of working; salt bridge must be labelled and must dip into both solutions. ALLOW concentration label of ‘equimolar’ or similar wording for Sn⁴⁺/Sn²⁺ half cell. ALLOW any strong acid. IF both half cells are correct with no concentrations, ALLOW 1 out of the 2 marks available for the 2 half cells. IGNORE any stated temperature or pressure, even if wrong.</td>
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<tr>
<td></td>
<td><strong>ANNOTE WITH TICKS AND CROSSES, etc</strong> Correct species <strong>AND</strong> balancing needed for each mark ALLOW equations as shown with equilibrium sign ALLOW multiples but <em>electrons</em> must not be shown. IF three equations have correct species but no balancing, AWARD 1 mark ALLOW not favoured kinetically.</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2Cr + 3Sn⁴⁺ → 2Cr³⁺ + 3Sn²⁺ ✓</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cr + 3Cu⁺ → Cr³⁺ + 3Cu ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sn²⁺ + 2Cu⁺ → Sn⁴⁺ + 2Cu ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conditions not standard <strong>OR</strong> concentrations not 1 mol dm⁻³ ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>High activation energy</strong> <strong>OR</strong> slow rate ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>ANNOTE WITH TICKS AND CROSSES, etc</strong> Correct species <strong>AND</strong> balancing needed ALLOW multiple, <em>ie</em> 2CH₃OH + 3O₂ → 2CO₂ + 4H₂O ALLOW CH₄O for formula of methanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>ANNOTE WITH TICKS AND CROSSES, etc</strong> Correct species <strong>AND</strong> balancing needed ALLOW multiple, <em>ie</em> 2CH₃OH + 3O₂ → 2CO₂ + 4H₂O ALLOW CH₄O for formula of methanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CH₃OH + 1½O₂ → CO₂ + 2H₂O ✓</td>
<td>1</td>
<td></td>
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<tr>
<td>(b) (i)</td>
<td>CH₃OH + H₂O → 6H⁺ + 6e⁻ + CO₂ ✓</td>
<td>1</td>
<td></td>
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<tr>
<td></td>
<td><strong>ANNOTE WITH TICKS AND CROSSES, etc</strong> Correct species <strong>AND</strong> balancing needed ALLOW multiple, <em>ie</em> 2CH₃OH + 3O₂ → 2CO₂ + 4H₂O ALLOW CH₄O for formula of methanol</td>
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<td></td>
<td>CH₃OH + H₂O → 6H⁺ + 6e⁻ + CO₂ ✓</td>
<td>1</td>
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</tr>
<tr>
<td></td>
<td>less CO₂ <strong>OR</strong> less greenhouse gases ✓ <strong>greater efficiency ✓</strong></td>
<td>2</td>
<td>ALLOW no CO₂ <strong>OR</strong> no greenhouse gases ALLOW (very) efficient IGNORE less pollution <strong>OR</strong> ‘renewable fuels’</td>
</tr>
<tr>
<td></td>
<td>methanol is a liquid <strong>AND</strong> methanol is easier to store/transport ✓</td>
<td>1</td>
<td>Both points required for mark Response <strong>MUST</strong> state that methanol is a liquid IGNORE methanol has a higher boiling point Assume that ‘it’ refers to methanol IGNORE safety issues, eg H₂ leakage, flammability, explosive</td>
</tr>
<tr>
<td>Question</td>
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<td>Mark</td>
<td>Guidance</td>
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<tr>
<td>5 (a)</td>
<td>A: forms fewer moles/molecules of gas ✓</td>
<td>4</td>
<td>Note: Responses must imply the key difference between the sides of the equation</td>
</tr>
<tr>
<td></td>
<td>B: forms gas from a liquid ✓</td>
<td></td>
<td>IGNORE comments about C(s)</td>
</tr>
<tr>
<td></td>
<td>C: forms liquid from gases ✓</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>D: forms more moles/molecules of gas ✓</td>
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| (b)      | \( \Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants}) \)  

\[
= 40 + 214 - 89 = 165 \text{ (J K}^{-1}\text{ mol}^{-1})
\]

\[= 0.165 \text{ (kJ K}^{-1}\text{ mol}^{-1}) \checkmark \]

At 25 °C, \( \Delta G = +178 - 298 \times 0.165 \checkmark \)

\[= (+)129 \checkmark \text{ units: kJ mol}^{-1} \checkmark \]

OR \( (+)129,000 \checkmark \text{ units: J mol}^{-1} \checkmark \)

As \( \Delta G > 0 \), reaction is not feasible

OR as \( \Delta G > 0 \), CaCO₃ is stable ✓

Minimum temperature for feasibility when

\[
0 = \Delta H - T\Delta S \text{ OR } \Delta H = T\Delta S \text{ OR } T = \frac{\Delta H}{\Delta S} \checkmark
\]

\[
= \frac{178}{0.165} = 1079 \text{ K OR } 806 \text{ °C} \checkmark
\]

The units must be with the stated temperature

As \( \Delta S < 0 \), reaction is not feasible ✓

Minimum temperature for feasibility when

\[
0 = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}} \text{ OR } \Delta S_{\text{system}} = \frac{\Delta H}{T}
\]

ALLOW 1080 K up to calculator value of 1078.787879, correctly rounded, eg 1078.79 is correct value to 6SF

DO NOT ALLOW 1078 (incorrect rounding)

IF 1079 K is given and additional temperature in °C is incorrect, IGNORE °C temperature (and vice versa)

<table>
<thead>
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Total 11
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<tr>
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</table>
| 6 (a) (i) | \((K_w = ) \ [\text{H}^+ (\text{aq})] \ [\text{OH}^- (\text{aq})]\) | 1 | IGNORE state symbols  
ALLOW \([\text{H}_3\text{O}^+ (\text{aq})] \ [\text{OH}^- (\text{aq})]\) |
| (ii) FIRST, CHECK THE ANSWER ON ANSWER LINE | IF answer = \(2.3 \times 10^{-10}\) (mol dm\(^{-3}\)), award 2 marks  
IF answer = \(2.34 \times 10^{-10}\) (mol dm\(^{-3}\)) , award 1 mark | 2 | IF there is an alternative answer, check to see if there is any  
ECF credit possible using working below  
ANNOTATE WITH TICKS AND CROSSES, etc  
ALLOW \(4.3 \times 10^{-5}\) up to calculator: \(4.265795188 \times 10^{-5}\)  
ALLOW 0.0000427  
Answer MUST be to 2 SF (in question)  
ALLOW \(2.3 \times 10^{-x}\) (mol dm\(^{-3}\)) for 1 mark  
(must be a negative power)  
ALLOW alternative approach based on pOH:  
pOH = \(14 - 4.27 = 9.63\) \(\text{(DO NOT ALLOW 9.6)}\)  
\([\text{OH}^-] = 10^{-\text{pOH}} = 10^{-9.63} = 2.3 \times 10^{-10}\) (mol dm\(^{-3}\)) |
| (b) (i) | Endothermic because \(K_w\) increases with temperature | 1 | Endothermic AND reason required for the mark  
ALLOW Endothermic because increasing temperature shifts equilibrium/reaction to the right |
| (ii) | \(K_w\) value from graph from 2.2 to \(2.6 \times 10^{-14}\) (mol\(^2\) dm\(^{-6}\)) | 3 | ANNOTATE WITH TICKS AND CROSSES, etc  
Actual \(K_w = 2.38 \times 10^{-14}\) mol\(^2\) dm\(^{-6}\)  
For this mark, candidate must use a value between 2.0 and \(3.0 \times 10^{-14}\) (mol\(^2\) dm\(^{-6}\)), \(\text{ie from the approximately correct region of the graph,}\)  
ALLOW 6.8 up to calculator value  
Note: You will need to calculate the pH value from the candidate’s estimate of \(K_w\) at 37 ºC before awarding the 3rd marking point  
ONLY award an ECF pH mark if candidate has generated a value of \([\text{H}^+])\) by attempting to take a square root of a value between 2.0 and \(3.0 \times 10^{-14}\) |
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<tbody>
<tr>
<td>6 (b) (iii)</td>
<td>(Work is) inaccurate OR invalid because $K_w$ varies with temperature ✓</td>
<td>1</td>
<td>Response requires reason for inaccuracy/invalidity in terms of $K_w$. ALLOW incorrect with reason. IGNORE unreliable. ALLOW inaccurate because wrong $K_w$ was used. For $K_w$ varies with temperature, ALLOW equilibrium shifts with temperature.</td>
</tr>
<tr>
<td>(c)</td>
<td>Acid and alkali mixed ✓</td>
<td></td>
<td>ANNOTATE WITH TICKS AND CROSSES, etc</td>
</tr>
<tr>
<td></td>
<td>Amounts of acid AND alkali stated ✓</td>
<td></td>
<td>ALLOW ‘base’ for ‘alkali throughout. ALLOW if mentioned anywhere which could be within a definition for enthalpy change of neutralisation.</td>
</tr>
<tr>
<td></td>
<td>Temperature taken at start AND finish ✓</td>
<td></td>
<td>Amounts could be expressed as amounts, moles, volumes OR concentrations.</td>
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<tr>
<td></td>
<td>energy, $Q = mc\Delta T$ OR in words AND meaning of $m$, $c$ AND $\Delta T$ given ✓</td>
<td></td>
<td>ALLOW temperature change.</td>
</tr>
<tr>
<td></td>
<td>Energy scaled up to form 1 mol of water ✓</td>
<td></td>
<td>$m = \text{mass/volume of solution/reactants/mixture, etc}$ (but NOT surroundings). $c = \text{(specific) heat capacity (of solution/water)}$ OR 4.18/4.2 $\Delta T = \text{temperature change}$.</td>
</tr>
<tr>
<td></td>
<td>$\Delta H_{\text{neut}} = -\text{energy change}$ ✓</td>
<td>6</td>
<td>ALLOW divide energy by moles. ALLOW ‘−’ sign shown in earlier part, ie $\Delta H_{\text{neut}} = -\frac{Q}{n}$. ALLOW a statement linking $\Delta H$ with temperature change, ie: IF temperature increases, $\Delta H_{\text{neut}}$ is −ve OR IF temperature decreases, $\Delta H_{\text{neut}}$ is +ve.</td>
</tr>
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</table>
### Question 6 (d)  Ionic radius
Potassium ion OR K⁺ OR K ion is smaller  
OR K⁺ has greater charge density ✓

#### Lattice enthalpy
Lattice enthalpy of KF is more negative than RbF ✓
OR  
K⁺ has greater attraction for F⁻

#### Hydration enthalpy
$\Delta H$(hydration) of K⁺ is more negative than Rb⁺ ✓
OR  
K⁺ has greater attraction for H₂O

#### Enthalpy change of solution
Idea that $\Delta H$(solution) is affected more by lattice enthalpy than by hydration enthalpy ✓  
4

#### Question 6 (e)  (During dissolving,) entropy/disorder increases  
OR disorder increases ✓

$T\Delta S > \Delta H$
OR $T\Delta S$ is more positive than $\Delta H$
OR $\Delta H - T\Delta S$ is negative ✓  
2

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</table>
| 6 (d)    | ionic radius  
Potassium ion OR K⁺ OR K ion is smaller  
OR K⁺ has greater charge density ✓ |
|          | Lattice enthalpy  
Lattice enthalpy of KF is more negative than RbF ✓  
OR  
K⁺ has greater attraction for F⁻ |
|          | Hydration enthalpy  
$\Delta H$(hydration) of K⁺ is more negative than Rb⁺ ✓  
OR  
K⁺ has greater attraction for H₂O |
|          | Enthalpy change of solution  
Idea that $\Delta H$(solution) is affected more by lattice enthalpy than by hydration enthalpy ✓ |
|          | (During dissolving,) entropy/disorder increases  
OR disorder increases ✓  
$T\Delta S > \Delta H$  
OR $T\Delta S$ is more positive than $\Delta H$  
OR $\Delta H - T\Delta S$ is negative ✓ |

---

| Total    | 20 |

### Guidance
- **ANNOTATE WITH TICKS AND CROSSES, etc**
- **Throughout question, ORA in terms of Rb⁺**  
**Throughout question, ALLOW energy for enthalpy**
- **DO NOT ALLOW** potassium OR K OR reference to atoms  
(ie reference to ions is required throughout a response)
- **ALLOW** lattice enthalpy of KF > lattice enthalpy of RbF
- **ALLOW** more energy needed to separate K⁺ AND F⁻  
**IGNORE** KF has stronger bonds
- **ALLOW** $\Delta H$(hydration) of K⁺ > $\Delta H$(hydration) of Rb⁺
- **ALLOW** more energy needed to separate K⁺ AND H₂O  
**IGNORE** K⁺ has a stronger bond to H₂O
- **ALLOW** a correct attempt to link the contribution of lattice enthalpy and hydration enthalpy to $\Delta H$(solution), ie lattice enthalpy is a more important factor than hydration enthalpy
- **ALLOW** entropy change is positive  
OR $\Delta S$ is positive  
OR $T\Delta S$ is positive
- **ALLOW** $\Delta S$(system) > $\Delta H/T$  
**ALLOW** $\Delta S$(system) is more positive than $\Delta H/T$ ✓
- **ALLOW** $\Delta S$(system) + $\Delta S$(surroundings) is positive
- **ALLOW** Energy contribution from increase in entropy is greater than decrease in energy from enthalpy change  
**OR** entropy change outweighs enthalpy change
- **IGNORE** $\Delta G$ is negative
### Question 7

<table>
<thead>
<tr>
<th>Sub-question</th>
<th>Answer</th>
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</table>
| (a) (i) | amount $S_2O_3^{2-}$ used  
  $= 0.00100 \times \frac{24.6}{1000} = 2.46 \times 10^{-5}$ mol | 4 | **ANNOTATE WITH TICKS AND CROSSES, etc**  
  ALLOW 0.0000246 (mol)  
  **ECF** = answer above  
  ALLOW 0.00000615 g  
  **ECF** = answer above $\times \frac{1000}{25}$  
  ALLOW 0.000246 g  
  **ECF** = answer above $\times 32 \times 1000$  
  ALLOW 7.9 OR 7.87  
  ALLOW 2 SF up to calculator value  
  Must be in mg for mark  
  **Note:** Candidate may work out steps 3 and 4 in the opposite order, *ie*  
  mass of $O_2$ in sample  
  $= 6.15 \times 10^{-6} \times 32 \times 1000 = 1.968 \times 10^{-1}$ mg  
  mass concentration of $O_2$ in mg dm$^{-3}$  
  $= 1.968 \times 10^{-1} \times \frac{1000}{25} = 7.872$ (mg dm$^{-3}$) | | |
| (a) (ii) | Comment  
  $7.872 > 5$ so fish can survive | 1 | **ECF** If final answer > 5 fish *can* survive  
  If final answer < 5 fish *cannot* survive |
<p>| (b) (i) | NO | 1 | <strong>ALLOW</strong> $N_2H_2$ |</p>
<table>
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<tbody>
<tr>
<td>7 (b) (ii)</td>
<td>$2\text{H}_2\text{O} + 2\text{I}^- + 2\text{NO}_2^- \rightarrow 2\text{NO} + \text{I}_2 + 4\text{OH}^-$ OR $2\text{H}^+ + 2\text{I}^- + 2\text{NO}_2^- \rightarrow 2\text{NO} + \text{I}_2 + 2\text{OH}^-$ species ✓ balance ✓</td>
<td>2</td>
<td>IGNORE state symbols ALLOW multiples For species ONLY, IGNORE any extra $\text{H}_2\text{O}$ or $\text{e}^-$ on either side of the equation ALLOW on LHS: $2\text{HI} + 2\text{NO}_2^-$ OR $2\text{I}^- + 2\text{HNO}_2$ ALLOW species and equation involving $\text{N}_2\text{H}_2$: $6\text{H}_2\text{O} + 8\text{I}^- + 2\text{NO}_2^- \rightarrow \text{N}_2\text{H}_2 + 4\text{I}_2 + 10\text{OH}^-$ OR $6\text{H}^+ + 8\text{I}^- + 2\text{NO}_2^- \rightarrow \text{N}_2\text{H}_2 + 4\text{I}_2 + 4\text{OH}^-$ species ✓ balance ✓</td>
</tr>
</tbody>
</table>
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