

**GCE**

**Chemistry A**

**H432/01: Periodic table, elements and physical chemistry**

Advanced GCE

**Mark Scheme for Autumn 2021**

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

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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**Tuesday 5 October 2021 –Afternoon**

**A Level Chemistry A**

**H432/01 Periodic table, elements and physical chemistry**

MARK SCHEME















**Duration:** 2 hours 15 minutes

**MAXIMUM MARK 100**

**Last updated: 17/10/2021  
Post-standardisation**

**This document consists of 27 pages**

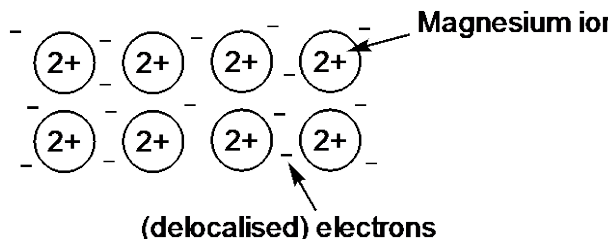
## 1. Annotations

<b>Annotation</b>	<b>Meaning</b>
	Correct response
	Incorrect response
	Omission mark
	Benefit of doubt given
	Contradiction
	Rounding error
	Error in number of significant figures
	Error carried forward
	Level 1
	Level 2
	Level 3
	Benefit of doubt not given
	Noted but no credit given
	Ignore

2. Abbreviations, annotations and conventions used in the detailed Mark Scheme (to include abbreviations and subject-specific conventions).

<b>Annotation</b>	<b>Meaning</b>
/	alternative and acceptable answers for the same marking point
✓	Separates marking points
<b>DO NOT ALLOW</b>	Answers which are not worthy of credit
<b>IGNORE</b>	Statements which are irrelevant
<b>ALLOW</b>	Answers that can be accepted
( )	Words which are not essential to gain credit
—	Underlined words must be present in answer to score a mark
<b>ECF</b>	Error carried forward
<b>AW</b>	Alternative wording
<b>ORA</b>	Or reverse argument

Question	Answer	Marks	AO element	Guidance
1	C	1	AO1.1	
2	B	1	AO1.2	
3	D	1	AO2.6	
4	B	1	AO2.2	
5	D	1	AO2.6	
6	C	1	AO2.6	
7	A	1	AO1.1	
8	B	1	AO2.2	
9	B	1	AO2.2	
10	A	1	AO2.6	
11	A	1	AO1.2	
12	C	1	AO1.2	
13	D	1	AO1.1	Accept 1
14	B	1	AO2.1	
15	C	1	AO2.3	
	<b>Total</b>	<b>15</b>		

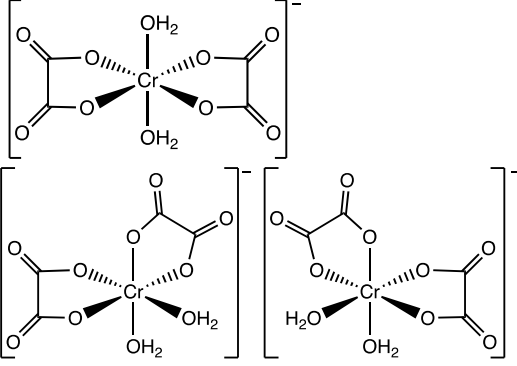
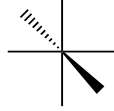
Question		Answer	Marks	AO element	Guidance																									
16	(a)	 <p>(delocalised) electrons</p> <p>Diagram with regular arrangement of <b>labelled 'Mg<sup>2+</sup> ions'</b> <b>OR '2+ ions'</b></p> <p><b>AND</b> attempt to show electrons ✓</p> <p><b>Labelled</b> electrons between other species</p> <p><b>AND</b> statement anywhere of <b>delocalised</b> electrons (can be in text or in diagram)</p> <p>Electrons move ✓</p>	3		<p>Regular arrangement must have at least two rows of correctly charged ions and a minimum of two ions per row</p> <p><b>ALLOW</b> as label: +2 ions <b>OR</b> + 2 cations <b>OR</b> +2/2+ seen within circle</p> <p><b>ALLOW</b> e<sup>-</sup> or 'e' as a <b>label</b> for electron</p> <p><b>IGNORE</b> "—" for electron label</p> <p><b>ALLOW</b> mobile/flow for move</p> <p><b>IGNORE</b> 'carry charge'</p>																									
	(b)	(i)	$\text{Mg}^{3+}(\text{g}) \rightarrow \text{Mg}^{4+}(\text{g}) + \text{e}^{-} \checkmark$	1	AO1.2	<p>State symbols required (ignore states on electrons)</p> <p><b>ALLOW</b> <math>\text{Mg}^{3+}(\text{g}) - \text{e}^{-} \rightarrow \text{Mg}^{4+}(\text{g})</math></p> <p><b>ALLOW</b> <math>\text{Mg}^{+3}(\text{g})</math></p> <p><b>ALLOW</b> e for e<sup>-</sup></p>																								
	(b)	(ii)	Big jump/larger difference between 2 and 3 ✓	1	AO1.2	<p><b>IGNORE</b> big jump between 10 and 11</p> <p><b>DO NOT ALLOW</b> other combinations.</p>																								
	(b)	(iii)	<p>1st <b>AND</b> 3rd <b>AND</b> 4th <b>AND</b> 5th <b>AND</b> 9th <b>AND</b> 11th ✓</p> <p>i.e.</p> <table border="1" data-bbox="421 1233 1075 1345"> <tr> <td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td> </tr> <tr> <td>✓</td><td></td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td>✓</td><td></td><td>✓</td><td></td> </tr> </table>	1	2	3	4	5	6	7	8	9	10	11	12	✓		✓	✓	✓				✓		✓		1	AO2.1	
1	2	3	4	5	6	7	8	9	10	11	12																			
✓		✓	✓	✓				✓		✓																				

Question		Answer	Marks	AO element	Guidance	
	(c)	(i)	(enthalpy change for) <b>1 mole</b> of a compound/substance/solid/solute <b>dissolving</b> ✓	1	AO1.1 IGNORE 'energy released' OR 'energy required'  For dissolving, <b>ALLOW</b> forms aqueous/hydrated ions <b>IGNORE</b> ionic <b>OR</b> covalent <b>DO NOT ALLOW</b> dissolving elements <b>DO NOT ALLOW</b> response that implies formation of <b>1 mole</b> of aqueous ions	
	(c)	(ii)	$\underline{\text{Mg}^{2+}(\text{aq}) + 2\text{F}^{-}(\text{g})}$ ✓  $\underline{\text{Mg}^{2+}(\text{aq}) + 2\text{F}^{-}(\text{aq})}$ ✓	2	AO2.2 ×2 <b>ALLOW</b> Mg <sup>2+</sup> (g) + 2F <sup>-</sup> (aq)  <b>ALLOW</b> MgF <sub>2</sub> (aq)	
	(c)	(iii)	-6 (kJ mol <sup>-1</sup> ) ✓  $\Delta_{\text{sol}}H(\text{MgF}_2) = -(-2926) + (2 \times -506) + (-1920)$	1	AO2.2 <b>1 mark ONLY</b>	
	(c)	(iv)	<b>Ionic radius</b> Halide <b>ion</b> gets larger down the group ✓  <b>Lattice enthalpy</b> Lattice enthalpy is less exothermic down group <b>OR</b> halide ion has less attraction for Mg <sup>2+</sup> ✓  <b>Hydration enthalpy</b> Hydration enthalpy is less exothermic down group <b>OR</b> halide ion has less attraction for H <sub>2</sub> O ✓  <b>Enthalpy of solution</b> Difficult to predict whether lattice enthalpy or hydration enthalpy has bigger effect ✓	4	AO1.2 ×3        AO3.2	<b>ALLOW ORA</b> throughout <b>ALLOW</b> ions closer together in MgF <sub>2</sub> <b>OR</b> further apart in MgI <sub>2</sub> <b>DO NOT ALLOW</b> atomic radius  <b>ALLOW</b> MgI <sub>2</sub> is less exothermic than MgF <sub>2</sub> for LE and hydration enthalpy -as trend 'down the group'.  <b>ALLOW</b> less negative/more positive <b>BUT</b> <b>IGNORE</b> is smaller/less
			<b>Total</b>	<b>14</b>		



Question		Answer	Marks	AO element	Guidance			
17	(a)	<p><b>Transition element:</b> Has an <b>ion</b> with an incomplete/partially-filled d <b>sub-shell/d-orbital</b> ✓</p> <p><b>d-block</b> d <b>sub-shell/d-orbital</b> is being filled/has highest energy <b>OR</b> Electron configurations shown for Sc: <math>1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2</math> <b>AND</b> Zn: <math>1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2</math> ✓</p> <p><i>Electron configurations of ions</i> Sc<sup>3+</sup>: <math>1s^2 2s^2 2p^6 3s^2 3p^6</math> <b>AND</b> d <b>sub-shell empty / d orbital(s) empty</b> ✓</p> <p>Zn<sup>2+</sup>: <math>1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}</math> <b>AND</b> d <b>sub-shell full / d-orbitals full</b> ✓</p>	4	AO1.1 x4	<p><b>FULL ANNOTATIONS MUST BE USED</b> -----</p> <p><b>DO NOT ALLOW</b> d shell</p> <p><b>IGNORE</b> d block</p> <p><b>IGNORE</b> outer electron</p> <p>electron configurations <b>ALLOW</b> 4s<sup>0</sup> <b>ALLOW</b> 4s<sup>2</sup> before 3d, i.e. ....4s<sup>2</sup>3d<sup>1</sup>; 4s<sup>2</sup>3d<sup>10</sup> <b>IGNORE</b> other Sc and Zn ions</p> <p><b>ALLOW ECF</b> for short hand notation.</p> <p>For Sc<sup>3+</sup>, <b>ALLOW</b> Sc<sup>+3</sup> <b>OR</b> Sc forms a 3+ ion;</p> <p>For Zn<sup>2+</sup>, <b>ALLOW</b> Zn<sup>+2</sup> <b>OR</b> Zn forms a 2+ ion;</p>			
	(b)	(i)			<p><b>Donates two electron pairs</b> (to a metal ion) <b>AND</b> forms <b>two coordinate bonds</b> (to a metal ion) ✓</p>	1	AO1.1 x1	<p><b>ALLOW</b> lone pairs for electron pairs</p> <p><b>ALLOW</b> dative (covalent) bonds for coordinate bonds</p> <p><b>TWO</b> is only needed once if bonds are plural, e.g. <b>Donates 2 electron pairs</b> to form coordinate <b>bonds</b> <b>Donates</b> electron <b>pairs</b> to form <b>2</b> coordinate <b>bonds</b></p>

Question	Answer	Marks	AO element	Guidance														
	<p>(ii)* <i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i></p> <p><b>Level 3 (5–6 marks)</b> Reaches a comprehensive conclusion with most detail and few errors to obtain: the formulae of <b>A</b> and <b>B</b> <b>AND</b> ionic equation for ligand substitution <b>AND</b> the 3D structures of <b>B</b> stereoisomers</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p><b>Level 2 (3–4 marks)</b> Reaches a sound conclusion with some detail and some errors for the formula of <b>A OR B</b> <b>AND</b> ionic equation for ligand substitution <b>OR</b> the 3D structures of <b>B</b> stereoisomers</p> <p><i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i></p> <p><b>Level 1 (1–2 marks)</b> Obtains the correct formula of <b>A OR B OR</b> 3D structures of <b>B</b> stereoisomers which are mostly correct.</p> <p><i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p> <p><b>0 marks</b> No response or no response worthy of credit.</p>	<b>6</b>	<p>AO2.2 ×2</p> <p>AO2.6 ×2</p> <p>AO3.1 ×2</p>	<p><b>Indicative scientific points:</b></p> <p><b><u>1. Formula of the hydrated salt A</u></b></p> <p><b>Formula of A:</b> <math>\text{Cr}_2\text{H}_{24}\text{O}_{24}\text{S}_3</math></p> <p><i>Example of working</i></p> <table style="margin-left: auto; margin-right: auto;"> <tr> <td style="text-align: center;">Cr</td> <td style="text-align: center;">:</td> <td style="text-align: center;">H</td> <td style="text-align: center;">:</td> <td style="text-align: center;">O</td> <td style="text-align: center;">:</td> <td style="text-align: center;">S</td> </tr> <tr> <td style="text-align: center;"><math>\frac{17.10}{52.0}</math></td> <td style="text-align: center;">:</td> <td style="text-align: center;"><math>\frac{3.94}{1.0}</math></td> <td style="text-align: center;">:</td> <td style="text-align: center;"><math>\frac{63.13}{16.0}</math></td> <td style="text-align: center;">:</td> <td style="text-align: center;"><math>\frac{15.83}{32.1}</math></td> </tr> </table> <p><b>There may be other methods</b></p> <p><b>Detail</b>    <i>Hydrated salt = <math>\text{Cr}_2(\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}</math></i></p> <p><b><u>2. Formula of B and ionic equation</u></b></p> <p><b>Formula of B:</b> <math>[\text{Cr}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)_2]^-</math></p> <p><b>Ionic equation</b></p> $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 2\text{C}_2\text{O}_4^{2-} \rightarrow [\text{Cr}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)_2]^- + 4\text{H}_2\text{O}$ <p><b>ALLOW</b> ligands in any order, e.g. <math>[\text{Cr}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^-</math></p> <p><b>Detail</b>    <i>Use of charges and brackets</i></p> <p><b><u>3. 3D structures of B stereoisomers</u></b></p>	Cr	:	H	:	O	:	S	$\frac{17.10}{52.0}$	:	$\frac{3.94}{1.0}$	:	$\frac{63.13}{16.0}$	:	$\frac{15.83}{32.1}$
Cr	:	H	:	O	:	S												
$\frac{17.10}{52.0}$	:	$\frac{3.94}{1.0}$	:	$\frac{63.13}{16.0}$	:	$\frac{15.83}{32.1}$												

Question	Answer	Marks	AO element	Guidance
				 <ul style="list-style-type: none"> <li>Consistent use of 2 'out wedges', 2 'in wedges', 2 lines in plane of paper <b>OR</b> 4 lines, 1 'out wedge' and 1 'in wedge'</li> </ul> <p><b>ALLOW</b> following orientations</p>  <p><b>Detail</b></p> <ul style="list-style-type: none"> <li>Most bonding shown from Cr to O of H<sub>2</sub>O and O<sup>-</sup> C<sub>2</sub>O<sub>4</sub><sup>2-</sup></li> </ul>
	Total	11		

Question		Answer	Marks	AO element	Guidance
18	(a)	Formula: $\text{CuCO}_3$ ✓ $\text{CuCO}_3 + 2\text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + \text{CO}_2 + \text{H}_2\text{O}$ ✓	2	AO1.2 AO2.6	<b>IGNORE state symbols</b> <b>ALLOW</b> formula within equation.  <b>ALLOW</b> other copper(II) compounds which can react with nitric acid to form a gas e.g. $\text{CuS}$ , $\text{CuSO}_3$ for mark 1, with correct equation for mark 2. e.g. $\text{CuSO}_3 + 2\text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + \text{SO}_2 + \text{H}_2\text{O}$
	(b)	$2\text{Cu}^{2+}(\text{aq}) + 4\text{I}^{-}(\text{aq}) \rightarrow 2\text{CuI}(\text{s}) + \text{I}_2(\text{aq})$ ✓	1	AO2.6	<b>ALLOW</b> multiples State symbols are required
	(c)	starch (solution) <b>AND</b> blue-black to colourless ✓	1	AO1.2	<b>ALLOW</b> blue <b>OR</b> black <b>OR</b> purple for colour of mixture  <b>ALLOW</b> blue colour disappears (to colourless) <b>IGNORE</b> 'clear' <b>IGNORE</b> 'colorimetry'
	(d)	<b>FIRST CHECK THE ANSWER ON ANSWER LINE</b> <b>If answer = 1.35 award 4 marks</b> ----- $n(\text{S}_2\text{O}_3^{2-}) = 0.0200 \times \frac{26.55}{1000}$ $= 5.31 \times 10^{-4} \text{ (mol) } \checkmark$  $n(\text{I}_2) = 2.655 \times 10^{-4}$ <b>OR</b> $n(\text{Cu}^{2+}) = 5.31 \times 10^{-4} \text{ (mol) } \checkmark$  $m(\text{Cu}/\text{Cu}^{2+}) \text{ in ore} = 63.5 \times 5.31 \times 10^{-4}$ $= 0.0337\text{..... (g) } \checkmark$  $\text{percentage} = \frac{0.0337\text{....}}{2.50} \times 100$ $= 1.35 \text{ ( \% ) } \checkmark$ ( <b>3SF</b> required)	4	AO2.8 ×5	<b>FULL ANNOTATIONS MUST BE USED</b> ----- <b>ALLOW ECF</b> throughout  If 1:2 ratio for $\text{I}_2:\text{Cu}^{2+}$ not used check ratio in b) and allow <b>ECF</b>  <b>IGNORE</b> rounding errors after 3 SF  Calculator: 0.0337185 <b>ALLOW</b> 3 SF (0.0337) up to calculator value  <b>ECF</b> dependent on the use of a calculated mass of $\text{Cu}/\text{Cu}^{2+}$

Question			Answer	Marks	AO element	Guidance
	(e)	(i)	Lower <b>AND</b> smaller titre ✓	1	AO3.4	<b>ALLOW</b> less I <sub>2</sub> produced / less Cu <sup>2+</sup> reacts
		(ii)	The same <b>AND</b> burette measures by difference ✓	1	AO3.4	<b>ALLOW AW</b>
	(f)		<p>Any two of the following:</p> <p>Make up a (standard solution) from Step 2 to a stated volume (e.g. 250 cm<sup>3</sup>)</p> <p><b>OR</b></p> <p>Repeat titrations <b>AND</b> Take mean of concordant/closest titres/ identify anomalies</p> <p><b>OR</b></p> <p>lower [S<sub>2</sub>O<sub>3</sub>]<sup>2-</sup> to increase titre volume (to reduce the percentage error).</p> <p><b>OR</b></p> <p>higher [S<sub>2</sub>O<sub>3</sub>]<sup>2-</sup> so not to refill the burette.</p> <p><b>OR</b></p> <p>Use a 3 dec place balance (to reduce the percentage error).</p>	2	AO3.4 x 2	
			<b>Total</b>	<b>12</b>		

Question			Answer	Marks	AO element	Guidance
19	(a)	(i)	<p><b>Complete</b> circuit with voltmeter  <b>AND</b> labelled salt bridge linking two half-cells ✓</p> <p>Cr electrode in Cr<sup>3+</sup> ✓  Pt electrode in MnO<sub>4</sub><sup>-</sup> <b>AND</b> H<sup>+</sup> <b>AND</b> Mn<sup>2+</sup> ✓</p>	3	AO1.2 ×3	<p>Half cells can be drawn in either order  Half cells must show electrodes dipping into solutions</p> <p><b>ALLOW</b> small gaps in circuit</p> <p><b>IGNORE</b> any stated concentrations</p> <p><b>IGNORE</b> state symbols</p> <p>In salt bridge, <b>ALLOW</b> any stated ion that may be present,  e.g. Cr<sup>3+</sup>, MnO<sub>4</sub><sup>-</sup>, Mn<sup>2+</sup>, H<sup>+</sup></p>
	(a)	(ii)	$5\text{Cr} + 3\text{MnO}_4^- + 24\text{H}^+ \rightarrow 5\text{Cr}^{3+} + 3\text{Mn}^{2+} + 12\text{H}_2\text{O} \checkmark$	1	AO2.6	<p><b>IGNORE</b> state symbols</p> <p><b>ALLOW</b> multiples</p>
	(b)	(i)	<p>Mn is oxidised from +6 (in MnO<sub>4</sub><sup>2-</sup>) to +7 (in MnO<sub>4</sub><sup>-</sup>) ✓  Mn is reduced from +6 (in MnO<sub>4</sub><sup>2-</sup>) to +4 (in MnO<sub>2</sub>) ✓</p>	2	AO2.1 ×2	<p><b>IGNORE</b> '6' (signs required)  <b>ALLOW</b> after number, e.g. 5+  <b>ALLOW</b> 1 mark for correct oxidation numbers but not linked to oxidation/reduction.  <b>IGNORE</b> any reference to electron loss/gain (even if wrong)</p>

Question		Answer	Marks	AO element	Guidance
	(b)	(ii)			
	(b)	(ii)	2	AO3.1 ×2	<p><b>IGNORE</b> 'lower/higher'  <b>ALLOW</b> reverse argument:  System 5 more positive than system 3, etc  Must be comparative  <b>ALLOW</b> response in terms of <math>E_{\text{cell}}</math>  <math>E = (+)1.14 \text{ V}</math> for system 5 – system 3</p> <p>Shift dependent on systems 3 and 5 correctly identified</p>
	(c)	(i)	1	AO2.6	<p><b>ALLOW</b> multiples  <b>ALLOW</b> <math>\text{H}_2 + 2\text{OH}^- - 2\text{e}^- \rightarrow 2\text{H}_2\text{O}</math>  <b>ALLOW</b> equation with equilibrium sign</p>
	(c)	(ii)	1	AO1.2	
	(c)	(iii)	1	AO1.1	<p><b>ALLOW</b> named fuel. e.g. hydrogen/<math>\text{H}_2</math>; ethanol; methanol, etc</p> <p><b>ALLOW</b> fuel cell requires <u>continuous</u> supply of fuel <b>AND</b> oxygen/an oxidant  <b>OR</b>  fuel cell operates <u>continuously</u> as long as a fuel <b>AND</b> oxygen/an oxidant are added</p> <p><b>IGNORE</b> 'reactants' 'products' and comments about pollution and efficiency</p>
			<b>Total</b>	<b>11</b>	

Question		Answer	Marks	AO element	Guidance
20	(a)	rate of forwards reaction = rate of backwards reaction  <b>OR</b> concentrations/pressure/temperature are constant /do not change ✓	1	AO1.1	<b>DO NOT ALLOW</b> “are the same”
	(b)	(i)	2	AO2.2 ×2	<b>ALLOW</b> -114000 – (298 × -147)  <b>ALLOW</b> -70 up to calculator value of -70.194 correctly rounded, i.e. -70 <b>OR</b> -70.2 <b>OR</b> -70.19  <b>ALLOW</b> -70000 up to -70194 (J mol <sup>-1</sup> )  <b>ALLOW ECF</b> for an incorrectly calculated <b>negative</b> value of ΔG linked to feasibility statement  <b>IGNORE</b> rounding after 3 SF  <b>ORA</b> for comment about – sign required for feasibility
	(b)	(ii)	1	AO2.2	
		776 (K) ✓  i.e. Maximum temperature = $\frac{\Delta H}{\Delta S} = \frac{-114}{-0.147} = 776$ (K) <b>3 SF required</b> (appropriate from supplied data)			



Question		Answer	Marks	AO element	Guidance
	(c)	(i)	4	AO2.4 ×4	<p><b>FULL ANNOTATIONS MUST BE USED</b></p> <p>-----</p> <p><b>ALLOW ECF throughout</b></p> <p><b>ALLOW</b> 20.6 from 3 SF partial pressures, 0.194, 0.436 and 0.581</p> <p><b>IF</b> there is an alternative answer, check to see if there is any <b>ECF</b> credit possible using working below</p> <p>-----</p> <p><b>Look for values to 3 SF here:</b> <b>0.194, 0.436 and 0.581</b></p> <p><b>ALLOW</b> <b>25.0 as ECF</b> (from omission of partial pressures for <b>3 marks</b>)</p>

**FIRST, CHECK FOR VALUE OF  $K_p$ .**  
**IF answer = 20.7 (MPa<sup>-1</sup>), award 4 marks**

-----

*Equilibrium amounts*

$$n(\text{NO}) = 0.4 \text{ (mol)}$$

**AND**  $n(\text{O}_2) = 0.9 \text{ (mol)}$

**AND**  $n(\text{NO}_2) = 1.2 \text{ (mol)} \checkmark$

*Total moles at equilibrium*

$$n_{\text{tot}} = 2.5 \text{ (mol)} \checkmark$$

*Partial pressures*

$$p(\text{NO}) = \frac{0.4}{2.5} \times 1.21 = 0.1936 \text{ (MPa)}$$

**AND**  $p(\text{O}_2) = \frac{0.9}{2.5} \times 1.21 = 0.4356 \text{ (MPa)}$

**AND**  $p(\text{NO}_2) = \frac{1.2}{2.5} \times 1.21 = 0.5808 \text{ (MPa)} \checkmark$

*$K_p$  value*

$$K_p = \frac{0.5808^2}{0.1936^2 \times 0.4356} = 20.7 \text{ to 3 SF (MPa}^{-1}\text{)} \checkmark$$

Question			Answer				Marks	AO element	Guidance																				
	(c)	(ii)	<table border="1"> <thead> <tr> <th>Change</th> <th><math>K_p</math></th> <th>Equilibrium amount of <math>\text{NO}_2</math></th> <th>Initial rate</th> </tr> </thead> <tbody> <tr> <td>Temperature increased</td> <td>smaller</td> <td>smaller</td> <td>greater</td> </tr> <tr> <td>Pressure increase</td> <td>same</td> <td>greater</td> <td>greater</td> </tr> <tr> <td>Catalyst added</td> <td>same</td> <td>same</td> <td>greater</td> </tr> <tr> <td></td> <td>✓</td> <td>✓</td> <td>✓</td> </tr> </tbody> </table>				Change	$K_p$	Equilibrium amount of $\text{NO}_2$	Initial rate	Temperature increased	smaller	smaller	greater	Pressure increase	same	greater	greater	Catalyst added	same	same	greater		✓	✓	✓	3	AO1.2 ×3	<p>Mark by <b>COLUMN</b></p> <p><b>ALLOW</b> obvious alternatives for greater/smaller/same, e.g. increases/decreases/more/less</p>
Change	$K_p$	Equilibrium amount of $\text{NO}_2$	Initial rate																										
Temperature increased	smaller	smaller	greater																										
Pressure increase	same	greater	greater																										
Catalyst added	same	same	greater																										
	✓	✓	✓																										
			<b>Total</b>				11																						

Question			Answer	Marks	AO element	Guidance
21	(a)	(i)	<p>(Expt 1 and 2)  <math>[S_2O_3^{2-}]</math> halves, (<math>[H^+]</math> constant),  <b>AND</b> rate halves  <b>AND</b> first order (with respect to <math>[S_2O_3^{2-}]</math>) ✓</p> <p>(Expt 2 and 3)  <math>[S_2O_3^{2-}]</math> quarter <b>AND</b> <math>[H^+]</math> halves,  <b>AND</b> rate quarters  <b>AND</b> zero order (with respect to <math>[H^+]</math>) ✓</p>	2	AO3.1 ×2	<p><b>ALLOW ORA</b> i.e.            (Expt 2 and 1)  <math>[S_2O_3^{2-}]</math> doubles, (<math>[H^+]</math> constant),  <b>AND</b> rate doubles  <b>AND</b> first order with respect to <math>[S_2O_3^{2-}]</math></p> <p><b>ALLOW</b> comparison of Expt 1 and 3:  <math>[S_2O_3^{2-}] \times 1/8</math> <b>AND</b> <math>[H^+]</math> halves,  <b>AND</b> rate <math>\times 1/8</math>  <b>AND</b> zero order with respect to <math>[H^+]</math></p>
	(a)	(ii)	<p><math>S_2O_3^{2-}</math> as only reactant species in step 1 ✓</p> <p>Rest of mechanism correct ✓</p>	2	AO3.2 ×2	<p>Step 1: <math>S_2O_3^{2-} \rightarrow S + SO_3^{2-}</math>            Step 2: <math>SO_3^{2-} + 2H^+ \rightarrow SO_2 + H_2O</math>  <b>OR</b>            Step 1: <math>S_2O_3^{2-} \rightarrow SO_2 + SO^{2-}</math>            Step 2: <math>SO^{2-} + 2H^+ \rightarrow S + H_2O</math></p> <p><b>Check with Team Leader for other equations</b></p>
	(b)	(i)	<p><b>Gradient</b>            gradient in range of <math>-5700</math> to <math>-6100</math> ✓</p> <p><b><math>E_a</math> calculation</b>  <math>E_a = (-)</math> gradient <math>\times 8.314</math>            e.g. from <math>-5900</math>, <math>E_a = (+)</math> <math>49052.6</math> (<math>J mol^{-1}</math>) ✓</p> <p><math>E_a</math> to <b>3SF</b> and in <math>kJ mol^{-1}</math> ✓            e.g. <math>49.1</math> (<math>kJ mol^{-1}</math>)</p>	3	AO2.8 ×3	<p><b>FULL ANNOTATIONS MUST BE USED</b>            -----            Marks are for intermediate calculations</p> <p><b>ALLOW ECF</b> from an incorrect gradient</p> <p><b>ALLOW ECF</b> on missing <math>\times 10^{-3}</math>,            e.g. <b>ALLOW</b> 2 marks for:            gradient = <math>-5.9</math>,            leading to <math>E_a = 49.0526</math> (<math>J mol^{-1}</math>)  <b>AND</b> <math>0.0491</math> (<math>kJ mol^{-1}</math>)</p> <p><b>DO NOT ALLOW</b> a negative <math>E_a</math></p>

Question			Answer	Marks	AO element	Guidance
	(b)	(ii)	ln A is intercept at 0 when 1/T <b>OR</b> x axis is 0 ✓	1	AO3.2	
		(iii)	<i>ln k</i> $\ln k = -2.59$ ✓  <i>Temperature</i> $1/T = 3.10 \times 10^{-3} \text{ (s}^{-1}\text{)}$  $T = 49.6 \text{ }^\circ\text{C}$ ✓	2	AO3.1  AO3.2	Correct T scores 2 marks  <b>ALLOW ECF</b> for 1/T from incorrect lnK <b>shown on the graph</b>  <b>ALLOW in the range</b> $1/T = 3.09 - 3.11 \text{ (} \times 10^{-3} \text{ s}^{-1}\text{)}$  $T = 48.5 \text{ to } 50.6 \text{ }^\circ\text{C}$  <b>ALLOW</b> $T = 50 \text{ }^\circ\text{C}$
			<b>Total</b>	<b>10</b>		

Question		Answer	Marks	AO element	Guidance
22	(a)	<p><b>FIRST CHECK THE ANSWER ON ANSWER LINE</b>  <b>If answer = 13.15 award 2 marks</b></p> <p>-----</p> $[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.140} = 7.14 \dots \times 10^{-14} \text{ (mol) } \checkmark$ $\text{pH} = -\log (7.14 \dots \times 10^{-14}) = 13.15 \checkmark$ <p style="text-align: center;"><b>2 DP required</b></p>	2	AO2.2 ×2	<p><b>ALLOW ECF</b> providing <math>\text{pH} &gt; 7</math></p> <p>Calculator: <math>7.142857143 \times 10^{-14}</math></p> <p><b>ALLOW</b> pOH method  <math>\text{pOH} = -\log(0.14) = 0.85 \dots \dots \dots \checkmark</math></p> $\text{pH} = 14.00 - (0.85 \dots \dots) = 13.15 \checkmark$
	(b)	(i)			
		$n(\text{H}_2\text{SO}_4) = 1.60 \times \frac{25.0}{1000} = 0.04(00) \text{ (mol)}$ <p><b>AND</b></p> $n(\text{NaOH}) = 1.50 \times \frac{55.0}{1000} = 0.0825 \text{ (mol) } \checkmark$ <p>0.04(00) mol <math>\text{H}_2\text{SO}_4</math> reacts with 0.08(00) mol NaOH  <b>OR</b>  1 mol <math>\text{H}_2\text{SO}_4</math> reacts with 2 mol NaOH <math>\checkmark</math></p>	2	AO2.2 ×2	<p><b>ALLOW</b> <math>0.0825 &gt; 0.08</math></p>

Question		Answer	Marks	AO element	Guidance
	(b) (ii)	$q = mc\Delta T = 80.0 \times 4.18 \times 13.0$ $= 4347.2 \text{ (J) OR } 4.3472 \text{ (kJ) } \checkmark$  $\Delta H_1 = (-) \frac{4.3472}{0.0400} = (-)108.68 \text{ kJ mol}^{-1} \checkmark$  $\Delta_{\text{neut}}H = (-) \frac{108.68}{2} = (-)54.34 \text{ kJ mol}^{-1} \checkmark$  – sign for $\Delta H$ value(s) $\checkmark$	4	AO2.4 ×4	<b>FULL ANNOTATIONS MUST BE USED</b> ----- <b>ALLOW</b> 3 SF up to calculated answer throughout  <b>ALLOW ECF</b> from $q$ <b>DO NOT ALLOW</b> division by $n(\text{NaOH})$  <b>ALLOW</b> $\Delta_{\text{neut}}H$ from $\Delta H_1 / 2$  <b>ALLOW</b> alternative methods
	(b) (iii)	The same <b>OR</b> $13^\circ\text{C} \checkmark$  (Double the moles so) <b>double</b> the energy is spread over <b>double</b> the volume	2	AO3.1 ×2	<b>ALLOW</b> explanation that uses a calculation based on moles, volumes  <b>ALLOW</b> mass for volume

Question		Answer	Marks	AO element	Guidance
	(c)*	<p><i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i></p> <p><b>Level 3 (5–6 marks)</b> Reaches a comprehensive conclusion with most detail and few errors for the formation of the buffer <b>AND</b> Calculation of the correct buffer pH <b>AND</b> Correct mass of N<sub>2</sub>O<sub>3</sub>. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p><b>Level 2 (3–4 marks)</b> Reaches a sound conclusion with some detail and some errors for Formation of buffer <b>AND</b> Calculation of the buffer pH <b>OR</b> Formation of buffer <b>AND</b> Mass of N<sub>2</sub>O<sub>3</sub>. <b>OR</b> Calculation of the buffer pH <b>AND</b> Mass of N<sub>2</sub>O<sub>3</sub>. <b>OR</b> Partial explanations of formation of the buffer <b>AND</b> buffer pH <b>AND</b> Mass of N<sub>2</sub>O<sub>3</sub>. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i></p> <p><b>Level 1 (1–2 marks)</b> Attempts, with some success, to: Describe formation of buffer <b>OR</b> Calculate buffer pH <b>OR</b> Obtain mass of N<sub>2</sub>O<sub>3</sub>. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p> <p><b>0 marks</b> No response or no response worthy of credit.</p>	6	<p>AO1.2 ×2</p> <p>AO2.6 ×2</p> <p>AO3.1 ×2</p>	<p><b>Indicative scientific points may include:</b></p> <p><b>1. Formation of buffer</b></p> <ul style="list-style-type: none"> <li>Acid / HNO<sub>2</sub> is in excess</li> <li>HNO<sub>2</sub> + NaOH → NaNO<sub>2</sub> + H<sub>2</sub>O</li> <li>Partial neutralisation of HNO<sub>2</sub> → formation of NO<sub>2</sub><sup>-</sup>/ NaNO<sub>2</sub></li> <li>Buffer contains HNO<sub>2</sub> <b>AND</b> NO<sub>2</sub><sup>-</sup>/NaNO<sub>2</sub></li> </ul> <p><b>2. Calculation of buffer pH</b></p> <ul style="list-style-type: none"> <li>n(HNO<sub>2</sub>) added = 0.0500 (mol)</li> <li>n(NaOH) added = 0.0150 (mol)</li> <li>n(NO<sub>2</sub><sup>-</sup>) formed = 0.0150 (mol)</li> <li>n(HNO<sub>2</sub>) remaining = 0.0500 – 0.0150 = 0.0350 (mol)</li> <li>K<sub>a</sub> = 10<sup>-3.34</sup> = 4.57... × 10<sup>-4</sup> (mol dm<sup>-3</sup>)</li> <li>Concentrations = mol (volume 1 dm<sup>3</sup>)</li> <li>[H<sup>+</sup>] = <math>\frac{4.57... \times 10^{-4} \times 0.0350}{0.0150}</math> = 1.0665... × 10<sup>-3</sup> (mol dm<sup>-3</sup>)</li> <li>pH = 2.97</li> <li>pH to 2 dec places</li> </ul> <p><b>3. Calculation of mass of N<sub>2</sub>O<sub>3</sub></b></p> <ul style="list-style-type: none"> <li>1 mol N<sub>2</sub>O<sub>3</sub> → 2 mol HNO<sub>2</sub> <b>OR</b> N<sub>2</sub>O<sub>3</sub> + H<sub>2</sub>O → 2HNO<sub>2</sub></li> <li>n(HNO<sub>2</sub>) = 0.0500 (mol)</li> <li>n(N<sub>2</sub>O<sub>3</sub>) = 0.0500/2 = 0.0250 (mol)</li> <li>m(N<sub>2</sub>O<sub>3</sub>) = 0.0250 × 76 = 1.9(0) g</li> </ul>
			<b>Total</b>	<b>16</b>	

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