

# Markscheme

**May 2021**

**Chemistry**

**Higher level**

**Paper 2**

24 pages

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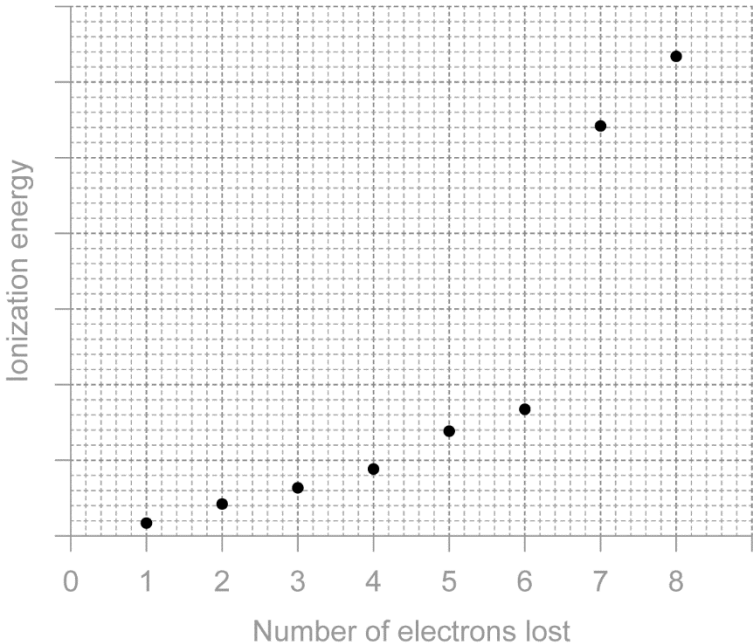
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## Subject Details: Chemistry Higher level Paper 2 Markscheme

Candidates are required to answer **ALL** questions. Maximum total = [90 marks].

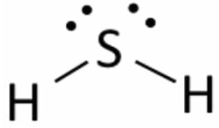
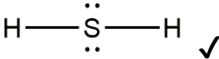
1. Each row in the “Question” column relates to the smallest subpart of the question.
2. The maximum mark for each question subpart is indicated in the “Total” column.
3. Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.
4. A question subpart may have more marking points than the total allows. This will be indicated by “**max**” written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.
5. An alternative word is indicated in the “Answers” column by a slash (/). Either word can be accepted.
6. An alternative answer is indicated in the “Answers” column by “**OR**”. Either answer can be accepted.
7. An alternative markscheme is indicated in the “Answers” column under heading **ALTERNATIVE 1** *etc.* Either alternative can be accepted.
8. Words inside chevrons « » in the “Answers” column are not necessary to gain the mark.
9. Words that are underlined are essential for the mark.
10. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.
11. If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by **OWTTE** (or words to that effect) in the “Notes” column.
12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.
13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script.
14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the “Notes” column.
15. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the “Notes” column. Similarly, if the formula is specifically asked for, do not award a mark for a correct name unless directed otherwise in the “Notes” column.
16. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the “Notes” column.
17. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the “Notes” column.

Question		Answers	Notes	Total
1.	a	mobile/delocalized «sea of >> electrons		1
1.	b	<p><i>Any two of:</i></p> <p>forms acidic oxides «rather than basic oxides» ✓</p> <p>forms covalent/bonds compounds «with other non-metals» ✓</p> <p>forms anions «rather than cations» ✓</p> <p>behaves as an oxidizing agent «rather than a reducing agent» ✓</p>	<p><i>Award [1 max] for 2 correct non-chemical properties such as non-conductor, high ionisation energy, high electronegativity, low electron affinity if no marks for chemical properties are awarded.</i></p>	2

Question			Answers	Notes	Total
1.	c		 <p>two regions of small increases <b>AND</b> a large increase between them ✓                      large increase from 6th to 7th ✓</p>	Accept line/curve showing these trends.	2
1.	d	i	electrostatic attraction ✓ between oppositely charged ions/between Fe <sup>2+</sup> and S <sup>2-</sup> ✓		2

Question			Answers	Notes	Total
1.	d	ii	X-ray crystallography ✓		1
1.	d	iii	$1s^2 2s^2 2p^6 3s^2 3p^6$ ✓	<i>Do not accept "[Ne] 3s<sup>2</sup> 3p<sup>6</sup>".</i>	1
1.	d	iv	«valence» electrons further from nucleus/extra electron shell/ electrons in third/3s/3p level «not second/2s/2p» ✓	<i>Accept 2,8 (for O<sup>2-</sup>) and 2,8,8 (for S<sup>2-</sup>)</i>	1
1.	d	v	allows them to explain the properties of different compounds/substances <b>OR</b> enables them to generalise about substances <b>OR</b> enables them to make predictions ✓	<i>Accept other valid answers.</i>	1
1.	e	i	$4\text{FeS(s)} + 7\text{O}_2\text{(g)} \rightarrow 2\text{Fe}_2\text{O}_3\text{(s)} + 4\text{SO}_2\text{(g)}$ ✓	<i>Accept any correct ratio.</i>	1
1.	e	ii	+6 <b>OR</b> -2 to +4 ✓	<i>Accept "6/VI". Accept "-II, 4/+4/IV". Do not accept 2- to 4+.</i>	1

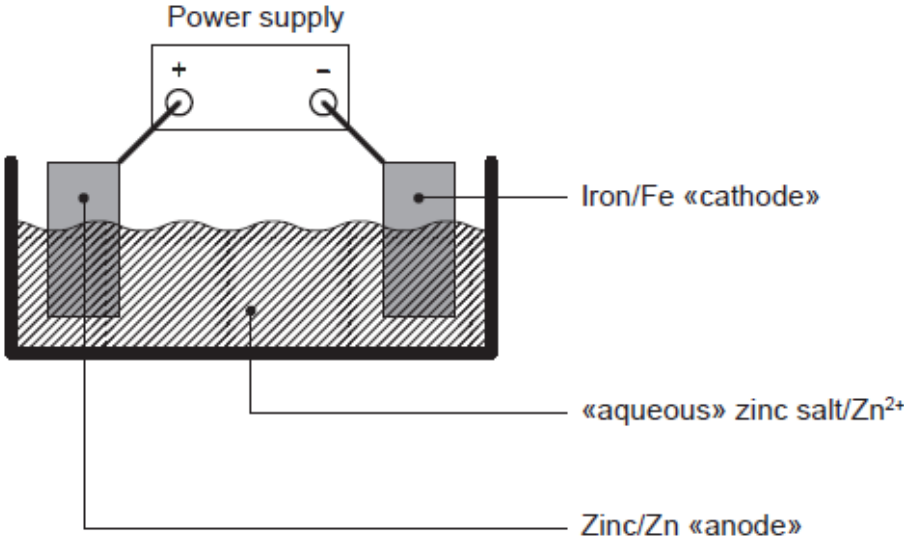
Question			Answers	Notes	Total
1.	e	iii	sulfur dioxide/SO <sub>2</sub> causes acid rain ✓	Accept sulfur dioxide/SO <sub>2</sub> /dust causes respiratory problems Do <b>not</b> accept just "causes respiratory problems" or "causes acid rain".	1
1.	f		disrupts the regular arrangement «of iron atoms/ions» <b>OR</b> carbon different size «to iron atoms/ions» ✓  prevents layers/atoms sliding over each other ✓		2

Question			Answers	Notes	Total
2.	a	i	 OR  ✓	Accept any combination of lines, dots or crosses to represent electrons.	1
2.	a	ii	bent/non-linear/angular/v-shaped ✓		1
2.	b	i	HS <sup>-</sup> ✓		1
2.	b	ii	weak <b>AND</b> strong acid of this concentration/[H <sup>+</sup> ] = 0.1 mol dm <sup>-3</sup> would have pH = 1 <b>OR</b> weak <b>AND</b> [H <sup>+</sup> ] = 10 <sup>-4</sup> < 0.1 «therefore only fraction of acid dissociated» ✓		1
2.	b	iii	10 <sup>-10</sup> «mol dm <sup>-3</sup> » ✓		1

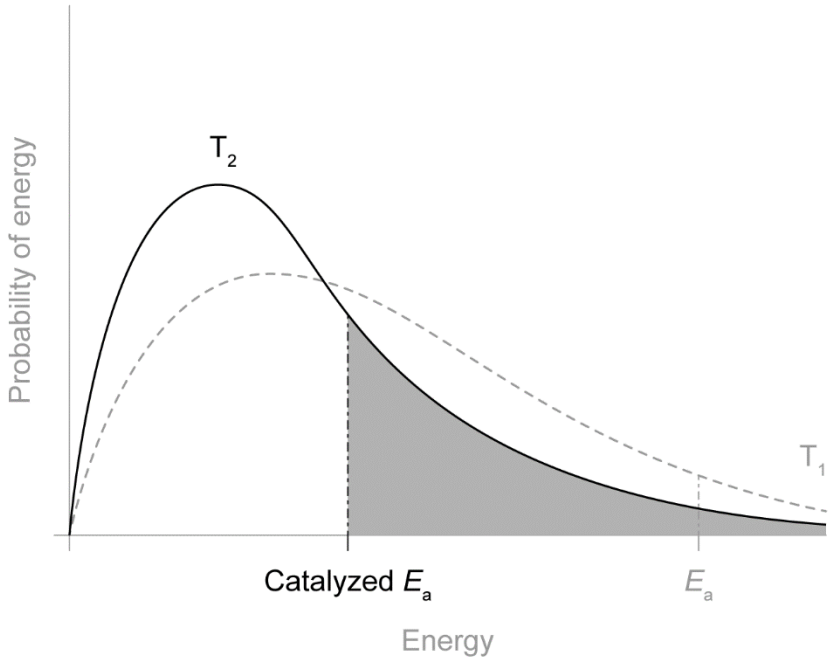




Question			Answers	Notes	Total																			
3.	a		1:2 ✓	Accept 2 Fe <sup>3+</sup> : 1 Fe <sup>2+</sup> Do <b>not</b> accept 2:1 only	1																			
3.	b	i	mass «spectroscopy»/MS ✓																					
3.	b	ii	<table border="1" style="width: 100%; text-align: center;"> <tr> <td></td> <td><i>Protons</i></td> <td></td> <td><i>Neutrons</i></td> <td></td> <td><i>Electrons</i></td> <td></td> </tr> <tr> <td></td> <td>26</td> <td rowspan="2"><b>AND</b></td> <td>28</td> <td rowspan="2"><b>AND</b></td> <td>26</td> <td>✓</td> </tr> <tr> <td></td> <td>26</td> <td>30</td> <td>23</td> <td>✓</td> </tr> </table>		<i>Protons</i>		<i>Neutrons</i>		<i>Electrons</i>			26	<b>AND</b>	28	<b>AND</b>	26	✓		26	30	23	✓	Award [1 max] for 4 correct values.	2
	<i>Protons</i>		<i>Neutrons</i>		<i>Electrons</i>																			
	26	<b>AND</b>	28	<b>AND</b>	26	✓																		
	26		30		23	✓																		
3.	c		specific heat capacity « $= \frac{q}{m \times \Delta T} / \frac{1000 \text{ J}}{50 \text{ g} \times 44 \text{ K}}$ » = 0.45 «J g <sup>-1</sup> K <sup>-1</sup> » ✓		1																			
3.	d		<p><i>Equation:</i> 2Fe<sup>3+</sup>(aq) + Fe(s) → 3Fe<sup>2+</sup>(aq) ✓</p> <p><i>Cell potential:</i> «+0.77 V - (-0.45 V) = +» 1.22 «V» ✓</p>	<p>Do <b>not</b> accept reverse reaction or equilibrium arrow.</p> <p>Do <b>not</b> accept negative value for M2.</p>	2																			

Question		Answers	Notes	Total
3.	e	 <p>left electrode/anode labelled zinc/Zn <b>AND</b> right electrode/cathode labelled iron/Fe ✓ electrolyte labelled as «aqueous» zinc salt/Zn<sup>2+</sup> ✓</p>	<p>Accept an inert conductor for the anode. Accept specific zinc salts such as ZnSO<sub>4</sub>.</p>	2
3.	f	<p>« Zn<sup>2+</sup> » has a full d-shell <b>OR</b> does not form « ions with » an incomplete d-shell</p>	<p>Do <b>not</b> accept “Zn is not a transition metal”.  Do <b>not</b> accept zinc atoms for zinc ions.</p>	1

Question		Answers	Notes	Total
3.	g	ligands donate pairs of electrons to metal ions <b>OR</b> forms coordinate covalent/dative bond ✓  ligands are Lewis bases <b>AND</b> metal «ions» are Lewis acids ✓		2

Question	Answers	Notes	Total
<p>4. a</p>	 <p>The graph plots 'Probability of energy' on the y-axis and 'Energy' on the x-axis. Two curves originate from the origin: a solid curve labeled <math>T_2</math> and a dashed curve labeled <math>T_1</math>. The <math>T_2</math> curve is higher and narrower than the <math>T_1</math> curve. A vertical dashed line marks the activation energy for <math>T_2</math> as 'Catalyzed <math>E_a</math>'. The area under the <math>T_2</math> curve to the left of this line is shaded grey. Another vertical dashed line marks the activation energy for <math>T_1</math> as '<math>E_a</math>'.</p> <p>curve higher <b>AND</b> to left of <math>T_1</math> ✓            new/catalysed <math>E_a</math> marked <b>AND</b> to the left of <math>E_a</math> of curve <math>T_1</math> ✓</p>	<p>Do <b>not</b> penalize curve missing a label, not passing exactly through the origin, or crossing x-axis after <math>E_a</math>.</p> <p>Do <b>not</b> award M1 if curve drawn shows significantly more/less molecules/greater/smaller area under curve than curve 1.</p> <p>Accept <math>E_a</math> drawn to <math>T_1</math> instead of curve drawn as long as to left of marked <math>E_a</math>.</p>	<p>2</p>

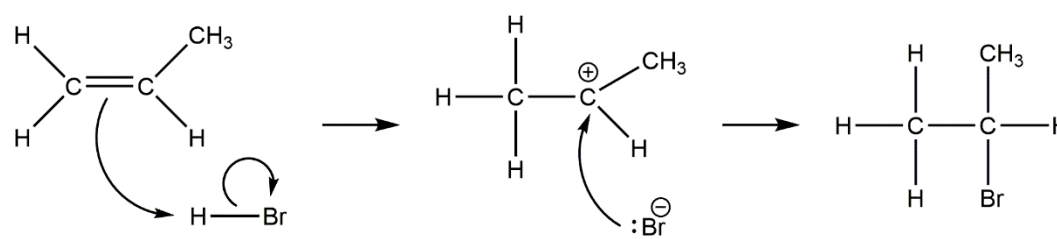
Question			Answers	Notes	Total
4.	b		methanoic acid/HCOOH/CHOOH <b>OR</b> methanal/HCHO ✓	Accept "carbon dioxide/CO <sub>2</sub> ".	1
4.	c	i	CH <sub>4</sub> (g) + H <sub>2</sub> O(g) ⇌ CH <sub>3</sub> OH(l) + H <sub>2</sub> (g) ✓	Accept arrow instead of equilibrium sign.	1
4.	c	ii	amount of methane = $\llcorner \frac{8.00 \text{ g}}{16.05 \text{ g mol}^{-1}} = \gg 0.498 \llcorner \text{mol} \gg \llcorner \checkmark$ amount of hydrogen = amount of methane / 0.498 $\llcorner \text{mol} \gg \llcorner \checkmark$ volume of hydrogen = $\llcorner 0.498 \text{ mol} \times 22.7 \text{ dm}^3 \text{ mol}^{-1} = \gg 11.3 \llcorner \text{dm}^3 \gg \llcorner \checkmark$	Award [3] for final correct answer. Award [2 max] for 11.4 $\llcorner \text{dm}^3$ due to rounding of mass to 16/moles to 0.5. $\gg$	3
4.	d	i	$\Sigma$ bonds broken = $4 \times 414 \llcorner \text{kJ} \gg + 2 \times 463 \llcorner \text{kJ} \gg / 2582 \llcorner \text{kJ} \gg \llcorner \checkmark$ $\Sigma$ bonds formed = $1077 \llcorner \text{kJ} \gg + 3 \times 436 \llcorner \text{kJ} \gg / 2385 \llcorner \text{kJ} \gg \llcorner \checkmark$ $\Delta H \llcorner = \Sigma$ bonds broken – $\Sigma$ bonds formed = $(2582 \text{ kJ} - 2385 \text{ kJ}) \gg = \llcorner + \gg 197 \llcorner \text{kJ} \gg \llcorner \checkmark$	Award [3] for final correct answer. Award [2 Max] for final answer of –197 $\llcorner \text{kJ} \gg$	3
4.	d	ii	bond energies are average values $\llcorner \text{not specific to the compound} \gg \llcorner \checkmark$		1

Question			Answers	Notes	Total
4.	d	iii	$K_c = \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]} \checkmark$		1
4.	d	iv	$K_c$ increases <b>AND</b> «forward» reaction endothermic $\checkmark$		1
4.	e	i	« $\Delta G^\ominus = -RT \ln K_c$ » $\Delta G^\ominus = -8.31 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} \times 298 \text{ «K»} \times \ln(1.01) / -24.6 \text{ «J mol}^{-1}\text{»} \checkmark$ $= -0.0246 \text{ «kJ mol}^{-1}\text{»} \checkmark$	Award [2] for correct final answer. Award [1 max] for +0.0246 «kJ mol <sup>-1</sup> ».	2
4.	e	ii	« $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ » $\Delta G^\ominus = -129 \text{ «kJ mol}^{-1}\text{»} - (298 \text{ «K»} \times \Delta S) = -0.0246 \text{ «kJ mol}^{-1}\text{»} \checkmark$ $\Delta S^\ominus = \text{«} \frac{(-129 \text{ kJ mol}^{-1} + 0.0246 \text{ kJ mol}^{-1}) \times 10^3}{298 \text{ K}} = \text{»} -433 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} \checkmark$	Award [2] for correct final answer. Award [1 max] for “-0.433 «kJ K <sup>-1</sup> mol <sup>-1</sup> »”. Award [1 max] for “433” or “+433” «J K <sup>-1</sup> mol <sup>-1</sup> ». Award [2] for -430 «J K <sup>-1</sup> mol <sup>-1</sup> » (result from given values).	2
4.	e	iii	«negative as» product is liquid and reactants gases <b>OR</b> fewer moles of gas in product $\checkmark$		1

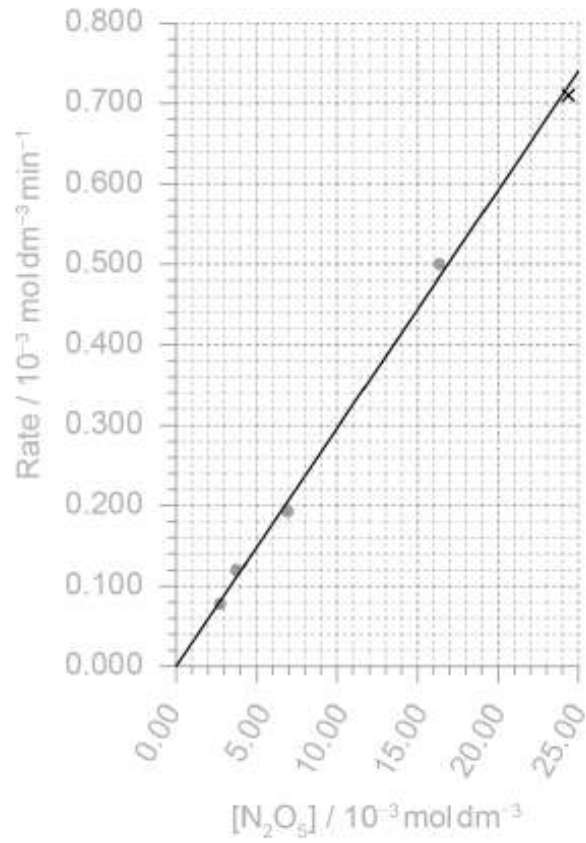
Question			Answers	Notes	Total
4.	e	iv	reaction «more» spontaneous/ $\Delta G$ negative/less positive <b>AND</b> effect of negative entropy decreases/ $T\Delta S$ increases/is less negative/more positive <b>OR</b> reaction «more» spontaneous/ $\Delta G$ negative/less positive <b>AND</b> reaction exothermic «so $K_c$ increases » ✓	<i>Award mark if correct calculation shown.</i>	1



Question			Answers	Notes	Total
5.	a	i	alkene ✓		1
5.	a	ii	C <sub>3</sub> H <sub>6</sub> ✓	<i>Accept structural formula.</i>	1
5.	b	i	hydrogen atoms/protons in same chemical environment ✓	<i>Accept "all H atoms/protons are equivalent". Accept "symmetrical"</i>	1
5.	b	ii	4.5 to 6.0 «ppm» ✓	<i>Accept a single value within this range.</i>	1
5.	c		carbon monoxide/CO <b>AND</b> carbon/C/soot ✓		1
5.	d		«addition» polymerization ✓		1

Question			Answers	Notes	Total
5.	e	i	 <p>curly arrow going from C=C to H of HBr <b>AND</b> curly arrow showing Br leaving ✓                      representation of carbocation ✓                      curly arrow going from lone pair/negative charge on Br<sup>-</sup> to C<sup>+</sup> ✓</p>	<p><i>Award [2 max] for mechanism producing 1-bromopropane.</i></p>	3
5.	e	ii	<p>«2-bromopropane involves» formation of more stable «secondary» carbocation/carbonium ion/intermediate  <b>OR</b>                      1-bromopropane involves formation of less stable «primary» carbocation/carbonium ion/intermediate ✓                      «increased» positive inductive/electron-releasing effect of extra -R group/-CH<sub>3</sub>/methyl «increases stability of secondary carbocation» ✓</p>	<p><i>Award [1] for “more stable due to positive inductive effect”.                      Do <b>not</b> award marks for quoting Markovnikov’s rule without any explanation.</i></p>	2
5.	e	iii	<p>sodium hydroxide/NaOH/potassium hydroxide/KOH ✓</p>	<p><i>Accept «aqueous» hydroxide ions/OH<sup>-</sup></i></p>	1
5.	e	iv	<p>Name of carbonyl compound:                      propanone ✓</p> <p>Type of reaction:                      reduction ✓</p>	<p><i>Accept other valid alternatives, such as “2-propyl ethanoate” for M1 and “hydrolysis” for M2.</i></p>	2

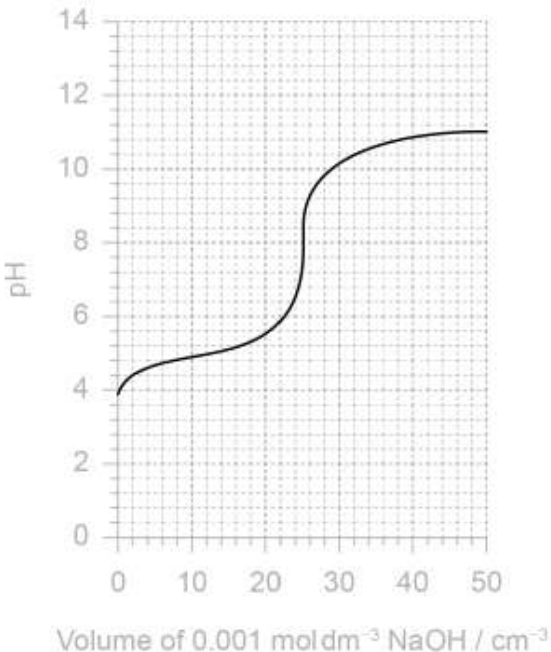
Question			Answers	Notes	Total
6.	a		use colorimeter <b>OR</b> change in colour <b>OR</b> change in volume <b>OR</b> change in pressure ✓	<i>Accept suitable instruments, e.g. pressure probe/oxygen sensor.</i>	1

Question			Answers	Notes	Total
6.	b	i	 <p>point correct ✓ straight line passing close to all points <b>AND</b> through origin ✓</p>	<p>Accept free hand drawn line as long as attempt to be linear and meets criteria for M2.</p>	2

Question			Answers	Notes	Total
6.	b	ii	greater frequency of collisions «as concentration increases» <b>OR</b> more collisions per unit time «as concentration increases» ✓	Accept “rate/chance/probability/likelihood” instead of “frequency”. Do <b>not</b> accept just “more collisions”.	1
6.	b	iii	rate = $k[\text{N}_2\text{O}_5]$ ✓		1
6.	b	iv	$k = \frac{\Delta \text{rate}}{\Delta [\text{N}_2\text{O}_5]}$ ✓  « $k = \frac{0.75 \times 10^{-3} \text{ «mol dm}^{-3} \text{ min}^{-1}\text{»}}{25 \times 10^{-3} \text{ «mol dm}^{-3}\text{»}} = \text{» } 0.030 \text{ «min}^{-1}\text{»}$ ✓  min <sup>-1</sup> ✓	M1 can be awarded from correct M2 if not explicitly stated.  Accept $k = \text{gradient}$ .  Accept values in the range 0.028–0.032.  Award <b>[3]</b> for correct final answer.	3

Question			Answers	Notes	Total
7.	a	i	$\begin{array}{c} \text{:}\ddot{\text{O}}\text{---}\ddot{\text{O}}\text{=}\ddot{\text{O}}\text{:} \\ \text{:}\ddot{\text{O}}\text{=}\ddot{\text{O}}\text{---}\ddot{\text{O}}\text{:} \end{array}$ <p style="text-align: center;"><i>OR</i></p> $\begin{array}{c} \text{:}\ddot{\text{O}}\text{=}\ddot{\text{O}}\text{---}\ddot{\text{O}}\text{:} \\ \text{:}\ddot{\text{O}}\text{---}\ddot{\text{O}}\text{=}\ddot{\text{O}}\text{:} \end{array}$ <p style="text-align: center;">✓</p>	<p>Accept any combination of lines, dots or crosses to represent electrons. Do <b>not</b> accept structures that represent 1.5 bonds.</p>	1
7.	a	ii	<p>both equal ✓ delocalization/resonance ✓</p>	<p>Accept bond length between 121 and 148 pm/ that of single O-O bond and double O=O bond for M1.</p>	2
7.	b		<p>bond in O<sub>3</sub> is weaker <b>OR</b> O<sub>3</sub> bond order 1.5/&lt; 2 ✓</p> <p>lower frequency/longer wavelength «UV light» has enough energy to break the O–O bond in O<sub>3</sub> «but not that in O<sub>2</sub>» ✓</p>	<p>Do <b>not</b> accept bond in O<sub>3</sub> is longer for M1.</p> <p>Accept “lower frequency/longer wavelength «UV light» has lower energy”.</p>	2
7.	c		<p>CCl<sub>2</sub>F<sub>2</sub>(g) → •CClF<sub>2</sub>(g) + Cl•(g) ✓</p> <p>Cl•(g) + O<sub>3</sub>(g) → O<sub>2</sub>(g) + ClO•(g) <b>AND</b> ClO•(g) + O<sub>3</sub>(g) → 2O<sub>2</sub>(g) + Cl•(g) ✓</p>	<p>Do <b>not</b> penalize missing radical.</p> <p>Accept:for M2: Cl•(g) + O<sub>3</sub>(g) → O<sub>2</sub>(g) + ClO•(g) <b>AND</b> ClO•(g) + O(g) → O<sub>2</sub>(g) + Cl•(g)</p>	2

Question		Answers	Notes	Total
8.	a	$K_a = 10^{-4.87} / 1.35 \times 10^{-5} \checkmark$ $[H^+] = \sqrt{1.35 \times 10^{-5} \times 0.001} = \sqrt{1.35 \times 10^{-8}} \Rightarrow 1.16 \times 10^{-4} \text{ «mol dm}^{-3}\text{»} \checkmark$ pH = 3.94 $\checkmark$	Accept alternative methods of calculation.  Award <b>[3]</b> for correct final answer.  Award <b>[3]</b> for 3.96 {answer if solved by quadratic}.	<b>3</b>

Question	Answers	Notes	Total
<p>8. b</p>	 <p>Any three of:                      correct "S" shape ✓                      equivalence point at 25 cm<sup>3</sup> ✓                      final pH tends to 11 ✓                      pH at equivalence point &gt;7 ✓                      starting pH between 3.8 - 4 ✓                      pH at half equivalence approx. 5 ✓</p>	<p><i>Do not penalize for incorrect points. Award any 3 correct.</i></p>	<p>3</p>