

# Markscheme

November 2022

Chemistry

Higher level

Paper 2

25 pages

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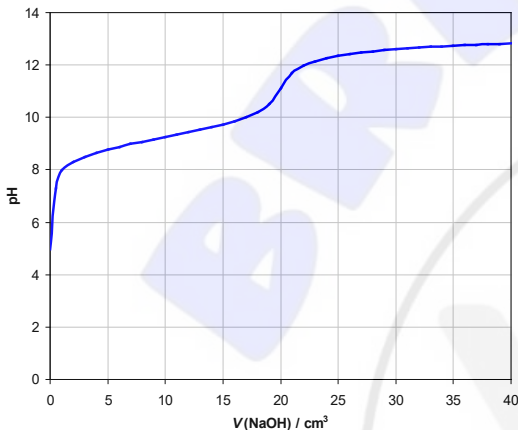
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## Subject Details: Chemistry higher level Paper 2 Markscheme

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)		$\%N = \frac{2 \times 14.01 \text{ g mol}^{-1}}{(2 \times 14.01 \text{ g mol}^{-1} + 4 \times 1.01 \text{ g mol}^{-1} + 3 \times 16.00 \text{ g mol}^{-1})} \times 100\% \Rightarrow 35.00\% \checkmark$		1
1.	(b)		«Brønsted-Lowry» acid <b>AND</b> can donate a proton/H <sup>+</sup> <b>OR</b> «Brønsted-Lowry» acid <b>AND</b> cannot accept proton/H <sup>+</sup> ✓		1
1.	(c)	(i)	$\text{pH} = -\log(1.07 \times 10^{-5}) \Rightarrow 4.97 \checkmark$		1
1.	(c)	(ii)	$\text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$ <b>OR</b> $\text{NH}_4\text{NO}_3(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{NaNO}_3(\text{aq}) \checkmark$	Accept NH <sub>4</sub> OH instead of NH <sub>3</sub> + H <sub>2</sub> O.	1
1.	(c)	(iii)	$n(\text{NH}_4\text{NO}_3) = 0.20 \text{ mol dm}^{-3} \times 0.02000 \text{ dm}^3 \Rightarrow 0.0040 \text{ «mol NH}_4\text{NO}_3\text{»} \checkmark$ $\text{«[NH}_3\text{] at equivalence point} = \frac{0.0040 \text{ mol}}{0.04000 \text{ dm}^3} \Rightarrow 0.10 \text{ «mol dm}^{-3}\text{»} \checkmark$ $\text{«}K_b = 10^{-\text{p}K_b} = 10^{-4.75} = 1.8 \times 10^{-5}\text{»}$ $\text{«[OH}^-] = \sqrt{K_b[\text{NH}_3]} = \sqrt{1.8 \times 10^{-5}(0.10)} \Rightarrow 0.0013 \text{ «mol dm}^{-3}\text{»} \checkmark$ $\text{«pOH} = -\log(0.0013) = 2.89\text{»}$ $\text{«pH} = 14.00 - \text{pOH} \Rightarrow 11.11 \checkmark$	Award [4] for correct final answer. Accept a range of 11.11 – 11.14.	4

Question			Answers	Notes	Total
1.	(c)	(iv)	 <p>non-symmetrical sigmoidal curve, starting pH 2–7 <b>AND</b> terminating pH&gt;12 ✓</p> <p>equivalence point pH approximately 11 <b>AND</b> at a volume 20 cm<sup>3</sup> ✓</p>		2

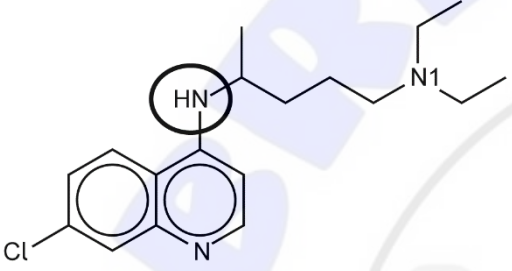
Question			Answers	Notes	Total
1.	(c)	(v)	<p>no <b>AND</b> the end point is not in the sharp part of the curve</p> <p><b>OR</b></p> <p>no <b>AND</b> the equivalence point does not fall within the end-point/pH range of the indicator</p> <p><b>OR</b></p> <p>no <b>AND</b> there is a large difference in volume between end point and equivalence point</p> <p><b>OR</b></p> <p>no <b>AND</b> no sharp rise in pH «near equivalence point» ✓</p>		1
1.	(d)	(i)	<p>«<math>q = mc\Delta T = 25.32 \text{ g} \times 4.18 \text{ J g}^{-1}\text{K}^{-1} \times (25.2^\circ\text{C} - 0.8^\circ\text{C}) \Rightarrow 2580 \text{ «J»} \checkmark</math></p>	Do <b>not</b> accept a negative value.	1
1.	(d)	(ii)	<p>«<math>2.58 \times 10^3 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times \frac{1 \text{ mol}}{25.69 \text{ kJ}} \Rightarrow 0.100 \text{ «mol»} \checkmark</math></p> <p>«<math>0.100 \text{ mol} \times 80.06 \text{ g mol}^{-1} \Rightarrow 8.01 \text{ «g»} \checkmark</math></p>	<p>Award <b>[2]</b> for the correct final answer.</p> <p>Accept range of 8.0 – 8.1 g.</p> <p>If <math>3.11 \times 10^3 \text{ J}</math> used then answer is 9.69 g.</p>	2

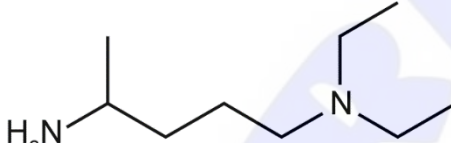
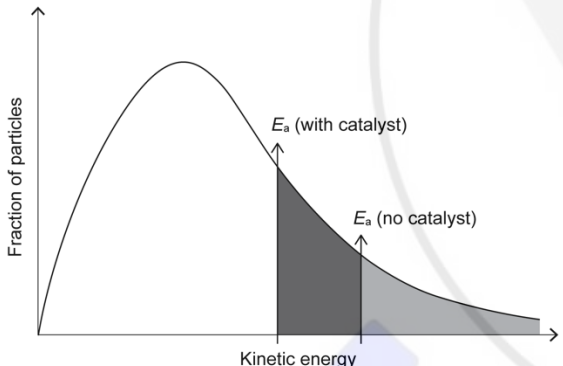
Question			Answers	Notes	Total
1.	(d)	(iii)	<p>«fractional / % uncertainty in <math>\Delta T = \frac{0.4}{24.4} / 0.02 / 2\% \checkmark</math></p> <p>«fractional / % uncertainty in <math>m = \frac{0.01}{25.32} / 0.0004 / 0.04\% \checkmark</math></p> <p><b>OR</b></p> <p>fractional / % uncertainty in <math>m</math> is much smaller than uncertainty in <math>\Delta T \checkmark</math></p> <p>«<math>2\% \times 8.01 \text{ g} = 0.2 \text{ g} \checkmark</math></p>	<p>Award [3] for correct final answer.</p> <p>Accept range of 0.1 g – 0.2 «g».</p> <p>If 6.55 g used then the answer is 0.1 «g».</p>	3
1.	(d)	(iv)	<p>«% error = <math>\left  \frac{9.50 \text{ g} - 8.01 \text{ g}}{9.50 \text{ g}} \right  \times 100 \% = 15.7\% \checkmark</math></p>	<p>Accept range 14.7 – 15.8«%».</p> <p>If 6.55 g used then answer is 31.1«%».</p>	1
1.	(d)	(v)	<p>«<math>\Delta S^\circ = 259.8 \text{ J mol}^{-1} \text{ K}^{-1} - 151.1 \text{ J mol}^{-1} \text{ K}^{-1} = 108.7 \text{ J mol}^{-1} \text{ K}^{-1} \checkmark</math></p>		1
1.	(d)	(vi)	<p>«<math>\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = 25.69 \text{ kJ mol}^{-1} - 298 \text{ K} \left( 108.7 \text{ J mol}^{-1} \text{ K}^{-1} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \right) = -6.70 \text{ kJ mol}^{-1} \checkmark</math></p>	<p>If <math>102.3 \text{ J mol}^{-1} \text{ K}^{-1}</math> is used then answer is <math>-4.80 \text{ kJ mol}^{-1}</math>.</p>	1
1.	(d)	(vii)	<p>«<math>\Delta G^\circ = -RT \ln K</math></p> <p>«<math>-6.70 \text{ kJ} \times \frac{1000 \text{ J}}{\text{kJ}} = -8.31 \text{ J K}^{-1} (298 \text{ K}) \ln K</math></p> <p>«<math>\ln K = 2.71 \checkmark</math></p> <p>«<math>K = e^{2.71} = 15.0 \checkmark</math></p>	<p>Award [2] for correct final answer.</p> <p>If <math>-7.84 \text{ kJ}</math> is used then answer is 23.7.</p>	2

Question			Answers	Notes	Total
1.	(d)	(viii)	product/right/solution/ $\text{NH}_4\text{NO}_3(\text{aq})$ is favoured <b>AND</b> $K > 1$ ✓	Accept $K$ large.  Accept other valid ways of justifying equilibrium position such as $\Delta G < 0$ /spontaneous/ $\Delta H < 0$ AND $\Delta S > 0$ .	1
1.	(e)		Anode: $\text{H}_2\text{O}(\text{l}) \rightarrow 1/2\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$ ✓  Cathode: $\text{H}^+(\text{aq}) + \text{e}^- \rightarrow 1/2\text{H}_2(\text{g})$ ✓	Do <b>not</b> accept other equations.	2
1.	(f)	(i)	$\text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{N}_2\text{O}(\text{g}) + 2\text{H}_2\text{O}(\text{l})$ ✓		1
1.	(f)	(ii)	«5.00 g ÷ 80.06 g mol <sup>-1</sup> ⇒ 0.0625 mol « $\text{NH}_4\text{NO}_3$ » ✓ «1:1 mol ratio» «0.0625 mol $\text{N}_2\text{O}$ × $\frac{22.7 \text{ dm}^3}{\text{mol}}$ ⇒ 1.42 «dm <sup>3</sup> » ✓	Award <b>[2]</b> for correct final answer.  Accept range 1.36 – 1.43 «dm <sup>3</sup> ».  Accept calculations based on $PV = nRT$ .	2

Question			Answers	Notes	Total
1.	(f)	(iii)	$2 \times -285.8 \text{ «kJ mol}^{-1}\text{»} \checkmark$  $\text{«1 mol (82 kJ mol}^{-1}\text{) + 2 mol (-285.8 kJ mol}^{-1}\text{) - 1 mol (-366 kJ mol}^{-1}\text{) =» -124 «kJ»} \checkmark$	<i>Award [2] for correct final answer.</i>	2
1.	(f)	(iv)	<p><i>Entropy change:</i></p> <p>positive <b>AND</b> formation of gas «and liquid from solid» <math>\checkmark</math></p> <p><i>Gibbs free energy change:</i></p> <p>negative <b>AND</b> increase in entropy/<math>\Delta S</math> positive <b>AND</b> exothermic reaction/<math>\Delta H</math> negative <math>\checkmark</math></p>		2



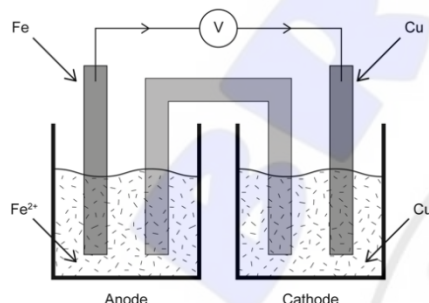
Question		Answers	Notes	Total
2.	(a)	 ✓		1
2.	(b)	nine/9 ✓		1
2.	(c)	seven/7 ✓		1
2.	(d)	«bond in ring is» shorter <b>AND</b> more electrons are shared <b>OR</b> «bond in ring is» shorter <b>AND</b> partial double/multiple bonding/bond order 1.5 ✓		1

Question			Answers	Notes	Total
2.	(e)	(i)	 <p>primary amine/-NH<sub>2</sub> ✓ rest of structure ✓</p>	Do not penalize using "N1".	2
2.	(e)	(ii)	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ / $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ <b>OR</b> $[\text{Ar}] 4s^1 3d^{10}$ / $[\text{Ar}] 3d^{10} 4s^1$ ✓		1
2.	(e)	(iii)	 <p>both <math>E_a</math> values marked <b>AND</b> left one labelled catalysed ✓</p>		1
2.	(e)	(iv)	increases rate <b>AND</b> there is a greater area under the curve past activation energy <b>OR</b> increases rate <b>AND</b> greater proportion of/more molecules have «kinetic» $E \geq E_a$ «(cat) than $E_a$ (uncat)» ✓	Do not award a mark for general statements about catalysts such as "provides alternative pathway" or "lowers $E_a$ ".	1

Question		Answers	Notes	Total
3.	(a)	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ <b>OR</b> $[\text{Ar}]3d^6 \checkmark$		1
3.	(b)	$\frac{(63 \times 69) + (65 \times 31)}{100}$ <b>OR</b> $65x + (1 - x)63 = 63.62$ <b>AND</b> $x = 0.31 / 31\% \checkmark$ <b>AND</b> $1 - x = 0.69 / 69\% \checkmark$		1

Question		Answers	Notes	Total
3.	(c)	<p><math>\text{Cu}^{2+}</math> <b>AND</b> fewer shielding electrons/less electron-electron repulsion «from same nuclear charge»</p> <p><b>OR</b></p> <p><math>\text{Cu}^{2+}</math> <b>AND</b> larger effective nuclear charge</p> <p><b>OR</b></p> <p><math>\text{Cu}^{2+}</math> <b>AND</b> more energy required to remove electron from positive ion than neutral parent atom</p> <p><b>OR</b></p> <p><math>\text{Cu}^{2+}</math> <b>AND</b> smaller radius</p> <p><b>OR</b></p> <p><math>\text{Cu}^{2+}</math> <b>AND</b> electron is being lost from a lower energy/inner/3d orbital ✓</p>		1

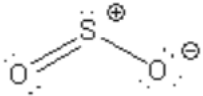
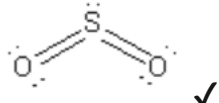
Question		Answers	Notes	Total
3.	(d)	<p><b>Alternative 1</b></p> $\langle E = 745 \text{ kJ mol}^{-1} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ atoms}} = \rangle 1.24 \times 10^{-21} \langle \text{kJ atom}^{-1} \rangle \checkmark$ <p><math>\langle E = h\nu \rangle</math></p> $\langle 1.24 \times 10^{-21} \text{ kJ} \times \frac{1000 \text{ J}}{1 \text{ kJ}} = 6.63 \times 10^{-34} \text{ J s} \times \nu \rangle$ <p><math>\langle \nu = \rangle 1.87 \times 10^{15} \langle \text{s}^{-1} \rangle \checkmark</math></p> <p><b>Alternative 2</b></p> <p><math>\langle E = h\nu \rangle</math></p> $\langle 745 \times 10^3 \text{ J mol}^{-1} = 6.63 \times 10^{-34} \text{ J s} \times \nu \rangle$ <p><math>\langle \nu = \rangle 1.12 \times 10^{39} \langle \text{s}^{-1} \text{ mol}^{-1} \rangle \checkmark</math></p> $\langle \nu = \frac{1.12 \times 10^{39} \text{ s}^{-1}}{6.02 \times 10^{23}} \rangle = 1.87 \times 10^{15} \langle \text{s}^{-1} \rangle \checkmark$	<p><i>Award [2] for correct final answer.</i></p>	2
3.	(e)	<p><math>\langle \text{iron atoms have 4} \rangle</math> unpaired electrons <math>\checkmark</math></p> <p>aligns with a magnetic field/paramagnetic</p> <p><b>OR</b></p> <p>has a magnetic moment</p> <p><b>OR</b></p> <p>ferromagnetic <math>\checkmark</math></p>	<p><i>For M1 accept diagrams showing unpaired electrons.</i></p>	2

Question			Answers	Notes	Total
3.	(f)	(i)	 <p>all 4 species correctly labelled ✓ arrow showing electron flow from anode to cathode in the external circuit ✓</p>	<p>Accept any soluble salt of copper(II) for <math>\text{Cu}^{2+}</math> and any soluble salt of iron(II) for <math>\text{Fe}^{2+}</math>.</p> <p>Do <b>not</b> apply ECF for M2.</p>	2
3.	(f)	(ii)	$\text{Fe(s)} \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \checkmark$	<p>Accept equilibrium arrow.</p> <p>Do <b>not</b> award ECF for <math>\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-</math>.</p>	1
3.	(f)	(iii)	<p>«keep» each half-cell/electrolyte «electrically» neutral ✓</p>	<p>Accept balance charges/ions.</p> <p>Accept allow ion flow «between cells».</p>	1

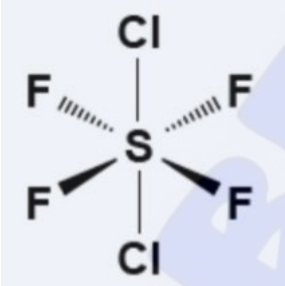
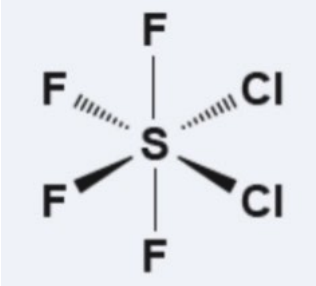
Question			Answers	Notes	Total
3.	(f)	(iv)	$\text{NO}_3^-$ to anode/Fe/left ✓ $\text{K}^+$ «and $\text{Fe}^{2+}$ » to cathode/Cu/right ✓	<p>Accept other specific anions in addition to nitrate for M1.</p> <p>Award <b>[1 max]</b> for “anions/negative ions to anode <b>AND</b> cations/positive ions to cathode”.</p>	2
3.	(f)	(v)	« $E^\ominus = + 0.34 \text{ V} - (- 0.45 \text{ V}) = +$ » 0.79 «V» ✓		1
3.	(f)	(vi)	« $\Delta G^\ominus = - nF E^\ominus = - 2 \text{ mol} \times (9.65 \times 10^4 \text{ C mol}^{-1}) \times (0.79 \text{ V}) \times =$ » -152 «kJ» ✓	Accept answers in the range 150 – 153.	1

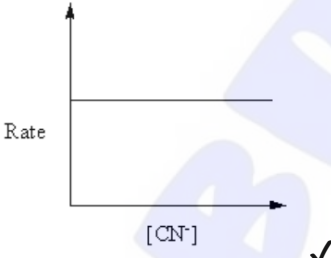
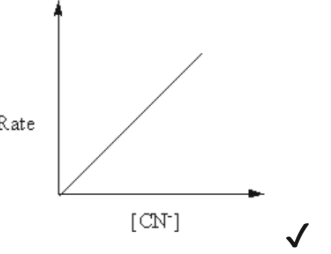
Question			Answers	Notes	Total
4.	(a)	(i)	<p>Structure:</p> <p>ester functional group ✓ rest of structure ✓</p> <p>Empirical Formula: C<sub>3</sub>H<sub>5</sub>O ✓</p>	Accept condensed/skeletal formula.	3
4.	(a)	(ii)	<p>dilute adds «excess» water <b>OR</b> water is a product ✓</p> <p>shift left <b>AND</b> decreases yield ✓</p>		2

Question			Answers	Notes	Total
4.	(a)	(iii)	<p><b>A</b> has hydrogen bonding/bonds «and dipole-dipole and London/dispersion forces»  <b>AND B</b> has dipole-dipole «and London/dispersion forces»</p> <p><b>OR</b></p> <p><b>A</b> has hydrogen bonding/bonds <b>AND B</b> does not ✓</p> <p>intermolecular forces are weaker in <b>B</b></p> <p><b>OR</b></p> <p>hydrogen bonding/bonds stronger «than dipole-dipole» ✓</p>		2
4.	(b)		<p>brown/orange/red/yellow to colourless ✓</p>	<p><i>Do not accept clear for colourless.</i></p>	1

Question		Answers	Notes	Total
5.	(a)	$\llcorner 0.40\% \times 500.0g = \gg 2.0 \llcorner g \gg \checkmark$  $\llcorner 2.0g \times \frac{1 \text{ mol } S}{32.07g} = 0.062 \text{ mol of } S \gg = 0.062 \llcorner \text{ mol of } SO_2 \gg \checkmark$	Award <b>[2]</b> for correct final answer.  Accept 0.063 «mol».	2
5.	(b)	$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$  <b>OR</b> $SO_2(g) + \frac{1}{2}O_2(g) \rightarrow SO_3(g)$ <b>AND</b> $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$  <b>OR</b> $SO_2(g) + \frac{1}{2}O_2(g) + H_2O(l) \rightarrow H_2SO_4(aq) \checkmark$	Accept ionized forms of acids.	1
5.	(c)	  <b>OR</b> 	Do <b>not</b> penalise missing formal charges.	1

Question		Answers	Notes	Total
5.	(d)	<p>Any <i>two</i> of:                      depth/volume «of solution» ✓                      colour/darkness/thickness/size/background of mark ✓                      intensity of lighting in the lab ✓</p>	<p>Accept same size flask.                      Accept position of observation/person observing.                      Accept same equipment/apparatus.                      Do <b>not</b> accept catalyst/particle size/pressure/time.</p>	2 max
5.	(e)	<p>Any <i>two</i> of:                      remove sulfur from coal ✓                      add lime during combustion ✓                      not allow sulfur oxides to be released into the environment ✓                      reduce proportion/percentage of energy/power produced by «the combustion of» coal ✓</p>	<p>Accept any valid method to wash coal and remove sulfur content for M1.                      Accept any valid combustion/post-combustion method to remove sulfur oxides.                      Accept any suggestion that would reduce the amount of coal that is burnt or would reduce the damage caused.                      Do <b>not</b> accept answers that only reduce production of SO<sub>2</sub>/CO<sub>2</sub> from other fuels.                      Accept “improve efficiency of energy production from coal”.                      Accept “use coal of lower sulfur content”                      OR “cleaner coal”.</p>	2 max

Question		Answers	Notes	Total
5.	(f)	<p><i>Non-polar isomer:</i></p>  <p><i>Polar isomer:</i></p> 	<p><i>Accept other methods of clearly representing 3D structure.</i></p>	2

Question		Answers	Notes	Total
6.	(a)	<p><math>S_N1</math> mechanism:</p>  <p><math>S_N2</math> mechanism:</p> 		2
6.	(b)	<p><math>S_N2</math> <b>AND</b> <math>S_N2</math> «mechanism» occurs with inversion of configuration</p> <p><b>OR</b></p> <p><math>S_N2</math> <b>AND</b> <math>S_N1</math> «mechanism» would create a racemic mixture ✓</p>	Accept appropriate diagrams.	1
6.	(c)	polarimeter ✓		1
6.	(d)	aprotic <b>AND</b> polar ✓		1

Question	Answers	Notes	Total
6. (e)	<p>slower <b>AND</b> C-Cl bond is stronger «than C-Br»</p> <p><b>OR</b></p> <p>slower <b>AND</b> Br/Br is a better leaving group ✓</p>		1
6. (f)	<p>arrow from – charge/lone pair to carbon attached to Br ✓</p> <p>arrow from C-Br bond to Br ✓</p> <p>transition state representing the partially formed and partially broken bonds ✓</p> <p><i>If S<sub>N</sub>1 was selected in 6 (b):</i></p> <p>arrow from C-Br bond to Br ✓</p> <p>carbocation intermediate ✓</p> <p>arrow from – charge/lone pair to carbocation ✓</p>		3

Question			Answers	Notes	Total
6.	(g)	(i)	<i>Number of signals:</i> 4 ✓  <i>Ratio of areas:</i> 3:1:2:3 ✓	<i>Accept ratio of areas in any order.</i>	2
6.	(g)	(ii)	<i>Splitting pattern of the signal of the hydrogen atoms in circle A:</i> doublet ✓  <i>Splitting pattern of the signal of the hydrogen atoms in circle B:</i> triplet ✓		2