



Markscheme

May 2022

Chemistry

Higher level

Paper 2

19 pages

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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	i	$2 \text{ Mg(s)} + \text{O}_2\text{(g)} \rightarrow 2 \text{ MgO(s)} \checkmark$	<i>Do not accept equilibrium arrows. Ignore state symbols.</i>	1
1.	a	ii	aluminium/Al \checkmark		1
1.	b	i	$\langle\langle \frac{53.726 \text{ g} - 47.372 \text{ g}}{24.31 \text{ g mol}^{-1}} = \frac{6.354 \text{ g}}{24.31 \text{ g mol}^{-1}} \rangle\rangle = 0.2614 \text{ «mol» } \checkmark$		1
1.	b	ii	mass of product « = $56.941 \text{ g} - 47.372 \text{ g} = 9.569 \text{ «g» } \checkmark$ $\langle\langle 100 \times \frac{2 \times 0.001 \text{ g}}{9.569 \text{ g}} = 0.0209 \rangle\rangle = 0.02 \text{ «%» } \checkmark$	<i>Award [2] for correct final answer Accept 0.021%.</i>	2
1.	b	iii	$\langle\langle 0.2614 \text{ mol} \times (24.31 \text{ g mol}^{-1} + 16.00 \text{ g mol}^{-1}) = 0.2614 \text{ mol} \times 40.31 \text{ g mol}^{-1} \rangle\rangle = 10.536 \text{ «g» } \checkmark$ $\langle\langle 100 \times \frac{9.569 \text{ g}}{10.536 \text{ g}} = 90.822 \rangle\rangle = 91 \text{ «%» } \checkmark$	<i>Award 0.2614 mol x 40.31 g mol⁻¹. Accept alternative methods to arrive at the correct answer. Accept final answer in the range 90.5-91.5%. [2] for correct final answer.</i>	2
1.	c	i	yes AND «each Mg combines with $\frac{2}{3}$ N, so» mass increase would be $14 \times \frac{2}{3}$ which is less than expected increase of $16 \times$ OR 3 mol Mg would form 101g of Mg_3N_2 but would form $3 \times \text{MgO} = 121 \text{ g}$ of MgO OR 0.2614 mol forms 10.536 g of MgO, but would form 8.796 g of $\text{Mg}_3\text{N}_2 \checkmark$	<i>Accept Yes AND “the mass of N/N₂ that combines with each g/mole of Mg is lower than that of O/O₂” Accept YES AND “molar mass of nitrogen less than of oxygen”.</i>	1

(continued...)

(Question 1 continued)

Question			Answers	Notes	Total
1.	c	ii	incomplete reaction OR Mg was partially oxidised already OR impurity present that evaporated/did not react ✓	Accept "crucible weighed before fully cooled". Accept answers relating to a higher atomic mass impurity consuming less O/O ₂ . Accept "non-stoichiometric compounds formed". Do not accept "human error", "wrongly calibrated balance" or other non-chemical reasons. If answer to (b)(iii) is >100%, accept appropriate reasons, such as product absorbed moisture before being weighed.	1
1.	d	i	«1» $\text{Mg}_3\text{N}_2(\text{s}) + 6 \text{H}_2\text{O}(\text{l}) \rightarrow 3 \text{Mg}(\text{OH})_2(\text{s}) + 2 \text{NH}_3(\text{aq})$ ✓		1
1.	d	ii	phenol red ✓	Accept bromothymol blue or phenolphthalein.	1
1.	d	iii	Mg_3N_2 : -3 AND NH_3 : -3 ✓	Do not Accept 3 or 3-.	1

(continued...)

(Question 1 continued)

Question			Answers	Notes	Total
1.	d	iv	<p><i>Acid–base:</i> yes AND N³⁻ accepts H⁺/donates electron pair«s» OR yes AND H₂O loses H⁺ «to form OH⁻»/accepts electron pair«s» ✓</p> <p><i>Redox:</i> no AND no oxidation states change ✓</p>	<p>Accept “yes AND proton transfer takes place”</p> <p>Accept reference to the oxidation state of specific elements not changing. Accept “not redox as no electrons gained/lost”.</p> <p>Award [1 max] for Acid–base: yes AND Redox: no, if no other mark is awarded.”</p>	2
1.	e	i	Protons: 7 AND Neutrons: 7 AND Electrons: 10 ✓		1
1.	e	ii	<u>isotope</u> «s» ✓		1
1.	e	iii	nitride AND smaller nuclear charge/number of protons/atomic number ✓		1
1.	e	iv	<p>nitrogen AND electron lost from first «energy» level/s sub-level/s-orbital AND magnesium from p sub-level/p-orbital/second «energy» level OR nitrogen AND electron lost from lower level «than magnesium» ✓</p>	Accept “nitrogen AND electron lost closer to the nucleus «than magnesium»”.	1

(continued...)

(Question 1 continued)

Question		Answers	Notes	Total
1.	f	<p>Any two of:</p> <p>subatomic particles «discovered» OR particles smaller/with masses less than atoms «discovered» OR «existence of» isotopes «same number of protons, different number of neutrons» ✓</p> <p>charged particles obtained from «neutral» atoms OR atoms can gain or lose electrons «and become charged» ✓</p> <p>atom «discovered» to have structure ✓</p> <p>fission OR atoms can be split ✓</p>	<p>Accept atoms can undergo fusion «to produce heavier atoms».</p> <p>Accept specific examples of particles.</p> <p>Award [2] for “atom shown to have a nucleus with electrons around it” as both M1 and M3.</p>	2

(continued...)

(Question 1 continued)

Question		Answers			Notes	Total
1.	g	Substance	Bond type	How the valence electrons produce these bonds	Award [1] for all bonding types correct. Award [1] for each correct description. Apply ECF for M2 only once.	4
		Magnesium	metallic AND	delocalized «throughout lattice attracted to cations» ✓ Accept reference to "sea"/flux of electrons «attracted to cations»		
		Oxygen	covalent AND	shared «between atoms» ✓		
		Magnesium oxide	ionic ✓	transferred «from magnesium to oxygen» OR lost by magnesium AND gained by oxygen ✓		

Question			Answers	Notes	Total
2.	a		<p>Alternative 1 put Mg in Zn^{2+} (aq) ✓ Zn/«black» layer forms «on surface of Mg» ✓</p> <p>Alternative 2 place both metals in acid ✓</p> <p>bubbles evolve more rapidly from Mg OR Mg dissolves faster ✓</p> <p>Alternative 3 construct a cell with Mg and Zn electrodes ✓</p> <p>bulb lights up OR shows (+) voltage OR size/mass of Mg(s) decreases <<over time>> OR size/mass of Zn increases <<over time>> ✓</p>	<p><i>Award [1 max] for “no reaction when Zn placed in Mg^{2+} (aq)”.</i></p> <p><i>Accept “electrons flow from Mg to Zn”. Accept Mg is negative electrode/anode OR Zn is positive electrode/cathode</i></p> <p><i>Accept other correct methods.</i></p>	2
2.	b	i	Cell potential: $\ll(-0.45\text{ V} - (-2.37\text{ V}))\gg = \ll+\gg 1.92\text{ V}\gg\checkmark$		1

(continued...)

(Question 2 continued)

Question			Answers	Notes	Total
2.	b	ii	$\Delta G^\circ = -nFE^\circ$ $n = 2$ OR $\Delta G^\circ = \langle - \rangle 2 \times 96500 \times 1.92 / \langle - \rangle 370,560 \text{ «J» } \checkmark$ $-371 \text{ «kJ» } \checkmark$	For $n = 1$, award [1] for -185 «kJ» . Award [1 max] for $(+)371 \text{ «kJ»}$.	2
2.	b	iii	$2 \text{ H}_2\text{O} + 2 \text{ e}^- \rightarrow \text{H}_2 + 2 \text{ OH}^- \checkmark$	Accept equation with equilibrium arrows.	1
2.	c	i	independent / not dependent \checkmark	Accept "zero order in Mg".	1
2.	c	ii	$\langle 2 \times 170 \text{ s} \rangle = 340 \text{ «s» } \checkmark$	Accept 320 – 360 «s». Accept 400 – 450 «s» based on no more gas being produced after 400 to 450s.	1
2.	c	iii	$\langle \text{relative/percentage} \rangle$ decrease in mass is $\langle \text{too} \rangle$ small/ $\langle \text{much} \rangle$ less \checkmark	Accept " $\langle \text{relative/percentage} \rangle$ uncertainty in mass loss $\langle \text{too} \rangle$ great". OR "density/molar mass of H_2 is $\langle \text{much} \rangle$ less than CO_2 ".	1

Question			Answers	Notes	Total
3.	a	i	$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$ ✓		1
3.	a	ii	same/unaffected/unchanged ✓		1
3.	a	iii	increasing pressure increases «all» concentrations OR increasing pressure decreases volume ✓ Q becomes less than K_c OR affects the lower line/denominator of Q expression more than upper line/numerator ✓ «for Q to once again equal K_c ,» ratio of products to reactants increases OR «for Q to once again equal K_c ,» equilibrium shifts to right/products ✓	Award [2 max] for answers that do not refer to Q.	3
3.	b	i	bonds broken: $N \equiv N + 3(H-H)$ / «1 mol×»945 «kJ mol ⁻¹ » + 3«mol»×436 «kJ mol ⁻¹ » / 945 «kJ» + 1308 «kJ» / 2253 «kJ» ✓ bonds formed: $6(N-H)$ / 6«mol»×391 «kJ mol ⁻¹ » / 2346 «kJ» ✓ $\Delta H = \text{«2253 kJ - 2346 kJ = » -93 «kJ»}$ ✓	Award [2 max] for (+)93 «kJ».	3
3.	b	ii	«N-H» bond enthalpy is an average «and may not be the precise value in NH_3 » ✓	Accept ΔH_f data are more accurate / are not average values.	1

(continued...)

(Question 3 continued)

Question			Answers	Notes	Total
3.	b	iii	increased temperature decreases yield «as shown on graph» ✓ shifts equilibrium in endothermic/reverse direction ✓		2
3.	c	i	spontaneous AND $\Delta G < 0$ ✓		1
3.	c	ii	$\ln K = \left\langle \left\langle -\frac{\Delta G}{R.T} \right\rangle \right\rangle = -\frac{-33000}{8.31 \times 298} / \left\langle \left\langle + \right\rangle \right\rangle 13.3$ ✓ $K = 6.13 \times 10^5$ ✓	Award [2] for correct final answer. Accept answers in the range 4.4×10^5 to 6.2×10^5 (arises from rounding of $\ln K$).	2
3.	c	iii	$\Delta G = \langle \Delta H - T\Delta S \rangle = -93000 \text{ «J»} - 298 \text{ «K»} \times \Delta S = -33000$ ✓ $\Delta S = \left\langle \left\langle \frac{-93000 \text{ J} - (-33000 \text{ J})}{298 \text{ K}} \right\rangle \right\rangle = -201 \text{ «J mol}^{-1} \text{ K}^{-1}\text{»}$ ✓	Do not penalize failure to convert kJ to J in both (c)(ii) and (c)(iii). Award [2] for correct final answer Award [1 max] for (+) 201 «J mol ⁻¹ K ⁻¹ ». Award [2] for -101 or -100.5 «J mol ⁻¹ K ⁻¹ ».	2
3	c	iv	«forward reaction involves» decrease in number of moles «of gas» ✓		1

Question			Answers	Notes	Total
4.	a		<u>conjugate</u> «acid and base» ✓		1
4.	b		amount of ammonia $\langle\langle = \frac{P.V}{R.T} = \frac{100.0 \text{ kPa} \times 900.0 \text{ dm}^3}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 300.0 \text{ K}} \rangle\rangle$ = 36.1 «mol» ✓ concentration $\langle\langle = \frac{n}{V} = \frac{36.1}{2.00} \rangle\rangle = 18.1 \text{ «mol dm}^{-3}\text{»} \checkmark$	Award [2] for correct final answer.	2
4.	c	i	$[\text{OH}^-] \langle\langle = \frac{K_w}{[\text{H}^+]} = \frac{10^{-14}}{10^{-9.3}} = 10^{-4.7} \rangle\rangle = 2.0 \times 10^{-5} \text{ «mol dm}^{-3}\text{»} \checkmark$		1
4.	c	ii	$K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} / \frac{10^{-4.7} \times 10^{-4.7}}{[\text{NH}_3]} \langle\langle = 10^{-4.75} \rangle\rangle \checkmark$ $[\text{NH}_3] = \langle\langle = \frac{10^{-9.4}}{10^{-4.75}} = 10^{-4.65} \rangle\rangle = 2.24 \times 10^{-5} \text{ «mol dm}^{-3}\text{»} \checkmark$	Accept other methods of carrying out the calculation. Award [2] for correct answer.	2
4.	c	iii	equilibrium shifts to right/H ⁺ reacts with NH ₃ ✓ «as large excess» ratio [NH ₃]:[NH ₄ ⁺] «and hence pH» almost unchanged ✓	Accept “strong acid/H ⁺ converted to a weak acid/NH ₄ ⁺ «and hence pH almost unchanged».	2
4.	d		Lewis acid ✓ accepts «a lone» electron pair «from the hydroxide ion» ✓	Do not accept electron acceptor without mention of electron pair.	2

(continued...)

(Question 4 continued)

Question		Answers	Notes	Total
4.	e	<p>ALTERNATIVE 1 <i>Property:</i> variable oxidation state ✓ <i>Comparison:</i> Mn compounds can exist in different valencies/oxidation states AND Mg has a valency/oxidation state of +2 in all its compounds ✓</p> <p>ALTERNATIVE 2 <i>Property:</i> coloured ions/compounds/complexes ✓ <i>Comparison:</i> Mn ions/compounds/complexes coloured AND Mg ions/compounds white/«as solids»/colourless «in aqueous solution» ✓</p> <p>ALTERNATIVE 3 <i>Property:</i> catalytic activity ✓ <i>Comparison:</i> «many» Mn compounds act as catalysts AND Mg compounds do not «generally» catalyse reactions ✓</p>	<p><i>Accept valency.</i> <i>Accept for second statement “Mg «always» has the same oxidation state”.</i></p> <p><i>Accept Mn forms coloured ions/compounds/complexes and Mg does not.</i></p> <p><i>For any property accept a correct specific example, for example manganate(VII) is purple.</i> <i>Do not accept differences in atomic structure, such as partially filled d sub-levels, but award ECF for a correct discussion.</i></p>	2

Question			Answers	Notes	Total
5.	a	i	2-methylpropan-2-ol /2-methyl-2-propanol ✓	Accept methylpropan-2-ol/ methyl-2-propanol. Do not accept 2-methylpropanol.	1
5.	a	ii	dipole-dipole ✓	Do not accept van der Waals' forces.	1
5.	a	iii	σ : 9 AND π : 1 ✓		1
5.	a	iv	sp^2 ✓		1
5.	a	v	butan-2-ol/ $CH_3CH(OH)C_2H_5$ ✓		1
5.	b	i			1
5.	b	ii	carbocation formed from $(CH_3)_3COH$ is more stable / $(CH_3)_3C^+$ is more stable than $(CH_3)_2CHCH_2^+$ ✓ «because carbocation has» greater number of alkyl groups/lower charge on the atom/higher e^- density OR «greater number of alkyl groups» are more electron releasing OR «greater number of alkyl groups creates» greater inductive/+I effect ✓	Do not award any marks for simply quoting Markovnikov's rule.	2

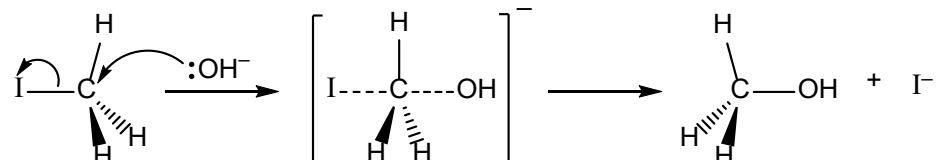
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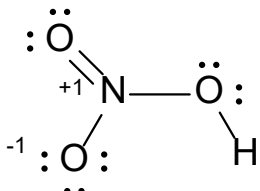
(Question 5 continued)

Question			Answers	Notes	Total
5.	b	iii	$\left[\begin{array}{cc} \text{CH}_3 & \text{H} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{CH}_3 & \text{H} \end{array} \right]_n \checkmark$	Do not penalize missing brackets or <i>n</i> . Do not award mark if continuation bonds are not shown.	1
5.	c		no change «in colour/appearance/solution» ✓		1
5.	d	i	«nucleophilic» substitution OR SN2 ✓	Accept “hydrolysis”. Accept SN1	1
5.	d	ii	energy/ $E \geq$ activation energy/ E_a ✓ correct orientation «of reacting particles» OR correct geometry «of reacting particles» ✓		2

(continued...)

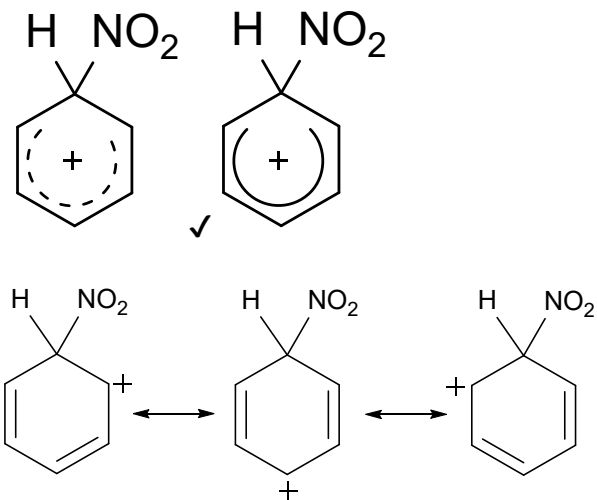
(Question 5 continued)

Question			Answers	Notes	Total
5.	d	iii	 <p>curly arrow going from lone pair/negative charge on O in :OH^- to C ✓ curly arrow showing I leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓</p>	<p>Accept OH^- with or without the lone pair. Do not allow curly arrows originating on H, rather than the -, in OH^-. Accept curly arrows in the transition state. Do not penalize if HO and I are not at 180°. Do not award M3 if $\text{OH}-\text{C}$ bond is represented. Award [2 max] if $\text{S}_{\text{N}}1$ mechanism shown.</p>	3
5.	d	iv	<p>decreases/less polar AND electronegativity «of the halogen» decreases ✓</p>	<p>Accept “decreases” AND a correct comparison of the electronegativity of two halogens. Accept “decreases” AND “attraction for valence electrons decreases”.</p>	1

Question			Answers	Notes	Total
6.	a	i	<p>2p <input type="text" value="↑"/> <input type="text" value="↑"/> <input type="text" value="↑"/></p> <p>2s <input type="text" value="↑↓"/></p> <p>1s <input type="text" value="↑↓"/> ✓</p>	<p>Accept all 2p electrons pointing downwards. Accept half arrows instead of full arrows.</p>	1
6.	a	ii	 <p>bonds and non-bonding pairs correct ✓ formal charges correct ✓</p>	<p>Accept dots, crosses or lines to represent electron pairs. Do not accept resonance structures with delocalised bonds/electrons. Accept + and – sign respectively. Do not accept a bond between nitrogen and hydrogen. For an incorrect Lewis structure, allow ECF for non-zero formal charges.</p>	2
6.	a	iii	<p>Any three of: two N-O same length/order ✓ delocalization/resonance ✓</p> <p>N-OH longer «than N-O» OR N-OH bond order 1 AND N-O bond order 1½ ✓</p>	<p>Award [2 max] if bond strength, rather than bond length discussed.</p> <p>Accept N-O between single and double bond AND N-OH single bond.</p>	3

(continued...)

(Question 6 continued)

Question			Answers	Notes	Total
6.	a	iv	X-ray crystallography ✓		1
6.	b	i	$\text{HNO}_3 + 2\text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + \text{H}_3\text{O}^+ + 2\text{HSO}_4^- \checkmark$	<p>Accept "$\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + \text{H}_2\text{O} + \text{HSO}_4^-$".</p> <p>Accept "$\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$" AND</p> <p>"$\text{H}_2\text{NO}_3^+ \rightleftharpoons \text{NO}_2^+ + \text{H}_2\text{O}$".</p> <p>Accept single arrows instead of equilibrium signs.</p>	1
6.	b	ii		<p>Accept any of the five structures.</p> <p>Do not accept structures missing the positive charge.</p>	1 max
6.	b	iii	<p>Number of signals: three/3 ✓</p> <p>Relative areas: 2 : 2 : 1 ✓</p>		2