Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2022

Chemistry

Higher level

Paper 2

19 pages

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	$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$ ✓	*Do not accept equilibrium arrows. Ignore state symbols.*	1
1.	a	ii	aluminium/Al ✓		1
1.	b	i	$\langle\langle \frac{53.726\ g - 47.372\ g}{24.31\ g\ mol^{-1}} = \frac{6.354\ g}{24.31\ g\ mol^{-1}} \rangle\rangle$ = 0.2614 «mol» ✓		1
1.	b	ii	mass of product « $= 56.941\ g - 47.372\ g$» = 9.569 «g» ✓ $\langle\langle 100\ x\ \frac{2\ x\ 0.001g}{9.569\ g} = 0.0209 \rangle\rangle$ = 0.02 «%» ✓	*Award **[2]** for correct final answer* *Accept 0.021%.*	2
1.	b	iii	$\langle\langle\ 0.2614\ mol\ x\ (24.31\ g\ mol^{-1} + 16.00\ g\ mol^{-1}) = \ 0.2614\ mol\ x\ 40.31\ g\ mol^{-1} \rangle\rangle$ = 10.536 «g» ✓ $\langle\langle 100\ x\ \frac{9.569\ g}{10.536g} = \ 90.822 \rangle\rangle$ = 91 «%» ✓	*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.*	2
1.	c	i	yes ***AND*** «each Mg combines with $^2/_3$ N, so» mass increase would be $14x^2/_3$ which is less than expected increase of 16x ***OR*** 3 mol Mg would form 101g of Mg_3N_2 but would form 3 x MgO = 121 g of MgO ***OR*** 0.2614 mol forms 10.536 g of MgO, but would form 8.796 g of Mg_3N_2 ✓	*Accept Yes **AND** "the mass of N/N_2 that combines with each g/mole of Mg is lower than that of O/O_2"* *Accept YES **AND** "molar mass of nitrogen less than of oxygen".*	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» $Mg_3N_2(s)$ + **6** $H_2O(l)$ $\rightarrow$ **3** $Mg(OH)_2(s)$ + **2** $NH_3(aq)$ ✓		**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**	*Acid–base:* yes ***AND*** N^{3-} accepts H^+/donates electron pair«s» ***OR*** yes ***AND*** H_2O loses H^+ «to form OH^-»/accepts electron pair«s» ✓ *Redox:* no ***AND*** no oxidation states change ✓	*Accept "yes **AND** proton transfer takes place"* *Accept reference to the oxidation state of specific elements not changing. Accept "not redox as no electrons gained/lost".* *Award [1 max] for Acid–base: yes AND Redox: no, if no other mark is awarded."*	**2**
1.	**e**	**i**	*Protons:* 7 ***AND*** *Neutrons:* 7 ***AND*** *Electrons:* 10 ✓		**1**
1.	**e**	**ii**	isotope«s» ✓		**1**
1.	**e**	**iii**	nitride ***AND*** smaller nuclear charge/number of protons/atomic number ✓		**1**
1.	**e**	**iv**	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*»* ✓	*Accept "nitrogen **AND** electron lost closer to the nucleus «than magnesium»".*	**1**

(continued…)

(Question 1 continued)

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

(continued…)

(Question 1 continued)

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>1.</td><td>g</td><td></td><td>
<table>
<tr><th>Substance</th><th>Bond type</th><th>How the valence electrons produce these bonds</th></tr>
<tr><td>Magnesium</td><td>metallic AND</td><td>delocalized «throughout lattice attracted to cations» ✓
Accept reference to “sea”/flux of electrons
«attracted to cations»</td></tr>
<tr><td>Oxygen</td><td>covalent
AND</td><td>shared «between atoms» ✓</td></tr>
<tr><td>Magnesium oxide</td><td>ionic ✓</td><td>transferred «from magnesium to oxygen»
OR
lost by magnesium AND gained by oxygen ✓</td></tr>
</table>
</td><td>Award [1] for all bonding types correct.
Award [1] for each correct description.
Apply ECF for M2 only once.</td><td>4</td></tr>
</table>

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

(continued…)

(Question 2 continued)

Question			Answers	Notes	Total
2.	**b**	**ii**	«$\Delta G^o = -nFE^o$» n = 2 ***OR*** ΔG^o = «-»2×96500×1.92 / «-»370,560 «J» ✓ -371 «kJ» ✓	*For n = 1, award [1] for –185 «kJ».* *Award **[1 max]** for (+)371 «kJ».*	**2**
2.	**b**	**iii**	$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$ ✓	*Accept equation with equilibrium arrows.*	**1**
2.	**c**	**i**	independent / not dependent ✓	*Accept "zero order in Mg".*	**1**
2.	**c**	**ii**	«2×170 s» = 340 «s» ✓	*Accept 320 – 360 «s».* *Accept 400 – 450 «s» based on no more gas being produced after 400 to 450s.*	**1**
2.	**c**	**iii**	«relative/percentage» decrease in mass is «too» small/«much» less ✓	*Accept "«relative/percentage» uncertainty in mass loss «too» great".* ***OR** "density/molar mass of H_2 is «much» 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≡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» ✓ ΔH = «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)

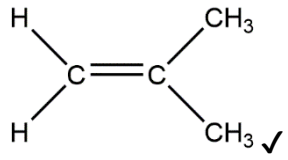
Question			Answers	Notes	Total
3.	**b**	**iii**	increased temperature decreases yield «as shown on graph» ✓ shifts equilibrium in endothermic/reverse direction ✓		**2**
3.	**c**	**i**	spontaneous ***AND*** $\Delta G < 0$ ✓		**1**
3.	**c**	**ii**	$\ln K = \langle\langle -\frac{\Delta G}{R.T} = \rangle\rangle \ -\frac{-33000}{8.31\ x\ 298}$ / «+»13.3 ✓ $K = 6.13\times10^5$ ✓	*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**	ΔG = «$\Delta H - T\Delta S$ =» -93000 «J» - 298«K» × ΔS = -33000 ✓ $\Delta S = \langle\langle\frac{-93000\ \text{J} - (-33000\ \text{J})}{298\ \text{K}}\rangle\rangle$ = -201 «J mol^{-1} K^{-1}» ✓	*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		conjugate «acid and base» ✓		1
4.	b		amount of ammonia ⟨⟨$= \frac{P.V}{R.T} = \frac{100.0\ kPa \times 900.0\ dm^3}{8.31\ J\ K^{-1}mol^{-1} \times 300.0\ K}$⟩⟩ = 36.1 «mol» ✓ concentration ⟨⟨$= \frac{n}{V} = \frac{36.1}{2.00}$⟩⟩ = 18.1 «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.*	2
4.	c	i	$[OH^-]$ ⟨⟨$= \frac{K_w}{[H^+]} = \frac{10^{-14}}{10^{-9.3}} = 10^{-4.7}$⟩⟩ $= 2.0 \times 10^{-5}$ ⟨⟨mol dm^{-3}⟩⟩ ✓		1
4.	c	ii	$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} / \frac{10^{-4.7} \times 10^{-4.7}}{[NH_3]}$ ⟨⟨$= 10^{-4.75}$⟩⟩ ✓ $[NH_3]$ = ⟨⟨$= \frac{10^{-9.4}}{10^{-4.75}} = 10^{-4.65}$⟩⟩ = 2.24×10^{-5} «mol dm^{-3}» ✓	*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…)

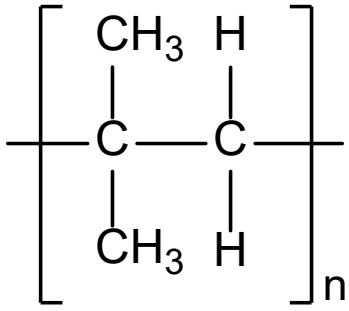
(Question 4 continued)

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

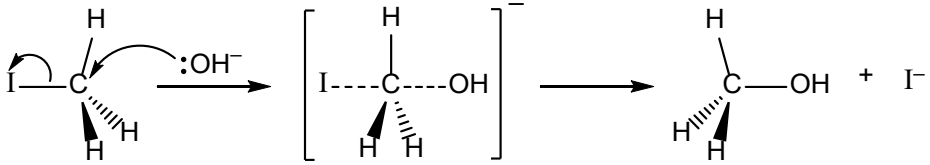
(continued…)

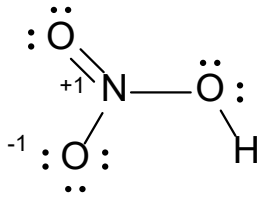
(Question 5 continued)

Question			Answers	Notes	Total
5.	**b**	**iii**	 ✓	*Do **not** penalize missing brackets or n.* *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 ≥ activation energy/E_a ✓ correct orientation «of reacting particles» *OR* correct geometry «of reacting particles» ✓		**2**

(continued…)

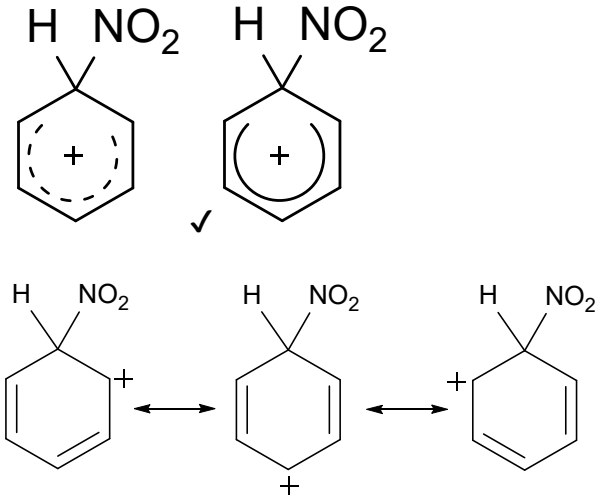
(Question 5 continued)

Question			Answers	Notes	Total
5.	**d**	**iii**	 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 ✓	*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 OH–C bond is represented.* *Award **[2 max]** if S_N1 mechanism shown.*	**3**
5.	**d**	**iv**	decreases/less polar ***AND*** electronegativity «of the halogen» decreases ✓	*Accept "decreases" **AND** a correct comparison of the electronegativity of two halogens.* *Accept "decreases" **AND** "attraction for valence electrons decreases".*	**1**

Question			Answers	Notes	Total
6.	a	i	2p ↑ ↑ ↑ 2s ↑↓ 1s ↑↓ ✓	*Accept **all** 2p electrons pointing downwards.* *Accept half arrows instead of full arrows.*	1
6.	a	ii	 bonds and non-bonding pairs correct ✓ formal charges correct ✓	*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*.	2
6.	a	iii	*Any three of:* two N-O same length/order ✓ delocalization/resonance ✓ N-OH longer «than N-O» ***OR*** N-OH bond order 1 ***AND*** N-O bond order 1½ ✓	*Award **[2 max]** if bond strength, rather than bond length discussed.* *Accept N-O between single and double bond **AND** N-OH single bond.*	3

(continued…)

(Question 6 continued)

Question			Answers	Notes	Total
6.	**a**	**iv**	X-ray crystallography ✓		**1**
6.	**b**	**i**	$HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + H_3O^+ + 2HSO_4^-$ ✓	*Accept "$HNO_3 + H_2SO_4 \rightleftharpoons NO_2^+ + H_2O + HSO_4^-$".* *Accept "$HNO_3 + H_2SO_4 \rightleftharpoons H_2NO_3^+ + HSO_4^-$" **AND** "$H_2NO_3^+ \rightleftharpoons NO_2^+ + H_2O$".* *Accept single arrows instead of equilibrium signs.*	**1**
6.	**b**	**ii**	 ✓	*Accept any of the five structures.* *Do **not** accept structures missing the positive charge.*	**1 max**
6.	**b**	**iii**	*Number of signals:* three/3 ✓ *Relative areas:* 2 : 2 : 1 ✓		**2**