Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2023

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.

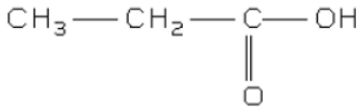
13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should 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.

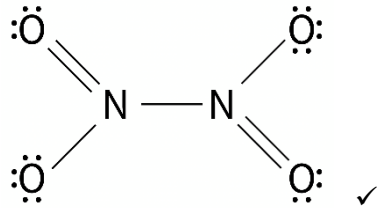
16. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the "Notes" column.

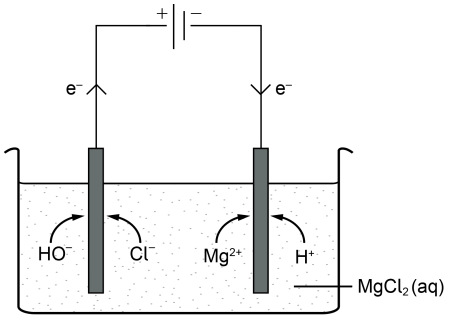
17. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

Question			Answers	Notes	Total
1.	(a)	(i)	«n(C) =» 4.05 «mol» ***AND*** «n(O) =» 2.70 «mol» ✓ «% H =» 8.2% ***OR*** «n(H) =» 8.12 «mol»✓ «empirical formula =» $C_3H_6O_2$ ✓	*Award **[2]** for the simplest ratio "1.5 C: 3 H: 1 O".*	**3**
1.	(a)	(ii)	*m/z 74:* molecular ion / M^+ / $C_3H_6O_2^+$ ✓ *m/z 45:* $COOH^+$ / $C_2H_5O^+$ ✓	*Accept **loss** of CH_3CH_2 / C_2H_5 / CHO for m/z 45.*	**2**
1.	(a)	(iii)	*A:* O-H «in carboxylic acids» ✓ *B:* C=O ✓		**2**
1.	(a)	(iv)	 ✓	*Do **not** accept molecular formula/$C_2H_6O_2$.*	**1**

Question			Answers	Notes	Total
1.	(b)		T=368 K ***AND*** P = 100.0 kPa ***AND*** V = 0.0810 dm^3 ***OR*** T=368 K ***AND*** P = 100 000 Pa ***AND*** V = 8.1 x 10^{-5} m^3 ✓ n «= $\frac{PV}{RT}$ = $\frac{100.0 \times 0.0810}{8.31 \times 368}$ »= 0.00265 «mol» ✓ M «= $\frac{m}{n}$ = $\frac{0.363\ g}{0.00265\ mol}$ »= 137 «g mol^{-1} » ✓	*Award **[3]** for correct final answer.*	**3**

2.	(a)	(i)	reaction hardly proceeds ***OR*** reverse reaction/formation of NO_2 is favoured ***OR*** «concentration of» reactants greater than «concentration of» products «at equilibrium» ✓	*Accept equilibrium lies to the left.*	**1**
2.	(a)	(ii)	$\Delta G^{\ominus}$ = «$-RT\ln K$ = −8.31 x 373 x ln(0.0665) =» 8.40 «kJ mol^{-1}» ✓		**1**
2.	(a)	(iii)	«K_c = $\frac{1}{0.0665}$ =» 15.0 ✓		**1**
2.	(a)	(iv)	« $\Delta H^{\ominus}$ = 2(33.18) – 9.16 =» «+» 57.20 «kJ mol^{-1}» ✓		**1**

Question			Answers	Notes	Total
2.	(a)	(v)	« $\Delta S^{\ominus}$ = 2(240.06) – 304.29 =» «+»175.83 «J K $^{-1}$ mol^{-1}» ✓		1
2.	(b)		 ✓	*Accept any combination of dots, crosses or lines to represent electron pairs.*	1
2.	(c)	(i)	it has resonance structures ✓	*Accept bond order = 1.5.* *Accept delocalized electrons «in NO bonds».*	1
2.	(c)	(ii)	110-120° ✓	*Accept any value in the range given. (Bond angle is actually 112.3°.)*	1
2.	(d)		$2NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$ ✓	*Accept $N_2O_4(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$*	1

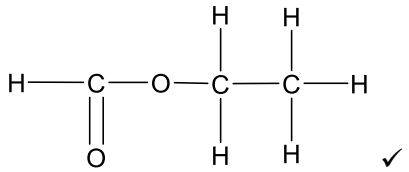
Question			Answers	Notes	Total
3.	(a)	(i)	 electron flow from anode to battery ***OR*** from battery to cathode ✓ Mg^{2+}/H^+ ions to – electrode ***AND*** Cl^-/OH^- ions to + electrode ✓	*Do not award M1 if electrons are shown in electrolyte.*	**2**
3.	(a)	(ii)	*Positive electrode:* $H_2O(l) \rightarrow ½\ O_2(g) + 2H^+(aq) + 2e^-$ ***OR*** $2OH^-(aq) \rightarrow ½O_2(g) + H_2O(l) + 2e^-$ ✓ *Negative electrode*: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ ***OR*** $2H^+(aq) + 2e^- \rightarrow H_2(g)$ ✓	*Accept $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$ for M1.* *Award **[1max]** for correct equations at wrong electrodes.*	**2**

Question			Answers	Notes	Total
3.	(a)	(iii)	layers «of carbon atoms in a giant structure» ✓ delocalized electrons «flow along layers» ✓	*Accept suitable diagram for M1.* *Accept two-dimensional network for M1.* *Accept electrons are mobile/flow for M2.*	**2**
3.	(b)	(i)	«$n(S_2O_3^{2-})$ = 0.00500 mol dm^{-3} x 0.0360 dm^3 =» 0.000180 / 1.80 x 10^{-4} «mol» ✓ «$n(O_2)$ =» $\frac{n(S_2O_3^{2-})}{4}$ / 0.0000450 / 4.50 x 10^{-5} «mol» ✓ «$[O_2] = \frac{4.50x10^{-5}\ mol}{0.150\ dm^3}$ =» 0.000300 / 3.00 x 10^{-4} «mol dm^{-3}» ✓	*Award **[3]** for correct final answer.*	**3**
3.	(b)	(ii)	titrate/measure dissolved oxygen in «another» water sample «stored under controlled conditions five days» later ✓ difference between two values «is BOD»✓		**2**
3.	(b)	(iii)	low levels of «organic/oxygen consuming» water pollution ✓		**1**

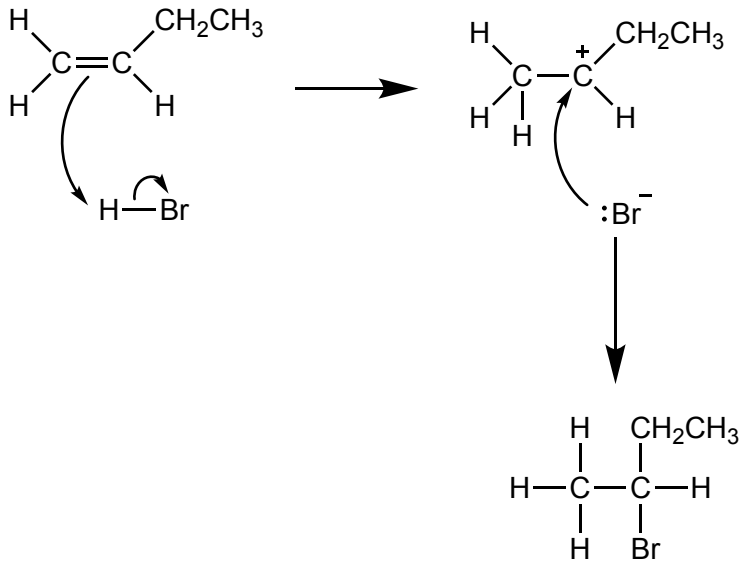
Question			Answers	Notes	Total
4.	(a)		*Any two ofthe following:* «group 15 so Bi has» 5 valence electrons ✓ «period 6 so Bi has» 6 «occupied» electron shells/energy levels ✓ «in p-block so» p orbitals are highest occupied ✓ occupied d/f orbitals ✓ has unpaired electrons ✓ has incomplete shell(s)/subshell(s) ✓	*Award **[1]** for full or condensed electron configuration, [Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^3$. Accept other valid statements about the electron configuration.*	**2 max**
4.	(b)		«layers of» cations slide over each other without disrupting bonding ***OR*** attraction between metal ions and delocalized electrons/metallic bonding is not disrupted by changing position of metal ions ***OR*** metallic bonds are non-directional ***OR*** changing the shape does not disrupt the bonding ✓		**1**
4.	(c)		«heat energy = 11.98 g x 0.902 J g^{-1} K^{-1} x 22.0 K =» 238 «J» ✓		**1**
4.	(d)	(i)	mass spectrometry ***OR*** mass spectroscopy ***OR*** mass spectrum ***OR*** MS ✓		**1**

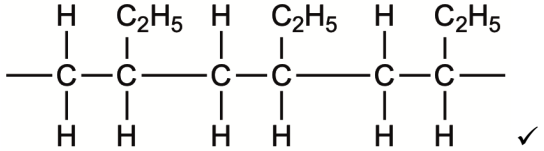
Question			Answers	Notes	Total
4.	**(d)**	**(ii)**	(0.0034 x 36) + (0.0006 x 38) + (0.996 x 40) ✓ 39.99 ✓	*Do not accept 39.96 which is the data booklet value.* *M2 can only be awarded for answer with 2 decimal places.* *Award **[2]** for correct final answer.*	**2**
5.	**(a)**	**(i)**	«$[OH^-]$ = 0.200 mol dm^{-3}» ***ALTERNATIVE 1:*** «pOH = $-\log_{10}(0.200)$ =» 0.699 ✓ «pH = 14.000 – 0.699 =» 13.301 ✓ ***ALTERNATIVE 2:*** «$[H^+] = \frac{1.00x10^{-14}}{0.200}$ = » 5.00 × 10^{-14} «mol dm^{-3}» ✓ «pH = $-\log_{10}(5.00 \times 10^{-14})$» = 13.301 ✓	*Award **[2]** for correct final answer.*	**2**
5.	**(a)**	**(ii)**	$HCOOH(aq) + NaOH(aq) \rightarrow HCOONa(aq) + H_2O(l)$ ✓	*Accept ionic equation or net ionic equation.*	**1**
5.	**(a)**	**(iii)**	«n(acid) = $n(OH^-)$» «[acid] = $\frac{0.200\ mol\ dm^{-3} \times 22.5 \times 10^{-3} dm^3}{25.0 \times 10^{-3} dm^3}$» = 0.180 «mol dm^{-3}» ✓		**1**

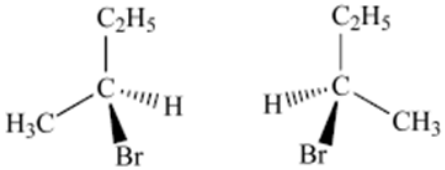
Question			Answers	Notes	Total
5.	(a)	(iv)	***ALTERNATIVE 1:*** «$K_a = 10^{-3.75} = 1.78 \times 10^{-4}$ » $[H^+] = \sqrt{K_a \times [HCOOH]} / \sqrt{1.78 \times 10^{-4} \times 0.180} / 5.66 \times 10^{-3}$ «mol dm^{-3}» ✓ pH «$= -\log_{10}(5.66 \times 10^{-3})$» = 2.247 ✓ ***ALTERNATIVE 2:*** pH = 0.5(pK_a – $\log_{10}$[HCOOH]) ✓ pH = 2.247 ✓	*Award **[2]** for correct final answer.*	**2**
5.	(a)	(v)	phenolphthalein ***OR*** phenol red ✓ colour change in the pH range of equivalence point ✓	*Accept pH «at equivalence»> 7 for M2*	**2**
5.	(b)		$HCOO^-(aq) + H_2O(l) \rightarrow HCOOH(aq) + OH^-(aq)$✓	*Accept $HCOO^-(aq) + Na^+(aq) + H_2O(l) \rightarrow HCOOH(aq) + Na^+(aq) + OH^-(aq)$*	**1**

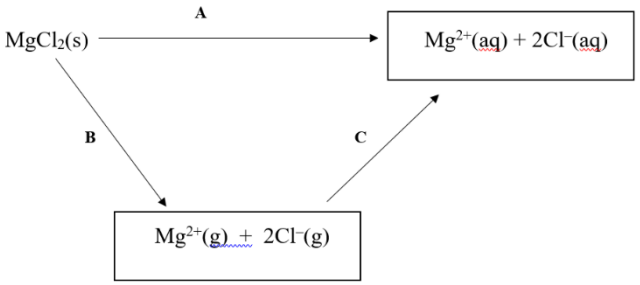
Question			Answers	Notes	Total
6.	**(a)**		«measure change in» mass ***OR*** pressure ***OR*** volume of gas/CO_2 produced ***OR*** «intensity of» colour ***OR*** «electrical» conductivity ***OR*** pH ✓ with time ✓	*Accept any of the following for M1:* *perform experiment on balance* ***OR*** *use pressure probe* ***OR*** *collect gas/gas syringe* ***OR*** *use colorimeter* ***OR*** *use conductivity meter* ***OR*** *use pH meter* *Do **not** accept "measure rate of change" for M2.*	**2**
6.	**(b)**		provides an alternative reaction pathway ***AND*** lower activation energy/E_a ✓ larger fraction/number of molecules with $E \geq E_a$/enough energy «for a successful collision» ✓		**2**
6.	**(c)**	**(i)**	*Structural formula*:  ✓ *Name:* ethyl methanoate ✓		**2**

Question			Answers	Notes	Total
6.	(c)	(ii)	*Number of signals:* 3 ✓ *Splitting patterns*: singlet/1 ***AND*** quartet/4 ***AND*** triplet/3✓		**2**
6.	(c)	(iii)	*Any two of the following:* chemical shift/signal outside range of common chemical shift/signal ✓ strong signal/12/all H atoms in same environment ✓ singlet/no splitting of signal ✓ volatile/easily separated/easily removed ✓ inert/stable ✓ soluble in most organic solvents ✓	*Do **not** accept chemical shift = 0.*	**2 max**
6.	(d)	(i)	$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$ ✓	*Accept C_2H_6O for ethanol.*	**1**
6.	(d)	(ii)	«bond breaking» 1 C-C + 5 C-H + 1 C-O + 1 O-H + 3 O=O / 346 + 5(414) + 358 + 463 +3(498) / 4731 «kJ» ✓ «bond forming» 4 C=O + 6 O-H / 4(804) + 6(463) / 5994 «kJ» ✓ ΔH «= 4731– 5994» = −1263 «kJ mol^{-1} » ✓	*Award **[3]** for correct final answer.*	**3**

Question			Answers	Notes	Total
7.	(a)		«electrophilic» addition/A_E ✓	*Do **not** accept nucleophilic addition.*	1
7.	(b)	(i)	 curly arrow going from C=C to H of HBr ***AND*** curly arrow showing Br leaving ✓ correct representation of carbocation ✓ curly arrow going from lone pair/negative charge on Br- to C^+ ✓ $CH_3CHBr(CH_2CH_3)$/correct final product ✓	*Award **[3 max]** for the correct mechanism of formation of the minor product.*	4

Question			Answers	Notes	Total
7.	(b)	(ii)	carbocation with ethyl group is stabilized ***OR*** secondary carbocation more stable «than primary carbocation» ✓ greater electron releasing/inductive effect of «two» electron releasing alkyl groups «on secondary carbocation compared to one on primary carbocation» ✓	*Do **not** accept 'Markovnikov's rule' /C with most hydrogen atoms without reference to stability of carbocation.*	**2**
7.	(c)		 ✓	*Ignore brackets and 'n'.* *Continuation bonds must be shown.* *Ethyl groups do not all have to be on one side.* *Accept head-to-tail or head-to-head orientation of monomer units.*	**1**
7.	(d)		«both» sp^2 ✓		**1**

Question			Answers	Notes	Total
7.	(e)		*Any three of the following:* mixing of an s ***AND*** two p orbitals forms «three» sp^2 /hybrid orbitals ✓ σ bond is overlap «of sp^2 orbitals» along axial/internuclear axis ***OR*** head-on/end-to-end overlap «of sp^2 orbitals» ✓ one p electron from each C does not hybridize ✓ π bond is overlap «of p-orbitals» above and below internuclear axis ***OR*** sideways overlap «of parallel p orbitals» ✓	*Accept suitable diagrams.*	**3**
7.	(f)		 correct isomer ✓ mirror image shown clearly ✓	*Do not accept Fischer projections.*	**2**

Question			Answers	Notes	Total
8.	(a)	(i)	 correct boxes ✓ *A:* enthalpy of solution / ΔHsolution / ΔHsol ***AND*** *B:* lattice enthalpy / ΔHlattice ***AND*** *C:* enthalpy of hydration / ΔHhydration ✓		**2**
8.	(a)	(ii)	«$\Delta H_{solution} = \Delta H_{lattice} + \Delta H_{hydration}$ = 2540 + (−1963) + 2(−359) =» −141 «kJ mol^{-1} »✓		**1**
8.	(b)		ionic radius Ba^{2+} is greater than that of Mg^{2+} ✓ weaker attraction between «Ba^{2+} and Cl^- » ions ✓		**2**
8.	(c)	(i)	$1s^2\ 2s^2 2p^6\ 3s^2 3p^6 3d^7$ ✓		**1**

Question			Answers	Notes	Total
8.	(c)	(ii)	*Type of bond:* coordinate/dative/covalent ✓ *How the bond forms:* oxygen/water molecule /ligand donates e^- pair to cobalt«(II) ion» ✓		**2**
8.	(c)	(iii)	magnitude of ΔE/energy gap between split d-orbitals differs «according to ligand» ✓ ΔE/energy gap determines the wavelength of light absorbed/colour «of complex» ***OR*** energy absorbed by electrons «to transition/to be promoted to higher levels» corresponds to different wavelengths of light/colour ✓	*Reference to different energy gap/splitting of d-orbitals needed for M1.*	**2**

9.	(a)		H^+: second order ***AND*** BrO_3^-: first order ***AND*** Br^-: first order ✓ «rate =» $k[Br^-][BrO_3^-][H^+]^2$ ✓	*Award **[2]** for correct rate equation.*	**2**

Question			Answers	Notes	Total
9.	(b)		«$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$» $\ln\left(\frac{1}{3}\right) = \frac{E_a}{8.31}\left(\frac{1}{323} - \frac{1}{298}\right)$ ✓ «$E_a = \frac{\ln\left(\frac{1}{3}\right) \times 8.31}{\left(\frac{1}{323} - \frac{1}{298}\right)}$» «$E_a$ = » 35.1 «kJ mol^{-1} »✓	*Award **[2]** for correct final answer.*	**2**