8823 – 6108M

Markscheme

November 2023

Chemistry

Higher level

Paper 2

20 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 <u>underlined</u> 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.

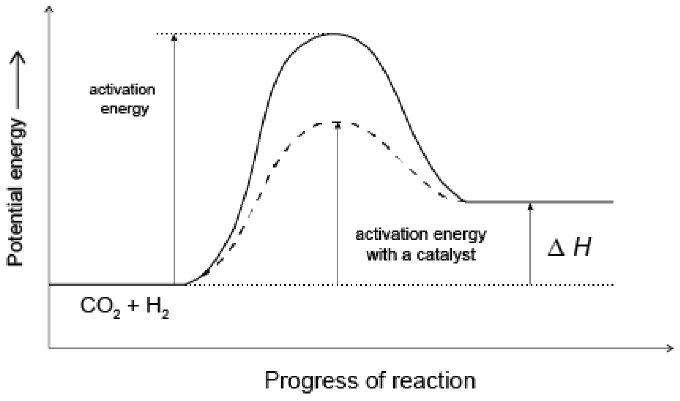
Question			Answers	Notes	Total
1	**a**		*Award **[1]** for **two** of the following:* same functional group/family same general formula «successive members» differ by a common structural unit/CH_2 ✓	*Accept "different chain lengths" for "differ by a common structural unit".*	**1**
1	**b**		M_r «= 12.01 + (2 x 1.01) + (2 x 16.00) »= 46.03 ✓ «M_r of O in molecule = 2 x 16.00 = 32.00» «percentage O = $100 \times \frac{32.00}{46.03}$ » = 69.52% ✓	*Award **[2]** for correct final answer.*	**2**
1	**c**	**i**	«strongest intermolecular forces in» methanoic acid are hydrogen/H-bonds ***AND*** ethanal dipole-dipole forces ✓ hydrogen/H-bonds stronger «than dipole-dipole forces so methanoic acid has higher boiling point» ✓	*Do **not** award marks for answers based on difference in polarity or molar mass.* *Do **not** accept van der Waals' forces for dipole-dipole forces.*	**2**
1	**c**	**ii**	«both can» form hydrogen bonds with water «molecules» ✓		**1**

Question			Answers	Notes	Total
1	**c**	**iii**	*Relative electrical conductivity:* ethanal < methanoic acid < hydrochloric acid ✓ conductivity depends on concentration/amount of ions ***OR*** solutions contain increasing concentrations/amounts of ions «in this order» ✓ hydrochloric acid is a strong acid/fully dissociated ***AND*** methanoic acid is a weak acid/partially dissociated ***AND*** ethanal is not acidic/minimally dissociated/undissociated ✓	*M2 should be awarded if implied through addressing extent of dissociation/ionization in the compounds.* *Accept equations with appropriate arrows for M3.*	**3**
1	**d**	**i**	[HCOOH] «$=0.100\ mol\,dm^{-3} \times \frac{20.7\ cm^3}{25.0\ cm^3}$» = 0.0828 «mol dm^{-3}» ✓ mass HCOOH «=2.00 dm^3 x 0.0828 mol dm^{-3} x 46.03 g mol^{-1}» = 7.62 «g» ✓	*Accept answers in the range 7.60-7.65.* *Award **[0]** for 0.096 g - mass of acid in 25 cm^3.*	**2**
1	**d**	**ii**	$K_a=10^{-3.75}/1.78\times10^{-4}$ ✓ [H^+] «$=\sqrt{1.78 \times 10^{-4} \times 0.0828} = \sqrt{1.47\times10^{-5}}$ =» 3.84×10^{-3} «mol dm^{-3}» ✓ pH = 2.42 ✓	*Award **[3]** for correct final answer.* *Accept alternative methods of calculation.* *Accept answers in the range 2.35 - 2.45.*	**3**

Question			Answers	Notes	Total
1	d	iii	$NaHCOO(aq) + H_2O(l) \rightleftharpoons HCOOH(aq) + NaOH(aq)$ ***OR*** $HCOO^-(aq) + H_2O(l) \rightleftharpoons HCOOH(aq) + OH^-(aq)$ ✓ methanoate ion acts as «Brønsted-Lowry» base ***AND*** pH >7 ***OR*** sodium hydroxide/NaOH/hydroxide ion/OH^- makes solution alkaline ***AND*** pH >7 ✓	*Accept arrows rather than equilibrium signs for M1.* *Do **not** accept the equation for the titration reaction for M1.* *Accept sodium methanoate is formed from a strong base and weak acid **AND** pH >7 for M2.* *The reason for M2 can be implied in the equation written without being separately stated.*	**2**
1	d	iv	the double/pi/π bond «in the methanoate ion» is delocalized ***OR*** resonance occurs ✓ shorter than the single bond ***AND*** longer than the double bond «in methanoic acid» / intermediate between single and double bond ✓	*Accept drawing showing delocalization of the bond or resonance structures for M1.*	**2**

Question			Answers	Notes	Total
2	**a**		it removes CO_2 «from the atmosphere» ✓ CO_2 is a «major» contributor to climate change / global warming ***OR*** CO_2 is a greenhouse gas ✓	*Accept reduces CO_2 emissions for M1.* *Award **[1]** for reactants are cheap/readily available.* *Award **[1]** for atom economy is 100%.* *Award **[1]** for methanoic acid can be used to manufacture other useful products.* *Award **[1]** for reference to depletion of fossil fuels as a source of organic chemicals.*	**2**
2	**b**		«$K_c =$» $\frac{[HCOOH]}{[CO_2][H_2]}$ ✓		**1**
2	**c**	**i**	***ALTERNATIVE 1*** «bond breaking» C=O + H-H / 804 + 436 / 1240 «kJ» ✓ «bond forming» C-H + C-O + O-H / 414 + 358 + 463 / 1235 «kJ» ✓ $\Delta H^\ominus$ «= 1240 – 1235» = «+»5 «kJ mol^{-1}» ✓ ***ALTERNATIVE 2*** «bond breaking» 2C=O + H-H / 2(804) + 436 / 2044 «kJ» ✓ «bond forming» C=O + C-H + C-O + O-H / 804 + 414 + 358 + 463 / 2039 «kJ» ✓ $\Delta H^\ominus$ «= 2044 – 2039» = «+»5 «kJ mol^{-1}» ✓	*Award **[3]** for correct final answer.*	**3**

Question			Answers	Notes	Total
2	c	ii	***ALTERNATIVE 1*** sum of absolute uncertainties «= 0.804 + 0.436 + 0.414 + 0.358 + 0.463 =» 2.475 «kJ mol^{-1}» ✓ percentage uncertainty «$= 100 \times \frac{2.475}{5} = 49.5\% =$ » 50 «%» ✓ ***ALTERNATIVE 2*** sum of absolute uncertainties «= 3(0.804) + 0.436 + 0.414 + 0.358 + 0.463 =» 4.083 «kJ mol^{-1}» ✓ percentage uncertainty «$= 100 \times \frac{4.083}{5} = 81.7\%$» = 80 «%» ✓	*Award **[2]** for correct final answer.*	**2**
2	c	iii	H-H ***AND*** it can only occur in the H_2 molecule ✓	*Accept H-H **AND** does not require averaging.*	**1**
2	d		enthalpy change is very small ✓		**1**
2	e		$\Delta S^{\ominus}$«$= \sum S^{\ominus}(\text{products}) - \sum S^{\ominus}(\text{reactants})$ = 251.0 J mol^{-1} K^{-1} – 130.7 J mol^{-1} K^{-1} - 213.8 J mol^{-1} K^{-1}» = -93.5 «J mol^{-1} K^{-1}» ✓		**1**

Question			**Answers**	**Notes**	**Total**
2	**f**	**i**	 two curves, each passing through a maximum ***AND*** same finishing point ✓ endothermic enthalpy change labelled ✓ both activation energies correctly labelled ✓	*Do **not** penalize curve showing multiple steps for the catalysis in M1.* *Accept double-headed arrows or lines in M2 and M3.* *Accept E_{cat} for catalysed E_a in M3.* *Award **[1 max]** for one curve drawn and correctly labelled.*	**3**
2	**f**	**ii**	increase pressure ✓	*Accept increase **«**reactant**»** concentration but **not** increase amount of reactant.*	**1**
2	**g**		+2 ✓	*Do **not** accept 2 or 2+.*	**1**

Question			Answers	Notes	Total
3	**a**		*Reagent:* methanol ✓ *Catalyst:* **«**concentrated**»** sulfuric acid ✓	*Do **not** accept formula for M1.* *For M2 accept H_2SO_4/phosphoric acid/H_3PO_4/hydrochloric acid/HCl, but do **not** accept nitric acid.*	**2**
3	**b**		***ALTERNATIVE 1*** expected yield «$=2.83\times\frac{60.06}{46.03}$» = 3.69 **«**g**»** ✓ percentage yield «$=100\times\frac{1.72}{3.69}$» = 46.6 **«**%**»** ✓ ***ALTERNATIVE 2*** **«**amount of methanoic acid used = $\frac{2.83}{46.03}$ =**»** 0.0615 **«**mol**»** ✓ **«**expected amount of methyl methanoate = 0.0615 mol**»** **«**actual amount of methyl methanoate = $\frac{1.72}{60.06}$ = 0.0286 mol**»** percentage yield **«**=$\frac{0.0286}{0.0615}\times 100$**»** = 46.5% ✓	*Award **[2]** for correct final answer.* *Award **[0]** for 60.8% (simple ratio of starting and final masses).*	**2**

Question			Answers	Notes	Total
3	**c**	**i**	*Similarity:* «absorption at» 1700-1750 «cm^{-1}» ***OR*** absorption by the carbonyl/C=O bond ***OR*** «absorption at» 2850-3090 «cm^{-1}» ***OR*** absorption by carbon-hydrogen/C- H bond ✓ *Difference:* methanoic acid «has absorption at» 2500-3000 «cm^{-1} which is absent for methyl methanoate» ***OR*** methanoic acid has absorption by the hydroxyl/O-H bond «which is absent for methyl methanoate» ✓	*Do **not** accept the bond without the wavenumber or reference to the spectrum (e.g. absorption, peak, trough).* *Do **not** accept absorption of C-O bond at 1050-1410* cm^{-1} *for M1 as it is outside range.* *Do **not** accept hydroxide instead of hydroxyl for M2.* *Do **not** accept 3200-3600 cm^{-1} for M2 as O-H is in carboxylic acid.*	**2**
3	**c**	**ii**	methyl methanoate ***AND*** the ratio «of areas under peaks» is 1:3 ✓	*Accept methyl methanoate **AND** methanoic acid would have a 1:1 ratio.* *Do **not** accept answers in terms of chemical shift.*	**1**
3	**d**		esters ✓		**1**

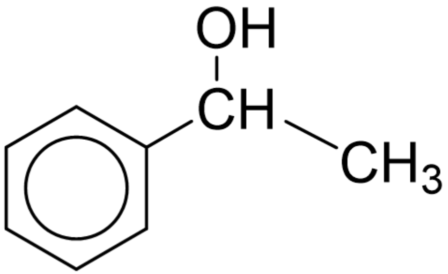
Question			Answers	Notes	Total
4	a	i	«Σ $\Delta H^{\ominus}{}_{f}$ (reactants) =» +88.7 + 2(-241.8) / -394.9 «kJ mol^{-1}» ***AND*** «Σ $\Delta H^{\ominus}{}_{f}$ (products) =» -393.5 + 2(-20.6) / -434.7 «kJ mol^{-1}» ✓ $\Delta H^{\ominus}$ «= -434.7 – (-394.9)» = -39.8 «kJ mol^{-1}» ✓	*Award **[2]** for correct final answer.* *Award **[1]** for +48.2 «kJ mol^{-1}» (obtained using -285.8 kJ mol^{-1} for $H_2O(l)$).*	2
4	a	ii	moles «of gas» same on both sides of equation ✓		1
4	a	iii	ΔG° «= ΔH° - T.ΔS°» = -39.8 «kJ mol^{-1}» ✓ $\ll lnK_c = -\frac{\Delta G^{\circ}}{R.T} = \frac{39800\,Jmol^{-1}}{8.31\,JK^{-1}mol^{-1}\ \times 500\,K} = 9.58 \gg$ K_c = 1.45 x 10^4 ✓	*Award **[2]** for correct final answer.* *Using –50.0 kJ mol^{-1} gives K_c = 1.68 x 10^5.* *If student obtained +48.2 kJ mol^{-1} for 4(a) then ECF gives K_c = 9.16 x 10^{-6}.*	2
4	a	iv	$K_c \ll= 1.45 \times 10^4 = \frac{[CO_2] \times [H_2S]^2}{[CS_2] \times [H_2O]^2} \gg$ $= \frac{X \times (2X)^2}{0.0400 \times (0.100)^2} / \frac{4X^3}{4.00 \times 10^{-4}}$ ✓ X $\ll= \sqrt[3]{1.45} \gg= 1.13 \ll$ mol dm^{-3} $\gg$ ✓	*Award **[2]** for correct final answer.* *Students who obtain K ~1 in 4(a)iii will obtain answers ~0.046 by ECF.* *Using 1.68 x 10^5 gives 2.56 «mol dm^{-3}».*	2

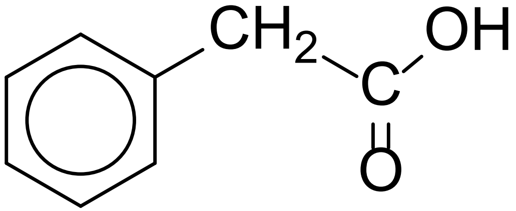
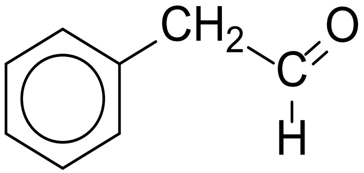
Question			Answers	Notes	Total
4	**b**		*Molecular geometry CS_2:* linear ***AND*** *Molecular geometry H_2S:* bent/V-shaped ✓ *Reason for difference:* «central atom in» H_2S has «two» lone/non-bonding «electron» pairs ***OR*** CS_2 has two ***AND*** H_2S has four electron domains/negative charge centres «around central atom» ✓	*Do **not** accept diagrams for M1 or M2.* *Accept central atom sp hybridized in CS_2 **AND** sp^3 hybridized in H_2S for M2.*	**2**
4	**c**	**i**	0.9x32 + 0.01x33 + 0.04x34 + 0.05x36 ✓ «A_r =» 32.29 ✓	*Award **[2]** for correct final answer.* *Do **not** accept 32.07 which is the data booklet value.* *M2 can only be awarded for answer with two decimal places.*	**2**
4	**c**	**ii**	amount of $^{36}_{16}S$ «= $\frac{0.0100}{100} \times \frac{1.00}{32.07}$ » $= 3.12 \times 10^{-6}$ « mol»✓ number of atoms «= 3.12×10^{-6} mol $\times 6.02 \times 10^{23}$ mol^{-1}» $= 1.88 \times 10^{18}$ ✓	*Award **[2]** for correct final answer.*	**2**

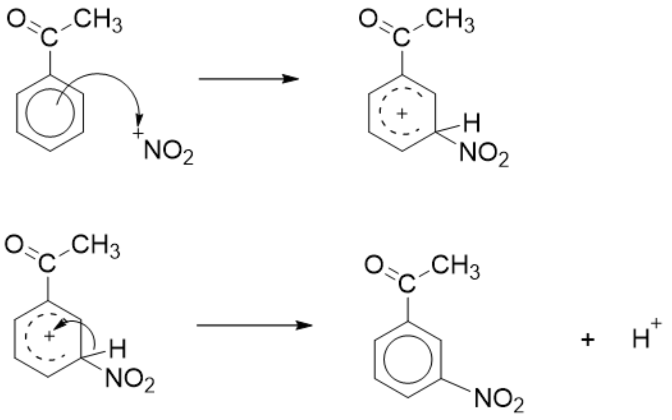
Question			**Answers**	**Notes**	**Total**
5	**a**	**i**	X-ray crystallography/diffraction ✓		**1**
5	**a**	**ii**	«between a lattice of» cations ***AND*** delocalized electrons ✓	*Do **not** accept metallic bonding on its own.* *Accept "sea of electrons" instead of "delocalized electrons".*	**1**
5	**b**	**i**	«contains» mobile/free moving ions ✓	*Accept has ions that can carry an «electric» current/charge.*	**1**
5	**b**	**ii**	*Electrode:* cathode ***AND*** *Polarity:* negative ✓		**1**
5	**b**	**iii**	$2\,Cl^- \rightarrow Cl_2 + 2\,e^-$ ✓	*Accept* $Cl^- \rightarrow {}^{1}/_{2}\,Cl_2 + e^-$. *Accept e for* e^-. *Do **not** apply ECF.*	**1**
5	**b**	**iv**	amount of electrons «$\frac{1.00\times10^{6}\text{ coulomb}}{9.65\times10^{4}\text{coulomb mol}^{-1}}$» $= 10.4$ mol ✓ mass «$= \frac{1}{2} \times 10.4$ mol $\times\ 9.01$ g mol^{-1}»$= 46.9$ «g» ✓	*Accept answers in the range 46.5 to 47.0.* *Award **[1 max]** for 93.37, as M1 met, even if amount of electrons not stated.*	**2**

Question			Answers	Notes	Total
5	**c**	**i**	 ✓		**1**
5	**c**	**ii**	«Be» does not have complete valence shell ✓	*Accept incomplete octet / exception to octet rule / electron deficient.*	**1**
5	**d**	**i**	sp^2 ✓	*Accept the “2” as a subscript or normal character.*	**1**
5	**d**	**ii**	chlorine «on one monomer» acts as a Lewis base ***AND*** beryllium «on the other monomer» acts as a Lewis acid ✓		**1**
5	**e**	**i**	has a partially filled d sub-shell «in a common oxidation state» ✓		**1**
5	**e**	**ii**	IE values of Fe gradually increase ***AND*** IE values of Be show a sudden rise ✓ first and second ionization energies close together therefore do not form a +1 oxidation state / singly charged ion ✓ further IEs of Fe are close to second IE, so the oxidation state/number of electrons Fe loses can vary «according to the oxidizing agents present» ✓	*Accept Be always loses 2 electrons / forms Be^{2+} / only has +2 oxidation state for M2.*	**3**
5	**f**	**i**	E° «= -0.83 – (-1.85)» = +1.02 «V» ✓		**1**
5	**f**	**ii**	spontaneous ***AND*** E° positive/>0 ✓	*Accept spontaneous **AND** ΔG negative.*	**1**

Question			Answers	Notes	Total
5	**g**		nuclear charge / number of protons increases «for both» ✓ Li and Be «outer electrons have» same subshell/shielding ✓ electron in B lost from p-subshell whereas that in Be lost from s-subshell ✓ «outer electron in» B/p-subshell experiences greater shielding / has higher energy ✓	*Do **not** accept explanations invoking distance of electrons from nucleus.*	**4**
5	**h**		frequency /wavelength of «the radiation at» convergence limit «is proportional to the ionization energy» ✓	*Accept highest frequency/shortest wavelength.*	**1**

Question			Answers	Notes	Total
6	**a**	**i**	 ✓	*Accept C_6H_5- instead of benzene ring.*	**1**
6	**a**	**ii**	it contains a chiral carbon atom ✓	*Accept it contains an asymmetric carbon / carbon with 4 different groups attached.* *Accept its mirror image is non-superimposable.*	**1**
6	**a**	**iii**	acidified/H^+ ***AND*** potassium dichromate(VI)/$K_2Cr_2O_7$/$Cr_2O_7^{2-}$ ***OR*** potassium permanganate(VII)/$KMnO_4$/MnO_4^- ✓		**1**

Question			Answers	Notes	Total
6	**a**	**iv**	 /phenylethanoic acid ✓ addition of water **«**in first step**»** produces primary alcohol **«**as a minor product**»** ✓	*Accept phenylethanal /*  *for M1.* *Accept anti-Markovnikov addition **«**of water**»** / water can add in opposite direction for M2.*	**2**
6	**b**	**i**	NO_2^+ / $^+NO_2$ ✓	*Do **not** accept equation for the equilibrium, as electrophile not identified.*	**1**

Question			Answers	Notes	Total
6	**b**	**ii**	 curly arrow going from delocalized electrons in benzene to $^+NO_2$ ✓ representation of carbocation with correct formula and positive charge on ring ✓ curly arrow going from C-H bond to benzene ring cation ✓ formation of organic product ***AND*** H^+/HSO_4^- accepting the H^+ ✓	*Do **not** penalize if NO_2^+ is written.* *Award **[3 max]** for substitution at other positions on the benzene ring.* *Allow mechanism with corresponding Kekulé structures.* *Accept curly arrow going to either an atom or the charge on $^+NO_2$ for M1.* *For M2 accept different variations of indicating delocalized electrons in ring.*	**4**

Question			Answers	Notes	Total
6	**c**		*k1/k2 = 2 **OR** k1/k2 = 0.5* ✓ ⟨⟨$ln\frac{k_1}{k_2} = ln2 = \frac{E_a}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right) = \frac{E_a}{8.31}\left(\frac{1}{298}-\frac{1}{308}\right)$⟩⟩ «$E_a = 8.31\ \text{J mol}^{-1}\text{K}^{-1}\left(\frac{308\text{ K x }298\text{ K}}{10\text{ K}}\right)\ln2$» $= 8.31 \text{ x } 9178 \text{ x } \ln2$ ✓ E_a «= 52868 J mol^{-1} » = 52.9 «kJ mol^{-1}» ✓	*Award **[3]** for correct final answer.* *Accept answers in the range 50 to 55 kJ mol$^{-1.}$* *Accept k_1 at 298 K and k_2 at 308 K, if ratio inverted.* *Accept other methods of calculation.* *Award **[2]** for 0.504 kJ mol^{-1} (not converting temperatures to Kelvin).*	**3**