

Markscheme

November 2020

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 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	$1s^2 2s^2 2p^6 3s^2 3p^5$ ✓	Do not accept condensed electron configuration.	1
1.	a	ii	Cl ⁻ AND more «electron–electron» repulsion ✓	Accept Cl ⁻ AND has an extra electron.	1
1.	a	iii	Cl has a greater nuclear charge/number of protons/ Z_{eff} «causing a stronger pull on the outer electrons» ✓ same number of shells OR same «outer» energy level OR similar shielding ✓		2
1.	a	iv	«two major» isotopes «of atomic mass 35 and 37» ✓		1
1.	a	v	«diatomic» molecule composed of «two» chlorine-37 atoms ✓ chlorine-37 is the least abundant «isotope» OR low probability of two ^{37}Cl «isotopes» occurring in a molecule ✓		2

Question			Answers	Notes	Total
1.	b	i	« $\frac{2.67 \text{ g}}{86.94 \text{ g mol}^{-1}} = \text{» } 0.0307 \text{ «mol» } \checkmark$		1
1.	b	ii	« $n_{\text{HCl}} = 2.00 \text{ mol dm}^{-3} \times 0.2000 \text{ dm}^3$ » = 0.400 mol \checkmark « $\frac{0.400}{4} = \text{» } 0.100 \text{ mol AND MnO}_2$ is the limiting reactant \checkmark	Accept other valid methods of determining the limiting reactant in M2.	2
1.	b	iii	« $0.0307 \text{ mol} \times 4 = 0.123 \text{ mol}$ » « $0.400 \text{ mol} - 0.123 \text{ mol} = \text{» } 0.277 \text{ «mol» } \checkmark$		1
1.	b	iv	« $0.0307 \text{ mol} \times 22.7 \text{ dm}^3 \text{ mol}^{-1} = \text{» } 0.697 \text{ «dm}^3\text{» } \checkmark$	Accept methods employing $pV = nRT$.	1
1.	b	v	MnO ₂ : +4 \checkmark MnCl ₂ : +2 \checkmark		2

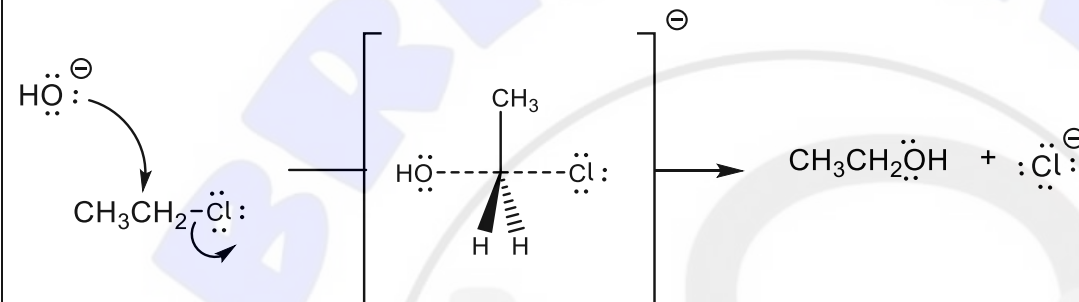
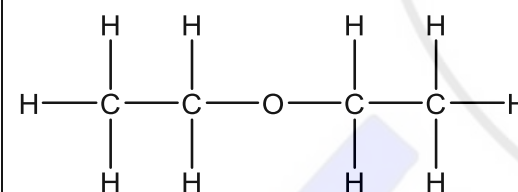
(continued...)

(Question 1b continued)

Question			Answers	Notes	Total
1.	b	vi	oxidizing agent AND oxidation state of Mn changes from +4 to +2/decreases ✓		1
1.	c	i	partially dissociates/ionizes «in water» ✓		1
1.	c	ii	ClO ⁻ ✓		1
1.	c	iii	«[H ⁺] = 10 ^{-3.61} ⇒ 2.5 × 10 ⁻⁴ «mol dm ⁻³ » ✓		1
1.	d	i	«free radical» substitution/S _R ✓	<i>Do not accept electrophilic or nucleophilic substitution.</i>	1
1.	d	ii	chloroethane AND C–Cl bond is weaker/324 kJ mol ⁻¹ than C–H bond/414 kJ mol ⁻¹ OR chloroethane AND contains a polar bond ✓	<i>Accept “chloroethane AND polar”.</i>	1

(continued...)

(Question 1d continued)

Question			Answers	Notes	Total
1.	d	iii	 <p>curly arrow going from lone pair/negative charge on O in ^-OH to C ✓ curly arrow showing Cl leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓</p>	<p>Accept OH^- with or without the lone pair.</p> <p>Do not accept curly arrows originating on H in OH^-.</p> <p>Accept curly arrows in the transition state.</p> <p>Do not penalize if HO and Cl are not at 180°.</p> <p>Do not award M3 if $OH-C$ bond is represented.</p>	3
1.	d	iv	 <p>/ $CH_3CH_2OCH_2CH_3$ ✓</p>	Accept $(CH_3CH_2)_2O$.	1

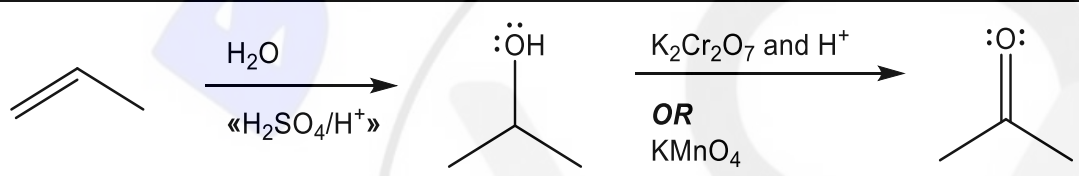
(continued...)

(Question 1d continued)

Question			Answers	Notes	Total
1.	d	v	2 «signals» ✓ 0.9–1.0 AND triplet ✓ 3.3–3.7 AND quartet ✓	Accept any values in the ranges. Award [1] for two correct chemical shifts or two correct splitting patterns.	3
1.	e	i	« $M(\text{CCl}_2\text{F}_2) \Rightarrow 120.91 \text{ g mol}^{-1}$ » ✓ $\frac{2 \times 35.45 \text{ g mol}^{-1}}{120.91 \text{ g mol}^{-1}} \times 100\% \Rightarrow 58.64 \text{ «\%»}$ ✓	Award [2] for correct final answer.	2
1.	e	ii	Any of: research «collaboration» for alternative technologies «to replace CFCs» OR technologies «developed»/data could be shared OR political pressure/Montreal Protocol/governments passing legislations ✓	Do not accept just “collaboration”. Do not accept any reference to CFC as greenhouse gas or product of fossil fuel combustion. Accept reference to specific measures, such as agreement on banning use/manufacture of CFCs.	1
1.	e	iii	$\text{O}_3 + \text{Cl}\cdot \rightarrow \text{O}_2 + \text{ClO}\cdot$ ✓ $\text{ClO}\cdot + \text{O}\cdot \rightarrow \text{O}_2 + \text{Cl}\cdot$ OR $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{Cl}\cdot + 2\text{O}_2$ ✓	Penalize missing/incorrect radical dot (·) once only.	2

Question		Answers	Notes	Total
2.	a	<i>Electron domain geometry: tetrahedral</i> ✓ <i>Molecular geometry: bent/V-shaped</i> ✓		2
2.	b	sp ² ✓		1
2.	c	σ-bonds: 3 AND π-bonds: 1 ✓		1
2.	d	B AND C=O absorption/1750 «cm ⁻¹ » OR B AND absence of O-H /3200–3600 «cm ⁻¹ absorption» ✓	<i>Accept any value between 1700–1750 cm⁻¹.</i>	1

Question	Answers	Notes	Total
<p>2. e</p>	<p>Accept any two C_3H_6O isomers except for propanone and propen-2-ol:</p> <div style="display: flex; flex-wrap: wrap; justify-content: space-around;"> <div style="text-align: center;"> $\begin{array}{c} \text{H} & & \text{H} \\ & & \\ \text{C}=\text{C} & -\text{O}- & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$ </div> <div style="text-align: center;"> $\begin{array}{c} \text{H} & \text{H} & \text{O} \\ & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \end{array}$ </div> </div> <div style="display: flex; flex-wrap: wrap; justify-content: space-around;"> <div style="text-align: center;"> $\begin{array}{c} & \text{H} & \text{H} \\ & / & \backslash \\ \text{O} & & \text{C} \\ & & / \backslash \\ \text{C} & - & \text{C} \\ / & & \backslash \\ \text{H} & & \text{H} \end{array}$ </div> <div style="text-align: center;"> $\begin{array}{c} & \text{H} & & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & -\text{O}-\text{H} \\ & & & \\ & \text{H} & & \text{H} \end{array}$ </div> </div> <div style="display: flex; flex-wrap: wrap; justify-content: space-around;"> <div style="text-align: center;"> $\begin{array}{c} & \text{H} & & \text{O} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & -\text{O}-\text{H} \\ & & & \\ & \text{H} & & \text{H} \end{array}$ </div> <div style="text-align: center;"> $\begin{array}{c} \text{H} & & \text{H} \\ & & \\ \text{C}=\text{C} & -\text{C}- & \text{O}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$ </div> </div> <div style="text-align: center;"> $\begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C} & -\text{C}=\text{C}- & \text{O}-\text{H} \\ & & \\ \text{H} & & \end{array}$ </div> <p style="text-align: right; margin-top: 10px;">✓✓</p>	<p>Penalize missing hydrogens in displayed structural formulas once only.</p>	<p>2</p>

Question			Answers	Notes	Total
2.	f	i	B AND K_c is greater than 1/large ✓		1
2.	f	ii	« $\Delta G^\ominus = -RT \ln K = 0.00831 \text{ kJ mol}^{-1} \text{ K}^{-1} (298 \text{ K}) (\ln 1.0 \times 10^8) =$ -46 «kJ mol ⁻¹ » ✓		1
2.	g	i	 <p> H_2O $\xrightarrow{\text{«H}_2\text{SO}_4/\text{H}^+\text{»}}$ </p> <p> $\text{K}_2\text{Cr}_2\text{O}_7 \text{ and } \text{H}^+$ OR KMnO_4 </p> <p> $\text{H}_2\text{O}/\text{water}$ «and H^+» ✓ $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3/\text{propan-2-ol}$ ✓ </p> <p> $\text{K}_2\text{Cr}_2\text{O}_7/\text{«potassium» dichromate(VI)}$ AND H^+ OR $\text{KMnO}_4/\text{«acidified potassium» manganate(VII)}$ ✓ </p>	Accept H_3O^+ .	3

Question			Answers	Notes	Total
2.	g	ii	primary carbocation «intermediate forms» OR minor product «of the water addition would be» propan-1-ol OR anti-Markovnikov addition of water ✓ primary alcohol/propan-1-ol oxidizes to an aldehyde/propanal ✓		2

Question		Answers	Notes	Total
3.	a	<p><i>Bonds broken:</i> $8(\text{C-H}) + 2(\text{C-C}) + 5(\text{O=O}) / 8 \times 414 \text{ «kJ mol}^{-1}\text{»} + 2 \times 346 \text{ «kJ mol}^{-1}\text{»} + 5 \times 498 \text{ «kJ mol}^{-1}\text{»} / 6494 \text{ «kJ»} \checkmark$</p> <p><i>Bonds formed:</i> $6(\text{C=O}) + 8(\text{O-H}) / 6 \times 804 \text{ «kJ mol}^{-1}\text{»} + 8 \times 463 \text{ «kJ mol}^{-1}\text{»} / 8528 \text{ «kJ»} \checkmark$</p> <p>«Enthalpy change = bonds broken – bonds formed = $6494 \text{ kJ} - 8528 \text{ kJ} = -2034 \text{ «kJ»} \checkmark$</p>	Award [3] for correct final answer.	3
3.	b	<p>$4(-241.8 \text{ «kJ»})$ AND $3(-393.5 \text{ «kJ»})$ AND «1»$(-105 \text{ «kJ»}) \checkmark$</p> <p>«$\Delta H^\ominus = 4(-241.8 \text{ «kJ»}) + 3(-393.5 \text{ «kJ»}) - \text{«1»}(-105 \text{ «kJ»}) = -2043 \text{ «kJ»} \checkmark$</p>	Award [2] for correct final answer. Award [1 max] for -2219 «kJ» .	2
3.	c	positive AND more moles «of gas» in products \checkmark		1
3.	d	<p>$4 \times 188.8 \text{ «JK}^{-1}\text{»}$ AND $3 \times 213.8 \text{ «JK}^{-1}\text{»}$ AND «1 \times» $270 \text{ «JK}^{-1}\text{»}$ AND $5 \times 205 \text{ «JK}^{-1}\text{»} \checkmark$</p> <p>«$\Delta S^\ominus = 4(188.8 \text{ JK}^{-1}) + 3(213.8 \text{ JK}^{-1}) - [1(270 \text{ JK}^{-1}) + 5(205 \text{ JK}^{-1})] = 102 \text{ «JK}^{-1}\text{»} \checkmark$</p>	Award [2] for correct final answer.	2
3.	e	<p>«$T = 5 + 273 = 278 \text{ K} \checkmark$</p> <p>«$\Delta G^\ominus = -2043 \text{ kJ} - (278 \text{ K} \times 0.102 \text{ kJ K}^{-1}) = -2071 \text{ «kJ»} \checkmark$</p>	Award [2] for correct final answer.	2

Question		Answers	Notes	Total
4.	a	provides an alternative pathway/mechanism AND lower E_a ✓	<i>Accept description of how catalyst lowers E_a (e.g. "reactants adsorb on surface «of catalyst»", "reactant bonds weaken «when adsorbed»").</i>	1
4.	b	more/greater proportion of molecules with $E \geq E_a$ ✓ greater frequency/probability/chance of collisions «between the molecules» OR more collision per unit of time/second ✓		2
4.	c	hydrogen bonding/bonds «and dipole–dipole and London/dispersion forces are present in» propan-2-ol ✓ dipole–dipole «and London/dispersion are present in» propanone ✓ propan-2-ol less volatile AND hydrogen bonding/bonds stronger «than dipole–dipole » OR propan-2-ol less volatile AND «sum of all» intermolecular forces stronger ✓		3

Question			Answers	Notes	Total
4.	d	i			1
4.	d	ii	« $-0.13\text{ V} - (-0.26\text{ V}) = +0.13\text{ V}$ » ✓		1
4.	d	iii	« $\Delta G^\ominus = -nFE^\ominus = -2 \times 96\,500 \times \frac{0.13}{1000} = -25\text{ kJ}$ » ✓		1
4.	d	iv	Bi/Cu/Ag/Pd/Hg/Pt/Au ✓	Accept Sb OR As.	1
4.	d	v	electrostatic attraction ✓ between «a lattice of» metal/positive ions/cations AND «a sea of» delocalized electrons ✓	Accept “mobile/free electrons”.	2

(continued...)

(Question 4d continued)

Question			Answers	Notes	Total
4.	d	vi	<p>Any of: malleability/hardness OR «tensile» strength/ductility OR density OR thermal/electrical conductivity OR melting point OR thermal expansion ✓</p>	<p><i>Do not accept corrosion/reactivity or any chemical property.</i></p> <p><i>Accept other specific physical properties.</i></p>	1

Question			Answers	Notes	Total
5.	a		$\text{CH}_3\text{COOH (aq)} + \text{KOH (aq)} \rightarrow \text{CH}_3\text{COOK (aq)} + \text{H}_2\text{O (l)} \checkmark$	Accept the ionic equation.	1
5.	b	i	B: CH_3COOH AND $\text{CH}_3\text{COO}^- \checkmark$ C: $\text{CH}_3\text{COO}^- \checkmark$	Accept names. Accept CH_3COOK for CH_3COO^-	2
5.	b	ii	phenolphthalein \checkmark	Accept "phenol red" or "bromothymol blue".	1
5.	b	iii	B AND the region where small additions «of the base/KOH » result in little or no change in pH OR B AND the flattest region of the curve «at intermediate pH/before equivalence point » OR B AND half the volume needed to reach equivalence point OR B AND similar amounts of weak acid/ CH_3COOH /ethanoic acid AND conjugate base/ CH_3COO^- /ethanoate \checkmark		1
5.	c		$K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{COOH}]}$	Accept H^+ instead of H_3O^+ .	1
5.	d		« $K_a = 10^{-4.76} = 1.7 \times 10^{-5}$ » « $K_w = K_a \cdot K_b = 1.0 \times 10^{-14} = 1.7 \times 10^{-5} \times K_b$ » « $K_b =$ » $5.8 \times 10^{-10} \checkmark$	Accept answers between $5.7\text{--}5.9 \times 10^{-10}$.	1

Question			Answers	Notes	Total
5.	e		$\llcorner n(\text{KOH}) = 0.02075 \text{ dm}^3 \times 1.00 \text{ mol dm}^{-3} \Rightarrow 0.0208 \text{ «mol»} \checkmark$ $\llcorner n(\text{KOH}) = n(\text{CH}_3\text{COOH})\llcorner$ $\llcorner [\text{CH}_3\text{COOH}] = \frac{0.0208 \text{ mol}}{0.02500 \text{ dm}^3} \Rightarrow 0.830 \text{ «mol dm}^{-3}\llcorner \checkmark$	<i>Award [2] for correct final answer.</i>	2
5.	f	i	systematic «error» \checkmark		1
5.	f	ii	$[\text{CH}_3\text{COOH}]$ would be higher \checkmark actual $[\text{KOH}]$ is lower «than the value in calculation» OR larger volume of KOH «solution» needed to neutralize the acid \checkmark	<i>Accept KOH partially neutralised by CO_2 from air.</i>	2

Question		Answers	Notes	Total
6.	a	$\llcorner E = \frac{745\,000\text{ J mol}^{-1}}{6.02 \times 10^{23}\text{ mol}^{-1}} \Rightarrow 1.24 \times 10^{-18}\text{ J} \checkmark$ $\llcorner E = h\nu$ $\llcorner 1.24 \times 10^{-18}\text{ J} = 6.63 \times 10^{-34}\text{ J s} \times \nu$ $\nu = 1.87 \times 10^{15}\text{ s}^{-1}/\text{Hz} \checkmark$	Award [2] for correct final answer. Award [1] for 1.12×10^{39} «Hz».	2
6.	b	orange light is absorbed «and the complementary colour is observed» \checkmark Any TWO from: partially filled d-orbitals \checkmark «ligands/water cause» d-orbitals «to» split \checkmark light is absorbed as electrons move to a higher energy orbital «in d-d transitions» OR light is absorbed as electrons are promoted \checkmark energy gap corresponds to «orange» light in the visible region of the spectrum \checkmark		3
6.	c	cathode/negative «electrode» AND Cu^{2+} reduced «at that electrode» \checkmark	Accept cathode/negative «electrode» AND copper forms «at that electrode».	1

Question		Answers	Notes	Total
7.	a	NO: second ✓ O ₂ : first ✓		2
7.	b	not possible AND «proposed» mechanism does not match experimental rate law OR not possible AND «proposed» mechanism shows zero/not first order with respect to oxygen ✓		1