

GCE

Chemistry A

H432/02: Synthesis and analytical techniques

Advanced GCE

Mark Scheme for June 2019

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

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Annotations available in RM Assessor

Annotation	Meaning
	Correct response
	Incorrect response
	Omission mark
	Benefit of doubt given
	Contradiction
	Rounding error
	Error in number of significant figures
	Error carried forward
	Level 1
	Level 2
	Level 3
	Benefit of doubt not given
	Noted but no credit given
	Ignore

Abbreviations, annotations and conventions used in the detailed Mark Scheme (to include abbreviations and subject-specific conventions).

Annotation	Meaning
DO NOT ALLOW	Answers which are not worthy of credit
IGNORE	Statements which are irrelevant
ALLOW	Answers that can be accepted
()	Words which are not essential to gain credit
—	Underlined words must be present in answer to score a mark
ECF	Error carried forward
AW	Alternative wording
ORA	Or reverse argument

Subject-specific Marking Instructions**INTRODUCTION**

Your first task as an Examiner is to become thoroughly familiar with the material on which the examination depends. This material includes:

- the specification, especially the assessment objectives
- the question paper
- the mark scheme.

You should ensure that you have copies of these materials.

You should ensure also that you are familiar with the administrative procedures related to the marking process. These are set out in the OCR booklet **Instructions for Examiners**. If you are examining for the first time, please read carefully **Appendix 5 Introduction to Script Marking: Notes for New Examiners**.

Please ask for help or guidance whenever you need it. Your first point of contact is your Team Leader.

SECTION A

Question	Answer	Marks	AO element	Guidance
1	A	1	AO1.2	
2	D	1	AO2.1	
3	C	1	AO1.2	
4	C	1	AO1.2	ALLOW E (This is the correct term)
5	D	1	AO2.5	
6	A	1	AO2.5	
7	B	1	AO1.2	ALLOW 6 (This is the number of chiral centres)
8	C	1	AO1.2	
9	A	1	AO2.5	
10	B	1	AO2.5	
11	A	1	AO2.4	
12	C	1	AO2.5	
13	C	1	AO1.2	
14	A	1	AO1.1	
15	B	1	AO1.2	
	Total	15		

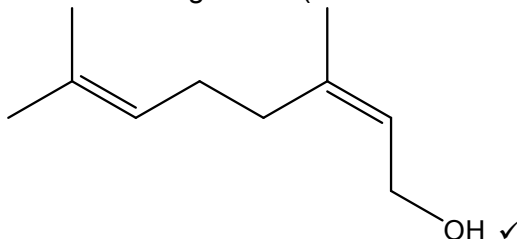
SECTION B

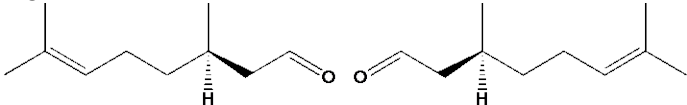
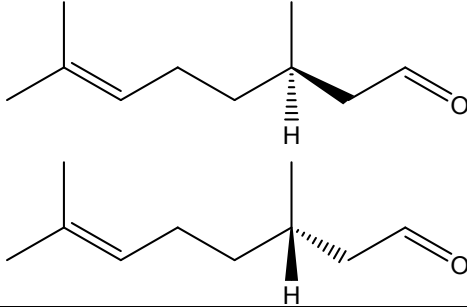
Question			Answer	Marks	AO element	Guidance
16	(a)	(i)	ANNOTATE ANSWER WITH TICKS AND CROSSES Curly arrow from C=C bond to H of H-Br ✓ DO NOT ALLOW partial charge on C=C Correct dipole shown on H-Br ✓ AND curly arrow showing breaking of H-Br bond ✓	4	AO1.2 AO1.2	NOTE: curly arrows can be straight, snake-like, etc. but NOT double headed or half headed arrows 1st curly arrow must - go to the H atom of H-Br AND - start from, OR be traced back to any point across width of C=C 2nd curly arrow must - start from, OR be traced back to any part of $\delta^+ \text{H}-\text{Br}^{\delta-}$ bond AND - go to $\text{Br}^{\delta-}$

Question			Answer	Marks	AO element	Guidance	
			Correct carbocation AND curly arrow from Br⁻ to C⁺ of carbocation ✓ DO NOT ALLOW δ+ on C of carbocation H₃C CHO C⁺ — C — H H₃C H Br⁻ OR CH₃ CHO H₃C — C — C⁺ — H H H Br⁻ ----- Correct product ✓ CH₃ CHO H₃C — C — C — H Br H OR CH₃ CHO H₃C — C — C — H H Br		AO2.5	IGNORE connectivity of CHO and CH₃ groups in carbocation and product e.g. ALLOW OR ALLOW COH for CHO (<i>reaction does not involve this group</i>) 3rd curly arrow must - go to the C⁺ of carbocation AND - start from, OR be traced back to any point across width of lone pair on :Br⁻ OR start from – charge of Br⁻ ion (Lone pair NOT needed if curly arrow shown from – charge of Br⁻ ion) IF Br₂ is used instead of HBr contact your Team Leader	
(a)	(ii)	(major product forms from) most/more stable	2		For carbocation,		

Question			Answer	Marks	AO element	Guidance
			intermediate/carbocation ✓ (major product forms from a) tertiary carbocation OR carbocation bonded to more C atoms / more alkyl groups OR carbocation bonded to no H atoms ✓		AO1.1 AO1.2	ALLOW carbonium ion or cation IGNORE descriptions of the major/minor product in terms of Markownikoff's rule e.g. H atom joins to C with most H IGNORE references to stability of the product ----- ALLOW ORA, i.e. (minor product forms from) least/less stable intermediate/carbocation ✓ (minor product forms from a) secondary carbocation OR carbocation bonded to fewer C atoms / more alkyl groups OR carbocation bonded to H atoms ✓ -----
	(b)	(i)	Tollens' (reagent) ✓	2	AO1.2	ALLOW ammoniacal silver nitrate OR Ag ⁺ /NH ₃

Question			Answer	Marks	AO element	Guidance
			Silver (mirror/precipitate/ppt/solid) with citronellal/the aldehyde ✓		×2	ALLOW black ppt OR grey ppt IGNORE references to acidified dichromate reacting with both compounds ----- ALLOW 2,4-DNP/2,4-DNPH ALLOW Brady's reagent ✓ Yellow/orange/red precipitate with citronellal/aldehyde/carbonyl group ✓ ----- IF other reagents are seen, contact your Team Leader
	(b)	(ii)	C ₁₀ H ₁₈ O ✓	1	AO1.2	DO NOT ALLOW C ₁₀ H ₁₇ OH
	(b)	(iii)	Same molecular formula AND Different structural formulae ✓ OR Both (geraniol and citronellal) have the molecular formula C₁₀H₁₈O AND Different structural formulae ✓	1	AO1.1	Same formula is not sufficient (no reference to molecular) Different arrangement of atoms is not sufficient (no reference to structure/structural) For structural formulae, ALLOW structure/displayed/skeletal formulae/functional groups DO NOT ALLOW any reference to spatial/space ALLOW ECF from incorrect molecular formula in (b)(ii)
		(iv)	Same structural formula	1	AO1.1	ALLOW structure/displayed/skeletal formula

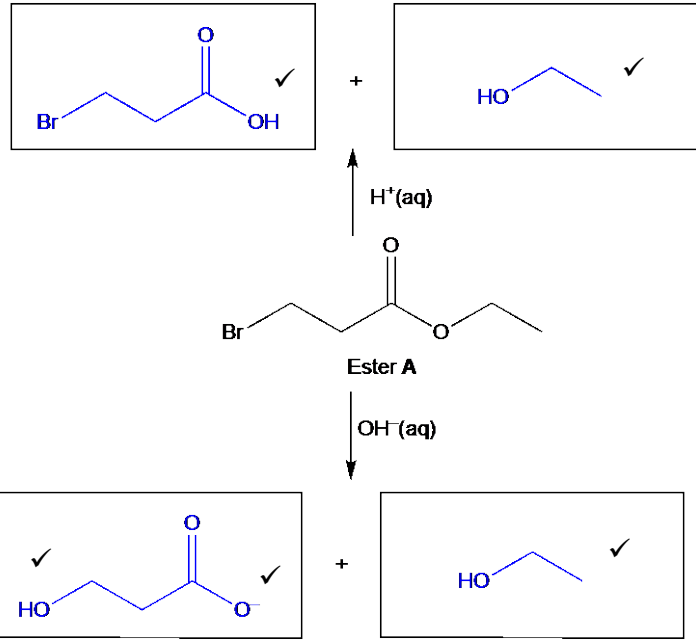
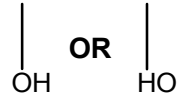
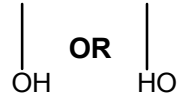
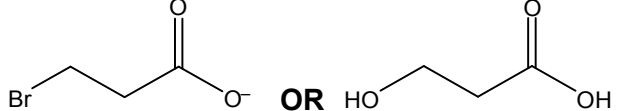
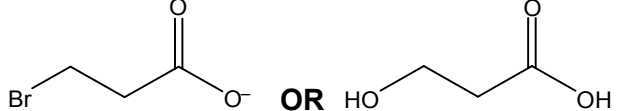
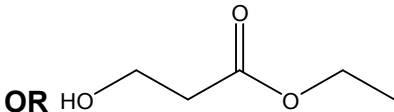
Question			Answer	Marks	AO element	Guidance
			AND Different arrangement (of atoms) in space OR different spatial arrangement (of atoms) ✓			DO NOT ALLOW same empirical formula OR same general formula IGNORE same molecular formula Reference to <i>E/Z</i> isomerism or optical isomerism is not sufficient
		(v)	Geraniol: (Carbon-carbon) double bond at carbon-2(,3) AND <i>E OR Z</i> ✓ Structure of <i>Z</i> geraniol (<i>E</i> isomer is shown in question)  OH ✓	4	AO1.2 AO2.5	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC CHECK diagrams of citronellal and geraniol for annotations that may be worthy of credit DO NOT ALLOW isomerism at C=C at carbon 6(,-7) ALLOW identification of carbon-2(,3) from correct <i>Z</i> geraniol isomer if not stated in text or diagram IGNORE <i>cis OR trans</i> isomerism (<i>none of the substituent groups attached to the C=C are the same</i>) IGNORE geometric ALLOW type of isomerism from <i>E/Z</i> labels, even if incorrectly assigned In geraniol, ALLOW C ₆ H ₁₁ OR R to represent alkenyl chain ALLOW CH ₃ O to represent CH ₂ OH

Question	Answer	Marks	AO element	Guidance
	Citronellal: chiral/asymmetric C at carbon-3 OR carbon-3 is bonded to 4 different groups AND optical isomerism ✓ Two 3D structures of citronellal that are mirror images ✓ e.g. 		AO1.2 AO2.5	ALLOW identification of carbon-3 from 3D structure citronellal if not stated in text or diagram IGNORE connectivity of groups around chiral C In citronellal, ALLOW C₆H₁₁ OR R to represent alkenyl chain ALLOW C₂H₃O to represent CH₂CHO IF structural formula of alkenyl chain is used IGNORE one small slip in one/both isomers e.g. (CH₃)₂CHCH₂CH₂ (<i>missing carbon-7</i>) ALLOW two 3D structures with 2 groups swapped e.g. 
	Total	13		

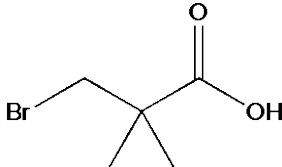
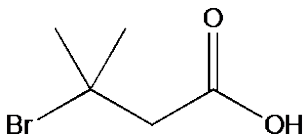
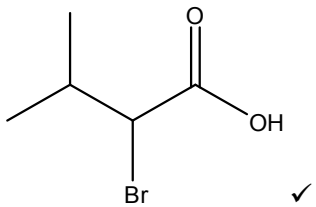
Question	Answer	Marks	AO element	Guidance
17 (a) (i)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{OH})-\text{COOH} \xrightarrow{\text{H}^+(\text{aq})} \text{H}_3\text{N}^+-\text{CH}(\text{CH}_2\text{OH})-\text{COO}^-$ (boxed ✓) $\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{OH})-\text{COOH} \xrightarrow{(\text{CH}_3)_2\text{CHOH} / \text{H}_2\text{SO}_4} \text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{OH})-\text{COOCH}(\text{CH}_3)_2$ (boxed ✓) $\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{OH})-\text{COOH} \xrightarrow{\text{Excess CH}_3\text{COCl}} \text{CH}_3\text{CONH}-\text{CH}(\text{CH}_2\text{OCOCH}_3)-\text{COOH}$ (boxed ✓ ✓)	4	AO2.5 ×4	ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous ALLOW protonation of NH_2 group in reaction with $(\text{CH}_3)_2\text{CHOH}$ i.e. ALL structures must be based on serine For reaction with excess CH_3COCl, IGNORE reaction of COOH to form an acid anhydride ----- ALLOW 1 mark for (both NH and OH groups reacted but acyl chloride instead of COOH) OR

Question	Answer	Marks	AO element	Guidance
				$\begin{array}{c} \text{CH}_3\text{CONH}-\text{C}-\text{C} \\ \quad \quad \quad \quad \quad // \\ \quad \quad \quad \text{CH}_2 \quad \quad \text{O} \\ \quad \quad \quad \quad \quad \quad \backslash \\ \quad \quad \quad \text{CH}_3\text{COO} \quad \quad \text{OH} \end{array}$ <i>(both NH and OH groups reacted but H missing from α C atom)</i> OR $\begin{array}{c} \text{CH}_3\text{CONH}-\text{C}-\text{C} \\ \quad \quad \quad \quad \quad // \\ \quad \quad \quad \text{CH}_2 \quad \quad \text{O} \\ \quad \quad \quad \quad \quad \quad \backslash \\ \quad \quad \quad \text{OH} \quad \quad \text{OH} \end{array}$ <i>(NH group reacted correctly but rest of serine unchanged)</i> OR $\begin{array}{c} \text{NH}_2-\text{C}-\text{C} \\ \quad \quad \quad \quad // \\ \quad \quad \text{CH}_2 \quad \quad \text{O} \\ \quad \quad \quad \quad \quad \backslash \\ \quad \quad \text{CH}_3\text{COO} \quad \quad \text{OH} \end{array}$ <i>(OH group reacted correctly but rest of serine unchanged)</i>
(ii)	IF $M_r(\text{amino acid}) = 131$ from titration analysis AWARD	4		

Question			Answer	Marks	AO element	Guidance
			first 3 marks ALLOW 3SF or more throughout IGNORE trailing zeroes, e.g. ALLOW 0.044 for 0.0440 $n(\text{HCl}) = 0.150 \times \frac{25.0}{1000}$ OR 3.75×10^{-3} (mol) ✓ $n(\text{amino acid})$ in 250 cm ³ $= 3.75 \times 10^{-3} \times \frac{250.0}{21.30}$ OR 0.0440 (mol) ✓ $M(\text{amino acid}) = \frac{5.766}{0.0440} = 131$ (g mol ⁻¹) ✓ Amino acid = (CH ₃) ₂ CHCH ₂ CH(NH ₂)COOH/leucine AND working to show R = 57 to justify choice OR evidence to show M _r leucine = 131 to justify choice ✓		AO2.8 AO2.8 AO2.8 AO3.2	ALLOW alternative approaches Calculator: 0.04401408451 ALLOW ECF from incorrect $n(\text{HCl})$ ALLOW ECF from incorrect $n(\text{amino acid})$ ALLOW ECF from incorrect $M(\text{amino acid})$ i.e. ECF for alkyl group closest to calculated $M(\text{alkyl group})$, e.g. for $M(\text{alkyl group}) = 15$, ALLOW CH ₃ CH(NH ₂)COOH Note: evidence may be shown with table
	(b)	(i)	R _f value in range 0.33 – 0.35 ✓	1	AO1.1	ALLOW 2 SF or more. But ignore digits after second sig fig ALLOW 0.3̇ for 0.33.....
		(ii)	gly(cine) ✓ Amino acid matches (leu(cine) and) glycine in Solvent W AND Amino acid matches (ala(nine) and) glycine in Solvent X ✓	2	AO2.3 ×2	ALLOW glycine has the same/similar R _f as the unknown in both solvents/chromatograms ALLOW suitable alternatives for R _f e.g. moves same distance
			Total	11		

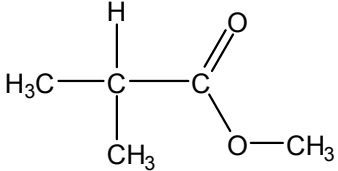
Question	Answer	Marks	AO element	Guidance
18 (a) (i)	ethyl 3-bromopropanoate ✓	1	AO1.2	ALLOW one word: ethyl3-bromopropanoate OR more words, e.g. ethyl 3-bromo propanoate IGNORE lack of hyphens, or addition of commas
	(ii) 	5	AO2.5 ×5	ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous ALLOW in either order ALLOW any vertical bond to the OH group e.g.  OR  DO NOT ALLOW OH– ALLOW in either order For reaction with OH–, ALLOW one mark for  OR  OR 

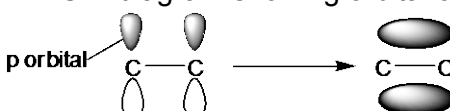
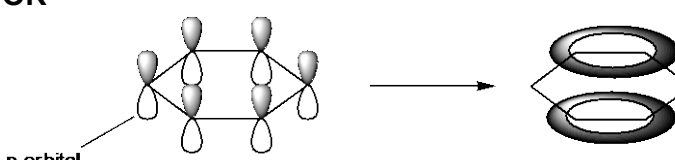
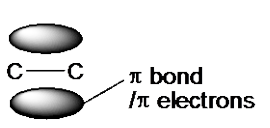
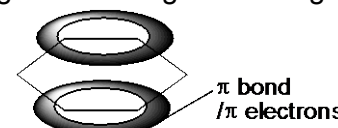
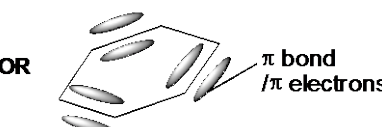
Question			Answer	Marks	AO element	Guidance															
		(iii)	hydrolysis ✓	1	AO1.1	IGNORE 'acid' and 'alkaline' IGNORE nucleophilic substitution															
	(b)		<table border="1"><thead><tr><th>Proton environment</th><th>Chemical shift</th><th>Splitting pattern</th></tr></thead><tbody><tr><td>1</td><td>3.0–4.3</td><td>Triplet</td></tr><tr><td>2</td><td>2.0–3.0</td><td>Triplet</td></tr><tr><td>3</td><td>3.0–4.3</td><td>Quartet</td></tr><tr><td>4</td><td>0.5–1.9</td><td>Triplet</td></tr></tbody></table> Mark by column Chemical shift: all 4 correct ✓✓ 3 correct ✓ Splitting pattern: all 4 correct ✓✓ 3 correct ✓	Proton environment	Chemical shift	Splitting pattern	1	3.0–4.3	Triplet	2	2.0–3.0	Triplet	3	3.0–4.3	Quartet	4	0.5–1.9	Triplet	4	AO3.1 × 4	ALLOW δ values ± 0.2 ppm, as a range or a value within the range ALLOW integers for δ values e.g. 2 is equivalent to 2.0 ALLOW quadruplet for quartet ALLOW diagrams to show splitting pattern e.g.  for triplet  for quartet ALLOW splitting patterns shown as numbers i.e. '3' for triplet, '4' for quartet
Proton environment	Chemical shift	Splitting pattern																			
1	3.0–4.3	Triplet																			
2	2.0–3.0	Triplet																			
3	3.0–4.3	Quartet																			
4	0.5–1.9	Triplet																			

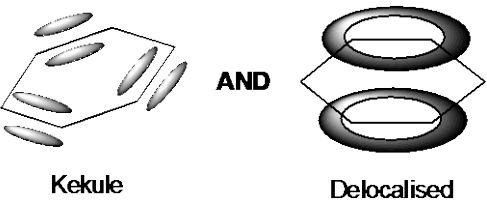
Question	Answer	Marks	AO element	Guidance
(c)	 OR  OR  ✓	1	AO3.1	ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous
(d)	IF answer on answer line = 24018, AWARD 2 marks IF answer on answer line = 27600, AWARD 1 mark ----- Relative mass of 200 molecules = $200 \times 138 = 27600$ ✓ M_r of polyester = $27600 - 199 \times 18 = 24018$ ✓	2	AO2.2 ×2	ALLOW ECF from incorrect M_r Alternative method based on repeat unit: M_r of 200 repeat units = $200 \times 120 = 24000$ ✓ M_r of polymer = $24000 + 1 + 17 = 24018$ ✓
(e)	(i)* Refer to marking instructions on page 4 of mark scheme	6	AO3.3	Indicative scientific points may include:

Question	Answer	Marks	AO element	Guidance
	<i>for guidance on marking this question.</i> Level 3 (5-6 marks) Correct calculation of the mass of (CH₃)₂CHCHO. AND Planned synthesis includes oxidation of aldehyde and formation of ester C with most of the reagents and conditions identified and equations are mostly correct. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) Calculation of the mass of (CH₃)₂CHCHO is partly correct AND Planned synthesis includes oxidation of aldehyde and formation of ester C with some of the reagents and conditions identified OR Attempts to calculate mass of (CH₃)₂CHCHO but makes little progress AND Planned synthesis includes oxidation of aldehyde and formation of ester C with most of the reagents and conditions identified and equations for each step are mostly correct <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i>		×6	Calculation of mass of (CH₃)₂CHCHO Using moles $n(\text{ester}) = \frac{12.75}{102.0}$ $= 0.125 \text{ (mol)}$ $n((\text{CH}_3)_2\text{CHCHO}) = 0.125 \times \frac{100}{40}$ $= 0.3125 \text{ (mol)}$ - Mass of (CH₃)₂CHCHO = 72.0×0.3125 $= 22.5 \text{ g}$ Using mass - Theoretical mass of ester = $12.75 \times \frac{100}{40}$ $= 31.875 \text{ (g)}$ - Theoretical $n((\text{CH}_3)_2\text{CHCHO}) = \frac{31.875}{102}$ $= 0.3125 \text{ (mol)}$ - Mass of (CH₃)₂CHCHO = 72.0×0.3125 $= 22.5 \text{ g}$ ALLOW small slip/rounding errors such as errors in Mr e.g. use of 71 instead of 72 for (CH₃)₂CHCHO ----- Examples of partly correct calculations Mass = 3.60 g from $0.125 \times \frac{40}{100} \times 72$ (% yield inverted) Mass = 9.00 g from 0.125×72 (% yield omitted)

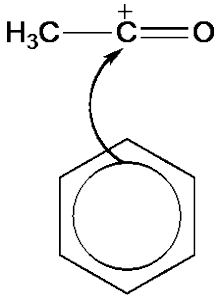
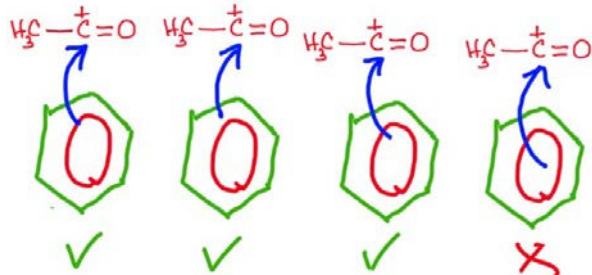
Question			Answer	Marks	AO element	Guidance
			Level 1 (1-2 marks) Calculation of the mass of $(\text{CH}_3)_2\text{CHCHO}$ is partly correct OR Planned synthesis includes both steps with some of the reagents and conditions identified OR Attempts equations for both steps but these may contain errors OR Describes one step of the synthesis with reagents, conditions and equation mostly correct <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.			<u>Synthesis: reagents and conditions</u> Step 1: Oxidation of aldehyde $(\text{CH}_3)_2\text{CHCHO}$ • Reagents: $\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$ • Conditions: reflux • Equation: $(\text{CH}_3)_2\text{CHCHO} + [\text{O}] \rightarrow (\text{CH}_3)_2\text{CHCOOH}$ Step 2: Formation of ester C • Reagents: methylpropanoic acid/$(\text{CH}_3)_2\text{CHCOOH}$ and methanol/CH_3OH • Conditions: acid (catalyst) reflux/heat • Equation: $(\text{CH}_3)_2\text{CHCOOH} + \text{CH}_3\text{OH} \rightarrow (\text{CH}_3)_2\text{CHCOOCH}_3 + \text{H}_2\text{O}$ IGNORE attempts to form methanol in synthesis
	(e)	(ii)		2	AO2.7 × 2	ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous

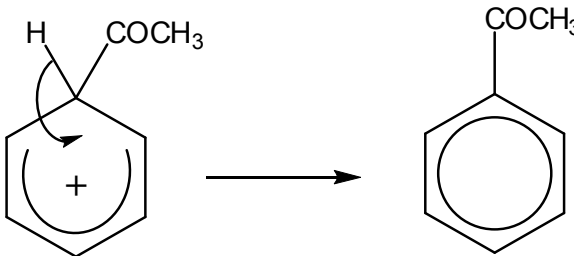
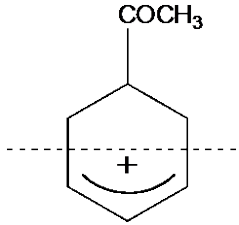
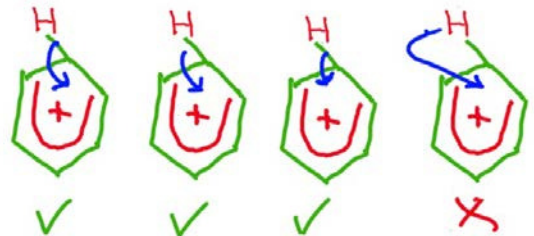
Question	Answer	Marks	AO element	Guidance
	Y (43) = $(\text{CH}_3)_2\text{CH}^+$ ✓ Z (71) $(\text{CH}_3)_2\text{CHCO}^+$ ✓ <i>If '+' charge is missing/incorrect but the structures of both fragments are correct, award one mark</i>			ALLOW positive charge to be anywhere on the structure For Y and Z, ALLOW structure of a feasible fragment ion formed from ester C  Ester C e.g. Y (43) = CH_3OC^+ Z (71) = $^+\text{CCOOCH}_3$ ALLOW 1 mark if both correct ions are shown but in the incorrect columns ALLOW 1 mark for both correct ions if one or both have an 'end bond' ALLOW 1 mark if both ions are shown using correct molecular formulae
	Total	22		

Question	Answer	Marks	AO element	Guidance
19 (a) (i)	Similarities Orbital overlap (sideways) overlap of p orbitals ✓ π bond π bond/system/ring above and below (bonding (C) atoms/ring/plane) ✓	3	AO1.1 × 3	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC ALLOW diagram showing orbital overlap e.g.  OR  p orbital label is required for first mark IGNORE C=C in diagram showing π bond IGNORE reference to s orbital overlap/σ bonds ALLOW from labelled diagram showing π bond e.g.  OR  OR  π bond/π electrons label is required for second mark

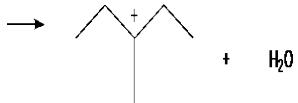
Question	Answer	Marks	AO element	Guidance
	Difference Kekule has: alternating π bonds OR 3 π bonds / localised (π electrons) / overlap in one direction / 2 electrons in π bond AND Delocalised has: π ring (system) / all p orbitals overlap OR (π electrons) spread around ring / overlap in both directions / 6 electrons in π bond /			----- ALLOW diagram showing π bond in both Kekule AND delocalised models e.g  Kekule AND Delocalised π bond labels not required for third mark
(ii)	Any 2 pieces of evidence from (✓ ✓) Bond length (C–C) bond length is between single (C–C) and double bond (C=C) OR all (C–C) bond lengths are the same ΔH hydrogenation ΔH hydrogenation less (exothermic) than expected Resistance to reaction Benzene is less reactive than alkenes OR bromination of benzene requires a catalyst/halogen carrier OR benzene does not react with/decolourise bromine (at room temperature) OR benzene reacts by substitution OR benzene does not (readily) react by addition	2	AO1.1 ×2	ALLOW (C–C) bond enthalpy is between single (C–C) and double bond (C=C) OR all (C–C) bond enthalpies are the same IGNORE enthalpy of hydration Benzene is unreactive is not sufficient (no comparison to alkene) For halogen carrier, ALLOW name or formula of suitable catalyst e.g. Fe, AlCl₃, FeBr₃

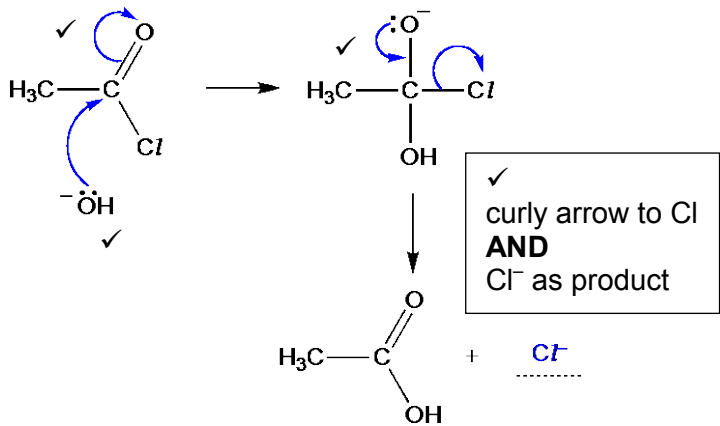
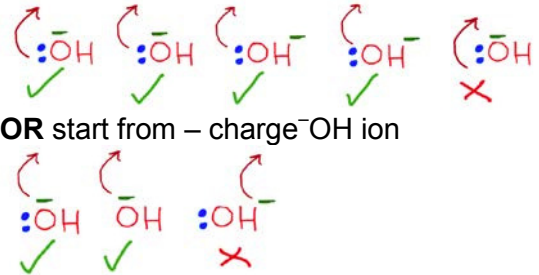
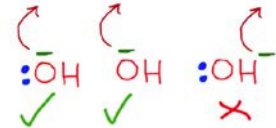
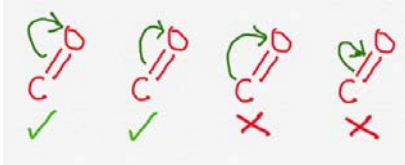
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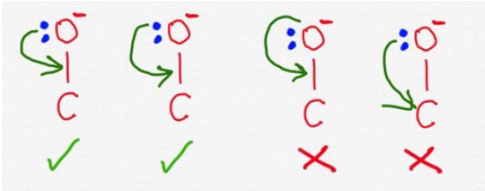
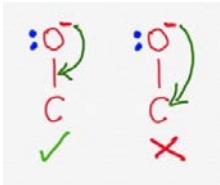
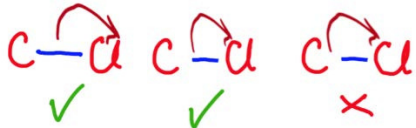
Question	Answer	Marks	AO element	Guidance
(ii)	D Addition / polyalkene AND E: Condensation / polyamide ✓	1	AO1.1	DO NOT ALLOW 'additional'
(iii)	Formation of electrophile $\text{CH}_3\text{COCl} + \text{AlCl}_3 \rightarrow \text{CH}_3\text{-C}^+=\text{O} + \text{AlCl}_4^- \checkmark$ Mechanism Curly arrow from π-bond to $\text{CH}_3\text{C}^+=\text{O}$ ✓  -----	5	AO2.5 AO2.5	ANNOTATE ANSWER WITH TICKS AND CROSSES ALLOW '+' charge anywhere on $\text{CH}_3\text{C}^+\text{O}$ <i>i.e.</i> CH_3CO^+ NOTE: curly arrows can be straight, snake-like, etc. but NOT double headed or half headed arrows 1st curly arrow must - go to the C of $\text{C}=\text{O}$ AND - start from, OR close to circle of benzene ring  IGNORE curly arrow shown on $\text{C}=\text{O}$

Question	Answer	Marks	AO element	Guidance
	Correct intermediate ✓ Curly arrow from C–H bond to reform π-ring ✓  Regeneration of catalyst $\text{H}^+ + \text{AlCl}_4^- \longrightarrow \text{AlCl}_3 + \text{HCl} \checkmark$		AO3.1 AO2.5 AO1.2	DO NOT ALLOW the following intermediate:  π-ring should cover approximately 4 of the 6 sides of the benzene ring structure AND the correct orientation, <i>i.e.</i> gap towards C with COCH_3 ALLOW + sign anywhere inside the 'hexagon' of intermediate curly arrow must start from, OR be traced back to, any part of C-H bond and go inside the 'hexagon' 

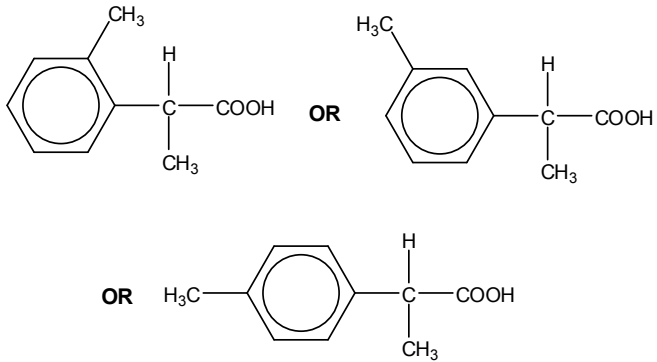
Question	Answer	Marks	AO element	Guidance
(iv)	one mark for each correct structure/reagent <chem>CC(C)(O)c1ccccc1</chem> (boxed, ✓) $\xrightarrow{\text{NaBr/Br}^- \text{ AND } \text{H}_2\text{SO}_4/\text{H}^+}$ ✓ <chem>CC(C)(#N)c1ccccc1</chem> (boxed, ✓) $\xrightarrow{\text{NH}_3 \text{ AND ethanol OR excess NH}_3}$ ✓ <chem>CC(C)(N)c1ccccc1</chem> (boxed, ✓) $\xrightarrow{\text{acid/H}^+/\text{H}_3\text{PO}_4/\text{H}_2\text{SO}_4}$ ✓ <chem>CC(C)(O)c1ccccc1</chem> (boxed, ✓) $\xrightarrow{\text{H}^+/\text{H}_2\text{SO}_4/\text{HCl}}$ ✓ <chem>CC(C)(#N)c1ccccc1</chem> (boxed, ✓) $\xrightarrow{\text{H}^+/\text{H}_2\text{SO}_4/\text{HCl}}$ <chem>CC(C)(N)c1ccccc1</chem> (boxed, ✓)	7	AO2.5 x7	ALLOW any vertical bond to the OH OR NH₂ groups e.g. ALLOW $\begin{array}{c} \\ \text{OH} \end{array}$ OR $\begin{array}{c} \\ \text{HO} \end{array}$ AND $\begin{array}{c} \\ \text{NH}_2 \end{array}$ OR $\begin{array}{c} \\ \text{H}_2\text{N} \end{array}$ DO NOT ALLOW OH⁻, OR NH₂⁻ but ALLOW ECF for subsequent use in this part For elimination, IGNORE 'concentrated', 'dilute' with acids BUT DO NOT ALLOW H₂O/steam/(aq) ALLOW HBr for NaBr/H₂SO₄ For hydrolysis. IGNORE missing (aq) ALLOW HNO₃ for hydrolysis but DO NOT ALLOW 'HNO₃ and H₂SO₄' ALLOW final 2 stages in opposite order i.e. NH₃ before acid hydrolysis $\xrightarrow{\text{NH}_3 \text{ AND ethanol OR excess NH}_3}$ <chem>CC(C)(#N)Nc1ccccc1</chem> (boxed) $\xrightarrow{\text{H}^+/\text{H}_2\text{SO}_4/\text{HCl}}$
	Total	23		

Question			Answer	Marks	AO element	Guidance
20	(a)	(i)	Movement of an electron pair ✓	1	AO1.1	For electron pair, ALLOW lone pair OR bonding pair OR 2 electrons
	(a)	(ii)	 Correct carbon skeleton ✓ ‘+’ charge on correct carbon skeleton ✓	2	AO3.1 ×2	ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous IGNORE any other products
	(a)	(iii)	Heterolytic one (bonded) atom/O receives both/2 electrons ✓ Fission Breaking of a covalent bond OR breaking of C-O bond ✓	2	AO1.2 AO1.1	ALLOW 2 electrons go to one (bonded) atom/O IGNORE formation of ions/radicals For O atom, ALLOW species DO NOT ALLOW element OR molecule ‘Bond breaking’ is not sufficient (no reference to covalent)

Question	Answer	Marks	AO element	Guidance
(b) (i)		4	AO3.2 ×4	IGNORE any dipoles shown NOTE: curly arrows can be straight, snake-like, etc. but NOT double headed or half headed arrows Curly arrow from OH⁻ must - go to the C of C=O AND - start from, OR be traced back to any point across width of lone pair on O of OH⁻  OR start from – charge⁻OH ion  Curly arrow from C=O bond must start from, OR be traced back to, any part of C=O bond and go to O  Curly arrow from O⁻ must

Question	Answer	Marks	AO element	Guidance
				- go to C=O bond AND - start from, OR be traced back to, any point across width of lone pair  OR start from '–' charge of O[–]  Curly arrow from C–Cl bond must start from, OR be traced back to, any part of C–Cl bond and go to Cl 
(b) (ii)	(OH [–]) donates an electron pair/lone pair OR (OH [–] acts as a) nucleophile ✓	1	AO1.2	
	Total	10		

Question	Answer	Marks	AO element	Guidance
21*	<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Structure is $\text{CH}_3\text{C}_6\text{H}_4\text{CH}(\text{CH}_3)\text{COOH}$ AND Most of the data analysed. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) A viable aromatic structure of $\text{C}_{10}\text{H}_{12}\text{O}_2$ that contains $\text{C}=\text{O}$ AND most key features consistent with spectral data AND Some of the spectral data analysed <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i>	6	AO1.2 × 2 AO3.1 × 2 AO3.2 × 2	Indicative scientific points: <u>Empirical and Molecular Formulae</u> $\begin{aligned} \text{C} : \text{H} : \text{O} &= \frac{73.17}{12.0} : \frac{7.32}{1.0} : \frac{19.51}{16.0} \\ &= 6.10 : 7.32 : 1.22 \\ &= 5 : 6 : 1 \end{aligned}$ - Empirical formula = $\text{C}_5\text{H}_6\text{O}$ - uses $m/z = 164.0$ to determine molecular formula as $\text{C}_{10}\text{H}_{12}\text{O}_2$ <u>Structure</u> ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous Key features of an aromatic structure consistent with spectral data COOH group 4 aromatic H atoms - single H atom that would give a quartet CH_3 group that would give a doublet CH_3 group that would give a singlet

Question	Answer	Marks	AO element	Guidance
	Level 1 (1–2 marks) Correct determination of empirical formula and/or molecular formula. OR Analyses some of the IR and NMR data. OR Analyses most of the NMR data. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.			Correct Structure $\text{CH}_3\text{C}_6\text{H}_4\text{CH}(\text{CH}_3)\text{COOH}$ ALLOW 2-, 3- OR 4- substitution of ring <i>i.e.</i>  Spectral analysis ^1H NMR $\delta = 1.6$ ppm, doublet, 3H $\text{CH}_3\text{—CH—}$ $\delta = 2.3$ ppm, singlet, 3H Ar—CH_3 $\delta = 2.7$ ppm, quartet, 1H CO—CH—CH_3 OR Ar—CH—CH_3 / $\text{C}_6\text{H}_5\text{—CH—CH}_3$ $\delta = 7.1\text{—}7.5$ ppm, multiplet, 4H $\text{C}_6\text{H}_4\text{—}$ ALLOW approximate values for chemical shifts. IR: - peak at $2300\text{—}3700\text{ cm}^{-1}$ is O—H - peak at $\sim 1720\text{ cm}^{-1}$ is C=O - unknown is a carboxylic acid ALLOW ranges from <i>Data Sheet</i> IGNORE references to C—O peaks
	Total	6		

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