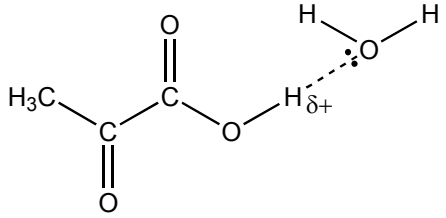
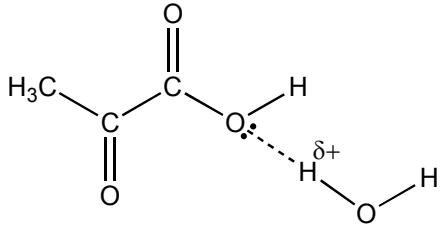
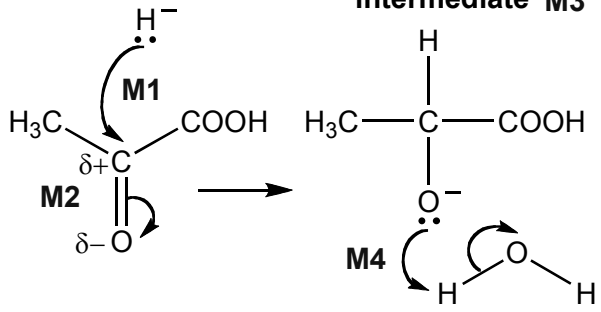
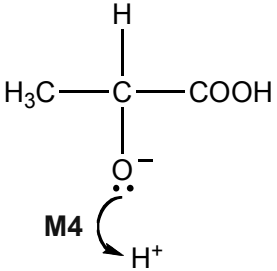
Question			Answer	Marks	Guidance
1	(a)		**M1 EITHER** in words: (pyruvic acid forms) hydrogen bonds with **water** **OR** correctly **labelled diagram** showing hydrogen bond between pyruvic acid and water ✓ **M2** diagram showing dashed/dotted line between $H^{\delta+}$ in COOH **and lone pair** of electrons on O in H_2O  **OR** diagram showing dashed/dotted line between $H^{\delta+}$ in H_2O and lone pair of electrons on O of OH in COOH ✓ 	2	**FOR M1 only: if use diagram ALLOW a** labelled hydrogen bond to O in C=O **FOR M2 only: IGNORE** a hydrogen bond to C=O, *i.e.* C=O - - - H–O **IGNORE** bond angles Diagram does **not** need to show all of pyruvic acid (**IGNORE** if wrong so allow ethanoic acid) but must have minimum of COOH **MIMIMUM requirement** is a $H^{\delta+}$ (on acid or water) and a lone pair on O (in acid or water) involved in a hydrogen bond ie IGNORE δ-
	(b)		$CH_3CH(OH)CH_2OH + 3[O] \rightarrow CH_3COCOOH + 2H_2O$ four correct formulae ✓ balanced ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous (**IGNORE** lack of brackets round 2° alcohol) **DO NOT ALLOW** molecular formulae **IF** propane1,3-diol used score 0

Question			Answer	Marks	Guidance
1	(c)			4	
			M1: 1 mark for curly arrow from H^- to C of C=O ✓		Curly arrow **MUST** start from – sign **OR** lone pair on H^- Lone pair **does not need** to be shown on H^-
			M2: 1 mark for correct dipoles on C=O **AND** curly arrow from double bond to $O^{\delta-}$ ✓		
			M3: 1 mark for correct intermediate with – charge on O ✓		Lone pair **does not need** to be shown on O^-
			M4: 1 mark for curly arrow from O^- of intermediate to H in H_2O **AND** curly arrow from the O—H **bond** to the O in H_2O: **Do not need** to show formation of OH^-		Curly arrow **MUST** start from – sign **OR** from lone pair on O^- of intermediate Lone pair **does not need** to be shown on O^- **For M4,** **ALLOW** mark for curly arrow from O^- of intermediate to H^+ 

Question			Answer	Marks	Guidance
1	(d)		***Either:*** **Use** Tollens' reagent **AND** correct reference to compound A being oxidised or Tollen's reagent acts as oxidising agent ✓ *Observation:* silver mirror/precipitate/ppt/solid ✓ ***or:*** **Use** $K_2Cr_2O_7$ **AND** H_2SO_4 **AND** correct reference to compound A being oxidised or $K_2Cr_2O_7$ acts as oxidising agent ✓ *Observation:* turns (dark) green **OR** blue ✓ ✎ **QWC** oxidised/oxidized/oxidation/redox *etc*. must be spelled **correctly at least ONCE** (*i.e.* **NOT** oxidisation, oxidated) to score 1st mark **UNLESS** 2,4-DNP(H)/Brady's reagent is used, when condensation/addition–elimination must be spelled **correctly at least ONCE**	3	**ALLOW** $AgNO_3$ in ammonia **OR** ammoniacal $AgNO_3$ **ALLOW** redox reaction **ALLOW** black ppt **OR** grey ppt **ALLOW** $Na_2Cr_2O_7$ **OR** $Cr_2O_7^{2-}$ for $K_2Cr_2O_7$ If formulae used, formulae must be correct **ALLOW** acidified dichromate If name given, **ALLOW** dichromate **OR** dichromate(VI) **IGNORE** reference to dilute/conc **ALLOW** H^+ **ALLOW** $KMnO_4$ **and** H_2SO_4 / acidified manganate(VII)/ permanganate / alkaline manganate(VII) **AND** correct reference to compound A being oxidised or $KMnO_4$ acts as oxidising agent *Observation:* decolourised **ALLOW** Benedict's or Fehling's reagent/solution **AND** correct reference to compound A being oxidised or Benedict's or Fehling's acts as oxidising agent *Observation:* (brick) red ppt **ALLOW** 2,4-DNP(H)/Brady's reagent **AND** measure melting point of derivative **AND** state it is a condensation reaction/addition-elimination reaction *Observation:* orange/yellow/red **precipitate** **ALLOW** solid **OR** crystals **OR** ppt as alternatives for precipitate

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>Guidance</th></tr>
<tr><td></td><td></td><td></td><td>$HOOCCH_2COOH$ ✓</td><td></td><td>ALLOW correct structural OR displayed OR skeletal formulae OR combination of above as long as unambiguous

ALLOW COO^- if used Tollens' or Fehling's or Benedict's

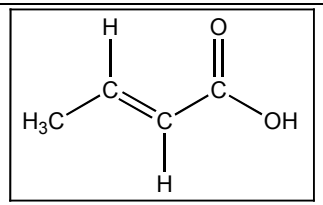
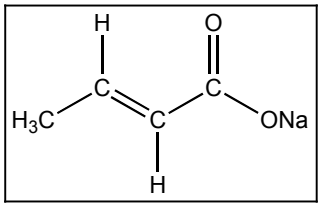
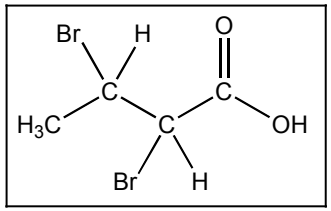
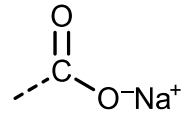
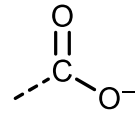
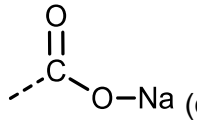
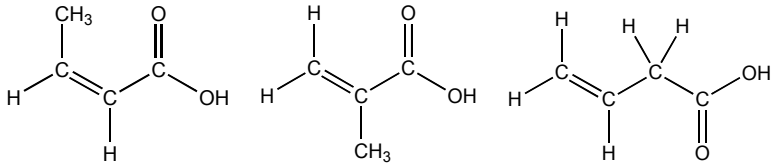
ALLOW correct unambiguous name:
propan(e-1,3-)dioic acid

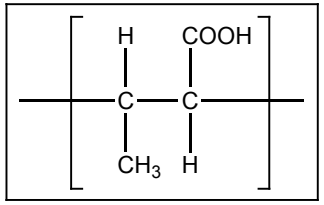
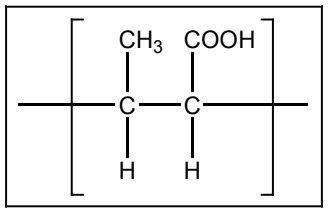
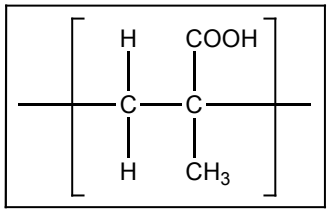
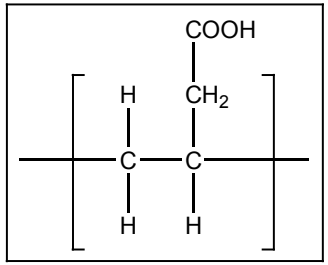
IGNORE dipropanoic acid
DO NOT ALLOW propan(e-1,3-)dicarboxylic acid

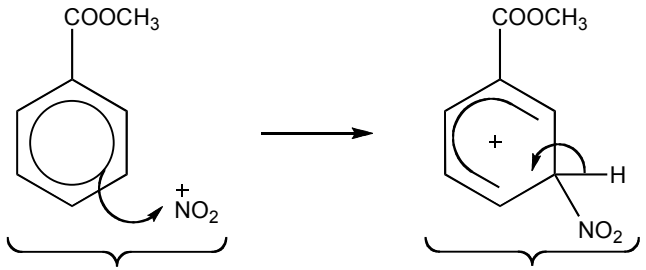
if used 2,4-DNP(H):
ALLOW correct hydrazone structure or name
ALLOW "(2,4-dinitrophenyl)hydrazone" (derivative)</td></tr>
<tr><td>1</td><td>(e)</td><td>(i)</td><td>
<table>
<tr><td></td><td>C</td><td>H</td><td>O</td></tr>
<tr><td>%</td><td>55.81%</td><td>7.02%</td><td>37.17%</td></tr>
<tr><td>mol</td><td>4.65</td><td>7.02</td><td>2.32</td></tr>
<tr><td>ratio</td><td>2</td><td>3</td><td>1</td></tr>
</table>
empirical formula = C_2H_3O ✓

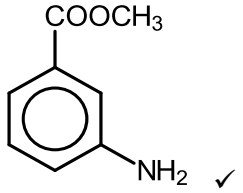
molecular formula = $C_4H_6O_2$ ✓</td><td>2</td><td>Alternative method scores 2 marks:
0.0702/1 x 86 = 6; 0.3717/16 x 86 = 2; 0.5581/12 x 86 = 4

$C_4H_6O_2$ answer alone worth 2 marks</td></tr>
</table>

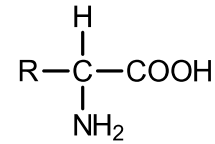
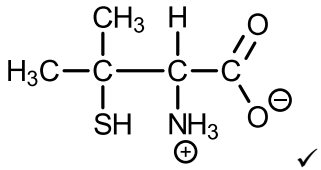
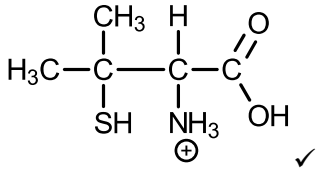
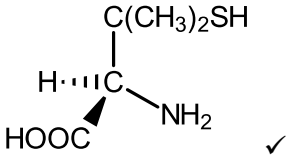
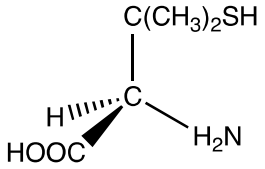
Question			Answer	Marks	Guidance
1	(e)	(ii)	 **compound B** ✓  **compound C** ✓  **compound D** ✓	4	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous eg COOH does not have to be displayed E/trans stereoisomer is needed **For compound C,**  **OR**  If charges shown on both O and Na then both must be correct **DO NOT ALLOW**  (covalent bond) **ALLOW ECF** for **C** and **D** if **B** is identified as one of the following three structures: 

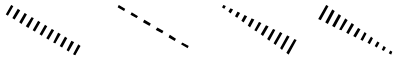
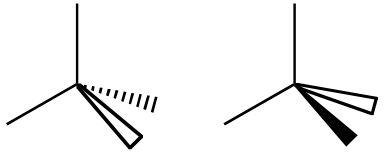
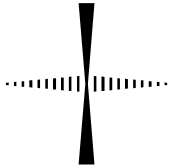
Question			Answer	Marks	Guidance
			 **one repeat unit of polymer E** ✓		**For polymer E**, brackets **not** required **IGNORE** n Free rotation so CH_3 can be shown at top, next to COOH **IF** more than one repeat unit has been drawn a single repeat unit **MUST** be identified by brackets or clear label **The only polymers to ALLOW as ECF from incorrect B are:**   
			Total	**17**	

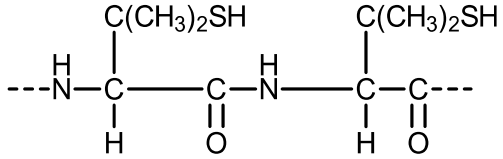
Question			Answer	Marks	Guidance
2	(a)	(i)	**M1**: $HNO_3 + H_2SO_4 \rightarrow H_2O + HSO_4^- + NO_2^+$ ✓  **M2:** curly arrow from ring to NO_2^+ **M2** ✓ **M3:** correct intermediate **M4:** curly arrow from C-H bond back to reform ring **M3** ✓ **M4** ✓ --- **Note**: **ALLOW M2 AND M4** for benzene **OR ANY** substituted benzene compound For **M3**, credit **ONLY** the **correct** intermediate --- **M5** $H^+ + HSO_4^- \rightarrow H_2SO_4$ ✓	5	**ALLOW** $HNO_3 + 2H_2SO_4 \rightarrow H_3O^+ + 2HSO_4^- + NO_2^+$ **ALLOW** $HNO_3 + H_2SO_4 \rightarrow HSO_4^- + H_2NO_3^+$ then $H_2NO_3^+ \rightarrow H_2O + NO_2^+$ **ALLOW** $^+NO_2$ **OR** NO_2^+ **ALLOW** first curly arrow from the ring **OR** from within the ring to any part of the NO_2^+ including the + charge **DO NOT ALLOW** intermediate with broken ring covering less than half the ring **DO NOT ALLOW incorrect orientation of horseshoe** **ALLOW** non-delocalized (Kekulé) structures **ALLOW** carbocation on either side of H/NO_2 substituents:  **IF** NO_2 is shown in incorrect position or $COOCH_3$ has been omitted in intermediate **DO NOT AWARD** M3 but can award other marks **(max 4)**
		(ii)	electrophilic substitution ✓	1	

Question			Answer			Marks	Guidance
2	(b)	(i)	 ✓			1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous
		(ii)	Reaction **1**	Sn **AND concentrated** HC*l*	✓	4	**IGNORE** temperature and reaction type/purpose of reagents
			Reaction **2**	HNO_2 **OR** $NaNO_2$ with (dil) HC*l* < 10°C	✓ ✓		**IGNORE** reference to concentration
			Reaction **4**	hot/heated **aqueous** NaOH	✓		**ALLOW** (heat under) reflux for 'hot' **IGNORE** warm/alkaline if temp stated accept 50º or greater **MUST** have aq or water or any stated concentration

Question			Answer	Marks	Guidance
2	(b)	(iii)	In **amine**, (lone) **pair** of electrons on N is (partially) **delocalised** into the ring ✓ ✎ **QWC** delocalised/delocalized/delocalise, *etc*. must be spelled correctly in the correct context **at least once** for 1st mark electron density is high(er) / increases ✓ great(er) attraction (from aromatic ring) for electrophile/diazonium ion ✓	3	**ALLOW** diagram to show movement of (lone) pair into ring but **delocalised** ring must be mentioned **ALLOW** (lone) pair of electrons on N is (partially) drawn/attracted/pulled into **delocalised** ring **ALLOW** electron density low(er) for benzene **IGNORE** 'activates the ring' **IGNORE** charge density alone but **ALLOW** electron charge density **DO NOT ALLOW** electronegativity **ALLOW** less/low attraction from benzene for electrophile/diazonium ion **ALLOW** amine is a **better** nucleophile/**more** susceptible to electrophilic attack **DO NOT ALLOW** reference to dipole induced in diazonium ion **DO NOT ALLOW** reference to bromine as electrophile
			Total	**14**	

Question			Answer	Marks	Guidance
3	(a)		Both NH_2 and COOH are attached to the same carbon ✓	1	**ALLOW** amine/amino and carboxyl(ic) **ALLOW** (it has the structure)  **ALLOW** $RCH(NH_2)COOH$ in any order but C and H must be adjacent (to each other)
	(b)	(i)	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** NH_3^+ **ALLOW** delocalised carboxylate
		(ii)	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** NH_3^+
	(c)		 ✓	1	**Connectivity is being tested:** Chiral C **must** be linked to the C of the COOH, the C of the $C(CH_3)_2SH$ and the N of the NH_2 **eg DO NOT ALLOW** an attempted NH_2 shown as below: 

Question			Answer	Marks	Guidance
					The structure must have four central bonds, with at least one wedge in AND one wedge out --- For bond into plane of paper, **ALLOW**:  For bond out of plane of paper, a solid wedge is expected, either way around:  **ALLOW** a hollow wedge for 'in bond' OR an 'out bond', provided it is different from the other in or out wedge e.g.:  **ALLOW** examples of other 3D representations provided they are possible: i.e.  **CARE**: This is a 3D representation so this is possible and the bond are clearly not 90º to one another

Question			Answer	Marks	Guidance
3	(d)	(i)	CH_2CIl_2 ✓	1	**ALLOW** CH_2Br_2 **OR** CH_2I_2 **OR** CH_2F_2 **OR** other dihalogenated methane derivatives eg CH_2BrCl **IGNORE** names
		(ii)	 peptide link ✓ rest of structure ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** —NH— at other end 'End bonds' **MUST** be shown (solid or dotted) **IGNORE** brackets and/or *n* around **two** repeat units 1st mark does not require amide group fully displayed ie **ALLOW** –CONH– **DO NOT ALLOW 2nd** mark if amide/peptide link wrong If more than 2 repeat units only first mark (peptide link) can be awarded
	(e)	(i)	penicillamine = 4 ✓ methionine = 5 ✓	2	
		(ii)	(CO)O**H**, N**H**/N**H**$_2$ **AND** S**H** ✓ all undergo proton exchange ✓	2	**ALLOW** (CO)O**D**, N**D**/N**D**$_2$, S**D**, **ALLOW** H (atoms/protons/ions) replaced by D (atoms/ions)

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>3</td><td>(e)</td><td>(iii)</td><td>
<table>
<tr><th colspan="4">^{1}H NMR spectrum for methionine</th><th></th></tr>
<tr><th>Type of proton(s)</th><th>Chemical shift</th><th>Splitting pattern</th><th>Relative peak area</th><th></th></tr>
<tr><td>NH$_2$</td><td>4.5</td><td>singlet</td><td>2</td><td></td></tr>
<tr><td>H$_3$C-S-</td><td>2.1</td><td>singlet</td><td>3</td><td>✓</td></tr>
<tr><td>-S-CH$_2$-</td><td>2.4</td><td>triplet</td><td>2</td><td>✓</td></tr>
<tr><td>S-CH$_2$-CH$_2$</td><td>0.7–2.0</td><td>multiplet OR quartet</td><td>2</td><td>✓</td></tr>
<tr><td>CHNH$_2$</td><td>2.0–3.0</td><td>triplet</td><td>1</td><td>✓</td></tr>
<tr><td>OH</td><td>11–12</td><td>singlet</td><td>1</td><td>✓</td></tr>
</table>
Rows can be in any order
IGNORE extra rows
Do not need to show bonds between atoms
</td><td>5</td><td>
ALLOW any value within ranges given for δ /ppm on the Data Sheet
IGNORE reference to NH$_2$ signals (given as example)

GUIDANCE
• mark by rows
• ALL data in row must be correct for each mark
• ALLOW “triplet of doublets” or “doublet of triplets” for multiplet/quartet signal from —CH$_2$CH$_2$S—

ALLOW quadruplet

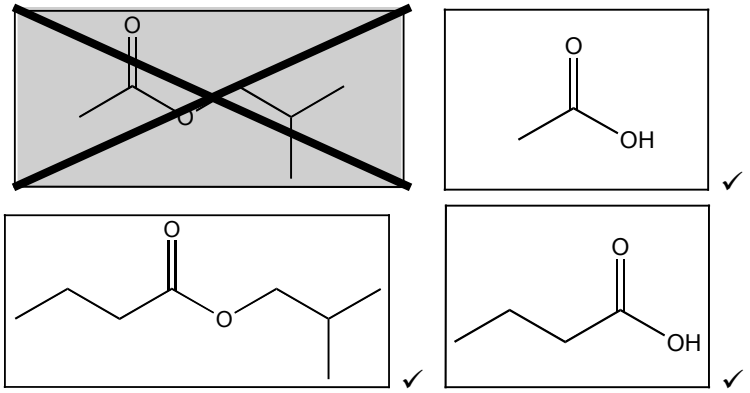
ALLOW a response that implies a single peak OR ‘no splitting’

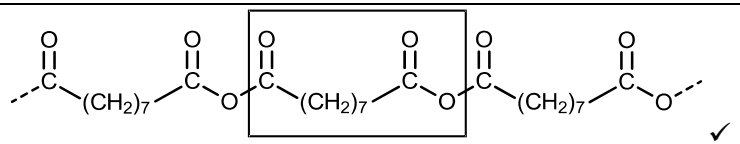
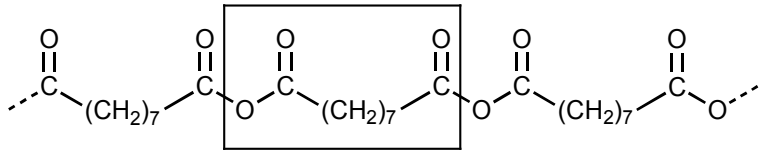
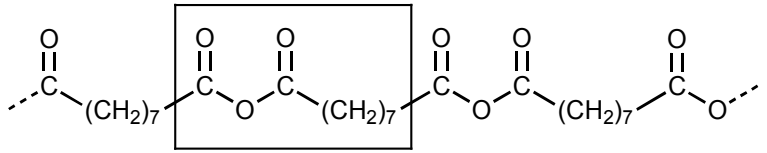
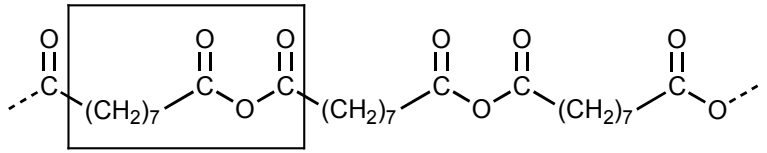
ALLOW a response that implies a splitting into three for a triplet/into four for a quartet

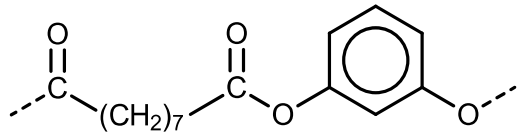
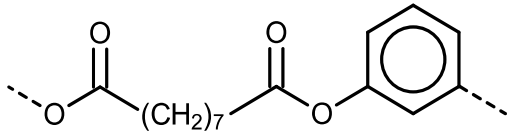
Clear and unambiguous identification of the protons (when more than one type is present) other than by position number should be credited
eg for CHNH$_2$ could be HCCO or CHN or HCN or CH$_2$CH

eg for S-CH$_2$-CH$_2$ could be CH$_2$C(H)NH$_2$ or CCH$_2$C or CH$_2$CH$_2$ or RCH$_2$R or RCHR

eg ‘CH between COOH and NH$_2$’ OR identification by number labels on chemical structures
</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>16</td><td></td></tr>
</table>

Question			Answer	Marks	Guidance
4	(a)	(i)	(2-)methylpropan-1-ol ✓	1	**ALLOW** without hyphens
		(ii)	 ✓ ✓ ✓	3	**DO NOT MARK** top left hand structure: (on paper) **ALLOW in any order** **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **If use displayed formulae but omit one or more H atoms DO NOT ALLOW each time**
	(b)	(i)	The time (from the injection of the sample) for the component/compound/substance to leave the column ✓	1	**IGNORE** (time for) gas to leave column **DO NOT ALLOW** time in GC/machine/apparatus **ALLOW** time from injection to detection **ALLOW** time spent in column **ALLOW** time taken to reach detector
		(ii)	They have similar retention times **OR** unknown compounds have no reference retention times for comparison ✓	1	**ALLOW** same retention times **ALLOW** both are esters therefore relative solubilities/ partition/adsorption/retention times will be very similar

Question			Answer	Marks	Guidance
4	(c)	(i)	 ✓	1	**IF end repeat unit shown** the line of the box must go through the continuation bond **ALLOW** other possibilities for showing structure with repeat unit displayed, eg repeat unit with O on left and not on right.  Other possibilities:  
		(ii)	Hydrolysis ✓	1	**IGNORE** decomposition/biodegradation **IGNORE** mention of acid/alkali

Question			Answer	Marks	Guidance
4	(c)	(iii)	broad absorption 2500–3300 (cm^{-1}) ✓ (because) (degradation) forms (di)carboxylic acid / COOH ✓	2	**ALLOW** carboxyl group **IGNORE** reference to carbonyl/1640–1750 (cm^{-1}) **IGNORE** reference to C—O/1000–1300 (cm^{-1})
		(iv)	 **M1** ester link ✓ **M2** the two oxygen atoms from benzene-1,3-diol linked at 1,3 positions ✓ **M3** one repeat unit fully correct ✓	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous Ester link does not need to be fully displayed eg accept –COO– **ALLOW** —O— at other end ie  'End bonds' **MUST** be shown (solid or dotted) **DO NOT ALLOW** more repeat units **IGNORE** brackets and/or *n* **IF** more than one repeat unit has been drawn a single repeat unit **MUST** be identified by brackets or clear label
			Total	**13**	