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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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### Mark Scheme

**ALLOW Kekulé structures throughout**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a)</td>
<td><img src="image" alt="Diagram" /></td>
<td>4</td>
<td><strong>ANNOTATIONS MUST BE USED</strong>&lt;br&gt;ALLOW skeletal CH₃&lt;br&gt;ALLOW &quot;NO₂ OR NO₂⁺&quot;&lt;br&gt;ALLOW 1st curly arrow from the ring OR from within the ring to any part of the NO₂⁺ including the + charge&lt;br&gt;DO NOT ALLOW intermediate with broken ring less than halfway down:&lt;br&gt;Horseshoe must have open end towards NO₂&lt;br&gt;&lt;br&gt;ALLOW Kekulé mechanism:&lt;br&gt;&lt;br&gt;ALLOW double bonds shown in other Kekulé arrangement&lt;br&gt;&lt;br&gt;IF CH₃ has been omitted completely (ie benzene shown),&lt;br&gt;DO NOT AWARD intermediate mark OR products mark (max 2)&lt;br&gt;IF NO₂ is shown in incorrect position in intermediate or product,&lt;br&gt;DO NOT AWARD intermediate mark but award other marks (max 3)</td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Mark</td>
<td>Guidance</td>
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<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>1 (b)</td>
<td><img src="image" alt="Chemical Structures" /></td>
<td>2</td>
<td>ALLOW any correct unambiguous structures&lt;br&gt;ALLOW NO₂⁻&lt;br&gt; Note: connectivity is NOT being assessed in this part</td>
</tr>
<tr>
<td>1 (c)</td>
<td><strong>1st stage</strong>&lt;br&gt;isomer: <strong>isomer 3 ✓</strong>&lt;br&gt;product: <img src="image" alt="Chemical Structure" /> &lt;br&gt;reagents: Sn AND (conc) HCl ✓&lt;br&gt;equation: <img src="image" alt="Chemical Reaction" /></td>
<td>2</td>
<td><strong>ANNOTATIONS MUST BE USED</strong>&lt;br&gt;ALLOW structure of <strong>isomer 3</strong> shown separately OR in equation&lt;br&gt;ALLOW structure of <strong>product</strong> shown separately OR in equation&lt;br&gt;ALLOW correct name (3,5-diaminomethylbenzene)&lt;br&gt;IGNORE incorrect name&lt;br&gt;DO NOT ALLOW <strong>CH₃C₆H₃(NH₂)₂</strong>&lt;br&gt;ALLOW Zn + HCl/H₂ + metal catalyst/LiAlH₄/Na in ethanol&lt;br&gt;IGNORE NaBH₄&lt;br&gt;ALLOW Sn and HCl followed by NaOH&lt;br&gt;DO NOT ALLOW Sn and HCl and NaOH&lt;br&gt;IF <strong>isomer 3 OR product</strong> are given in equation but not shown previously then credit here&lt;br&gt;Also credit reagents here if shown (eg above arrow)&lt;br&gt;ALLOW correct structural OR displayed OR skeletal formula&lt;br&gt;ALLOW combination of formulae as long as unambiguous</td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Mark</td>
<td>Guidance</td>
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</tr>
</tbody>
</table>
| (c) (i)  | 2nd stage organic compound: HOOC–CH₂–COOH ✓ | 6 | DO NOT ALLOW molecular formula

ALLOW name of compound: propanedioic acid OR propane-1,3-dioic acid
ALLOW absence of ‘e’ after ‘propan’

ALLOW acyl dichloride: ClOC–CH₂–COCl
ALLOW cyclic acid anhydride of propanedioic acid:

 ALLOW Nylon or Kevlar
DO NOT ALLOW polypeptide
DO NOT ALLOW amide |

<p>| | | Total 12 |</p>
<table>
<thead>
<tr>
<th>Question</th>
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<th>Guidance</th>
</tr>
</thead>
</table>
| 2 (a)    | propane-1,2,3-triol ✓ | 1    | ALLOW absence of ‘e’ after ‘propan’  
ALLOW 1,2,3-propanetriol  
ALLOW absence of hyphens  
1, 2 and 3 must be clearly separated:  
ALLOW full stops: 1.2.3 OR spaces: 1 2 3  
DO NOT ALLOW 123 |
| 2 (b)    | (i) methanol OR ethanol  
AND  
renewable ✓ | BOTH points required for the mark  
ALLOW correct structural OR displayed OR skeletal formula  
DO NOT ALLOW molecular formulae |
|          | (ii) equilibrium shifts to right ✓ | 1    | ALLOW equilibrium shifts in forward direction  
ALLOW more products form  
ALLOW greater yield OR fully reacts OR goes to completion  
DO NOT ALLOW improves atom economy |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (c)</td>
<td>CH₃CH₂COOH + CH₃CH₂OH → CH₃CH₂COOCH₂CH₃ + H₂O ✓</td>
<td>2</td>
<td>ALLOW  correct structural OR displayed OR skeletal formula</td>
</tr>
<tr>
<td></td>
<td>(CH₃CH₂CO)₂O + CH₃CH₂OH → CH₃CH₂COOCH₂CH₃ + CH₃CH₂COOH ✓</td>
<td></td>
<td>ALLOW combination of formulae as long as unambiguous</td>
</tr>
<tr>
<td></td>
<td>(CH₃CH₂CO)₂O + 2CH₃CH₂OH → 2CH₃CH₂COOCH₂CH₃ + H₂O</td>
<td></td>
<td>DO NOT ALLOW molecular formulae</td>
</tr>
<tr>
<td></td>
<td>ALLOW further esterification, ie</td>
<td></td>
<td>ALLOW linear formula for anhydride, ie</td>
</tr>
<tr>
<td></td>
<td>CH₃CH₂COOCOCH₂CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>If incorrect carboxylic acid/anhydride/alcohol is used, ALLOW ECF for second equation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Mark</td>
<td>Guidance</td>
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<td>----------</td>
<td>--------</td>
<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>2 (d)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[A] HO–CH₂–CH₂–COOH</td>
<td></td>
<td>• A can be any of the alternatives in the 1st column</td>
</tr>
<tr>
<td></td>
<td>[B] O–CH₂–CH₂–CH₂–C</td>
<td></td>
<td>• B can be any of the alternatives in the 2nd column</td>
</tr>
<tr>
<td></td>
<td>[B] O–CH₂–C</td>
<td></td>
<td>• C can be any of the alternatives in the 3rd column</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–CH₂–C</td>
<td></td>
<td>ALLOW correct structural OR displayed OR skeletal formula</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>ALLOW combination of formulae as long as unambiguous</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>DO NOT ALLOW molecular formulae</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>ALLOW correct names for A, B and C</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>For B accept diester</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>For C, IGNORE ‘n’ OR brackets (even if wrong);</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>ALLOW solid side bonds</td>
</tr>
<tr>
<td></td>
<td>[C] O–CH₂–C</td>
<td></td>
<td>Minimum is one correct repeat unit. Polymer must be open at both ends</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 8</td>
</tr>
<tr>
<td>Question</td>
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<td>Guidance</td>
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</tr>
</tbody>
</table>
| 3 (a)    | **observation**: silver OR Ag ✓ | 3    | **ALLOW** black OR grey  
**ALLOW** redox  
**ALLOW** correct structural OR displayed OR skeletal formula  
**ALLOW** combination of formulae as long as unambiguous  
**DO NOT ALLOW** molecular formulae  
**ALLOW** carboxylate, \(-\text{COO}^–\) |
|          | **type of reaction**: oxidation ✓ |      |          |
|          | **organic product**: |      |          |
|          | ![Chemical Structure](image) |      |          |
| 3 (b)    | ![Chemical Structure](image) | 4    | **ANNOTATIONS MUST BE USED**  
**ALLOW** mechanism showing curly arrows from lone pair on H⁻ and O⁻ of intermediate  
Dipole not required on H–O–H  
**DO NOT ALLOW** incorrect dipole on H–O–H  
**ALLOW** 1 mark for correct intermediate with ‘–’ charge on O  
**AND** curly arrow from O⁻ to H⁺ of H–O–H  
**IGNORE** missing OH⁻  
**DO NOT ALLOW** incorrect second product  
1 mark for curly arrow from H⁻ to C of C=O ✓  
1 mark for correct dipole on C=O  
**AND** curly arrow from double bond to O⁻ ✓  
1 mark for correct intermediate with negative charge on O  
**AND** curly arrow from O⁻ to H of H–O–H  
**AND** curly arrow from H–O to O of H–O–H ✓  
1 mark for correct **organic** product ✓ |
<table>
<thead>
<tr>
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<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (c)</td>
<td>reagent: Br₂ ✓</td>
<td>3</td>
<td>DO NOT ALLOW ECF from incorrect reagent, eg 2,4-DNP</td>
</tr>
<tr>
<td></td>
<td>observation: decolourised OR orange to colourless ✓</td>
<td></td>
<td>DO NOT ALLOW goes clear</td>
</tr>
<tr>
<td></td>
<td>organic product: ✓</td>
<td></td>
<td>ALLOW red/orange/yellow/brown in any combination</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /></td>
<td></td>
<td>ALLOW organic product from reaction of one of the double bonds only, ie</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /> OR <img src="image" alt="Structure" /></td>
<td></td>
<td>ALLOW correct structural OR displayed OR skeletal formula</td>
</tr>
<tr>
<td></td>
<td>ALLOW combination of formulae as long as unambiguous</td>
<td></td>
<td>DO NOT ALLOW molecular formulae</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /> OR <img src="image" alt="Structure" /></td>
<td></td>
<td>ALTERNATIVE reagents</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /></td>
<td></td>
<td>For 1st mark, ALLOW H₂ OR Cl₂ OR I₂ OR HCl OR HBr OR HI OR H₂O</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /></td>
<td></td>
<td>For 2nd mark, there must be a statement of no change OR no observation or similar that implies there is no visible change EXCEPT for I₂ which has an observation of ‘decolourised’ OR brown to colourless</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Structure" /></td>
<td></td>
<td>For 3rd mark, correct organic product must be shown that could be from reaction of both or one of the double bonds.</td>
</tr>
</tbody>
</table>

Total 10
<table>
<thead>
<tr>
<th>Question</th>
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</tr>
</thead>
</table>
| 4 (a) (i) | ClCH(\(\text{CH}_3\))COOH + 3NH\(_3\) → H\(_2\)NCH(\(\text{CH}_3\))COO\(^-\) + NH\(_4^+\) + NH\(_4\)Cl | 1 | ALLOW use of two NH\(_3\): ClCH(\(\text{CH}_3\))COOH + 2NH\(_3\) → H\(_2\)NCH(\(\text{CH}_3\))COO\(^-\) + NH\(_4^+\) + HCl
ALLOW products as above OR H\(_2\)NCH(\(\text{CH}_3\))COOH + NH\(_4\)Cl
ALLOW use of one NH\(_3\): ClCH(\(\text{CH}_3\))COOH + NH\(_3\) → H\(_2\)NCH(\(\text{CH}_3\))COO\(^-\) + H\(^+\) + HCl
ALLOW products as above OR H\(_2\)NCH(\(\text{CH}_3\))COOH + HCl
For alternatives below,
for NH\(_4\)Cl, ALLOW NH\(_4^+\)Cl\(^-\) OR NH\(_4^+\) + Cl\(^-\)
for HCl, ALLOW H\(^+\)Cl\(^-\) OR H\(^+\) + Cl\(^-\)
for H\(_2\)NCH(\(\text{CH}_3\))COO\(^-\) + NH\(_4^+\)
ALLOW H\(_2\)NCH(\(\text{CH}_3\))COONH\(_4\)
ALLOW R in equation in place of \(\text{CH}_3\) (either or both sides)
ALLOW correct structural OR displayed OR skeletal formula
ALLOW combination of formulae as long as unambiguous
DO NOT ALLOW molecular formulae |
| (a) (ii) | ![Image](https://example.com/image.png) | 1 | ALLOW correct structural OR displayed OR skeletal formula
ALLOW combination of formulae as long as unambiguous
ALLOW product from carboxylate ion as nucleophile: |
<table>
<thead>
<tr>
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<th>Answer</th>
<th>Mark</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (b) (i)</td>
<td><img src="image1" alt="Structure 1" /> OR <img src="image2" alt="Structure 2" /></td>
<td>1</td>
<td><strong>DO NOT ALLOW</strong> any structure containing C OR H (except in OH)</td>
</tr>
</tbody>
</table>
| 4 (b) (ii) | ![Structure 3](image3) CH₂COOH ![Structure 4](image4) CH₂COOH | 2 | **ALL** bond linkages must be correct, eg the chiral C must be linked to the C of the COOH, the C of the CH₂COOH and the N of the NH₂ (connectivity is being tested)  
This could be any amino acid **EXCEPT** glycine  
**DO NOT** penalise connectivity more than once  
**ALLOW** R in equation in place of CH₂COOH (either or both sides)  
Each structure **must** have four central bonds, with at least two wedges, one in; one out  
For bond into paper, accept: |
| 4 (c) Disadvantages | Any two from:  
- (one stereoisomer might have harmful) side effects ✓  
- reduces the (pharmacological) activity/effectiveness ✓  
- cost OR difficulty in separating stereoisomers ✓  
**Synthesis of a single optical isomer**  
Any two from:  
- using enzymes or bacteria ✓  
- using a chiral catalyst  
**OR** transition metal complex/transition metal catalyst ✓  
- using chiral synthesis  
**OR** chiral starting material  
**OR** natural amino acid ✓ | 2 max | **ANNOTATIONS MUST BE USED**  
**ALLOW** optical isomer **OR** enantiomers as alternative for stereoisomers  
**ALLOW** a response that implies an increased dose |

**Total** 8
<table>
<thead>
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</tr>
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</table>
| 5 (a) (i) | Adsorption ✓ (onto the stationary phase) | 1 | ALLOW adsorption or absorb(s) or adsorbed spelled correctly at least once  
DO NOT ALLOW anything that begins with ab... |
|          | Quality of Written Communication ✓ | | |
| 5 (a) (ii) | 0.2 ✓ | 1 | ALLOW any value in the range 0.1 – 0.3  
IGNORE significant figures  
DO NOT ALLOW fraction/percent as final answer |
| 5 (a) (iii) | Spot may contain more than one compound/component ✓ | 1 | ALLOW compounds have similar $R_f$ values/adsorptions  
OR compounds have not (fully) separated  
OR B is spread over a large region  
OR compounds are similar  
IGNORE retention times |
| 5 (b) (i) | GC separates the components/compounds AND | 1 | ALLOW chromatography for GC  
ALLOW they have different retention times |
<p>|          | MS is compared to a database/reference ✓ | | |
|          | nerol and geraniol AND | | |
|          | they are stereoisomers OR primary alcohols ✓ | 1 | Compounds AND reason required for the mark |
| 5 (b) (ii) | stereoisomers have the same structural formula AND | 1 | ALLOW different arrangements in space |
|          | different 3D arrangements ✓ | | |
| 5 (b) (iv) | <img src="image" alt="Diagram" /> ✓ | 1 | Circle must include the correct C=C double bond AND must not extend further than the adjacent atoms in the main chain, ie limit is: |</p>
<table>
<thead>
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</thead>
</table>
| (b) (v) | ![Diagram](image) | 2 | **ALL THREE** chiral centres required for 2 marks  
**ANY TWO** chiral centres required for 1 mark  
If more than three asterisks are shown, mark incorrect asterisk(s) first |
| 5 (c)   | Correctly calculates amount of myrcene  
= $\frac{34}{136}$ OR 0.25 (mol) ✓  
Correctly calculates 60% yield of menthol  
= $0.25 \times 60/100$ OR 0.15 (mol) ✓  
Correctly calculates mass of menthol  
= $0.15 \times 156 = 23.4$ (g) ✓ | 3 | **ANNOTATIONS MUST BE USED**  
ALLOW amount of myrcene × 60/100  
ALLOW amount of menthol × 156  
ALLOW alternative approach based on reacting masses  
(using same ECF principles as above):  
correctly calculates mass of myrcene that could be obtained from 34 g myrcene:  
mass = $34 \times \frac{156}{136} = 39$ (g)  
$\times 156$ ✓; $\div 136$ ✓  
60% of 39 g = $39 \times 60/100 = 23.4$ (g) ✓  
ALLOW final answer to 2 or more significant figures correctly rounded  
Correct answer of 23.4 (g) with no working scores all 3 marks |
<p>|         |        | 12   |          |
| <strong>Total</strong> | 12     |      |          |</p>
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</thead>
<tbody>
<tr>
<td>6 (a)</td>
<td>a singlet for position 2 OR a singlet because it has no adjacent H’s ✓</td>
<td></td>
<td>ANNOTATIONS MUST BE USED</td>
</tr>
<tr>
<td></td>
<td>A triplet for positions 4 and 6</td>
<td></td>
<td>ALLOW a response that implies a single peak OR ‘no splitting’</td>
</tr>
<tr>
<td></td>
<td>OR a triplet because it has 2 adjacent H’s ✓</td>
<td>3</td>
<td>ALLOW a response that implies a splitting into three</td>
</tr>
<tr>
<td></td>
<td>A quintet for position 5 OR a quintet because it has four adjacent H’s ✓</td>
<td></td>
<td>DO NOT ALLOW implications of more than one triplet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALLOW ‘pentet’</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OR a response that implies a splitting into five</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OR multiplet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALLOW 1 mark for singlet and triplet and quintet/pentet/multiplet with no identification of protons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Any suggestion that the oxygens cause a splitting scores a maximum of 2 marks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• All 3 remaining splitting patterns correct 2 marks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Any 2 correct 1 mark.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IF number labels for protons in diagram are not identified, ALLOW identification by chemical shifts for 2 marks max:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• singlet at 3.3–4.2 AND a triplet at 3.3–4.2 ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• quintet/pentet/multiplet at 0.7–2.0 ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clear and unambiguous identification of the protons other than by position number should be credited, ie ‘CH₂ between two oxygens’</td>
</tr>
</tbody>
</table>

**Quality of Written Communication**

singlet OR triplet OR quintet OR pentet OR multiplet (see Guidance) must be spelled correctly at least once
<table>
<thead>
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<tbody>
<tr>
<td>6 (b)</td>
<td><strong>ANY 5 marks plus correct structure (in box)</strong>&lt;br&gt;Molecular ion/M$^+$ peak at (m/z of) 106 ✓&lt;br&gt;Fragment peak at 91 is C$_6$H$_4$–CH$_3$/C$_6$H$_5$–CH$_2$ ✓&lt;br&gt;Molecular formula is C$<em>8$H$</em>{10}$&lt;br&gt;(or implied, ie any one of the structures below) ✓&lt;br&gt;<img src="image_url" alt="Structures" />&lt;br&gt;$^1$C NMR spectrum shows 5 C environments ✓&lt;br&gt;Peak near 20 is a C attached at another carbon, C–C OR peaks at ~125–140 for aromatic Cs ✓</td>
<td><strong>ANNOTATIONS MUST BE USED</strong>&lt;br&gt;ALLOW molecular mass OR relative molecular mass&lt;br&gt;ALLOW C$_6$H$_4$–CH$_3$/C$_6$H$_5$–CH$_2$&lt;br&gt;ALLOW peak at 91 represents loss of CH$_3$&lt;br&gt;ALLOW correct structural OR displayed OR skeletal formula&lt;br&gt;ALLOW combination of formulae as long as unambiguous&lt;br&gt;ALLOW a correct name eg a dimethylbenzene&lt;br&gt;ALL FOUR structures needed for 1 mark&lt;br&gt;ALLOW correct names</td>
<td>ALLOW NMR spectrum shows five different types of carbon&lt;br&gt;DO NOT ALLOW 'NMR spectrum has five peaks' – the mark is for realising what the peaks show, not for just describing the spectrum</td>
</tr>
<tr>
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<td>Mark</td>
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</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>6 (b)</td>
<td>Number of peaks for other three isomers matched to structures: &lt;br&gt; <strong>Any 2 correct for 2 marks ✓✓</strong> &lt;br&gt; <strong>1 correct for 1 mark ✓</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><img src="image1.png" alt="Structure 1" /> 4 peaks &lt;br&gt; <img src="image2.png" alt="Structure 2" /> 3 peaks &lt;br&gt; <img src="image3.png" alt="Structure 3" /> 6 peaks</td>
<td></td>
<td>ALLOW ‘carbon environments’ for peaks</td>
</tr>
<tr>
<td></td>
<td>Correct structure shown: &lt;br&gt; <img src="image4.png" alt="Correct Structure" /></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong> 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OCR (Oxford Cambridge and RSA Examinations)
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