



## Mark Scheme (Results)

January 2022

Pearson Edexcel International Advanced Level  
In Chemistry (WCH14)  
Paper 01: Rates, Equilibria and Further Organic  
Chemistry

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January 2022

Question paper log number P69507A

Publications Code WCH14\_01\_2201\_MS

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## General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.
- Mark schemes will indicate within the table where, and which strands of QWC, are being assessed. The strands are as follows:
  - i) ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
  - ii) select and use a form and style of writing appropriate to purpose and to complex subject matter
  - iii) organise information clearly and coherently, using specialist vocabulary when appropriate

## Using the Mark Scheme

Examiners should look for qualities to reward rather than faults to penalise. This does NOT mean giving credit for incorrect or inadequate answers, but it does mean allowing candidates to be rewarded for answers showing correct application of principles and knowledge. Examiners should therefore read carefully and consider every response: even if it is not what is expected it may be worthy of credit.

The mark scheme gives examiners:

- an idea of the types of response expected
- how individual marks are to be awarded
- the total mark for each question
- examples of responses that should NOT receive credit.

/ means that the responses are alternatives and either answer should receive full credit.

( ) means that a phrase/word is not essential for the award of the mark, but helps the examiner to get the sense of the expected answer.

Phrases/words in **bold** indicate that the meaning of the phrase or the actual word is **essential** to the answer.

ecf/TE/cq (error carried forward) means that a wrong answer given in an earlier part of a question is used correctly in answer to a later part of the same question.

Candidates must make their meaning clear to the examiner to gain the mark. Make sure that the answer makes sense. Do not give credit for correct words/phrases which are put together in a meaningless manner. Answers must be in the correct context.

**Section A (multiple choice)**

Question Number	Correct Answer	Mark
<b>1(a)</b>	<p><b>The only correct answer is B</b> (<math>\frac{1}{2}\text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})</math>)</p> <p><i>A is incorrect because atomisation of an element is from its standard state and iodine is a solid</i></p> <p><i>C is incorrect because atomisation produces 1 mole of atoms and requires solid iodine</i></p> <p><i>D is incorrect because atomisation produces 1 mole of atoms</i></p>	(1)
<b>1(b)</b>	<p><b>The only correct answer is A</b> (<math>-298 \text{ kJ mol}^{-1}</math>)</p> <p><i>B is incorrect because this value has had 28 added to <math>-270</math> rather than subtracted from it</i></p> <p><i>C is incorrect because first electron affinity values are always exothermic</i></p> <p><i>D is incorrect because first electron affinity values are always exothermic and the wrong sign has been used for the enthalpy change of hydration</i></p>	(1)
<b>2</b>	<p><b>The only correct answer is B</b> (<math>-1650 \text{ kJ mol}^{-1}</math>)</p> <p><i>A is incorrect because this uses the wrong sign for the enthalpy change of solution</i></p> <p><i>C is not correct because this uses only one mole of chloride ions</i></p> <p><i>D is not correct because this does not change the sign of the lattice enthalpy</i></p>	(1)

Question Number	Correct Answer	Mark
<b>3(a)</b>	<p><b>The only correct answer is A</b> (the mole fraction of carbon dioxide)</p> <p><i>B is incorrect because the equilibrium will move to the left hand side so this will decrease</i></p> <p><i>C is not correct because the rate of both reactions will decrease at lower temperature</i></p> <p><i>D is incorrect because the equilibrium will move to the left hand side so this will decrease</i></p>	(1)

Question Number	Correct Answer	Mark
<b>3(b)</b>	<p><b>The only correct answer is C</b> (0.474)</p> <p><i>A is incorrect because this answer divides the mole fraction of carbon dioxide by 2</i></p> <p><i>B is incorrect because this answer divides the mole fraction of carbon monoxide by 2</i></p> <p><i>D is incorrect because this is the partial pressure of carbon monoxide</i></p>	(1)

Question Number	Correct Answer	Mark
<b>4</b>	<p><b>The only correct answer is A</b> (<math>\text{dm}^9 \text{mol}^{-3}</math>)</p> <p><i>B is incorrect because the units of concentration should be raised to the power of -3 not -2</i></p> <p><i>C is incorrect because the units should be the reciprocal of concentration raised to the power of -3 not -2</i></p> <p><i>D is incorrect because the units should be the reciprocal of concentration raised to the power of -3 not -2</i></p>	(1)

Question Number	Correct Answer	Mark
<b>5</b>	<p><b>The only correct answer is D</b> (phenolphthalein)</p> <p><i>A is incorrect because the indicator needs a range contained between pH 8 and pH 11</i></p> <p><i>B is incorrect because the indicator needs a range contained between pH 8 and pH 11</i></p> <p><i>C is incorrect because the indicator needs a range contained between pH 8 and pH 11</i></p>	(1)

Question Number	Correct Answer	Mark
<b>6</b>	<p><b>The only correct answer is A</b> (the dissociation of water is endothermic, so the concentration of hydrogen ions is higher at 100°C than it is at 25°C)</p> <p><i>B is incorrect because at higher temperatures more hydrogen ions are present</i></p> <p><i>C is incorrect because the dissociation of water is endothermic</i></p> <p><i>D is incorrect because the dissociation of water is endothermic</i></p>	(1)

Question Number	Correct Answer	Mark
<b>7</b>	<p><b>The only correct answer is C</b> (C<sub>16</sub>H<sub>14</sub>O<sub>3</sub>)</p> <p><i>A is incorrect because there are 16 carbon atoms in ketoprofen</i></p> <p><i>B is incorrect because this answer has one hydrogen too few</i></p> <p><i>D is incorrect because this answer assumes there is 1 hydrogen on each carbon in the benzene rings</i></p>	(1)

Question Number	Correct Answer	Mark
<b>8</b>	<p><b>The only correct answer is C (3)</b></p> <p><i>A is incorrect because there are three chiral centres</i></p> <p><i>B is incorrect because there are three chiral centres</i></p> <p><i>D is incorrect because there are three chiral centres</i></p>	(1)

Question Number	Correct Answer	Mark
<b>9</b>	<p><b>The only correct answer is D (propanone with HCN)</b></p> <p><i>A is incorrect because the product, 2-chlorobutane, is chiral and each enantiomer is formed in equal amounts</i></p> <p><i>B is incorrect because the product, 2-chlorobutane, is chiral and each enantiomer is formed in equal amounts</i></p> <p><i>C is incorrect because the product, 2-hydroxybutanenitrile is chiral and each enantiomer is formed in equal amounts</i></p>	(1)

Question Number	Correct Answer	Mark
<b>10</b>	<p><b>The only correct answer is C (the reaction proceeds via a carbocation intermediate)</b></p> <p><i>A is incorrect because while it is true, it does not explain the observation</i></p> <p><i>B is incorrect because this would lead to only one enantiomer</i></p> <p><i>D is incorrect because while this is true, it does not explain the observation</i></p>	(1)



Question Number	Correct Answer	Mark
<b>11</b>	<p><b>The only correct answer is C (4)</b></p> <p><i>A is incorrect because there are 4 aldehydes with this molecular formula that are structural isomers</i></p> <p><i>B is incorrect because there are 4 aldehydes with this molecular formula that are structural isomers</i></p> <p><i>D is incorrect because there are 4 aldehydes with this molecular formula that are structural isomers</i></p>	(1)

Question Number	Correct Answer	Mark
<b>12(a)</b>	<p><b>The only correct answer is D (CH<sub>3</sub>COCH<sub>2</sub>I    CHI<sub>3</sub>)</b></p> <p><i>A is incorrect because CH<sub>3</sub>I is not formed in acidic conditions</i></p> <p><i>B is incorrect because CH<sub>3</sub>COCl<sub>3</sub> is not formed in acidic conditions</i></p> <p><i>C is incorrect because CH<sub>3</sub>I is not formed in alkaline conditions</i></p>	(1)

Question Number	Correct Answer	Mark
<b>12(b)</b>	<p><b>The only correct answer is C (2.5)</b></p> <p><i>A is incorrect because the value of the pH has been divided by 3</i></p> <p><i>B is incorrect because the concentration of H<sup>+</sup> ions has been multiplied by 3 rather than divided</i></p> <p><i>D is incorrect because this value is adding 1/3 of 2 onto 2</i></p>	(1)

Question Number	Correct Answer	Mark
<b>13</b>	<p><b>The only correct answer is D</b> (<math>\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{CH}_2\text{OH}</math> hot acidified <math>\text{K}_2\text{Cr}_2\text{O}_7</math>)</p> <p><i>A is incorrect because the compound W is correct but <math>\text{LiAlH}_4</math> is a reducing agent</i></p> <p><i>B is incorrect because both the compound W and reagent are incorrect</i></p> <p><i>C is incorrect because the compound W is the wrong compound</i></p>	(1)

Question Number	Correct Answer	Mark
<b>14</b>	<p><b>The only correct answer is C</b> (<math>(\text{CH}_3)_2\text{CHCOOCH}_2\text{CH}_3</math>)</p> <p><i>A is incorrect because this product could not be formed as compound Y must have 4 carbon atoms and the ester Z must be formed from ethanol</i></p> <p><i>B is incorrect because this product could not be formed as compound Y must have 4 carbon atoms and the ester Z must be formed from ethanol</i></p> <p><i>D is incorrect because this product could not be formed as compound Y must have 4 carbon atoms and the ester Z must be formed from ethanol</i></p>	(1)

Question Number	Correct Answer	Mark
<b>15</b>	<p><b>The only correct answer is B</b> (<math>\text{C}_3\text{H}_7\text{OH}</math>)</p> <p><i>A is incorrect because the alcohol formed would be <math>\text{C}_3\text{H}_7\text{OH}</math></i></p> <p><i>C is incorrect because no carboxylic acid is formed under these reaction conditions</i></p> <p><i>D is incorrect because the sodium salt of ethanoic acid would be formed</i></p>	(1)

Question Number	Correct Answer	Mark
<b>16</b>	<p><b>The only correct answer is B</b> (forces of attraction to the liquid)</p> <p><i>A is incorrect because these do not affect passage through the stationary phase</i></p> <p><i>C is incorrect because this is not the main reason and does not directly affect passage through the stationary phase</i></p> <p><i>D is incorrect because these do not affect passage through the stationary phase</i></p>	(1)

Question Number	Correct Answer	Mark
<b>17</b>	<p><b>The only correct answer is D</b> (Liquid Solid)</p> <p><i>A is incorrect because high performance liquid chromatography has a liquid mobile phase</i></p> <p><i>B is incorrect because high performance liquid chromatography has a liquid mobile phase</i></p> <p><i>C is incorrect because high performance liquid chromatography has a solid stationary phase</i></p>	(1)

**(Total for Section A = 20 marks)**

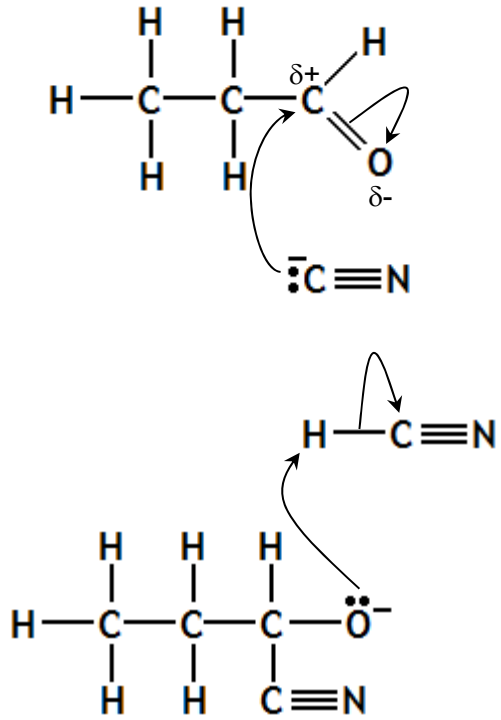
## Section B

Question Number	Answer	Additional Guidance	Mark
<b>18(a)(i)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• order with respect to <math>\text{H}^+</math> is 2</li> </ul> <p>and</p> <ul style="list-style-type: none"> <li>• order with respect to <math>\text{Br}^-</math> is 1</li> </ul> <p>(1)</p> <ul style="list-style-type: none"> <li>• (in experiments 1 and 2 the concentration of bromide ions and bromate ions remains constant) while the concentration of hydrogen ions doubles and rate quadruples (so hydrogen ion is order 2)</li> </ul> <p>(1)</p> <ul style="list-style-type: none"> <li>• (in experiments 1 and 3) the concentration of bromate ions increases 1.5 times and the concentration of bromide ions doubles (whilst the concentration of hydrogen ions stays constant). Rate increases by 3 times (so bromide ion is order 1)</li> </ul> <p>(1)</p> <ul style="list-style-type: none"> <li>• rate = <math>k [\text{BrO}_3^-][\text{Br}^-][\text{H}^+]^2</math></li> </ul> <p>(1)</p>	<p>Accept <math>[\text{H}^+]^2</math></p> <p>Accept <math>[\text{Br}^-]^1 / [\text{Br}^-]</math></p> <p>Allow mathematical solutions of ratios to give the order</p> <p>In experiments 3 and 4 the concentration of bromide ions halves and the concentration of hydrogen ions doubles (whilst the concentration of bromate ions doesn't change.) The rate doubles (so bromide ion is order 1.)</p> <p>ALLOW TE on incorrect orders deduced</p> <p>M2 and M3 can be given even if resulting orders are incorrect</p> <p>Allow annotations on table</p>	<b>(4)</b>

Question Number	Answer	Additional Guidance	Mark
<b>18(a)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• expression for <math>k</math> rearranged</li> <li>• value of <math>k</math></li> <li>• units</li> </ul>	<p>Example calculation</p> $k = \frac{\text{rate}}{[\text{BrO}_3^-][\text{Br}^-][\text{H}^+]^2}$ <p>OR</p> $k = \frac{2.01 \times 10^{-4}}{0.15 \times 0.25 \times 0.60^2}$ $k = 0.014889 / 0.015 / 1.4889 \times 10^{-2} / 1.5 \times 10^{-2}$ $\text{dm}^9 \text{ mol}^{-3} \text{ s}^{-1}$ <p>ALLOW TE on (a)(i)  Allow units in any order  Allow sec for seconds</p> <p>ALLOW use of other experimental data instead of experiment 4</p> <p>IGNORE SF except 1SF</p> <p>Correct answer with no working scores (2)</p> <p>Correct answer with no working and correct units scores (3)</p>	<b>(3)</b>

Question Number	Answer	Additional Guidance	Mark
<b>18(b)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• there are only 4 particles in the rate equation and 12 in the equation for the reaction</li> </ul> <p>OR</p> <p>collisions with more than 2 particles are unlikely</p>	<p>Accept the number of particles in the rate equation does not match the equation for the reaction</p> <p>Accept the chances of collisions of 3 / 4 / many particles is unlikely</p> <p>Do not accept other numbers of particles</p> <p>Accept comparison of numbers of particles of individual ions in the equation of the reaction and in the rate equation / order of reaction, e.g. 5 [Br<sup>-</sup>] in the equation but only 1 in the rate equation</p> <p>ALLOW molecules / ions / species / concentrations instead of particles</p> <p>ALLOW TE for comparison on (a)(i) and (a)(ii)</p>	<b>(1)</b>

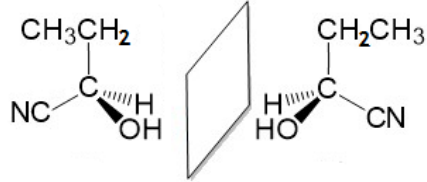
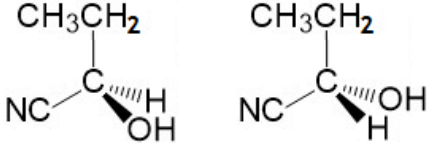
**(Total for Question 18 = 8 marks)**

Question Number	Answer	Additional Guidance	Mark
<b>19(a)(i)</b>	<p>An answer that makes reference to the following points:</p> <p>Step 1</p> <ul style="list-style-type: none"> <li>• lone pair of electrons on C of C≡N</li> <li>• curly arrow from anywhere on the C of C≡N to C in propanal including the charge</li> <li>• curly arrow from C=O bond to or just beyond O</li> <li>• dipole on C=O</li> </ul> <p>Step 2</p> <ul style="list-style-type: none"> <li>• lone pair on O in intermediate Step 1 or Step 2</li> <li>• curly arrow from the O (or minus charge) of intermediate to H of H-C≡N</li> <li>• curly arrow from H-C bond to C of H-C≡N</li> </ul>	 <p>All 7 points scores 4 marks  5 or 6 points scores 3 marks  3 or 4 points scores 2 marks  2 points scores 1 mark  Ignore formula of products even if incorrect  Ignore all dipoles on HCN  Penalise dipoles on C-O in the intermediate</p>	<b>(4)</b>

Question Number	Answer	Additional Guidance	Mark
<b>19(a)(ii)</b>	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• the value of <math>K_a</math> / dissociation is (very) small / the equilibrium lies (very) well to the left</li> <li>• so the concentration of <math>\text{CN}^-</math> ions is (very) low / there is a lack of <math>\text{CN}^-</math> ions</li> </ul>	<p><b>(1)</b> Allow it is a (very) weak acid Allow it is partially dissociated</p> <p><b>(1)</b> Allow a comment that all / most <math>\text{CN}^-</math> in the reaction come from KCN</p> <p>Ignore references to <math>K_a</math> of KCN Ignore references to rate of dissociation</p>	<b>(2)</b>



Question Number	Answer	Additional Guidance	Mark
<b>19(a)(iii)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• (it increases the rate of reaction by) providing <b>CN<sup>-</sup> ions</b> in the same phase/state</li> <li>• and it / KCN / CN<sup>-</sup> ion is regenerated in Step 2 (so overall is not used up in the reaction)</li> </ul>	<p><b>(1)</b> Ignore incorrect phases</p> <p><b>(1)</b> Allow it is regenerated at the end (of the reaction)</p> <p>Ignore references to adsorbing and desorbing</p> <p>If no other mark is scored for it is in the same phase/state <b>and</b> is not used up (1) OR A homogeneous catalyst / KCN is in the same phase/state <b>and</b> speeds up the reaction/provides an alternative pathway with lower activation energy (1)</p>	<b>(2)</b>

Question Number	Answer	Additional Guidance	Mark
<b>19(b)</b>	<ul style="list-style-type: none"> <li>a three-dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted bond <b>and</b> at least one wedged bond which are next to each other <b>(1)</b></li> <li>the mirror image of the first structure <b>(1)</b></li> </ul>	<p>Allow just a three dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted and one wedged bond</p> <p>Diagrams may show a mirror / plane of symmetry though this is not necessary</p>  <p>Allow diagrams that swap two of the four substituents e.g.</p>  <p>If not other marks are scored allow two tetrahedral structures which are mirror images that do not have wedged and dotted bonds scores (1)</p>	<b>(2)</b>

		Ignore connectivity errors Allow TE in M2 for incorrect compounds	
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**(Total for Question 19 = 10 marks)**

Question Number	Answer	Additional Guidance	Mark
<b>20(a)(i)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li> <math display="block">K_a = \frac{[C_5H_{11}COO^-][H^+]}{[C_5H_{11}COOH]}</math> </li> </ul>	<p>Accept <math>[CH_3CH_2CH_2CH_2CH_2CO_2^-]</math> and <math>[CH_3CH_2CH_2CH_2CH_2CO_2H]</math>  Accept <math>[H_3O^+]</math> instead of <math>[H^+]</math>  Accept other representations of the chain of hexanoic acid / hexanoate ion, such as <math>[CH_3(CH_2)_4COO^-]</math>  Ignore equation for dissociation  Do not award <math>[H^+]^2/[C_5H_{11}COOH]</math>  Do not award brackets that are not square brackets  Do not award molecular formulae</p>	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>20(a)(ii)</b>	<ul style="list-style-type: none"> <li>• uses expression for <math>pK_a</math> <b>(1)</b></li> <li>• use of <math>K_a</math> expression <b>(1)</b></li> <li>• rearrange and solve for <math>H^+</math> <b>(1)</b></li> <li>• find pH <b>(1)</b></li> </ul>	<p>Example calculation</p> $K_a = 10^{-pK_a} / K_a = 10^{-4.88} / pK_a = -\log_{10}K_a / 4.88 = -\log_{10}K_a / K_a = 0.000013183 / 1.3183 \times 10^{-5}$ $10^{-4.88} / 1.3183 \times 10^{-5} / 0.000013183 = \frac{[H^+]^2}{0.1}$ $[H^+] = \sqrt{0.000013183 \times 0.1} = 0.0011482 / 0.00115 / 1.1482 \times 10^{-3} / 1.15 \times 10^{-3} \text{ (mol dm}^{-3}\text{)}$ $pH = -\log_{10}[H^+] = 2.94 / 2.9400$ <p>Do not award M4 with units</p> <p>Final correct answer with no working scores (4) Final correct answer scores (4)</p> <p>Allow TE at each stage Omitting the square root gives 5.88 scores (3) Use of 4.88 for <math>K_a</math> gives 0.1558 scores (3)</p> <p>Ignore SF except 1 SF</p>	<b>(4)</b>

Question Number	Answer	Additional Guidance	Mark
<b>20(a)(iii)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• hexanoic acid forms more hydrogen bonds (per molecule) with water than butyl ethanoate does <b>(1)</b></li> <li>• hexanoic acid has an -OH group which forms hydrogen bonds (with water) <b>(1)</b></li> <li>• butyl ethanoate / hexanoic acid has a C=O group which forms hydrogen bonds (with water) <b>(1)</b></li> </ul>	<p>All marks may be scored with a diagram or diagrams</p> <p>Allow hexanoic forms two hydrogen bonds per molecule but butyl ethanoate forms only one</p> <p>Ignore references to the strength of the hydrogen bonds Ignore all references to other intermolecular forces</p>	<b>(3)</b>

Question Number	Answer	Additional Guidance	Mark																
<b>20(b)(i)</b>	<ul style="list-style-type: none"> <li>• calculate mass of oxygen <b>(1)</b></li> <li>• divides masses by atomic mass <b>(1)</b></li> <li>• divides by smallest to find the simplest ratio</li> </ul> <p><b>and</b></p> <p>correct empirical formula <b>(1)</b></p>	<p>Example calculation</p> <p>Mass of O = 10 - 6.21 - 1.03 = 2.76(g)</p> <table border="1" data-bbox="1128 389 1960 608"> <thead> <tr> <th>Element</th> <th>C</th> <th>H</th> <th>O</th> </tr> </thead> <tbody> <tr> <td>Mass</td> <td>6.21</td> <td>1.03</td> <td>2.76</td> </tr> <tr> <td>Mass / Atomic Mass</td> <td>6.21 / 12 = 0.5175</td> <td>1.03 / 1 = 1.03</td> <td>2.76 / 16 = 0.1725</td> </tr> <tr> <td>Ratio</td> <td>3</td> <td>6</td> <td>1</td> </tr> </tbody> </table> <p><math>C_3H_6O</math></p> <p>Correct answer with mass/atomic mass ratios calculated scores (3)</p> <p>Do not award <math>C_6H_{12}O_2</math> stated as empirical formula</p> <p>Ignore SF</p> <p>Ignore reference to <math>C_6H_{12}O_2</math> after finding empirical formula</p> <p>Allow 1 mark for <math>CH_2</math> deduced without finding the mass of oxygen</p> <p>Allow max 1 mark for incorrect masses of oxygen divided correctly by atomic mass</p> <p>Correct answer with no working scores (1)</p>	Element	C	H	O	Mass	6.21	1.03	2.76	Mass / Atomic Mass	6.21 / 12 = 0.5175	1.03 / 1 = 1.03	2.76 / 16 = 0.1725	Ratio	3	6	1	<b>(3)</b>
Element	C	H	O																
Mass	6.21	1.03	2.76																
Mass / Atomic Mass	6.21 / 12 = 0.5175	1.03 / 1 = 1.03	2.76 / 16 = 0.1725																
Ratio	3	6	1																

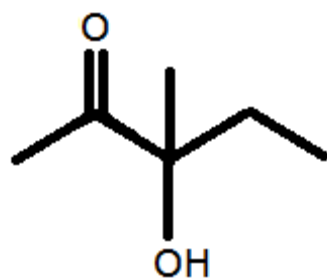
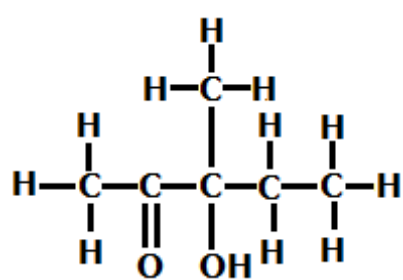
Question Number	Answer	Additional Guidance	Mark
<b>20(b)(ii)</b>	An answer that makes reference to the following points: <ul style="list-style-type: none"><li data-bbox="427 357 1106 459">• molecular ion peak / peak at highest mass will be at twice the mass of the empirical formula / will be at 116</li></ul>	Ignore references to n.m.r or i.r.	<b>(1)</b>

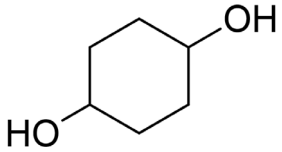


Question Number	Answer	Additional guidance	Mark												
20(b)(iii)	<p>This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.</p> <p>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.</p> <p>The following table shows how the marks should be awarded for indicative content.</p> <table border="1" data-bbox="398 603 913 970"> <thead> <tr> <th data-bbox="398 603 651 783">Number of indicative marking points seen in answer</th> <th data-bbox="651 603 913 783">Number of marks awarded for indicative marking points</th> </tr> </thead> <tbody> <tr> <td data-bbox="398 783 651 820">6</td> <td data-bbox="651 783 913 820">4</td> </tr> <tr> <td data-bbox="398 820 651 857">5-4</td> <td data-bbox="651 820 913 857">3</td> </tr> <tr> <td data-bbox="398 857 651 893">3-2</td> <td data-bbox="651 857 913 893">2</td> </tr> <tr> <td data-bbox="398 893 651 930">1</td> <td data-bbox="651 893 913 930">1</td> </tr> <tr> <td data-bbox="398 930 651 967">0</td> <td data-bbox="651 930 913 967">0</td> </tr> </tbody> </table> <p>The following table shows how the marks should be awarded for structure and lines of reasoning.</p>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5-4	3	3-2	2	1	1	0	0	<p>Guidance on how the mark scheme should be applied:</p> <p>The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</p> <p>In general, an answer with 5 or 6 IPs would score 2 reasoning marks, 3 or 4 IPs would score 1 reasoning mark, 0, 1 or 2 IPs would score 0 reasoning marks.</p>	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points														
6	4														
5-4	3														
3-2	2														
1	1														
0	0														



	<p><b>Indicative content</b></p> <ul style="list-style-type: none"> <li>• <b>IP1</b> Misty fumes suggest OH group present</li> <li>• <b>IP2</b> Orange precipitate suggests a carbonyl group is present (so no carboxylic acid, must be alcohol)</li> <li>• <b>IP3</b> (Negative) Benedict's / Fehling's reagent suggests no aldehyde group present / a ketone is present</li> <li>• <b>IP4</b> Acidified potassium dichromate(VI) suggests not a primary, a secondary alcohol or an aldehyde present</li> <li>• <b>IP5</b> Polarimetry indicates a chiral centre is present / it is a chiral molecule</li> <li>• <b>IP6</b> Structure of 3-hydroxy-3-methylpentan-2-one</li> </ul>	<p>Accept alcohol or carboxylic acid group present (must state both)</p> <p>Accept ketone or aldehyde present (must state both) Ignore C=O is present</p> <p>Accept just 'no oxidisable groups present / cannot be oxidised' in either IP3 or IP4 but not both</p> <p>Allow tertiary alcohol is present Accept just no primary or secondary alcohol present Ignore references to ketone and carboxylic acid giving no result</p> <p>Ignore S<sub>N</sub>2 Allow 4 different groups on a carbon Allow optically active Allow contains a single enantiomer</p> <p>Allow the correct name Allow displayed or structural formula or combinations Allow contractions such as CH<sub>3</sub>- C<sub>2</sub>H<sub>5</sub>-</p>	
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Question Number	Answer	Additional Guidance	Mark
<b>20(c)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• a structure containing <b>two</b> -OH groups</li>   <li>• correct structure</li> </ul>	<p><b>(1)</b> Do not award an -OH group and a -COOH group Award this mark even if the structure does not contain a ring of six atoms.</p> <p><b>(1)</b></p> <div style="text-align: center;">  </div> <p>Structure may be skeletal or displayed or a mixture, as long as it is clear. Allow, for example, a displayed formula with condensed CH<sub>2</sub>.</p> <p>Ignore connectivity of -OH</p>	<b>(2)</b>

**(Total for Question 20 = 20 marks)**

Question Number	Answer	Additional Guidance	Mark
<b>21(a)(i)</b>	<ul style="list-style-type: none"> <li>• calculates moles of acid present in the mixture <b>(1)</b></li> <li>• calculates moles of ester and water present in the mixture <b>(1)</b></li> <li>• calculates moles of ethanol present in the mixture <b>(1)</b></li> <li>• expression for <math>K_c</math> and final answer <b>(1)</b></li> </ul>	<p>Example calculation</p> <p>mol of acid = mol of NaOH = <math>\frac{34.8}{1000} \times 2.50 = 0.087</math> (mol)</p> <p>mol of ester = mol of water = <math>0.2 - 0.087 = 0.113</math>(mol)</p> <p>mol of ethanol = <math>0.150 - 0.113 = 0.037</math></p> <p>If the expression for <math>K_c</math> is incorrect, e.g. no water, allow TE on M1-3 for example not calculating moles of water as well as ester</p> <p><math>K_c = \frac{0.113/V \times 0.113/V}{0.087/V \times 0.037/V} = 3.9668 / 4.0</math> (no units)</p> <p>OR</p> <p><math>K_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]} = 3.9668 / 4.0</math> <b>and</b> statement that volumes cancel</p> <p>Do not penalise lack of square brackets in equilibrium expression</p> <p>Assumption that 0.087 is moles of acid used gives moles ethanol = 0.063 moles ester = water = 0.087  <math>K_c = 1.0632</math> scores max (3)</p> <p>Calculation of acid moles at equilibrium larger than acid moles at the start can score M4 only</p> <p>If no other mark is scored Award (1) for calculation of 0.087(mol) however it is used, Ignore SF</p>	<b>(4)</b>

Question Number	Answer	Additional Guidance	Mark
<b>21(a)(ii)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• same type of / similar bonds being broken and made</li> <li>• same number of each type of bond being broken and made</li> </ul>	<p><b>(1)</b> Allow O-H and C-O bonds being broken and made  Allow the same bond being broken and made  Allow C-OH  Ignore C-O-H and COH  Ignore CO without the bond shown</p> <p><b>(1)</b> Award 2 marks for a complete list of the bonds being broken and made e.g.  Bonds broken and made are 1 x C-O and 1 x O-H scores 2  Allow ester link as C-O  If no other mark is scored award 1 mark for 1 O-H bond is broken and made  Or  1 C-O bond is broken and made  If no other mark is scored allow the energy required to break the bonds is similar to the energy released making the bonds for  <b>(1)</b></p>	<b>(2)</b>

Question Number	Answer	Additional Guidance	Mark
<b>21(b)(i)</b>	<ul style="list-style-type: none"> <li>• methanoic acid</li> <li>• (concentrated) sulfuric acid</li>   <li>• 2-methylpropan-1-ol</li> </ul>	<p>All three correct scores (2) Any two correct scores (1)</p> <p>Allow hydrochloric acid / H<sub>2</sub>SO<sub>4</sub> / HCl Ignore H<sup>+</sup> Ignore (aq) after formulae Ignore hydrogen chloride in words</p> <p>Allow methylpropan-1-ol Allow 2-methyl-1-propanol Allow methyl-1-propanol Do not award 2-methylpropanol</p>	<b>(2)</b>

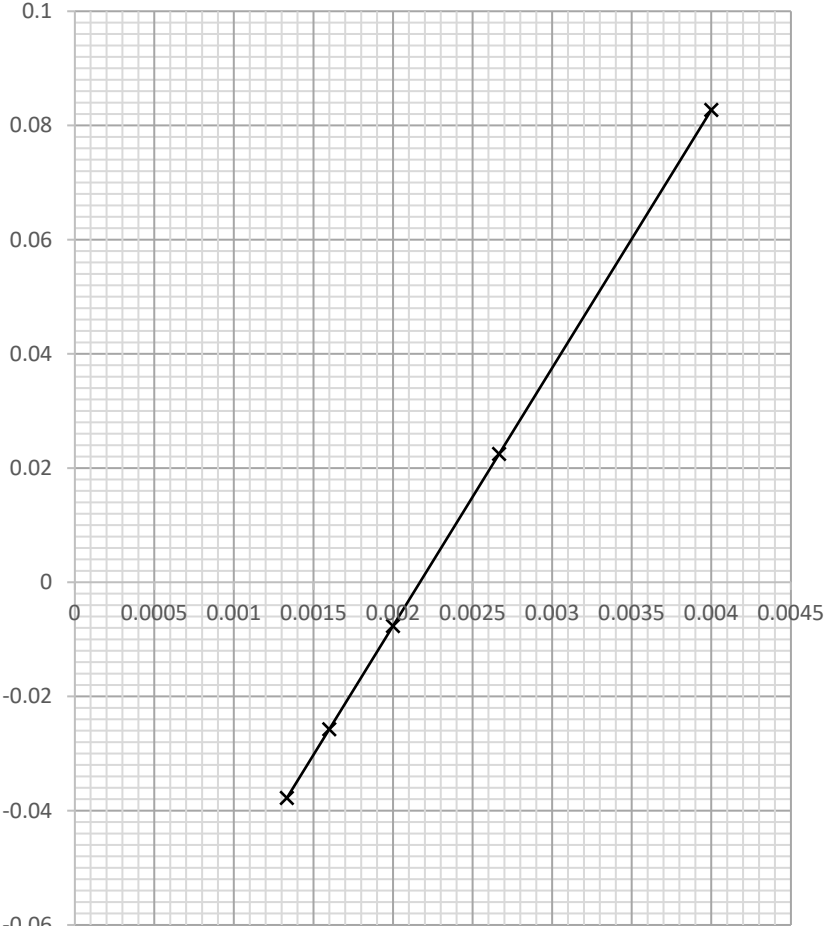


Question Number	Answer	Additional Guidance	Mark
<b>21(b)(ii)</b>	<p>Any one advantage:</p> <ul style="list-style-type: none"> <li>• no heat required / works at room temperature <b>(1)</b></li> <li>• so reduces energy cost <b>(1)</b></li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• no catalyst required <b>(1)</b></li> <li>• reducing product purification costs / making purification easier / no need to recover catalyst <b>(1)</b></li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• reaction is not an equilibrium / reaction goes to completion <b>(1)</b></li> <li>• so produces a higher yield <b>(1)</b></li> </ul> <p>Any one disadvantage:</p> <ul style="list-style-type: none"> <li>• hydrogen chloride produced is acidic / corrosive <b>(1)</b></li> <li>• corrosion resistant plant/equipment required (which is more expensive) <b>(1)</b></li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• HCl is toxic <b>(1)</b></li> <li>• use a fume cupboard / clean exhaust gases / capture the gas (for sale) <b>(1)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Accept the reaction is (much) faster</li> <li>• so no energy required</li> </ul> <p>Ignore just lower cost</p> <p>Ignore more product Allow reactants are not wasted</p> <p>Ignore reference to atom economy</p>	<b>(4)</b>

**(Total for Question 21 = 12 marks)**  
**(Total for Section B = 50 marks)**

### Section C

Question Number	Answer	Additional Guidance	Mark
<b>22(a)</b>	<ul style="list-style-type: none"> <li data-bbox="416 357 808 389">• states or uses equation <span style="float: right;"><b>(1)</b></span></li>   <li data-bbox="416 501 719 533">• calculate <math>S^{\circ}_{\text{products}}</math> <span style="float: right;"><b>(1)</b></span></li> </ul>	$\Delta S^{\circ}_{\text{system}} = S^{\circ}_{\text{products}} - S^{\circ}_{\text{reactants}}$ $-98.0 = S^{\circ}_{\text{products}} - ((0.5 \times 192) + (1.5 \times 131))$ $S^{\circ}_{\text{products}} = 292.5 - 98$ $S^{\circ}_{\text{products}} = (+)194.5 / 195 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ If units are given they must be correct  Allow TE on incorrect $S^{\circ}_{\text{reactants}}$  Comment Correct answer with no working scores (2) $S^{\circ}_{\text{products}} = 63.5$ scores max (1) $S^{\circ}_{\text{products}} = 225$ scores max (1)	<b>(2)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(b)</b>	<ul style="list-style-type: none"> <li data-bbox="439 284 976 389">• 5 points plotted on the graph to within one square <b>(1)</b></li> <li data-bbox="439 427 976 533">• straight line of best fit passing through all points <b>(1)</b></li> </ul>	 <p>The graph displays a set of five data points and a line of best fit. The x-axis is labeled from 0 to 0.0045 in increments of 0.0005. The y-axis is labeled from -0.06 to 0.1 in increments of 0.02. The data points are plotted as 'x' marks at approximately (0.0013, -0.038), (0.0016, -0.028), (0.0020, -0.005), (0.0026, 0.022), and (0.0040, 0.082). A straight line is drawn through these points, showing a positive linear correlation.</p>	<b>(2)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(c)(i)</b>	An answer that makes reference to the following points: <ul style="list-style-type: none"> <li>uses the line or points from the data to calculate the gradient <b>and</b> units</li> </ul>	Example of calculation  $\text{Gradient} = \frac{8.27 \times 10^{-2} - -0.76 \times 10^{-2}}{4.00 \times 10^{-3} - 2.00 \times 10^{-3}}$ $= 45.15 \text{ kJ mol}^{-1}$ Allow an answer between 42.0 – 48.0 Ignore SF except 1 SF	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(c)(ii)</b>	An answer that makes reference to the following points: <ul style="list-style-type: none"> <li>enthalpy change of reaction / <math>\Delta_r H</math> (of the Haber process)</li> </ul>	Allow $-\Delta_r H$ Allow enthalpy change / $\Delta H$ / $-\Delta H$	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(c)(iii)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>value of <math>T</math> found either by reading from the graph the value of <math>T</math> when <math>\Delta S_{\text{total}} = 0</math></li> </ul> <p>or</p> <p>by calculation</p>	<p>460 (K)</p> <p>Allow an answer between 440 - 480</p> <p>= <math>\frac{\text{answer to (c)(i)}}{98}</math></p> <p>= <math>\frac{45150}{98} = 460.71 / 460</math> (K)</p> <p>Or</p> <p>= <math>\frac{-\text{answer to (b)}}{-98}</math></p> <p>= <math>\frac{-45150}{-98} = 460.71 / 460</math> (K)</p> <p>ALLOW TE on graph or on answer to (c)(i)</p>	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(d)(i)</b>	<ul style="list-style-type: none"> <li>total entropy, <math>\Delta S = R \ln K</math></li> </ul> <p>or</p> $\ln K = \Delta S / R$ <p>or</p> $K = e^{\frac{\Delta S}{R}}$		<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(d)(ii)</b>	<ul style="list-style-type: none"> <li>calculation of <math>\ln K</math></li> <li>evaluation of <math>K</math></li> </ul>	<p>Example of calculation</p> $-37.7 = 8.31 \times \ln K$ <p><b>(1)</b> <math>\ln K = -4.5367</math></p> <p><b>(1)</b> <math>K = 0.01071 / 1.071 \times 10^{-2}</math></p> <p>Final answer with no working scores (2)</p> <p>Allow TE on M1 to M2 No TE on incorrect expression</p> <p>Ignore units Ignore SF except 1 SF</p>	<b>(2)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(d)(iii)</b>	<p>An answer that makes reference to the following points:</p> <p>Either</p> <ul style="list-style-type: none"> <li>• (<math>\Delta S_{\text{total}}</math> decreases because) <math>\Delta S_{\text{system}}</math> (and <math>\Delta H</math>) do not change with temperature (significantly) <b>(1)</b></li> <li>• therefore <math>\Delta S_{\text{surroundings}}</math> must decrease (so that <math>\Delta S_{\text{total}}</math> decreases) <b>(1)</b></li> <li>• this is because <math>\Delta S_{\text{surroundings}} = -\Delta H/T</math> (so as <math>T</math> increases <math>-\Delta H/T</math> becomes less positive because <math>\Delta H</math> is exothermic) <b>(1)</b></li> </ul> <p>Or</p> <ul style="list-style-type: none"> <li>• the reaction is exothermic <b>and</b> so increasing temperature shifts the equilibrium to the left / towards the reactants <b>(1)</b></li> <li>• the value of <math>K</math> decreases <b>(1)</b></li> <li>• because <math>\Delta S_{\text{total}}</math> is proportional to <math>K</math> / <math>S_{\text{total}} = R \ln K</math> the value of <math>\Delta S_{\text{total}}</math> decreases <b>(1)</b></li> </ul>	<p>Allow more negative / less positive</p> <p>Accept the backward reaction is favoured</p>	<b>(3)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(d)(iv)</b>	<ul style="list-style-type: none"> <li>overall conversion to ammonia is increased by recycling unused reactants</li> </ul>	<p>Allow remove the ammonia from the equilibrium / as it is formed</p> <p>Ignore references to catalysts, temperature and pressure</p>	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(e)(i)</b>	<ul style="list-style-type: none"> <li>formula of diammonium hydrogenphosphate <b>(1)</b></li> <li>balanced equation <b>(1)</b></li> </ul>	<p><math>(\text{NH}_4)_2\text{HPO}_4</math></p> <p><math>2\text{NH}_3 + \text{H}_3\text{PO}_4 \rightarrow (\text{NH}_4)_2\text{HPO}_4</math></p> <p>Allow multiples Allow ions for the product</p> <p>Allow for M2 <math>\text{NH}_3 + \text{H}_3\text{PO}_4 \rightarrow (\text{NH}_4)\text{H}_2\text{PO}_4</math> Allow ions for the product</p> <p>No other TE</p> <p>Ignore state symbols even if incorrect</p>	<b>(2)</b>



Question Number	Answer	Additional Guidance	Mark
<b>22(e)(ii)</b>	<ul style="list-style-type: none"> <li>• <math>\text{NH}_4^+ \rightleftharpoons \text{NH}_3 + \text{H}^+</math></li>   <li>OR</li>   <li>• <math>\text{NH}_4^+ + \text{H}_2\text{O} \rightleftharpoons \text{NH}_3 + \text{H}_3\text{O}^+</math></li> </ul>	<p>Allow <math>\rightarrow</math> instead of <math>\rightleftharpoons</math></p> <p>Do not award reactions reversed</p> <p>Allow  <math>\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}</math>  Allow <math>\rightleftharpoons</math> instead of <math>\rightarrow</math></p> <p>Ignore state symbols even if incorrect</p>	<b>(1)</b>

Question Number	Answer	Additional Guidance	Mark
<b>22(e)(iii)</b>	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>the mixture contains a large amount/ (large) reservoir of <b>both</b> ammonium ions and ammonia <b>(1)</b> / of <math>\text{NH}_4^+</math> and <math>\text{NH}_3</math></li> </ul> <p><b>Either</b></p> <ul style="list-style-type: none"> <li>added <math>\text{H}^+</math> reacts with ammonia to form ammonium ions / <math>\text{H}^+ + \text{NH}_3 \rightleftharpoons \text{NH}_4^+</math></li> </ul> <p><b>Or</b></p> <ul style="list-style-type: none"> <li>added <math>\text{H}^+</math> combines with <math>\text{OH}^-</math> ions in water to form water / <math>\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}</math></li> </ul> <p><b>And</b></p> <ul style="list-style-type: none"> <li>ammonia reacts with water to produce <math>\text{OH}^-</math> ions / <math>\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-</math> <b>(1)</b></li> </ul> <ul style="list-style-type: none"> <li>ratio of ammonium ions to ammonia hardly changes <b>(1)</b></li> </ul>	<p>Do not award incorrect formulae such as <math>\text{NH}_3^-</math> in M1 and M2 but allow TE in M3 Ignore comments about acid / base in relation to <math>\text{NH}_4^+</math> / <math>\text{NH}_3</math> unless defined</p> <p>Allow <math>\rightarrow</math> instead of <math>\rightleftharpoons</math> Allow <math>\text{H}_3\text{O}^+</math></p> <p>Allow <math>\rightarrow</math> instead of <math>\rightleftharpoons</math></p> <p>This marking point must include at least one ionic equation</p> <p>Allow remains constant</p> <p>Allow pH is unchanged / changes very little because added <math>\text{H}^+</math> removed <b>and</b> change in concentration of <math>\text{NH}_3</math> <b>and</b> <math>\text{NH}_4^+</math> is small</p>	<b>(3)</b>

**(Total for Question 22 = 20 marks)**

**(Total for Section C = 20 marks)**

**Total for Paper = 90 marks**

