Pearson Edexcel

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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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 <u>meaning</u> 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
1(a)	**The only correct answer is B** (½I_2(s) → I(g)) ***A*** *is incorrect because atomisation of an element is from its standard state and iodine is a solid* ***C*** *is incorrect because atomisation produces 1 mole of atoms and requires solid iodine* ***D*** *is incorrect because atomisation produces 1 mole of atoms*	(1)

Question Number	Correct Answer	Mark
1(b)	**The only correct answer is A** (−298 kJ mol^{-1}) ***B*** *is incorrect because this value has had 28 added to −270 rather than subtracted from it* ***C*** *is incorrect because first electron affinity values are always exothermic* ***D*** *is incorrect because first electron affinity values are always exothermic and the wrong sign has been used for the enthalpy change of hydration*	(1)

Question Number	Correct Answer	Mark
2	**The only correct answer is B** (−1650 kJ mol^{-1}) ***A*** *is incorrect because this uses the wrong sign for the enthalpy change of solution* ***C*** *is not correct because this uses only one mole of chloride ions* ***D*** *is not correct because this does not change the sign of the lattice enthalpy*	(1)

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

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

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

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

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

Question Number	Correct Answer	Mark
7	**The only correct answer is C** ($C_{16}H_{14}O_3$) ***A*** *is incorrect because there are 16 carbon atoms in ketoprofen* ***B*** *is incorrect because this answer has one hydrogen too few* ***D*** *is incorrect because this answer assumes there is 1 hydrogen on each carbon in the benzene rings*	(1)

Question Number	Correct Answer	Mark
8	**The only correct answer is C** (3) ***A*** *is incorrect because there are three chiral centres* ***B*** *is incorrect because there are three chiral centres* ***D*** *is incorrect because there are three chiral centres*	(1)

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

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

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

Question Number	Correct Answer	Mark
12(a)	**The only correct answer is D** (CH_3COCH_2I CHI_3) ***A*** *is incorrect because* CH_3I *is not formed in acidic conditions* ***B*** *is incorrect because* CH_3COCI_3 *is not formed in acidic conditions* ***C*** *is incorrect because* CH_3I *is not formed in alkaline conditions*	(1)

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

Question Number	Correct Answer	Mark
13	**The only correct answer is D** ($HOCH_2CH(OH)CH_2CH_2OH$ hot acidified $K_2Cr_2O_7$) ***A*** *is incorrect because the compound **W** is correct but $LiAlH_4$ is a reducing agent* ***B*** *is incorrect because both the compound **W** and reagent are incorrect* ***C*** *is incorrect because the compound **W** is the wrong compound*	(1)

Question Number	Correct Answer	Mark
14	**The only correct answer is C** ($(CH_3)_2CHCOOCH_2CH_3$) ***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* ***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* ***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*	(1)

Question Number	Correct Answer	Mark
15	**The only correct answer is B** (C_3H_7OH) ***A*** *is incorrect because the alcohol formed would be C_3H_7OH* ***C*** *is incorrect because no carboxylic acid is formed under these reaction conditions* ***D*** *is incorrect because the sodium salt of ethanoic acid would be formed*	(1)

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

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

(Total for Section A = 20 marks)

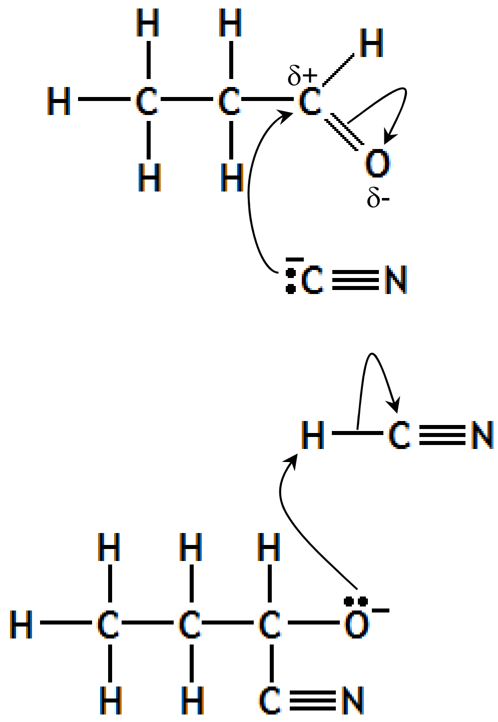
Section B

Question Number	Answer	Additional Guidance	Mark
18(a)(i)	An answer that makes reference to the following points: • order with respect to H^+ is 2 and order with respect to Br^- is 1 **(1)** • (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) **(1)** • (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) **(1)** • rate = $k\,[BrO_3^-][Br^-][H^+]^2$ **(1)**	Accept $[H^+]^2$ Accept $[Br^-]^1$ / $[Br^-]$ Allow mathematical solutions of ratios to give the order 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.) ALLOW TE on incorrect orders deduced M2 and M3 can be given even if resulting orders are incorrect Allow annotations on table	**(4)**

Question Number	Answer	Additional Guidance	Mark
18(a)	An answer that makes reference to the following points: • expression for *k* rearranged **(1)** • value of *k* **(1)** • units **(1)**	Example calculation $k = \dfrac{\text{rate}}{[BrO_3^-][Br^-][H^+]^2}$ OR $k = \dfrac{2.01 \times 10^{-4}}{0.15 \times 0.25 \times 0.60^2}$ $k = 0.014889 / 0.015 / 1.4889 \times 10^{-2} / 1.5 \times 10^{-2}$ $dm^9\ mol^{-3}\ s^{-1}$ ALLOW TE on (a)(i) Allow units in any order Allow sec for seconds ALLOW use of other experimental data instead of experiment 4 IGNORE SF except 1SF Correct answer with no working scores (2) Correct answer with no working and correct units scores (3)	**(3)**

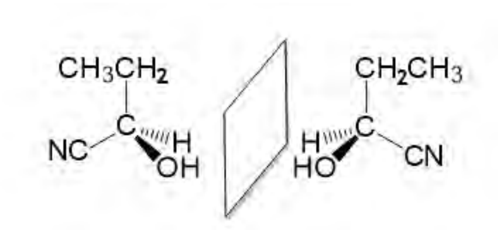
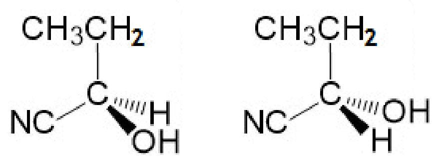
Question Number	Answer	Additional Guidance	Mark
18(b)	An answer that makes reference to the following points: • there are only 4 particles in the rate equation and 12 in the equation for the reaction OR collisions with more than 2 particles are unlikely	Accept the number of particles in the rate equation does not match the equation for the reaction Accept the chances of collisions of 3 / 4 / many particles is unlikely Do not accept other numbers of particles 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^-] in the equation but only 1 in the rate equation ALLOW molecules / ions / species / concentrations instead of particles ALLOW TE for comparison on (a)(i) and (a)(ii)	**(1)**

(Total for Question 18 = 8 marks)

Question Number	Answer	Additional Guidance	Mark
19(a)(i)	An answer that makes reference to the following points: Step 1 • lone pair of electrons on C of C≡N • curly arrow from anywhere on the C of C≡N to C in propanal including the charge • curly arrow from C=O bond to or just beyond O • dipole on C=O Step 2 • lone pair on O in intermediate Step 1 or Step 2 • curly arrow from the O (or minus charge) of intermediate to H of H-C≡N • curly arrow from H-C bond to C of H-C≡N	 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	**(4)**

Question Number	Answer	Additional Guidance	Mark
19(a)(ii)	An explanation that makes reference to the following points: • the value of K_a / dissociation is (very) small / the equilibrium lies (very) well to the left **(1)** • so the concentration of CN^- ions is (very) low / there is a lack of CN^- ions **(1)**	Allow it is a (very) weak acid Allow it is partially dissociated Allow a comment that all / most CN^- in the reaction come from KCN Ignore references to K_a of KCN Ignore references to rate of dissociation	**(2)**

Question Number	Answer		Additional Guidance	Mark
19(a)(iii)	An answer that makes reference to the following points: • (it increases the rate of reaction by) providing **CN^- ions** in the same phase/state • and it / KCN / CN^- ion is regenerated in Step 2 (so overall is not used up in the reaction)	 **(1)** **(1)**	 Ignore incorrect phases Allow it is regenerated at the end (of the reaction) Ignore references to adsorbing and desorbing If no other mark is scored for it is in the same phase/state **and** is not used up (1) OR A homogeneous catalyst / KCN is in the same phase/state **and** speeds up the reaction/provides an alternative pathway with lower activation energy (1)	**(2)**

Question Number	Answer	Additional Guidance	Mark
19(b)	• a three-dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted bond **and** at least one wedged bond which are next to each other **(1)** • the mirror image of the first structure **(1)**	Allow just a three dimensional diagram of 2-hydroxybutanenitrile showing at least one dotted and one wedged bond Diagrams may show a mirror / plane of symmetry though this is not necessary  Allow diagrams that swap two of the four substituents e.g.  If not other marks are scored allow two tetrahedral structures which are mirror images that do not have wedged and dotted bonds scores (1)	**(2)**

		Ignore connectivity errors Allow TE in M2 for incorrect compounds	

(Total for Question 19 = 10 marks)

Question Number	Answer	Additional Guidance	Mark
20(a)(i)	An answer that makes reference to the following points: • $K_a = \frac{[C_5H_{11}COO^-][H^+]}{[C_5H_{11}COOH]}$	Accept $[CH_3CH_2CH_2CH_2CH_2CO_2^-]$ and $[CH_3CH_2CH_2CH_2CH_2CO_2H]$ Accept $[H_3O^+]$ instead of $[H^+]$ Accept other representations of the chain of hexanoic acid / hexanoate ion, such as $[CH_3(CH_2)_4COO^-]$ Ignore equation for dissociation Do not award $[H^+]^2/[C_5H_{11}COOH]$ Do not award brackets that are not square brackets Do not award molecular formulae	**(1)**

Question Number	Answer	Additional Guidance	Mark
20(a)(ii)	• uses expression for pK_a **(1)** • use of K_a expression **(1)** • rearrange and solve for H^+ **(1)** • find pH **(1)**	Example calculation $K_a = 10^{-pK_a}$ / $K_a = 10^{-4.88}$ / p$K_a = -\log_{10}K_a$ / $4.88 = -\log_{10}K_a$ / $K_a = 0.000013183$ / 1.3183×10^{-5} $10^{-4.88}$ / 1.3183×10^{-5} / $0.000013183 = \frac{[H^+]^2}{0.1}$ $[H^+] = \sqrt{0.000013183 \times 0.1} = 0.0011482$ / 0.00115 / 1.1482×10^{-3} / 1.15×10^{-3} (mol dm^{-3}) pH = $-\log_{10}[H^+]$ = 2.94 / 2.9400 Do not award M4 with units Final correct answer with no working scores (4) Final correct answer scores (4) Allow TE at each stage Omitting the square root gives 5.88 scores (3) Use of 4.88 for K_a gives 0.1558 scores (3) Ignore SF except 1 SF	**(4)**

Question Number	Answer	Additional Guidance	Mark
20(a)(iii)	An answer that makes reference to the following points: • hexanoic acid forms more hydrogen bonds (per molecule) with water than butyl ethanoate does **(1)** • hexanoic acid has an -OH group which forms hydrogen bonds (with water) **(1)** • butyl ethanoate / hexanoic acid has a C=O group which forms hydrogen bonds (with water) **(1)**	All marks may be scored with a diagram or diagrams Allow hexanoic forms two hydrogen bonds per molecule but butyl ethanoate forms only one Ignore references to the strength of the hydrogen bonds Ignore all references to other intermolecular forces	**(3)**

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>20(b)(i)</td><td>

calculate mass of oxygen (1)
divides masses by atomic mass (1)
divides by smallest to find the simplest ratio

and

correct empirical formula (1)

</td><td>
Example calculation

Mass of O = 10 - 6.21 - 1.03 = 2.76(g)

<table>
<tr><td>Element</td><td>C</td><td>H</td><td>O</td></tr>
<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>
</table>

C_3H_6O

Correct answer with mass/atomic mass ratios calculated scores (3)

Do not award $C_6H_{12}O_2$ stated as empirical formula

Ignore SF

Ignore reference to $C_6H_{12}O_2$ after finding empirical formula

Allow 1 mark for CH_2 deduced without finding the mass of oxygen

Allow max 1 mark for incorrect masses of oxygen divided correctly by atomic mass

Correct answer with no working scores (1)
</td><td>(3)</td></tr>
</table>

Question Number	Answer	Additional Guidance	Mark
20(b)(ii)	An answer that makes reference to the following points: • molecular ion peak / peak at highest mass will be at twice the mass of the empirical formula / will be at 116	Ignore references to n.m.r or i.r.	**(1)**

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>20(b)(iii)</td><td>This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

<table><tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table>
The following table shows how the marks should be awarded for structure and lines of reasoning.</td><td>Guidance on how the mark scheme should be applied:
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).

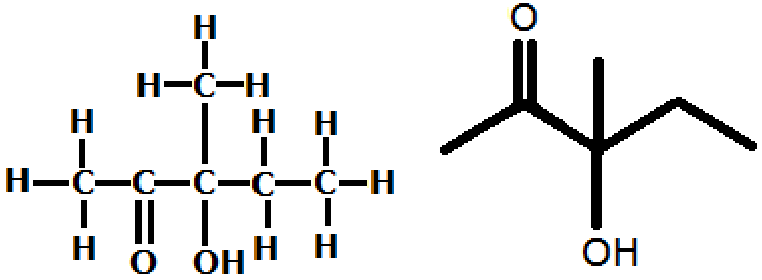
In general, an answer with 5 or 6 IPs would score 2 reasoning marks, 3 or 4 IPs would score 1 reasoning mark, 0, 1 or 2 IPs would score 0 reasoning marks.</td><td>(6)</td></tr>
</table>

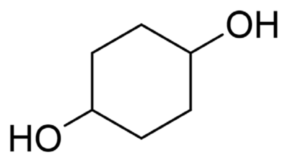
	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2
Answer is partially structured with some linkages and lines of reasoning.	1
Answer has no linkages between points and is unstructured.	0

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded, do not deduct mark(s).

Candidates may treat each test separately or may build on each test. Accept statements in any order.

	Indicative content		
	• **IP1** Misty fumes suggest OH group present	Accept alcohol or carboxylic acid group present (must state both)	
	• **IP2** Orange precipitate suggests a carbonyl group is present (so no carboxylic acid, must be alcohol)	Accept ketone or aldehyde present (must state both Ignore C=O is present	
	• **IP3** (Negative) Benedict’s / Fehling’s reagent suggests no aldehyde group present / a ketone is present	Accept just ‘no oxidisable groups present / cannot be oxidised’ in either IP3 or IP4 but not both	
	• **IP4** Acidified potassium dichromate(VI) suggests not a primary, a secondary alcohol or an aldehyde present	Allow tertiary alcohol is present Accept just no primary or secondary alcohol present Ignore references to ketone and carboxylic acid giving no result	
	• **IP5** Polarimetry indicates a chiral centre is present / it is a chiral molecule	Ignore S_N2 Allow 4 different groups on a carbon Allow optically active Allow contains a single enantiomer	
	• **IP6** Structure of 3-hydroxy-3-methylpentan-2-one	Allow the correct name Allow displayed or structural formula or combinations Allow contractions such as CH_3- C_2H_5-	

Question Number	Answer	Additional Guidance	Mark
20(c)	An answer that makes reference to the following points: • a structure containing **two** –OH groups **(1)** • correct structure **(1)**	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.  Structure may be skeletal or displayed or a mixture, as long as it is clear. Allow, for example, a displayed formula with condensed CH_2. Ignore connectivity of -OH	**(2)**

(Total for Question 20 = 20 marks)

Question Number	Answer	Additional Guidance	Mark
21(a)(i)	• calculates moles of acid present in the mixture **(1)** • calculates moles of ester and water present in the mixture **(1)** • calculates moles of ethanol present in the mixture **(1)** • expression for K_c and final answer **(1)**	Example calculation mol of acid = mol of NaOH = $\frac{34.8}{1000}$ x 2.50 = 0.087 (mol) mol of ester = mol of water = 0.2 – 0.087 = 0.113(mol) mol of ethanol = 0.150 – 0.113 = 0.037 If the expression for Kc is incorrect, e.g. no water, allow TE on M1-3 for example not calculating moles of water as well as ester $K_c = \frac{0.113/V \times 0.113/V}{0.087/V \times 0.037/V}$ = 3.9668 / 4.0 (no units) OR $K_c = \frac{[CH_3COOC_2H_5][H_2O]}{[CH_3COOH][C_2H_5OH]}$ = 3.9668 / 4.0 **and** statement that volumes cancel Do not penalise lack of square brackets in equilibrium expression Assumption that 0.087 is moles of acid used gives moles ethanol = 0.063 moles ester = water = 0.087 Kc = 1.0632 scores max (3) Calculation of acid moles at equilibrium larger than acid moles at the start can score M4 only If no other mark is scored Award (1) for calculation of 0.087(mol) however it is used, Ignore SF	**(4)**

Question Number	Answer		Additional Guidance	Mark
21(a)(ii)	An answer that makes reference to the following points:			**(2)**
	• same type of / similar bonds being broken and made	**(1)**	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	
	• same number of each type of bond being broken and made	**(1)**	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 (1)	

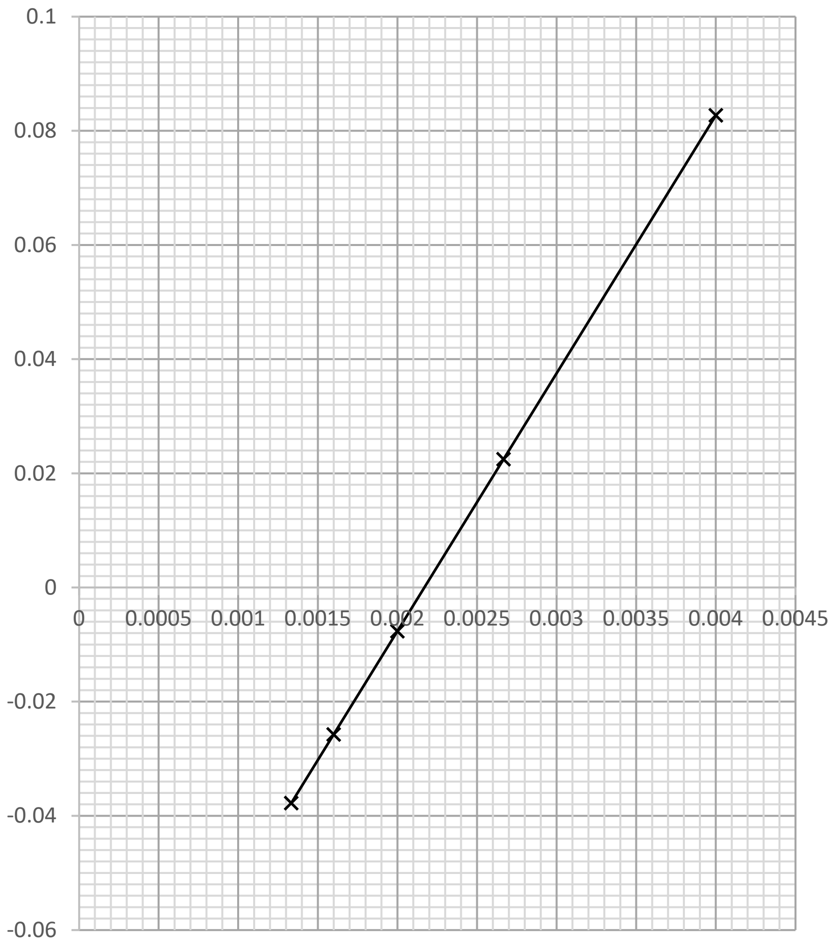
Question Number	Answer	Additional Guidance	Mark
21(b)(i)	• methanoic acid • (concentrated) sulfuric acid • 2-methylpropan-1-ol	All three correct scores (2) Any two correct scores (1) Allow hydrochloric acid / H_2SO_4 / HCl Ignore H^+ Ignore (aq) after formulae Ignore hydrogen chloride in words Allow methylpropan-1-ol Allow 2-methyl-1-propanol Allow methyl-1-propanol Do not award 2-methylpropanol	**(2)**

Question Number	Answer	Additional Guidance	Mark
21(b)(ii)	Any one advantage: • no heat required / works at room temperature **(1)** • so reduces energy cost **(1)** or • no catalyst required **(1)** • reducing product purification costs / making purification easier / no need to recover catalyst **(1)** or • reaction is not an equilibrium / reaction goes to completion **(1)** • so produces a higher yield **(1)** Any one disadvantage: • hydrogen chloride produced is acidic / corrosive **(1)** • corrosion resistant plant/equipment required (which is more expensive) **(1)** or • HCl is toxic **(1)** • use a fume cupboard / clean exhaust gases / capture the gas (for sale) **(1)**	• Accept the reaction is (much) faster • so no energy required Ignore just lower cost Ignore more product Allow reactants are not wasted Ignore reference to atom economy	**(4)**

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

Section C

Question Number	Answer	Additional Guidance	Mark
22(a)	• states or uses equation **(1)** • calculate $S^\ominus_{products}$ **(1)**	$\Delta S^\ominus_{system} = S^\ominus_{products} - S^\ominus_{reactants}$ $-98.0 = S^\ominus_{products} - ((0.5 \times 192) + (1.5 \times 131))$ $S^\ominus_{products}$ = 292.5 – 98 $S^\ominus_{products}$ = (+)194.5 / 195 (J K^{-1} mol^{-1}) If units are given they must be correct Allow TE on incorrect $S^\ominus_{reactants}$ Comment Correct answer with no working scores (2) $S^\ominus_{products}$ = 63.5 scores max (1) $S^\ominus_{products}$ = 225 scores max (1)	**(2)**

Question Number	Answer	Additional Guidance	Mark
22(b)	• 5 points plotted on the graph to within one square **(1)** • straight line of best fit passing through all points **(1)**		**(2)**

Question Number	Answer	Additional Guidance	Mark
22(c)(i)	An answer that makes reference to the following points: • uses the line or points from the data to calculate the gradient **and** units	Example of calculation Gradient = $\dfrac{8.27 \times 10^{-2} - -0.76 \times 10^{-2}}{4.00 \times 10^{-3} - 2.00 \times 10^{-3}}$ = 45.15 kJ mol^{-1} Allow an answer between 42.0 – 48.0 Ignore SF except 1 SF	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(c)(ii)	An answer that makes reference to the following points: • enthalpy change of reaction / $\Delta_r H$ (of the Haber process)	Allow $-\Delta_r H$ Allow enthalpy change / ΔH / $-\Delta H$	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(c)(iii)	An answer that makes reference to the following points: • value of *T* found either by reading from the graph the value of *T* when $\Delta S_{total} = 0$ or by calculation	460 (K) Allow an answer between 440 - 480 $= \frac{\text{answer to (c)(i)}}{98}$ $= \frac{45150}{98} = 460.71 / 460$ (K) Or $= \frac{-\text{answer to (b)}}{-98}$ $= \frac{-45150}{-98} = 460.71 / 460$ (K) ALLOW TE on graph or on answer to (c)(i)	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(d)(i)	• total entropy, $\Delta S = R\ln K$ or $\ln K = \Delta S / R$ or $K = e^{\frac{\Delta S}{R}}$		**(1)**

Question Number	Answer	Additional Guidance	Mark
22(d)(ii)	• calculation of ln K **(1)** • evaluation of K **(1)**	Example of calculation $-37.7 = 8.31 \times \ln K$ $\ln K = -4.5367$ $K = 0.01071 / 1.071 \times 10^{-2}$ Final answer with no working scores (2) Allow TE on M1 to M2 No TE on incorrect expression Ignore units Ignore SF except 1 SF	**(2)**

Question Number	Answer	Additional Guidance	Mark
22(d)(iii)	An answer that makes reference to the following points: Either • (ΔS_{total} decreases because) ΔS_{system} (and ΔH) do not change with temperature (significantly) **(1)** • therefore $\Delta S_{surroundings}$ must decrease (so that (ΔS_{total} decreases) **(1)** • this is because $\Delta S_{surroundings} = -\Delta H/T$ (so as T increases $-\Delta H/T$ becomes less positive because ΔH is exothermic) **(1)** Or • the reaction is exothermic **and** so increasing temperature shits the equilibrium to the left / towards the reactants **(1)** • the value of K decreases **(1)** • because ΔS_{total} is proportional to K / $S_{total} = R \ln K$ the value of ΔS_{total} decreases **(1)**	 Allow more negative / less positive Accept the backward reaction is favoured	**(3)**

Question Number	Answer	Additional Guidance	Mark
22(d)(iv)	• overall conversion to ammonia is increased by recycling unused reactants	Allow remove the ammonia from the equilibrium / as it is formed Ignore references to catalysts, temperature and pressure	**(1)**

Question Number	Answer	Additional Guidance	Mark
22(e)(i)	• formula of diammonium hydrogenphosphate **(1)** • balanced equation **(1)**	$(NH_4)_2HPO_4$ $2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$ Allow multiples Allow ions for the product Allow for M2 $NH_3 + H_3PO_4 \rightarrow (NH_4)H_2PO_4$ Allow ions for the product No other TE Ignore state symbols even if incorrect	**(2)**

Question Number	Answer	Additional Guidance	Mark
22(e)(ii)	• $NH_4^+ \rightleftharpoons NH_3 + H^+$ OR • $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$	Allow $\rightarrow$ instead of $\rightleftharpoons$ Do not award reactions reversed Allow $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$ Allow $\rightleftharpoons$ instead of $\rightarrow$ Ignore state symbols even if incorrect	**(1)**

Question Number	Answer		Additional Guidance	Mark
22(e)(iii)	An answer that makes reference to the following points: • the mixture contains a large amount/ (large) reservoir of **both** ammonium ions and ammonia / of NH_4^+ and NH_3 **Either** • added H^+ reacts with ammonia to form ammonium ions / $H^+ + NH_3 \rightleftharpoons NH_4^+$ **Or** • added H^+ combines with OH^- ions in water to form water / $H^+ + OH^- \rightarrow H_2O$ **And** ammonia reacts with water to produce OH^- ions / $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ • ratio of ammonium ions to ammonia hardly changes	**(1)** **(1)** **(1)**	Do not award incorrect formulae such as NH_3^- in M1 and M2 but allow TE in M3 Ignore comments about acid / base in relation to NH_4^+ / NH_3 unless defined Allow $\rightarrow$ instead of $\rightleftharpoons$ Allow H_3O^+ Allow $\rightarrow$ instead of $\rightleftharpoons$ This marking point must include at least one ionic equation Allow remains constant Allow pH is unchanged / changes very little because added H^+ removed **and** change in concentration of NH_3 **and** NH_4^+ is small	**(3)**

(Total for Question 22 = 20 marks)
(Total for Section C = 20 marks)
Total for Paper = 90 marks

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