Pearson Edexcel

Mark Scheme (Results)

November 2021

Pearson Edexcel GCE
In Chemistry (9CH0)
Paper 2: Advanced Organic and Physical 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 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.

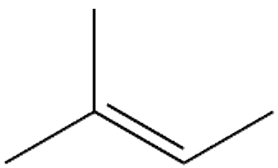
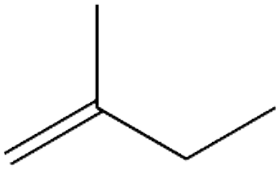
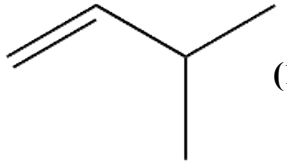
Quality of Written Communication
Questions which involve the writing of continuous prose will expect candidates to:
- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities.
Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

Question Number	Answer	Mark
1	**The only correct answer is D** (3.6×10^{23}) **A** *is not correct because the number of moles of $(NH_4)_2SO_4$ has been divided by 3, rather than multiplied by 3* ***B*** *is not correct because it is the number of SO_4^{2-} ions* ***C*** *is not correct because it is the number of NH_4^+ ions*	**(1)**

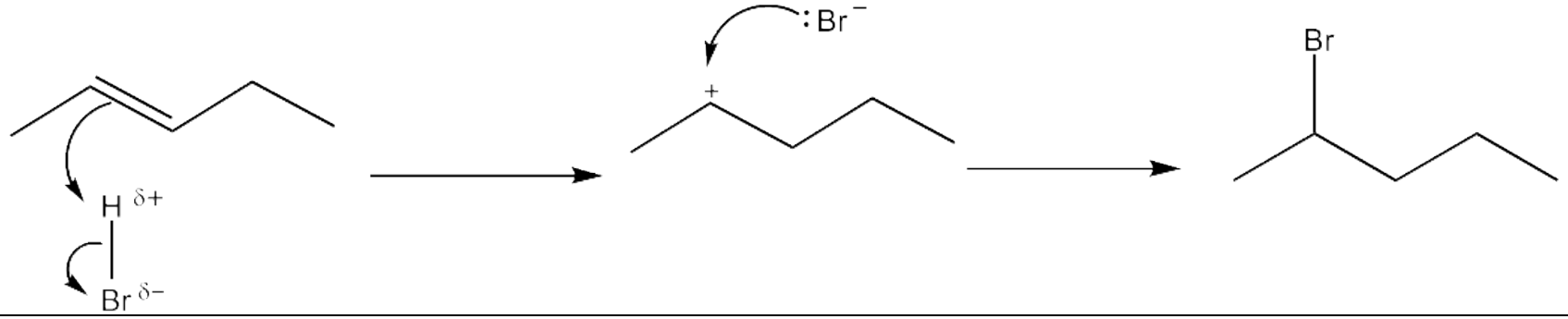
Question Number	Answer	Mark
2	**The only correct answer is C** ($31.2\ dm^3$) **A** *is not correct because the answer assumes a 1:1 ratio of butane to oxygen* **B** *is not correct because the answer assumes a 1:2 ratio of butane to oxygen* **D** *is not correct because the answer assumes a 1:13 ratio of butane to oxygen*	**(1)**

Question Number	Answer	Mark
3	**The only correct answer is A** (*E*-2-methylbut-2-enoic acid) ***B*** *is incorrect because the two high priority groups are on opposite sides* ***C*** *is incorrect because the methyl group is on carbon 2* ***D*** *is incorrect because the two high priority groups are on opposite sides and the methyl group is on carbon 2*	**(1)**

Question Number	Answer	Additional Guidance	Mark
4(a)	 **(1)**  **(1)**  **(1)**	Allow (2) for three correct displayed or structural formulae Allow (1) for any two correct displayed or structural formulae	**(3)**

Question Number	Answer	Mark
4(b)	**The only correct answer is D** $CH_3CH_2CH(OH)CH_2CH_3$ only **A** *is not correct because it will not form pent-2-ene* **B** *is not correct because it will only form pent-1-ene* **C** *is not correct because $CH_3CH(OH)CH_2CH_2CH_3$ will also form pent-1-ene*	**(1)**

Question Number	Answer	Additional Guidance	Mark
4(c)	• arrow from double bond to $\partial+$ H in HBr **(1)** • arrow from bond in HBr to $Br^{\partial-}$ **(1)** • structure of carbocation **(1)** • arrow from lone pair on Br^- to C^+ in carbocation and final products **(1)**	Penalise lack of dipole only once in M1 or M2 Do not award M1 if arrow from C=C to C also shown Formation of 3-bromopropane can potentially score M1, M2 and M4 as a TE	**(4)**



Question Number	Answer	Additional Guidance	Mark
4(d)	• calculation of moles of pent-1-ene **(1)** • conversion of volume and temperature **(1)** • rearrangement of ideal gas equation and calculation of *p* **(1)** • final answer to 2 or 3 SF **and** units **(1)**	<u>Example of calculation</u> 1.33 / 70 = 0.019 (mol) 500 x 10^{-6} m^3 and 333 K Allow conversion of volume to 0.5 dm^3 if units for M3 and / or M4 shown as kPa *P = (nRT) / V* = (0.019 x 8.31 x 333) / 500 x 10^{-6} = 105154.74 = 105000 Pa / 1.05 x 10^5 Pa / 1.1 x 10^5 Pa Allow N m^{-2} for Pa Allow 105 kPa Allow TE at each stage Penalise rounding to 1SF in M1 but then allow TE Correct answer with units and no working scores (4)	**(4)**

(Total Question 4 = 12 marks)

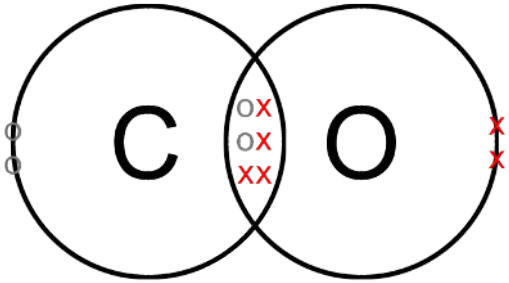
Question Number	Answer	Additional Guidance	Mark
5(a)	• Name of the three functional groups **(2)**	Alcohol / diol, ester and alkene Allow hydroxy / hydroxyl (group) for alcohol Ignore primary Do not award incorrect structures of functional groups in conjunction with correct name Do not award secondary or tertiary alcohol Three correct functional groups scores (2) Two correct functional groups scores (1) One or zero correct functional groups (0) Four groups named with three correct scores (1)	**(2)**

Question Number	Answer	Additional Guidance	Mark
5(b)	An answer that makes reference to the following point • the ester (functional group) will react (with the water) in a hydrolysis reaction	Ignore reference to H-bonds between water and OH groups Allow 'hydrolysis reaction' if equation showing break up of ester group also shown	**(1)**

Question Number	Answer	Mark
5(c)(i)	**The only correct answer is C** (fractional distillation) ***A*** *is incorrect because the process is used to produce smaller hydrocarbons* ***B*** *is incorrect because the process is used to produce branched and cyclic hydrocarbons* ***D*** *is incorrect because the process is used to heat reaction mixtures*	**(1)**

Question Number	Answer	Additional Guidance	Mark
5(c)(ii)	An explanation that makes reference to one of the following pairs of points Either • the OH groups (in compound **X**) can form hydrogen bonds **(1)** • so more energy is needed to vaporise compound **X** / break intermolecular forces in compound X **(1)** Or • hydrocarbons have only London forces, but compound **X** has hydrogen bonds (as well) **(1)** • hydrogen bonds are stronger (than London forces) **(1)**	Ignore references to dipole-dipole interactions Allow 'the oxygen (in compound X) can form hydrogen bonds') Allow 'more energy is needed to break bonds in compound **X**' if H bonds discussed Any reference to the breaking of **covalent** bonds loses M2 only	**(2)**

(Total Question 5 = 6 marks)

Question Number	Answer	Additional Guidance	Mark
6(a)	• 3 bond pairs showing triple bond, one of which must be a dative bond **(1)** • both lone pairs on C and O **(1)**	Example of dot and cross diagram:  Allow 1 mark if correct number of electrons shown, but all as crosses or all as dots Ignore lines showing covalent bonds	**(2)**

Question Number	Answer	Additional Guidance	Mark
6(b)	• Expression of numerator and denominator for atom economy **(1)** • evaluation **(1)**	Example of calculation **28 ÷ [28 + 106]** (x 100) / **[28 ÷ 134]** (x 100) 20.896 = 20.9% Ignore SF except 1 SF Allow TE for M2 for 1 M_r error in M1 Allow 1 mark for (106 ÷ 134) x 100 = 79.1 %	**(2)**

Question Number	Answer	Additional Guidance	Mark
6(c)(i)	<table><tr><th>Temperature / K</th><th>Rate / mol dm^{-3} s^{-1}</th><th>1/Temperature</th><th>ln rate</th></tr><tr><td>700</td><td>0.0108</td><td>1.43 x 10^{-3}</td><td>– 4.53</td></tr><tr><td>850</td><td>4.90</td><td>1.18 x 10^{-3}</td><td>1.59</td></tr></table>	values must be to at least 3SF Allow −4.5282 1.1765 × 10^{-3}	**(1)**

Question Number	Answer	Additional Guidance	Mark
6(c)(ii)	• recognition that (difference in ln rate) / (difference in 1/T) = – E_a / R **(1)** • calculation of – E_a / R **(1)** • calculation of E_a with correct units **(1)**	<u>Example of calculation</u> – 6.12 / 2.5 x 10^{-4} Can be subsumed within M2 = – 24480 (K) 24480 x 8.31 = (+) 203428.8 J mol^{-1} = (+) 203000 J mol^{-1} = (+) 203 kJ mol^{-1} Ignore SF final answer between 200 -204 kJ mol^{-1} with **no** working scores (3)	**(3)**

Question Number	Answer	Additional Guidance	Mark
6(d)(i)	• order with respect to Hb = 1		(1)

Question Number	Answer	Additional Guidance	Mark
6(d)(ii)	• order with respect to CO = 1 **(1)** • justification **(1)**	standalone mark Either using experiments 1 and 3 the concentration of Hb goes up by a factor of 1.56 and the concentration of CO doubles and the rate goes up by a factor of 3.12 Or using experiments 2 and 3 the concentration of Hb goes down by a factor of 0.78 but the rate increases by a factor of 1.56 so doubling the concentration of CO means doubling the rate M2 dependent on M1	(2)

Question Number	Answer	Additional Guidance	Mark
6(d)(iii)	• rate equation	<u>Example of rate equation</u> rate = k[Hb][CO] allow e.g R / r for rate and K for k Allow expressed in terms of k Allow TE from 6(d)(i) and 6(d)(ii) Note – must be consistent with 6(d)(i) and 6(d)(ii)	**(1)**

Question Number	Answer	Additional Guidance	Mark
6(d)(iv)	• rearrangement of rate equation to find k **(1)** • calculation of k **(1)** • correct units of k **(1)**	<u>Example of calculation</u> k = rate / [Hb][CO] $8.20 \times 10^{-7} / (2.09 \times 10^{-6} \times 1.40 \times 10^{-6})$ = 280246 = 280000 Ignore SF except 1 SF $dm^3\ mol^{-1}\ s^{-1}$ Allow units in any order Allow use of data from experiments 2 or 3 Correct answer including units with no working scores 3 marks Allow TE on rate equation from (d)(iii) No TE for mistake with rate equation **within** (d)(iv) e.g. rearrangement error	**(3)**

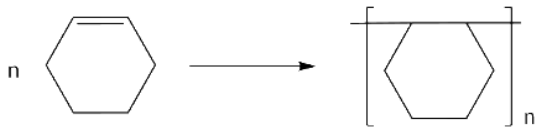
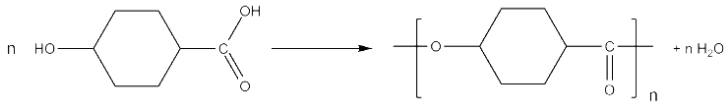
(Total Question 6 = 15 marks)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*7(a)</td>
<td>
This question assesses the 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><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></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>

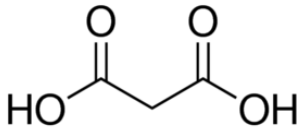
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
</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, a response with four 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 were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages).
</td>
<td>(6)</td>
</tr>
</table>

	Indicative content • **IP1** in both cases many monomers join (by covalent bonds to form polymers) • **IP2** cyclohexene forms an addition polymer / the polymer is formed by an addition reaction • **IP3** 4-hydroxycyclohexanecarboxylic acid forms a condensation polymer / the polymer is formed by a condensation reaction • **IP4** no additional products from when cyclohexene polymerises, but water is also formed when 4-hydroxycyclohexanecarboxylic acid polymerises • **IP5**  • **IP6** 	Allow both polymerisations require a catalyst Allow both polymers are formed from a single type of monomer Allow unsaturated monomer forms saturated polymer Allow 'only 1 product in addition but two products in condensation' Allow only one functional group is needed for addition polymerisation but two different functional groups are needed for condensation polymerisation Allow cyclohexene polymerisation has 100% atom economy, 4-hydroxycyclohexanecarboxylic polymerisation has less than 100% atom economy Ignore omitted or misplaced n in **IP5** and **IP6** Allow 1 IP for IP5 and IP6 if both correct repeat units shown Allow 2 oxygen atoms on RHS and none on LHS for IP6 repeat unit	

Question Number	Answer	Additional Guidance	Mark
7(b)	An answer that makes reference to the following points • recycling **(1)** • incineration to release energy / generate electricity **(1)** • use as a feedstock (for cracking) **(1)**	Allow re-use Allow 'use as a fuel' Allow 'break down into monomers' / 'hydrolyse to form monomers' / 'break down to form small(er) molecules' Ignore 'remove toxic waste gases from incineration' / developing biodegradable polymers	**(3)**

(Total Question 7 = 9 marks)

Question Number	Answer	Additional Guidance	Mark
8(a)	• calculation of mass of C and H in CO_2 and H_2O **(1)** • calculation of mass of O in acid **(1)** • calculation of moles of C, H and O **(1)** • deduction of empirical formula **(1)**	<u>Example of calculation</u> 0.68455 g C and 0.076667 g H 1.21878 g of O Amount of C = 0.68455/12 = 0.05705 mol Amount of H = 0.076667/1 = 0.076667 mol Amount of O = 1.21878/16 = 0.076174 mol 1 : 1.34 : 1.34 = 3:4:4 $C_3H_4O_4$ Allow TE throughout Ignore SF Ignore minor rounding errors e.g. 0.684 g of C NOTE do not award (2.51 + 0.69) – 1.98 = 1.22 g for M2 as this is molecular oxygen from combustion NOT oxygen from compound Y	**(4)**

Question Number	Answer	Additional Guidance	Mark
8(b)	• calculation of amount of sodium hydroxide **(1)** • calculation of amount of **Y** in 25.0 cm^3 **(1)** • calculation of amount of **Y** in 250 cm^3 **(1)** • calculation of molar mass of **Y** **(1)** • deduction of structure of **Y** **(1)**	<u>Example of calculation</u> 26.10/1000 x 0.320 = 8.352 x 10^{-3} (mol) 8.352 x 10^{-3} / 2 = 4.176 x 10^{-3} (mol) 4.176 x 10^{-3} x (250/25) = 4.176 x 10^{-2} (mol) 4.34 / 4.176 x 10^{-2} = 103.9 / 104 (g mol^{-1})  Allow structural / displayed / skeletal or any combination Allow TE throughout M1-M4 Penalise 1 SF in M1	**(5)**

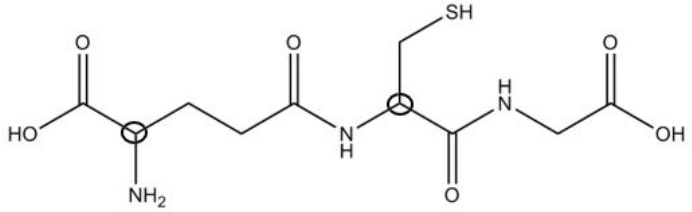
Question Number	Answer	Mark
8(c)	**The only correct answer is A** ($LiAlH_4$ and ether) ***B*** *is incorrect as acidified* $KMnO_4$ *is an oxidising agent* ***C*** *is incorrect as Sn/HCl is too mild a reducing agent* ***D*** *is incorrect as acidified* $Na_2Cr_2O_7$ *is an oxidising agent*	**(1)**

(Total Question 8 = 10 marks)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>9(a)</td><td>• number of peaks in first product (1)
• number of peaks in second product (1)</td><td><table><tr><td>Number of peaks in the ^{13}C NMR spectrum</td><td>4</td><td>6</td></tr></table></td><td>(2)</td></tr>
</table>

Question Number	Answer	Additional Guidance	Mark
9(b)	• calculate amount paracetamol **(1)** • calculate mass of phenol if 100% yield **(1)** • calculate mass of phenol taking into account overall yield **(1)** OR • Target mass of paracetamol, accounting for % yield **(1)** • Target moles of paracetamol, accounting for % yield **(1)** • calculate mass of phenol taking into account overall yield **(1)**	<u>Example of calculation</u> 1000 ÷ 151 = 6.6225 (mol) 6.6225 × 94.0 = 622.52 (g) 622.52 × (100 ÷ 19.04) = 3269.5 g = 3.27 kg 1000 x 100 ÷19.04 = 5252.1 (g) 5252.1 ÷ 151 = 34.782 (mol) 34.782 x 94 = 3269.5 (g) = 3.27 kg NOTE overall % yield is 0.32 x 0.85 x 0.7 = 19.04 % Allow full marks for final answer calculated from intermediate values rounded to 2 or more SF e.g. 3.28 from 19.0 and 622.5 Allow TE throughout Ignore SF except 1 SF Correct answer with no working scores (3)	**(3)**

Question Number	Answer	Mark
9(c)(i)	**The only correct answer is C** (oxidation) ***A*** *is incorrect as there is no evidence the species have added to the benzene ring* ***B*** *is incorrect as there is no evidence of chemical breakdown due to reaction with water* ***D*** *is incorrect as the -NH group and -OH group have lost hydrogen atoms*	**(1)**

Question Number	Answer	Additional guidance	Mark
9(c)(ii)	• both carbon atoms circled	 Allow any other labelling e.g. asterisk / arrow Do not award additional incorrect carbon atoms	**(1)**

Question Number	Answer	Mark
9(c)(iii)	**The only correct answer is B** (glutamic acid and cysteine) ***A*** *is incorrect as aspartic acid has only 4 carbon atoms* ***C*** *is incorrect as the sulfur atom in methionine has a methyl group attached* ***D*** *is incorrect as the sulfur atom in methionine has a methyl group attached and aspartic acid has only 4 carbon atoms*	**(1)**

Question Number	Answer	Additional Guidance	Mark
9(d)	An explanation that makes reference to the following points • amino acids exist as zwitterions **(1)** • so ionic bonds form between the zwitterions / amino acids **(1)**	maybe shown on a diagram allow (a single molecule of an amino acid) forms positive and negative ions Allow 'strong electrostatic forces' if ions clearly referenced in response Ignore reference to hydrogen bonds	**(2)**

(Total Question 9 = 10 marks)

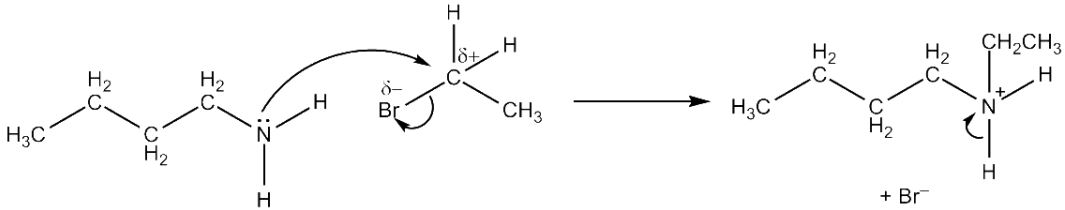
Question Number	Answer	Additional Guidance	Mark
10(a)(i)	• balanced equation	Example of equation $C_4H_9NH_2 + H_2O \rightleftharpoons C_4H_9NH_3^+ + OH^-$ + sign can be on N Product ions must be shown as 2 species Allow arrow for ⇌ Ignore state symbols even if incorrect	**(1)**

Question Number	Answer	Additional Guidance	Mark
10(a)(ii)	An explanation that makes reference to the following points • lone pair of electrons on the nitrogen atom **(1)** • the interaction of the lone pair and the pi electrons of the ring **(1)** • so less able to accept a proton **(1)** allow 2 possible marking points for reverse argument • butyl group pushes electrons towards lone pair on nitrogen • so it is more able to accept a proton	Allow the lone pair delocalises into the benzene ring	**(3)**

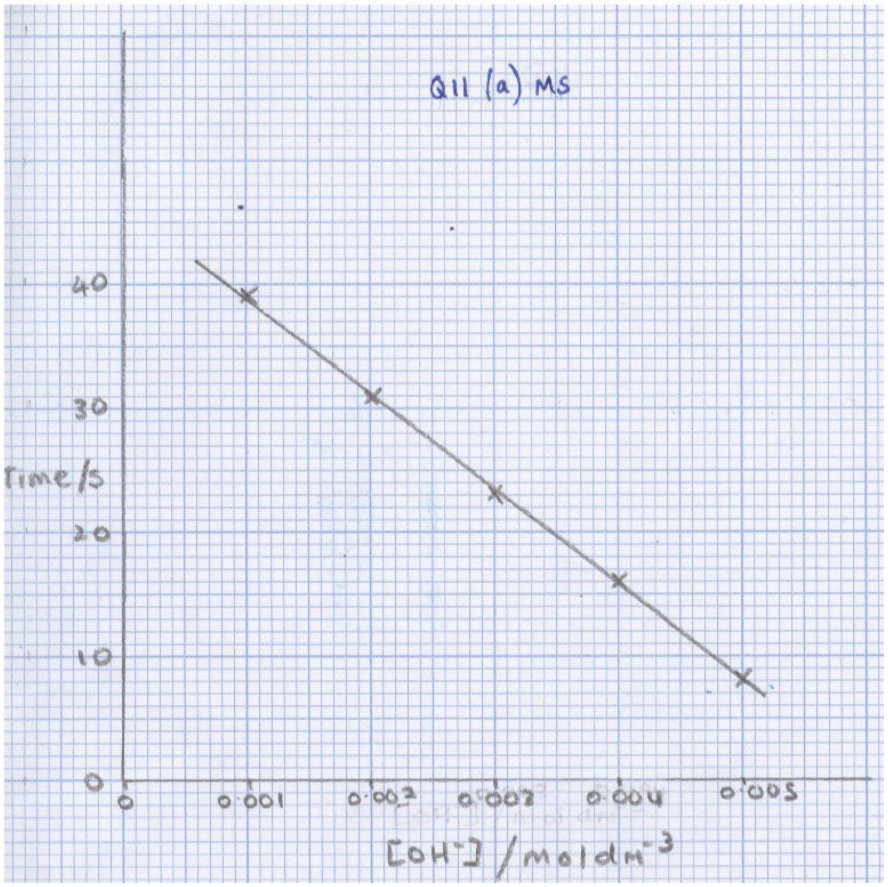
Question Number	Answer	Additional Guidance	Mark
10(b)	• correct name **(1)** • correct formula **(1)**	Propanoyl chloride Allow propanoic anhydride CH_3CH_2COCl Allow $(CH_3CH_2CO)_2O$ Allow displayed or skeletal formula Allow 1 mark for correct name **and** formula for propanoic acid Allow 1 mark for name and formulae of acyl chloride / acid anhydride with incorrect number of carbon atoms	**(2)**

Question Number	Answer	Mark
10(c)	**The only correct answer is A** (blue solution) **B** *is incorrect because the product is not a precipitate* **C** *is incorrect because the product is not yellow* **D** *is incorrect because the product is neither yellow nor a precipitate*	**(1)**

Question Number	Answer	Mark
10(d)(i)	**The only correct answer is D** (nucleophilic substitution) ***A*** *is incorrect because the reaction is not an addition or electrophilic* ***B*** *is incorrect because the attacking species is not an electrophile* ***C*** *is incorrect because the reaction is not an addition*	**(1)**

Question Number	Answer	Additional Guidance	Mark
10(d)(ii)	• arrow from lone pair on nitrogen atom to carbon atom **(1)** • dipole shown **and** arrow from C-Br bond to Br or just beyond **(1)** • formula of intermediate including + charge on the N atom and Br^- **(1)** • arrow from N-H bond to N^+ **(1)**	 Ignore transition state Ignore arrow from Br^- ion to H in intermediate	**(4)**

(Total Question 10 = 12 marks)

Question Number	Answer	Additional Guidance	Mark
11(a)	• **M1** axes labelled with units on axes, suitable uniform scale with points covering at least half the available space in both directions **(1)** • **M2** all points plotted correctly with straight line of best fit **(1)**	Example of graph  Allow variables on either axis	**(2)**

Question Number	Answer	Additional Guidance	Mark
11(b)	An answer that makes reference to the following points • zero order with respect to hydroxide ions **(1)** • The graph is a straight line so the rate of reaction is independent of the concentration of the hydroxide ions **(1)**	M2 dependent on M1	**(2)**

Question Number	Answer	Additional Guidance	Mark
11(c)	An answer that makes reference to the following points • S_N1 **(1)** • as there is only one reactant in the rate determining step / as the hydroxide ions do not affect the rate **(1)**	Mark consequentially on order Allow TE from (b) e.g. if first order in (b) allow S_N2	**(2)**

Question Number	Answer	Additional Guidance	Mark
11(d)	• the chloroalkane is tertiary	Allow TE from first order in (b) and/or S_N2 in (c) e.g. if S_N2 in (c) allow primary NOTE if first order wrt hydroxide ions in (b) but S_N1 given in (c) can score 1 mark in (d) for tertiary	**(1)**

(Total for Question 11 = 7 marks)

Question Number	Answer	Additional Guidance	Mark
12	• 2-bromo-2-methylbutane reacts with Mg **(1)** • Dry ether **(1)** • $CH_3CH_2C(MgBr)(CH_3)CH_3$ **(1)** • react Grignard reagent with HCHO **(1)** • $CH_3CH_2C(CH_3)_2CH_2OMgBr$ **(1)** • (hydrolyse) with (dilute) acid **(1)** OR • 2-bromo-2-methylbutane reacts with KCN **(1)** • ethanol (as solvent) **(1)** • $CH_3CH_2C(CN)(CH_3)CH_3$ **(1)** • nitrile (hydrolysed) with (dilute) acid **(1)** • $CH_3CH_2C(COOH)(CH_3)CH_3$ **(1)** • carboxylic acid (reduced) with $LiAlH_4$ (in dry ether) **(1)**	Note – award of reagent or solvent marks must be in context of attempt to carry out an appropriate reaction e.g. use of **ethanolic** KCN to react with a ketone would not score OR M2 do not award HCOH Allow with water / H^+ Ignore HCN Allow methanol Allow H^+	**(6)**

(Total for Question 12 = 6 marks)
TOTAL FOR PAPER = 90 MARKS

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