Examiners' Report
June 2024

IAL Chemistry WCH12 01

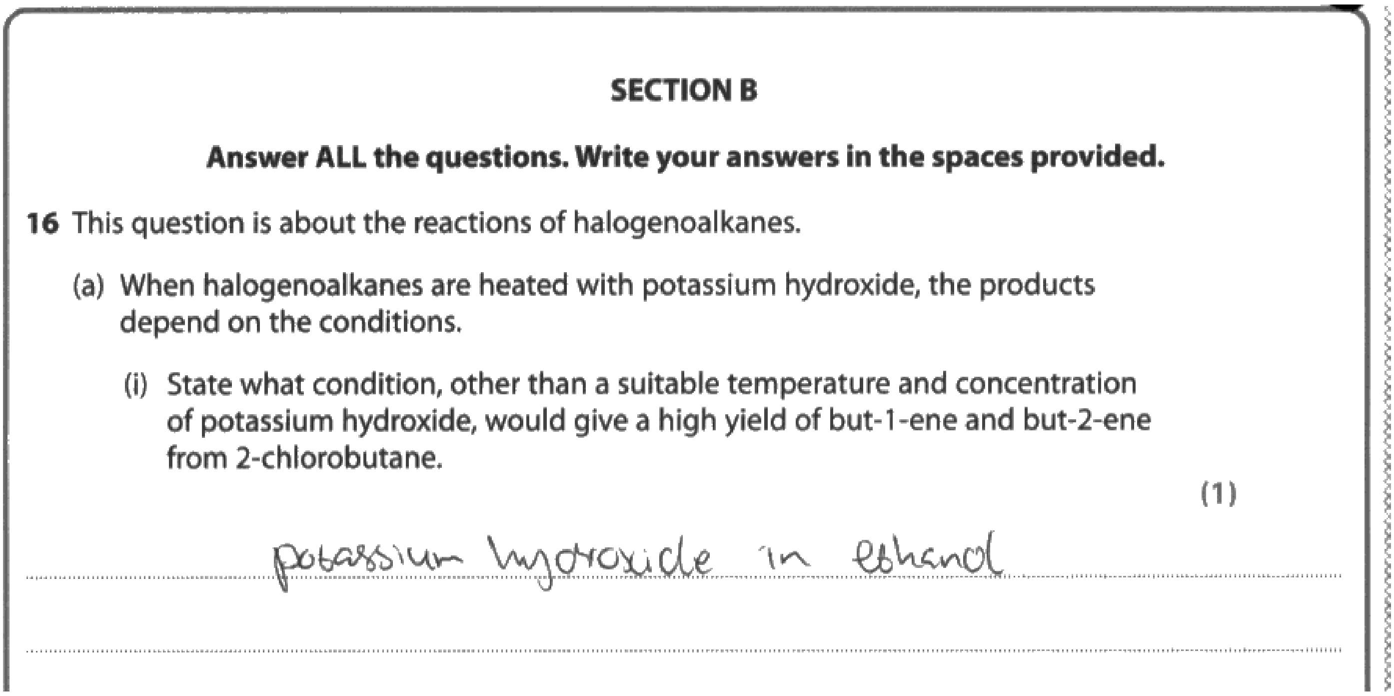
Introduction

This paper proved accessible to most candidates, with a mean score of 36 marks. Candidates were very well prepared for some of the more traditional questions such as the mechanism in Question 16(b)(ii) and the deduction of a molecular formula, in Question 18(b)(iv). Questions which required application of knowledge were more challenging than some previous examples in earlier papers, such as the dot-and-cross diagram for the structure of the free radical ClO_2 in Question 18(a)(i). Some candidates found it difficult to apply their knowledge in these unusual contexts.

The multiple-choice questions in Section A proved to be very accessible, with an average of 12 marks scored on these questions. Candidates seemed well prepared for the challenges of multiple-choice, with evidence seen, for example, of candidates eliminating answers which they thought could not be correct, and so reducing their options – a very worthy technique. The hardest of the multiple-choice questions were Question 3 and Question 15(b) with only one quarter of candidates securing the mark, while Question 4(a), Question 7, Question 8, Question 12 and Question 15(c) were all scored by over 70% of candidates.

Question 16 (a)(i)

Part (a) of Question 16 focuses on the reaction of halogenoalkanes with potassium hydroxide, looking in particular at the two types of reactions which occur between these two reagents. In (a)(i) candidates are asked to identify the reagent to convert a halogenoalkane, 2-chlorobutane, into a mixture of alkenes. The condition required to achieve this is for the reaction to be carried out in solution in ethanol. There were various ways for candidates to express this condition which were acceptable. The question was focusing primarily on the choice of solvent compared to that used in Question 16(b) so other conditions such as pressure were ignored. Temperature and concentration of potassium hydroxide were ignored as candidates were told to ignore these in the question. About half of the candidates were able to score this mark. Some who did not score the mark confused the conditions here with those required for substitution reactions needed in Question 16(b).



SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

16 This question is about the reactions of halogenoalkanes.

(a) When halogenoalkanes are heated with potassium hydroxide, the products depend on the conditions.

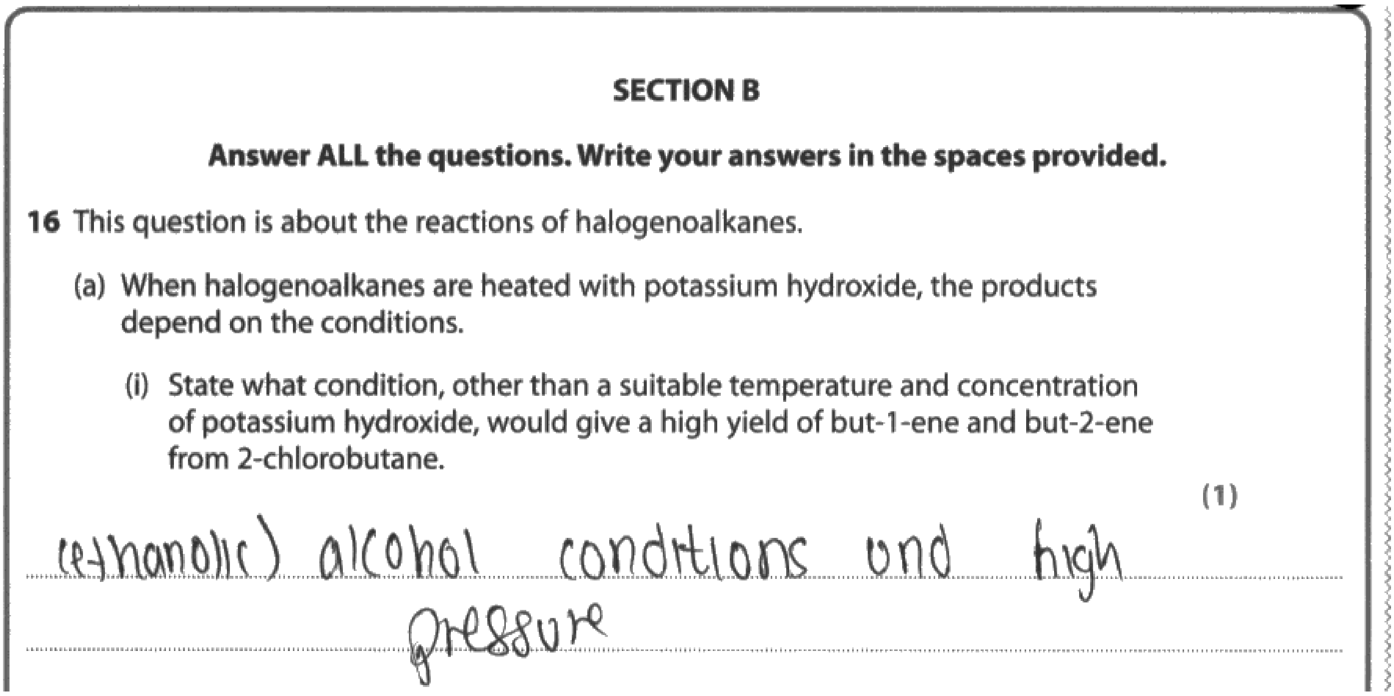
(i) State what condition, other than a suitable temperature and concentration of potassium hydroxide, would give a high yield of but-1-ene and but-2-ene from 2-chlorobutane.

(1)

potassium hydroxide in ethanol

ResultsPlus
Examiner Comments

One way of scoring the mark was to state that the reaction was carried out in ethanol. Here the candidate says that the potassium hydroxide is in ethanol and scores the mark.



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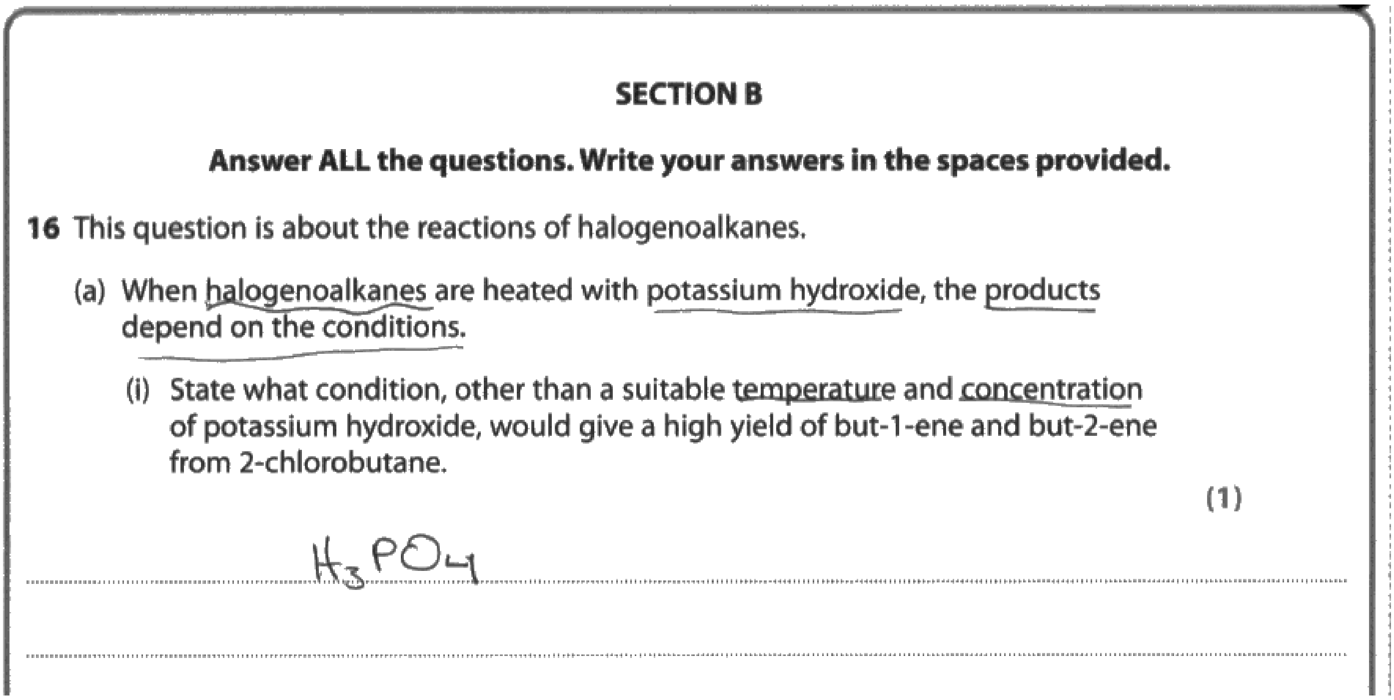
(1)

(ethanolic) alcohol conditions and high pressure

ResultsPlus
Examiner Comments

Here the candidate has stated alcoholic conditions and clarified by including ethanolic in brackets. Either of these answers on their own would have been acceptable. The reaction does not require a high pressure, but this was ignored in this case.



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(1)

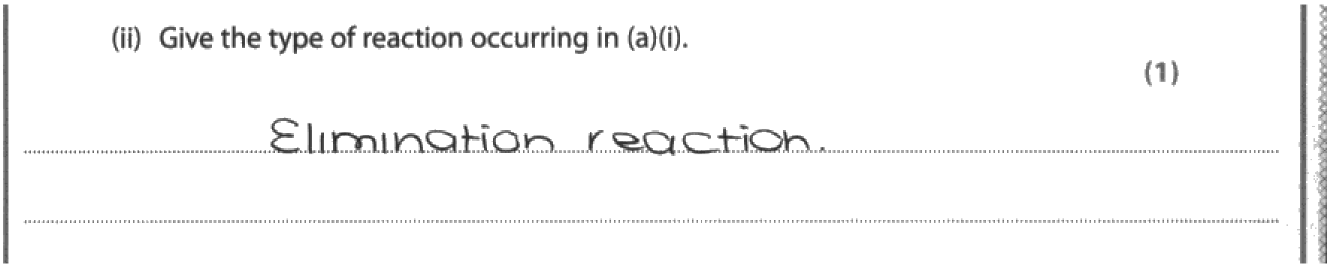
H_3PO_4

ResultsPlus
Examiner Comments

Phosphoric acid, or its formula as in this case, was a common wrong answer. Phosphoric acid is used to eliminate water from an alcohol to give an alkene, not eliminate a hydrogen halide to give an alkene, as in this case.

Question 16 (a)(ii)

There was only one correct answer for this question. A number of different suggestions were given by candidates, but only one answer was acceptable.



(ii) Give the type of reaction occurring in (a)(i).

(1)

Elimination reaction.

ResultsPlus
Examiner Comments

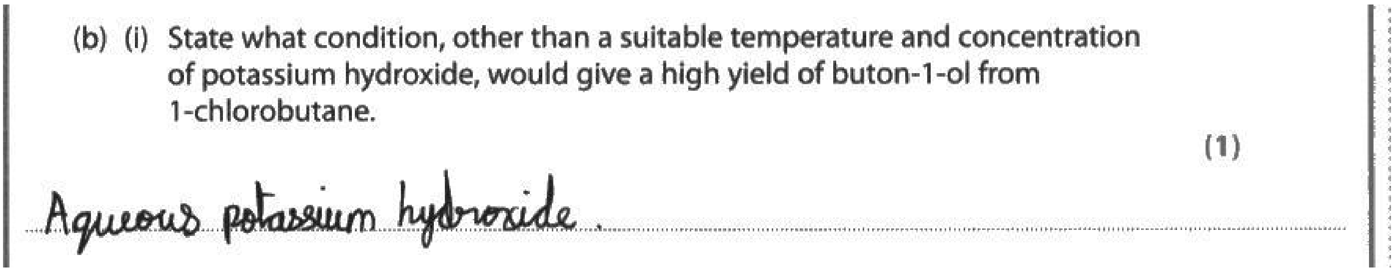
The reaction is an elimination reaction which eliminates hydrogen chloride from 2-chlorobutane, so this scores the mark.

ResultsPlus
Examiner Tip

Learn the conditions and types of reactions for each of the process in the specification.

Question 16 (b)(i)

This question contrasts the conditions required to convert halogenoalkanes into alcohols instead of alkenes in Question 16(a). The difference is the choice of solvent. Water is used as the solvent for this substitution reaction.



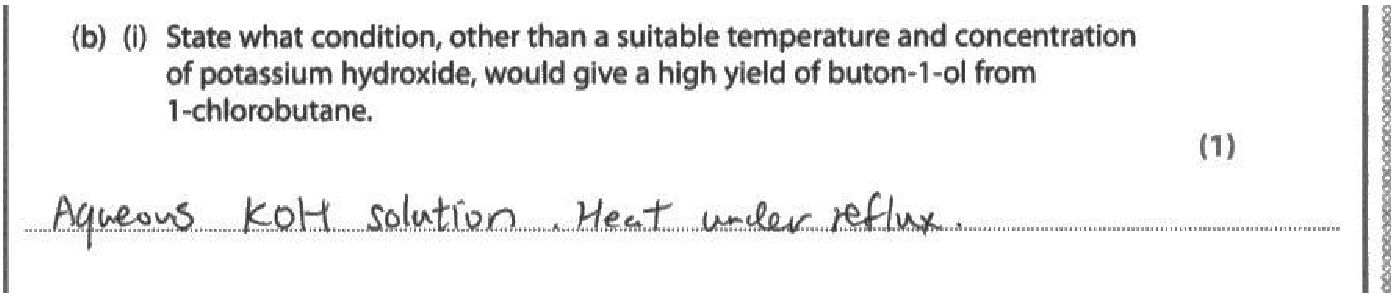
(b) (i) State what condition, other than a suitable temperature and concentration of potassium hydroxide, would give a high yield of buton-1-ol from 1-chlorobutane.

(1)

Aqueous potassium hydroxide .

ResultsPlus
Examiner Comments

Aqueous is a term which is synonymous with solution in water, and so this scores the mark.



(b) (i) State what condition, other than a suitable temperature and concentration of potassium hydroxide, would give a high yield of buton-1-ol from 1-chlorobutane.

(1)

Aqueous KOH solution . Heat under reflux .

ResultsPlus
Examiner Comments

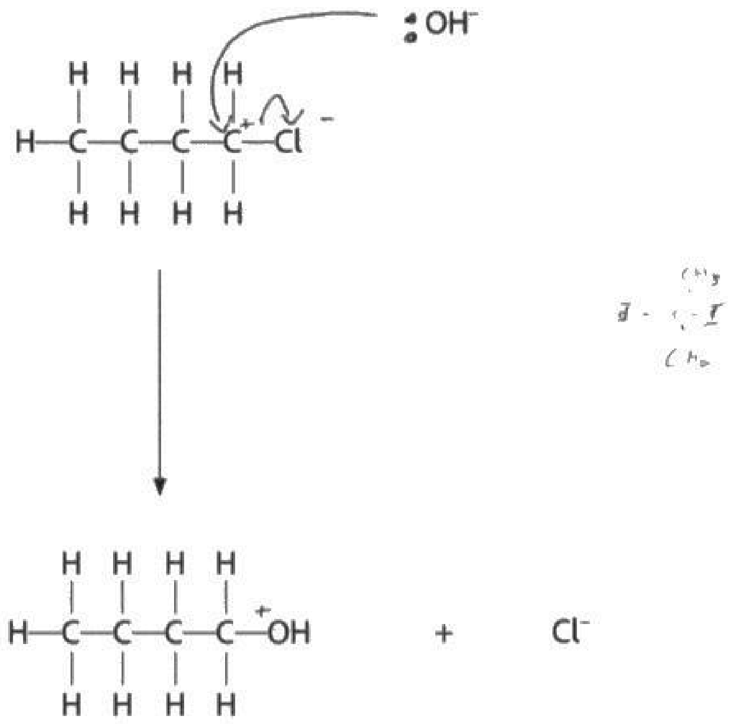
As in Question 16(a)(i), we are focusing on the solvent required so the heat under reflux was ignored here. This scored the mark.

Question 16 (b)(ii)

The mechanism for the substitution reaction is now quite a well known question with most candidates scoring both marks. The important features in this reaction are the lone pair of electrons on the oxygen of the OH^- and the dipole on the C-Cl bond. Two curly arrows show the transfer of pairs of electrons in this one step process. All four of these points correct gave two marks, while 2 or 3 correct points gave 1.

It was quite unusual, but very sensible to avoid clutter, that candidates put the top curly arrow around the C-H bond as this candidate has done.

(ii) Complete the mechanism for the reaction of potassium hydroxide with 1-chlorobutane to form butan-1-ol.
Use curly arrows and show relevant dipoles and lone pairs.



ResultsPlus
Examiner Comments

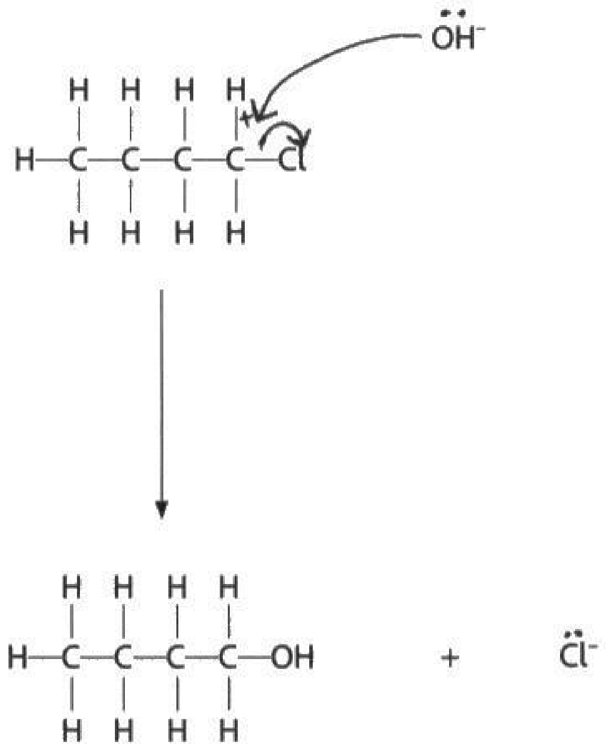
The lone pair on O and the top arrow both are correct, scoring 1 mark. The charges on the C and Cl should be partial charges, d+ and d-, rather than full charges and the arrow to the chlorine should be from the C-Cl bond.

ResultsPlus
Examiner Tip

Curly arrows should always start from lone pairs or from bonds, not from empty spaces.

Some candidates put a lone pair on the oxygen atom, but then started the arrow from somewhere else. Since the arrows show the movement of this pair of electrons it should start from the lone pair.

(ii) Complete the mechanism for the reaction of potassium hydroxide with 1-chlorobutane to form butan-1-ol.
Use curly arrows and show relevant dipoles and lone pairs.



ResultsPlus
Examiner Comments

The lone pair of electrons is correct and the arrow from the C-Cl bond was on the borderline of what we find acceptable so scores. These arrows should start from the bond. The arrow from the O is not from the lone pair, it points towards the C though it is a long way from it. This is excused by the + charge, though this, in itself, is incorrect.

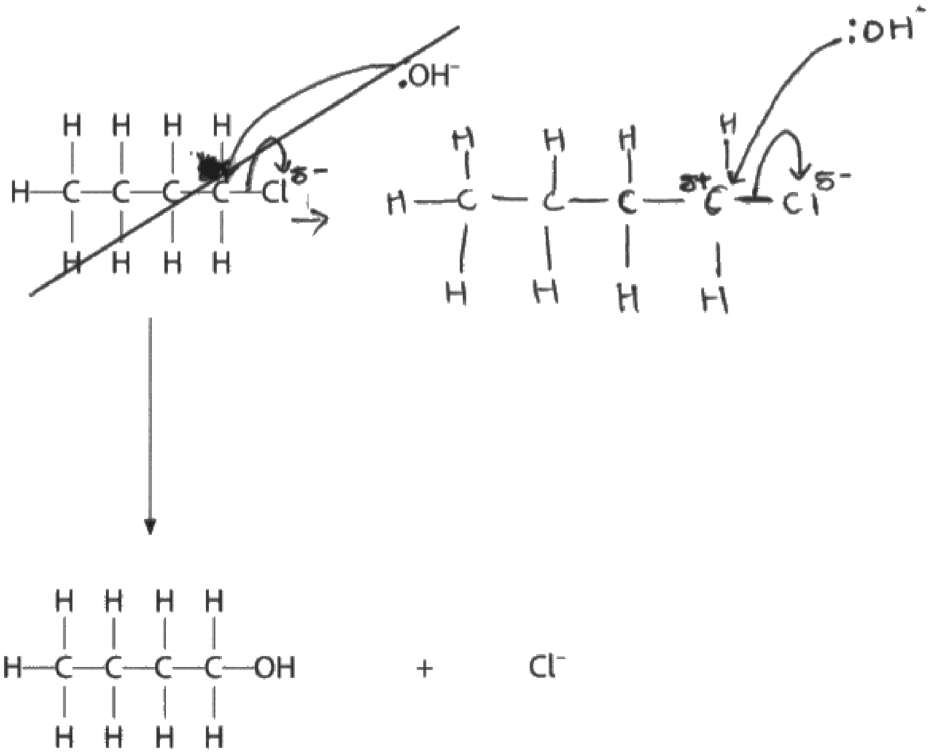
ResultsPlus
Examiner Tip

Start curly arrows from lone pairs or bonds and the arrow points to where the electrons are going.

Candidates should not be afraid to cross out and redraw if they make a mistake or think their diagram or mechanism is too unclear.

(ii) Complete the mechanism for the reaction of potassium hydroxide with 1-chlorobutane to form butan-1-ol.
Use curly arrows and show relevant dipoles and lone pairs.

(2)



ResultsPlus
Examiner Comments

The mechanism here shows all four points very well after this candidate has very sensibly redrawn the structure after making a mistake.

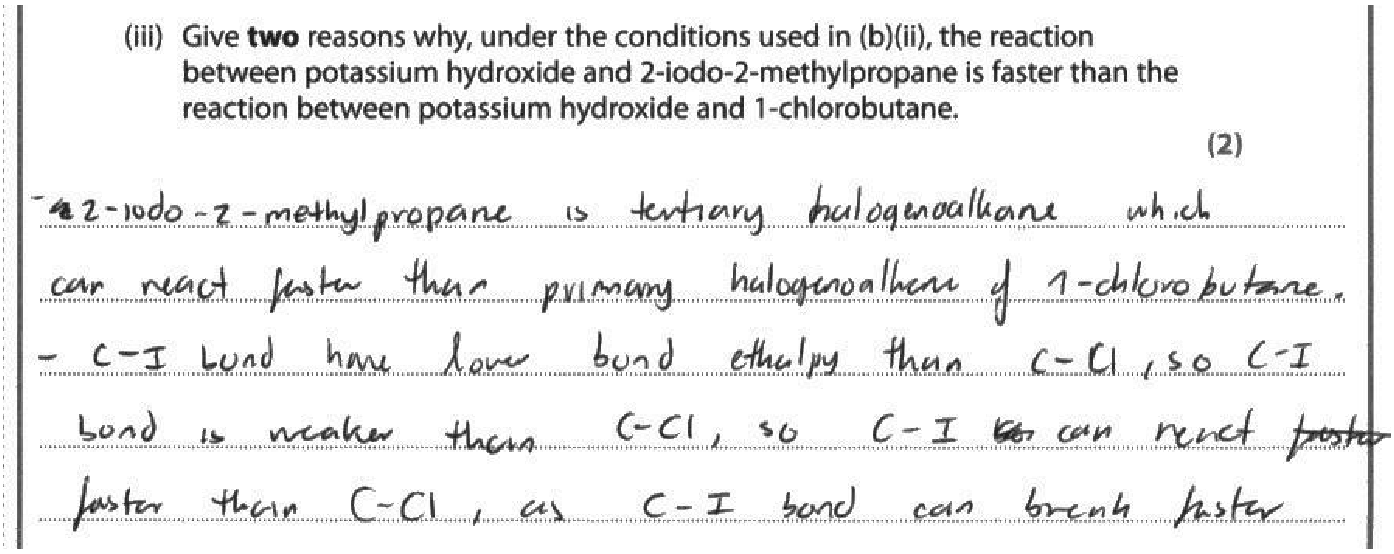
ResultsPlus
Examiner Tip

Redraw diagrams if they have become cluttered or if a mistake is made so your answer can easily be seen.

Question 16 (b)(iii)

This question looks at the two reasons for the different rate of reaction of these two halogenoalkanes. These are the structure of the carbon chain and the strength of the bond between the carbon and the halogen which is being removed. The tertiary halogenoalkane reacts more rapidly than the primary, and the C-I bond is weaker so the iodoalkane reacts faster than the chloroalkane. While many candidates were clearly aware of the factors involved, some found it difficult to express themselves with enough clarity and accuracy to score one or both of the marks available.

The best answers focused clearly on two reasons for the different rates of reaction, the structure and the bond strength.



(iii) Give **two** reasons why, under the conditions used in (b)(ii), the reaction between potassium hydroxide and 2-iodo-2-methylpropane is faster than the reaction between potassium hydroxide and 1-chlorobutane.

(2)

- ~~a~~ 2-iodo-2-methylpropane is tertiary halogenoalkane which can react faster than primary halogenoalkane of 1-chlorobutane.
- C-I bond have lower bond ethalpy than C-Cl, so C-I bond is weaker than C-Cl, so C-I ~~bo~~ can react ~~faster~~ faster than C-Cl, as C-I bond can break faster

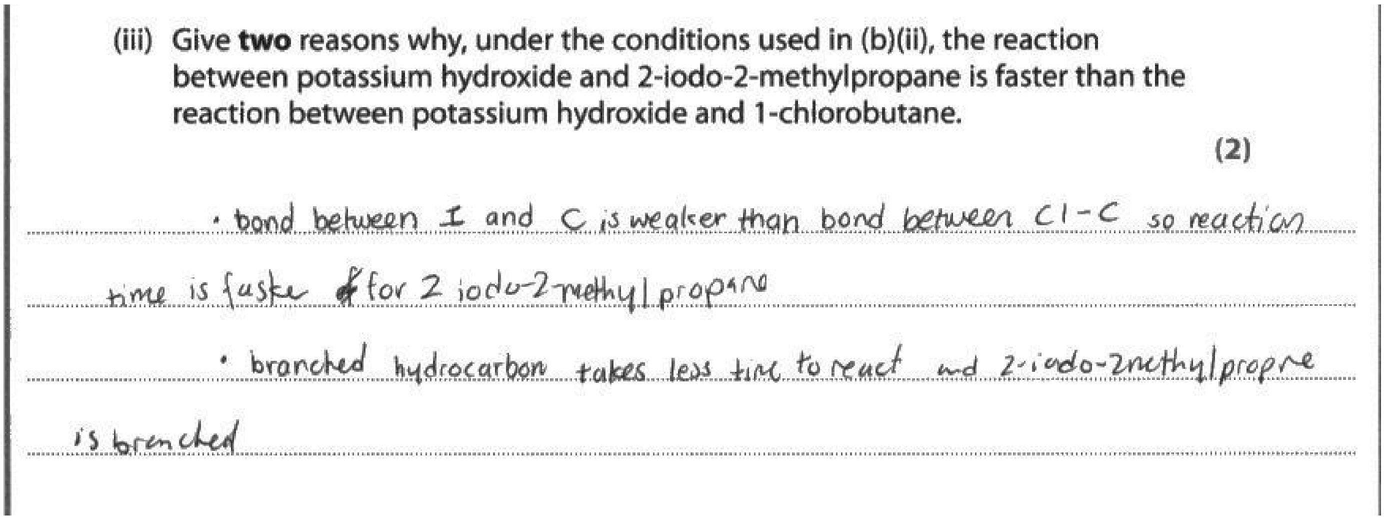
ResultsPlus
Examiner Comments

This candidate has clearly expressed both differences and scores both marks.

ResultsPlus
Examiner Tip

Read the question carefully. **Bold** script is there to provide indications of what is needed.

Here two reasons are given, but the second lacks the necessary detail and accuracy to score the mark.



(iii) Give **two** reasons why, under the conditions used in (b)(ii), the reaction between potassium hydroxide and 2-iodo-2-methylpropane is faster than the reaction between potassium hydroxide and 1-chlorobutane.

(2)

- bond between I and C is weaker than bond between Cl-C so reaction time is faster ~~f~~ for 2 iodo-2-methyl propane
- branched hydrocarbon takes less time to react and 2-iodo-2methylpropane is branched

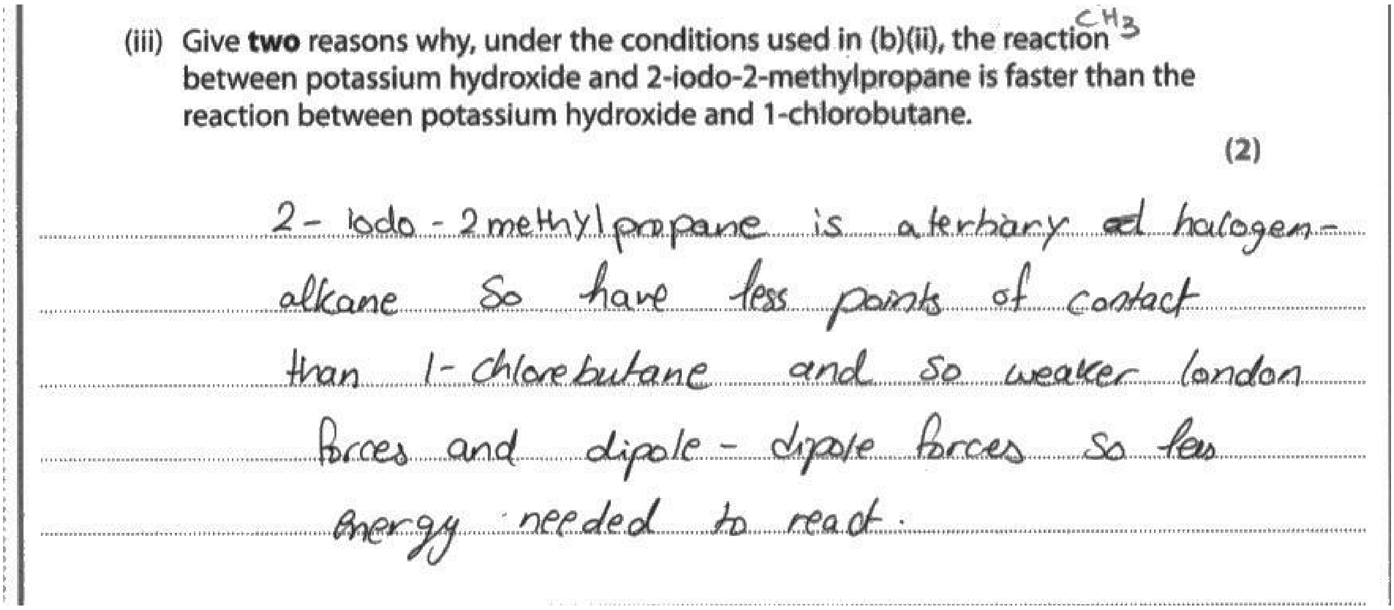
ResultsPlus Examiner Comments

The first bullet point scores a mark. The second does not give the type of the halogenoalkane, and although 2-iodo-2-methylpropane is more branched that the 1-chlorobutane, it is the position of the iodine relative to the branching which makes it more reactive, and that is not expressed in this answer.

ResultsPlus Examiner Tip

Make sure you make your points clearly and precisely.

This candidate has recognised the significance of the type of halogenoalkane, identifying that 2-iodo-2-methylpropane is a tertiary haloalkane. Unfortunately, they have linked this to the relative boiling temperature of the compound rather than its reactivity. Points of contact were seen commonly in this session. The phrase is not particularly common but is used to refer to the relative packing together of molecules when talking about melting and boiling temperatures due to the strength of London forces.



(iii) Give **two** reasons why, under the conditions used in (b)(ii), the reaction CH_3 between potassium hydroxide and 2-iodo-2-methylpropane is faster than the reaction between potassium hydroxide and 1-chlorobutane.

(2)

2- iodo - 2methylpropane is a tertiary ~~ad~~ halogen-alkane so have less points of contact than 1- chlorobutane and so weaker london forces and dipole - dipole forces so less energy needed to react.

ResultsPlus
Examiner Comments

This does not score as the discussion is about boiling temperatures rather than reactivity.

Question 17 (a-c)

This question was concerned with a thermometric titration. A very wide range of marks were seen, with all possible marks being scored. The most common marks were 7 and 8 out of the 9 available marks for this question, so it proved accessible to candidates. The average mark for this part was just over 5 marks, with 10% of candidates scoring all 9 marks.

The first part deals with the graphical processing of results and the use of lines of best fit to find the temperature rise and the volume of ammonia added to neutralise the ethanoic acid present. The other two parts dealt with the use of these values to determine the enthalpy change of neutralisation of the reaction.

In 17(a), there were two common mistakes in the plotting of the lines of best fit. One was to simply join the points, which were generally straight except where the temperature change stopped being upward and started going downwards. The second was to use two straight lines but to have them meet at the highest temperature. This meant the line for the falling temperatures was not a line of best fit. A common mistake in the identification of the points was to misunderstand the term 'end-point'. In acid-base titrations this is the same as the point of neutralisation, but many candidates thought it meant the point for the last addition of ammonia.

In 17(b), some candidates calculated the number of moles of ammonia in each 5cm^3 addition.

in 17(c), common errors were to not include the 30cm^3 of the ethanoic acid solution in the mass of water being heated and to use the final temperature rather than the temperature rise. The final answer was usually given correctly as negative, though some candidates gave more than 2 or 3 significant figures so did not score the final mark.

This is a fully correct and succinct answer.

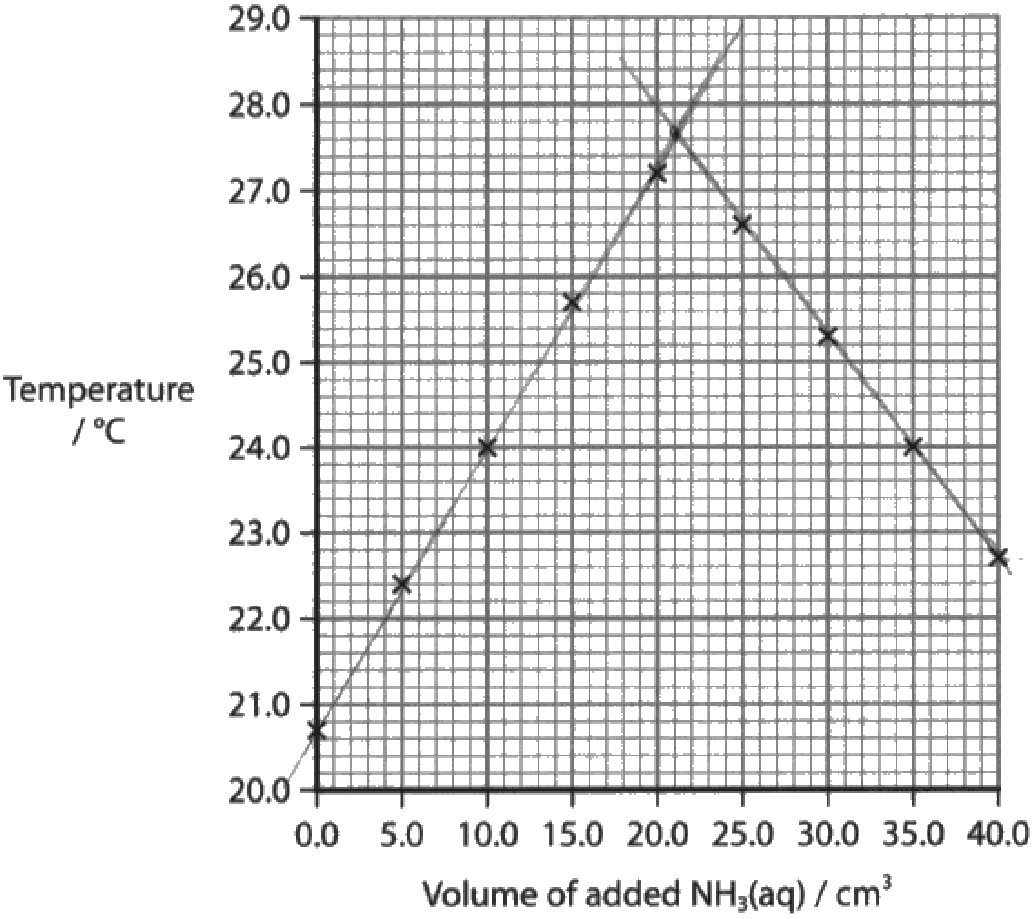
17 In a titration between a weak acid and a weak base indicators do not give a distinct colour change, so other techniques must be used.
One technique is thermometric titration.

Procedure

Step **1** The temperature of 30.0 cm^3 of dilute ethanoic acid in a polystyrene cup is recorded.

Step **2** Ammonia solution of concentration 1.30 mol dm^{-3} is added to the acid in the polystyrene cup in separate 5.00 cm^3 portions.
After each addition the mixture is stirred and the temperature measured.

A student carried out the experiment and plotted the graph shown.



(a) Find the end-point volume and the maximum temperature by adding appropriate lines of best fit to the graph.

(3)

End-point volume = ~~27.7 cm^3~~ 21 cm^3

Maximum temperature = ~~27.7 - 20.7~~ 27.7 °C

(b) Calculate the number of moles of ammonia added at the end-point.

(1)

$1.3 \times \frac{21}{1000} = 0.0273$ mol

(c) The reaction that occurs is shown.

$$CH_3COOH(aq) + NH_3(aq) \rightarrow CH_3COONH_4(aq)$$

Calculate the enthalpy change of neutralisation for this reaction, in kJ mol^{-1}. Give your answer to an appropriate number of significant figures and include a sign with your answer.

[Assume that the density of all solutions is 1.00 g cm^{-3} and that the specific heat capacity of all solutions is 4.18 J g^{-1} °C^{-1}]

(5)

enery tansfered : $(27.7 - 20.7) \times 4.18 \times (30 + 21)$

$= 1492$ J

~~1.492~~

$\Delta H = \frac{-1.492}{0.0273} = -54.7$ kJ mol^{-1}

ResultsPlus
Examiner Comments

This response matches the mark scheme in all respects. Two straight lines are drawn and acceptable values are read from the graph for Q17(a).

In Q17(b) the value for the end-point volume is used correctly to calculate the number of moles.

The volume is used to find the mass at neutralisation in Q17(c) along with the temperature rise, both of which are used in the recalled equation giving a value for the energy transferred. The molar enthalpy change of neutralisation is calculated with the correct sign and number of significant figures.

ResultsPlus
Examiner Tip

It is good to show intermediate steps or parts of calculations, for example the (27.7 – 20.7) and (30 + 21) shown here as these things make calculations easy to follow

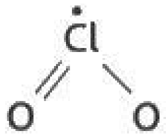
Question 18 (a)(i)

This question focused on chlorine dioxide, ClO_2, and its synthesis.

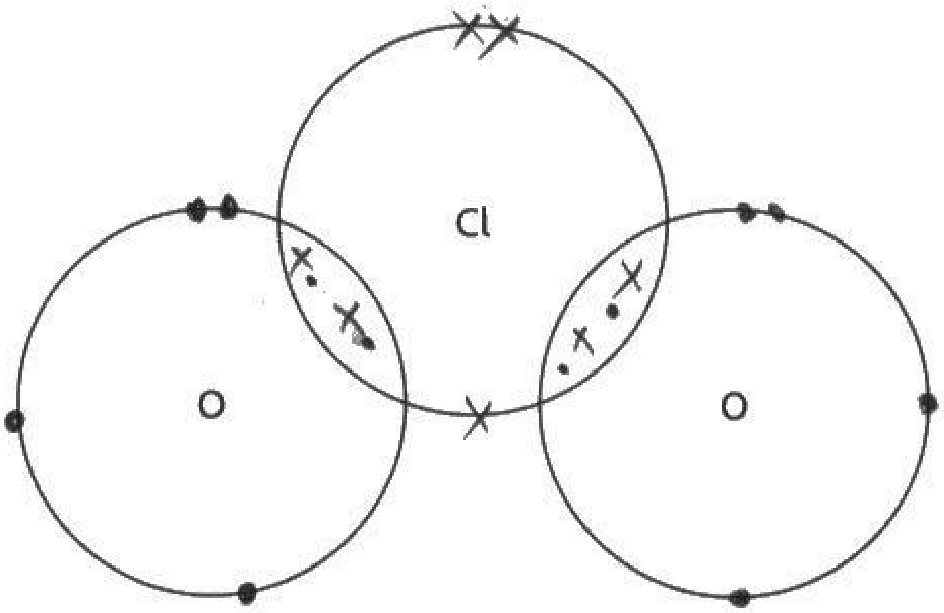
In Q18(a) the bonding in chlorine dioxide was considered. This dot-and-cross diagram was rather more challenging that these usually are, as the candidates first needed to recognise that this compound is a radical, as indicated by the dot on the structure. Then they had to realise that chlorine would exceed the octet in its outer shell and finally deduce that there was one double bond and a dative covalent single bond with the oxygen atoms. This proved a challenging question, and although some excellent answers were seen scoring on this part was quite low. Only 6% of candidates were able to score both marks. Two common answers which were not fully correct were to have two double bonds between the oxygens and the chlorine and one with a normal covalent bond replacing the dative covalent bond. This made the oxygen atom the one with the unpaired electron. Both of these answers scored 1.

This is a typical example of a structure deduced which has two double bonds. This is a perfectly correct alternative structure for ClO2 but does not match the bonding shown in the diagram as it has two double bonds, so this scored 1 of the 2 marks.

18 Chlorine dioxide, ClO_2, can be used to treat water to make it safe for drinking. The molecule is a free radical. One suggested structure is shown.



(a) (i) Complete the dot-and-cross diagram for this structure.
Use dots (•) for oxygen electrons and crosses (×) for chlorine electrons.



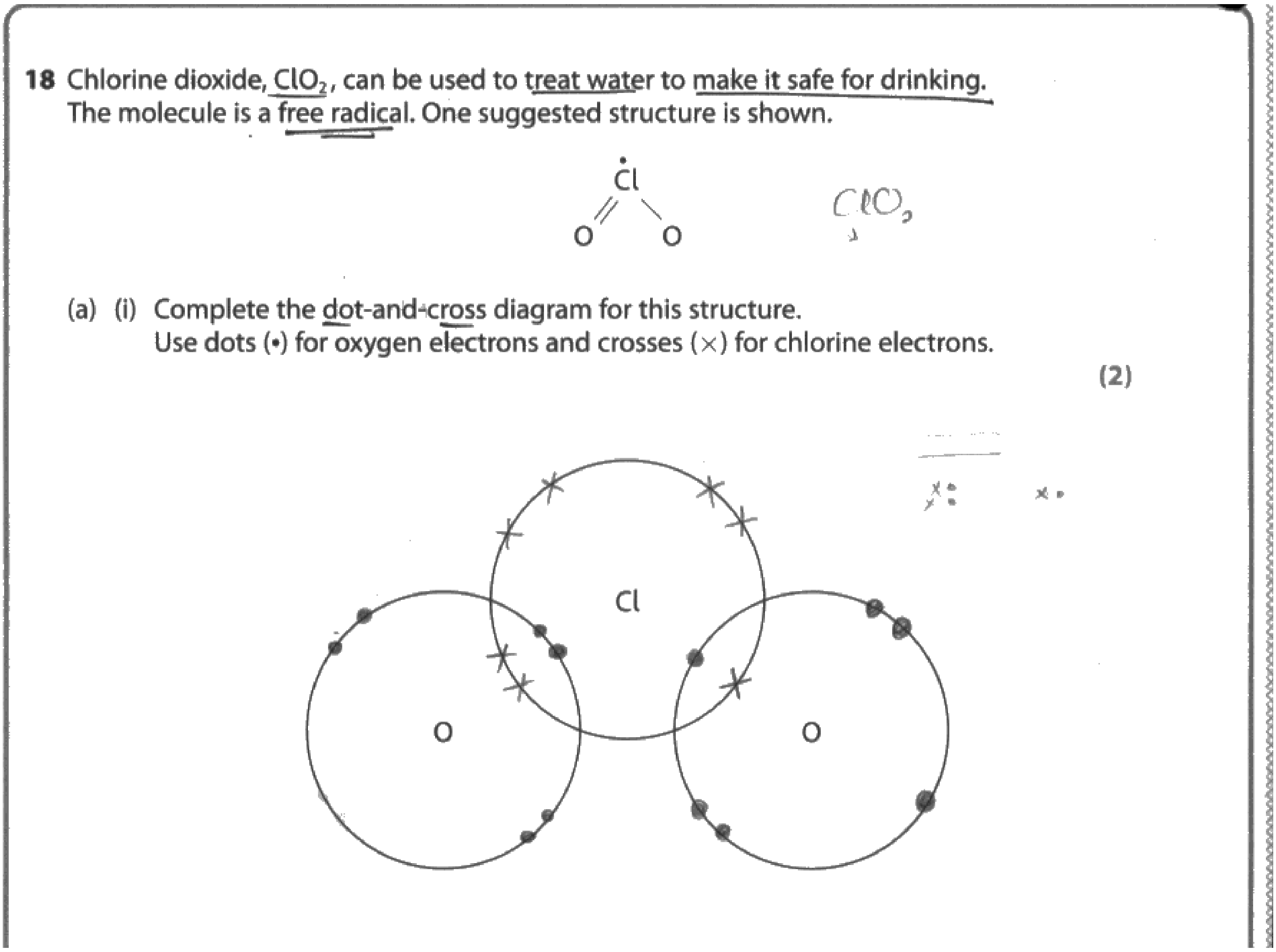
ResultsPlus
Examiner Comments

The electrons did not need to be shown in pairs. This scored 1 mark as described.

ResultsPlus
Examiner Tip

It is possible for atoms in Period 3 and above to exceed 8 electrons in their outer shell, for example in compounds like PCl_5 and SF_6 which leads to their characteristic shapes.

This example shows the structure with the covalent rather than dative covalent bond between the chlorine and oxygen. This is also an alternative structure for ClO2, but has the unpaired electron on the O rather than on the Cl. This also scores 1.



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(a) (i) Complete the dot-and-cross diagram for this structure.
Use dots (•) for oxygen electrons and crosses (×) for chlorine electrons.

(2)

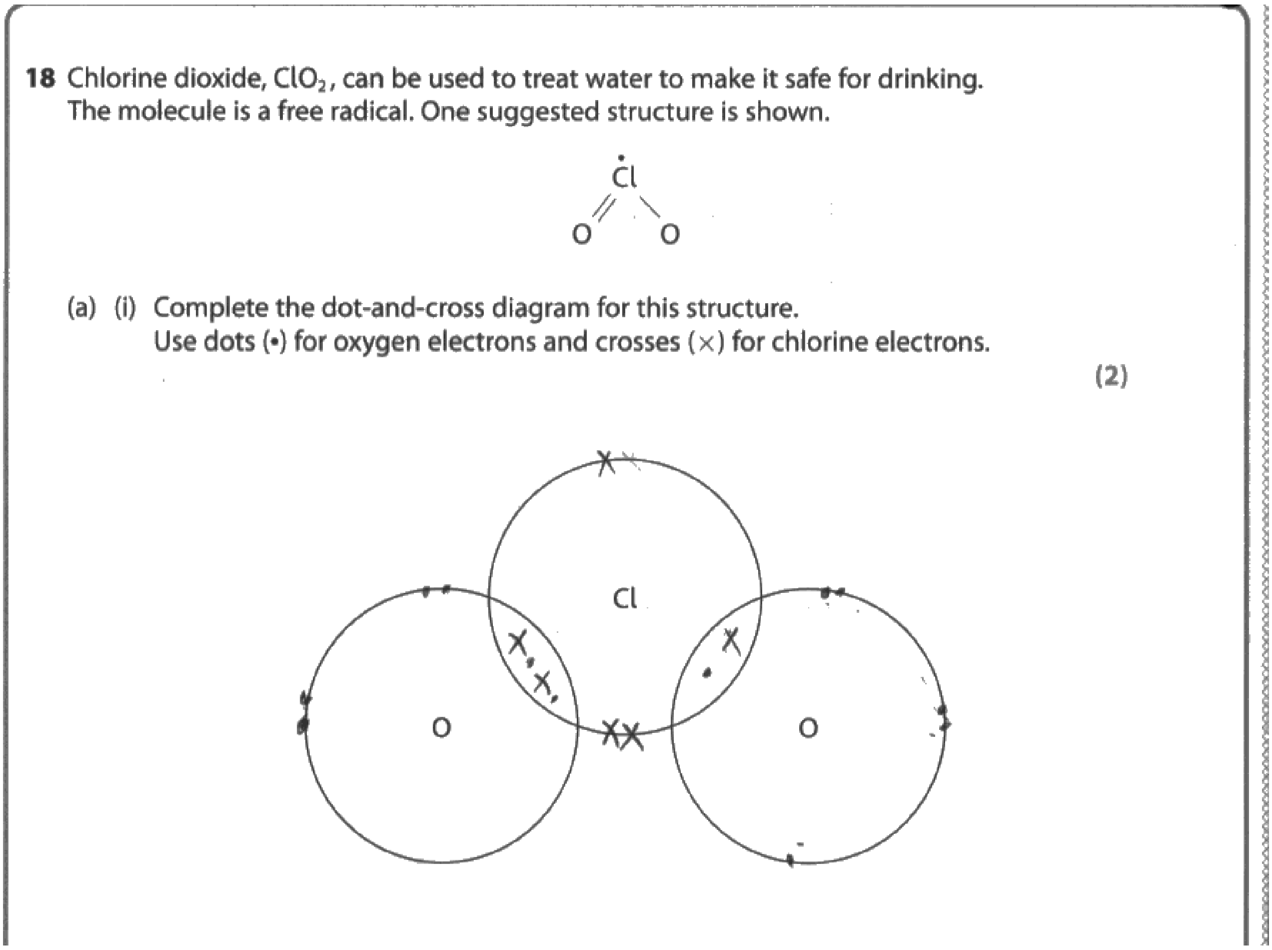
ResultsPlus
Examiner Comments

The electrons in the overlap can be shown on the curves, like this example, or in the space between them. This diagram is particularly neat and easy to understand.

ResultsPlus
Examiner Tip

Try to work out your structure first before starting to place the electrons to avoid crossing out where possible, which can make the diagrams difficult to understand.

At first glance, this looks like both of the common one mark answers, but actually it is neither and does not score.



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(a) (i) Complete the dot-and-cross diagram for this structure. Use dots (•) for oxygen electrons and crosses (×) for chlorine electrons.

(2)

ResultsPlus
Examiner Comments

This has the normal covalent bond between Cl and O, and the correct single electron for the oxygen that would result. Unfortunately, this candidate has perhaps realised the chlorine should have an unpaired electron and has removed one from the top of the atom. This structure is not correct as there are only 6 crosses, representing electrons which originally belonged to chlorine, which should have 7.

ResultsPlus
Examiner Tip

Count the electrons in the final structure to make sure that you have the correct number that came originally from each atom.

This final example has the correct electrons in the bonds and the correct non-bonding electrons on the oxygen, but the structure is missing one electron and has a positive charge as a result. There is no indication of a positive charge on the structure given.

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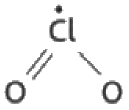
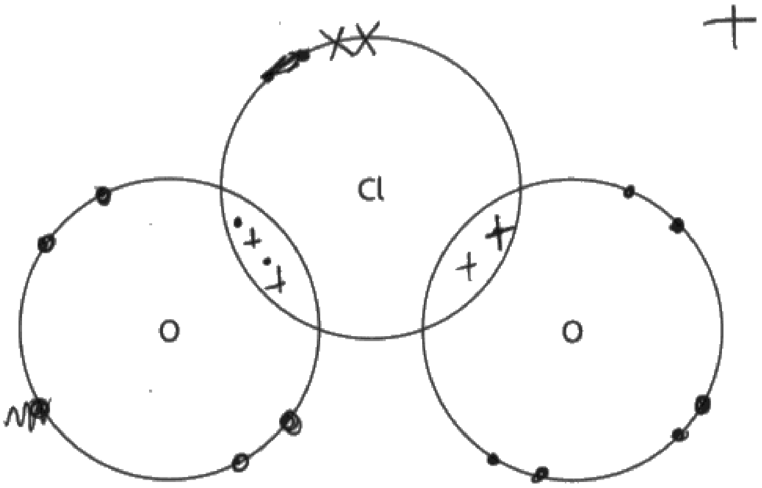


(a) (i) Complete the dot-and-cross diagram for this structure.
Use dots (•) for oxygen electrons and crosses (×) for chlorine electrons.

(2)



ResultsPlus
Examiner Comments

This example has had the unpaired electron from the chlorine removed resulting in the positive charge. This can score 1 for the electrons in the bonds.

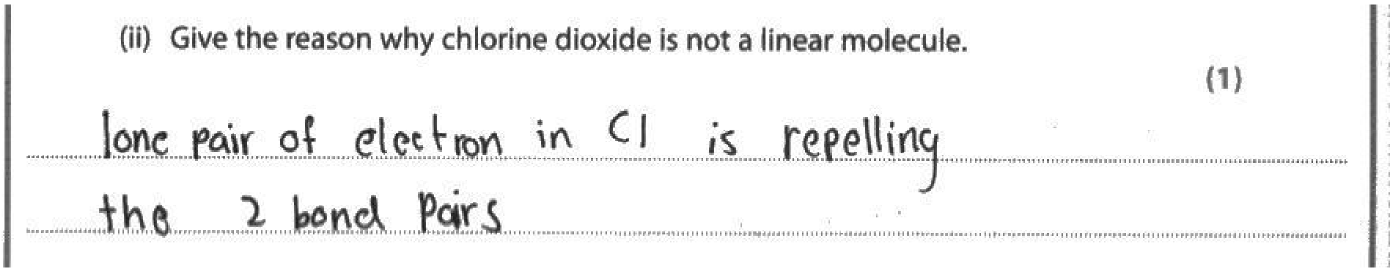
ResultsPlus
Examiner Tip

Once again, count the electrons. The chlorine here has only six.

Question 18 (a)(ii)

The repulsion of electrons, in this case the non-bonding electrons of chlorine and the bonding pairs of electrons in the C-O and C=O bonds, results in the shape of this molecule. Typical errors on this type of question include talking about the electrons repelling the attached atom, in this case the oxygen or the lone pairs of electrons on that atom rather than the bonding electrons. Many candidates just said there were non-bonding electrons without justifying the no-linear shape being discussing repulsion between electrons.

The actual number of electrons involved in the repulsion was ignored as this was tested in the previous item. The expected answer from the correct structure would be the lone pair and single electron on chlorine repelling the electrons in the chlorine to oxygen bonds.



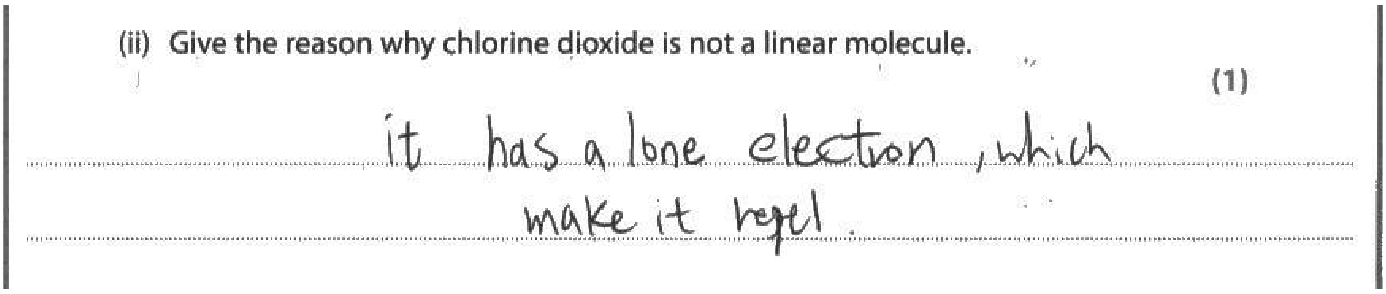
(ii) Give the reason why chlorine dioxide is not a linear molecule.

(1)

lone pair of electron in Cl is repelling the 2 bond Pairs

ResultsPlus
Examiner Comments

This scores the mark for the lone pair repelling the bond pairs



(ii) Give the reason why chlorine dioxide is not a linear molecule.

(1)

it has a lone electron, which make it repel.

ResultsPlus
Examiner Comments

The lone electron repelling would be enough if it said what was being repelled, so this did not score.

Question 18 (b)(i-iii)

The first three parts of Question 18(b) looked at oxidation numbers in compounds in the synthesis of ClO_2. The first was often scored by candidates, though one common mistake was to say that the Roman numeral represented the oxidation number of the chlorate ion rather than the chlorine in the chlorate ion. Finding the oxidation number in chlorine dioxide was well understood. The final deduction was understood by many candidates, but often they were not able to express their answers accurately enough to score both marks. Some assumed the starting compound had a chlorine with the oxidation state of 5, or used their answer to Question 18(b)(iv)-(v) to deduce this, rather than say that it could be 5 or 6 from the information available.

In the first part of this set of three items we are looking for the oxidation number of the chlorine in the chlorate ions.

The second part, Question 18(b)(ii), should be +4 and the final answer should be +5 or +6 because the oxidation state of chlorine goes to +4 and +7 so the oxidation state of chlorine in **A** should be between these two values.

(b) Chlorine dioxide can be made from potassium chlorate(V), $\overset{+5}{\mathrm{KClO_3}}$, in a two-step process.

Step 1 Potassium chlorate(V) reacts with concentrated sulfuric acid to form compound **A**.

Step 2 Compound **A** then undergoes a disproportionation reaction to form chlorine dioxide and hydrogen chlorate(VII), $\mathrm{HClO_4}$.$^{+7}$

(i) State the meaning of the Roman numerals in chlorate(V) and chlorate(VII).

(1)

The number of ions in the molecule

(ii) State the oxidation number of chlorine in chlorine dioxide.

(1)

+4

(iii) In Step **2**, compound **A** undergoes disproportionation.
Deduce the possible range of oxidation numbers for the chlorine in compound **A**. Justify your answer.

(2)

Chlorine oxidation and reduction in this reaction its oxidation number is +5 at the start. In chlorine dioxide it lose ~~elect~~ oxygen and comes +4 and in $\mathrm{HClO_4}$ its gain oxygen and its number is +7 so the reaction is a disproportionation reaction

ResultsPlus
Examiner Comments

This scores a mark for (b)(ii).

In (b)(iii) the candidate assumes that the starting material is +5, which is true, but does not address the possible values it could be. The reasoning that it goes to +4 and +7 is correct so scores 1 mark. This was a common type of answer.

ResultsPlus
Examiner Tip

Read the question with care so you answer the question rather than something similar.

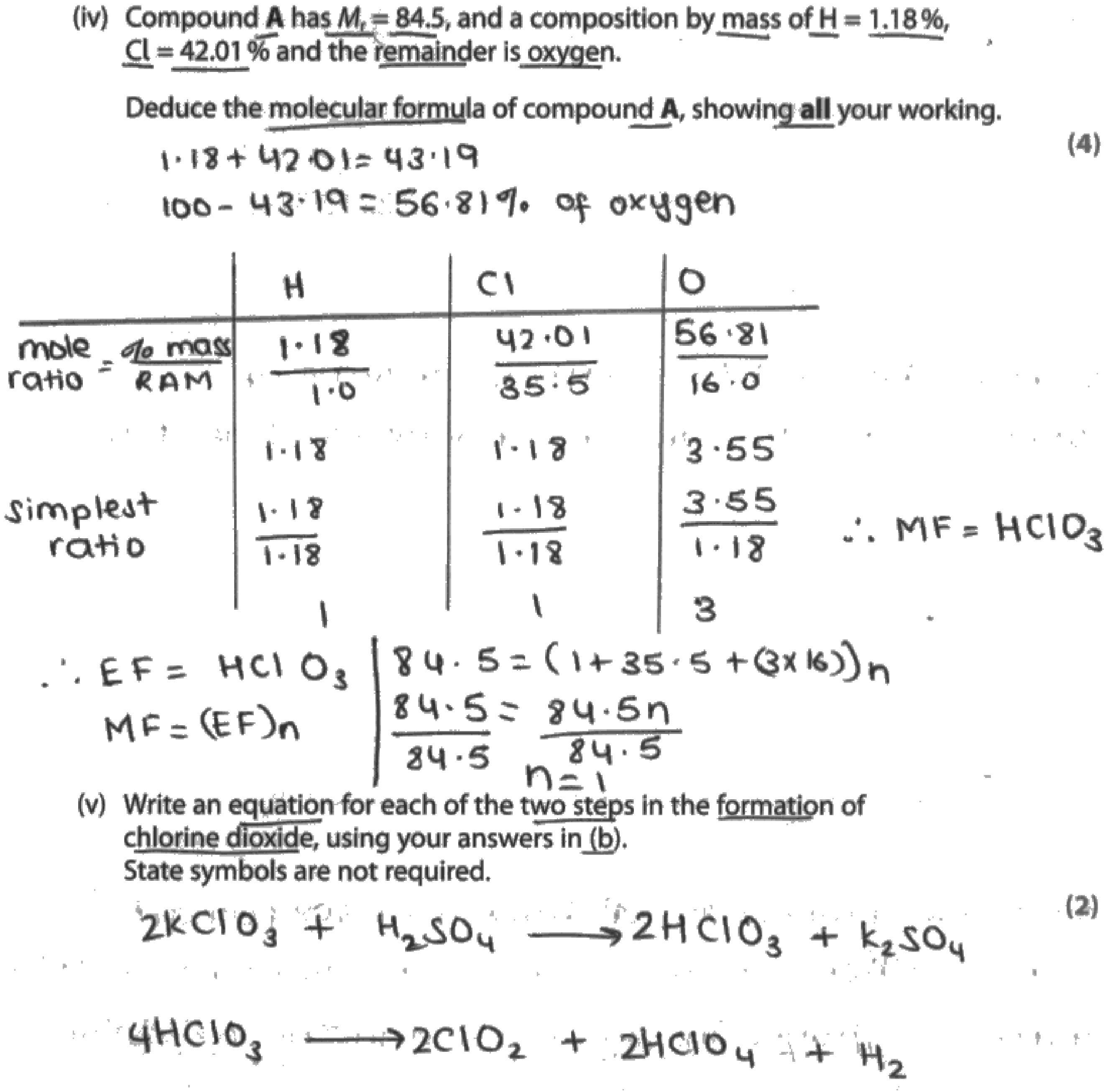
Question 18 (b)(iv-v)

The calculation in Question 18(b)(iv) was very high scoring, while Question 18(b)(v) proved very challenging.

In (b)(iv), it is important with empirical formula and molecular formula calculations to show all your working. Some candidates deduced the molecular formula was the same as the empirical formula without demonstrating this in their answer, so only scored 3 instead of 4 marks.

For the final equations, both of the acceptable answers for the first equation were seen. In the second equation some candidates recognised the correct chlorine containing compounds for the second equation but did not balance the change in oxidation state of the chlorine or did not recognise that water would also be produced. Very few candidates scored this final mark.

The calculation here is very clearly laid out. This approach means that marks can easily be awarded. The calculations being done are labelled so it is clear what the candidate is doing and this candidate has remembered to show working for the final step, the determination of the molecular formula.



(iv) Compound **A** has $M_r = 84.5$, and a composition by mass of H = 1.18 %, Cl = 42.01 % and the remainder is oxygen.

Deduce the molecular formula of compound **A**, showing **all** your working.

(4)

$1.18 + 42.01 = 43.19$

$100 - 43.19 = 56.81\%$ of oxygen

	H	Cl	O
mole ratio = $\frac{\%\ \text{mass}}{\text{RAM}}$	$\frac{1.18}{1.0}$	$\frac{42.01}{35.5}$	$\frac{56.81}{16.0}$
	1.18	1.18	3.55
simplest ratio	$\frac{1.18}{1.18}$	$\frac{1.18}{1.18}$	$\frac{3.55}{1.18}$
	1	1	3

$\therefore MF = HClO_3$

$\therefore EF = HClO_3$

$MF = (EF)n$

$84.5 = (1 + 35.5 + (3 \times 16))n$

$\frac{84.5}{84.5} = \frac{84.5n}{84.5}$

$n = 1$

(v) Write an equation for each of the two steps in the formation of chlorine dioxide, using your answers in (b). State symbols are not required.

(2)

$2KClO_3 + H_2SO_4 \longrightarrow 2HClO_3 + K_2SO_4$

$4HClO_3 \longrightarrow 2ClO_2 + 2HClO_4 + H_2$

ResultsPlus
Examiner Comments

This scores 4 marks for 18(iv).

The first equation is correct showing one of the two possible correct answers.

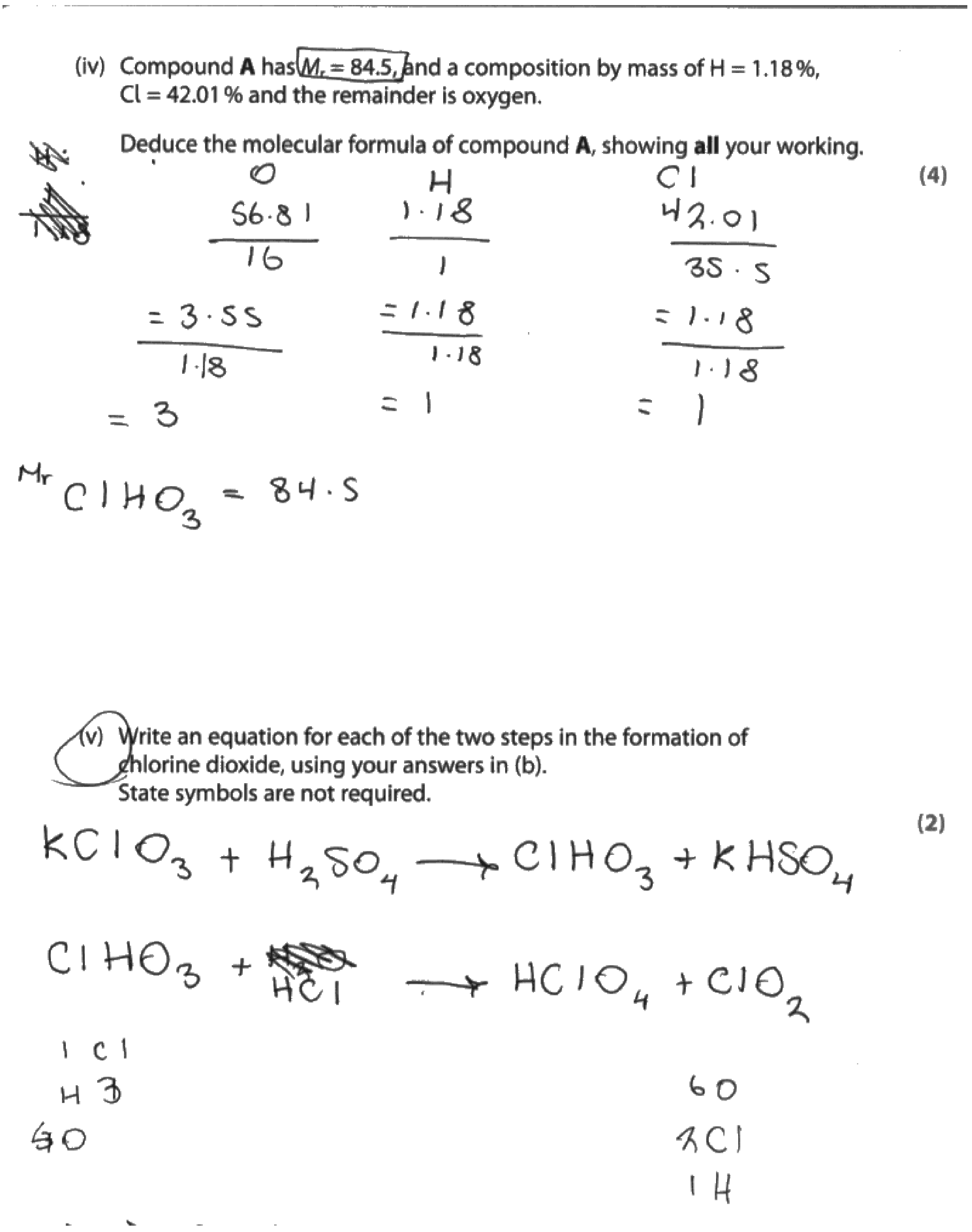
The second equation has the three correct chlorine containing compounds, and it balances for the atoms, but not for the changes in oxidation state. Chlorine is +5 in $HClO_3$ and goes to +4 in ClO_2 and +7 in $HClO_4$. The change of 2 from +5 to +7 must be balanced by a change of 2 from +5 to +4. Therefore, the products must be in a 2:1 ratio of ClO_2 : $HClO_4$.

ResultsPlus
Examiner Tip

In redox equations, balance the charge as well as the numbers of atoms. It is usually best to balance the charge first.

The calculation here is neatly laid out in columns, though with no explanation. It is still easy to see what has been done, so 3 marks can be awarded.

The first equation is one of the correct possibilities so scores 1. The order of the atoms in hydrogen chlorate(V) is ignored.



(iv) Compound **A** has $M_r = 84.5$, and a composition by mass of H = 1.18 %, Cl = 42.01 % and the remainder is oxygen.

Deduce the molecular formula of compound **A**, showing **all** your working. **(4)**

O	H	Cl
$\frac{56.81}{16}$	$\frac{1.18}{1}$	$\frac{42.01}{35.5}$
$= \frac{3.55}{1.18}$	$= \frac{1.18}{1.18}$	$= \frac{1.18}{1.18}$
$= 3$	$= 1$	$= 1$

M_r $ClHO_3 = 84.5$

(v) Write an equation for each of the two steps in the formation of chlorine dioxide, using your answers in (b).
State symbols are not required. **(2)**

$KClO_3 + H_2SO_4 \rightarrow ClHO_3 + KHSO_4$

$ClHO_3 +$ ~~[illegible]~~ $HCl \rightarrow HClO_4 + ClO_2$

1 Cl
H 3
4O

6O
2Cl
1H

ResultsPlus
Examiner Comments

There is no justification for the molecular formula, just a statement that the mass is 84.5.

This needs a clarifying statement or calculation to score the 4th mark.

The second equation has the correct substances but does not balance for charge. The addition of HCl on the left does balance the atoms but this is not the correct equation.

ResultsPlus
Examiner Tip

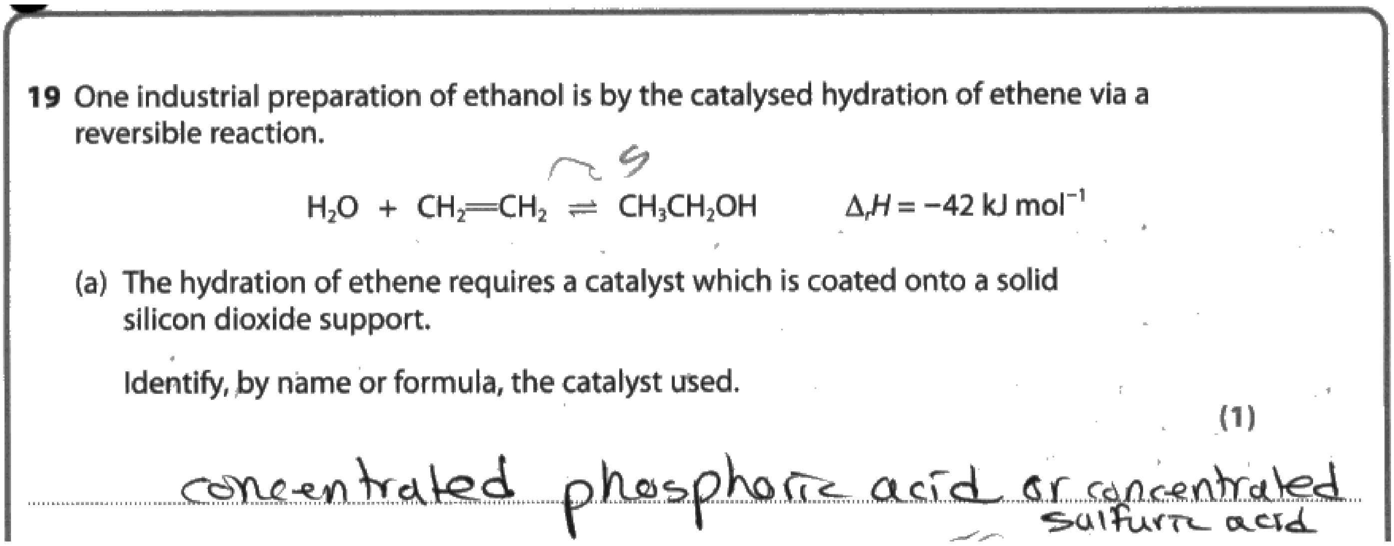
Balance the charges on the chlorine containing species, then add water on the product side (in this case) to balance the equation.

Question 19 (a)

Question 19 concerned the industrial preparation of ethanol. As a rule, this question proved quite challenging, with candidates finding it hard to express themselves with sufficient accuracy to demonstrate their knowledge and understanding. Care should be taken when describing how changes of conditions change equilibria. The idea of the equilibrium shifting to the left or the right, while perfectly valid, is often misunderstood by candidates whose answer can prove contradictory.

The first part, Question 19(a), required the recall of the catalyst used for the reaction between ethene and water to produce ethanol.

The expected answers were either phosphoric(V) acid or sulfuric(VI) acid. The oxidation states of these were not required. Formulae were also acceptable answers. All these were seen, but phosphoric acid was the most common.



19 One industrial preparation of ethanol is by the catalysed hydration of ethene via a reversible reaction.

$$H_2O + CH_2{=}CH_2 \rightleftharpoons CH_3CH_2OH \qquad \Delta_r H = -42\ \text{kJ mol}^{-1}$$

(a) The hydration of ethene requires a catalyst which is coated onto a solid silicon dioxide support.

Identify, by name or formula, the catalyst used.

(1)

concentrated phosphoric acid or concentrated sulfuric acid

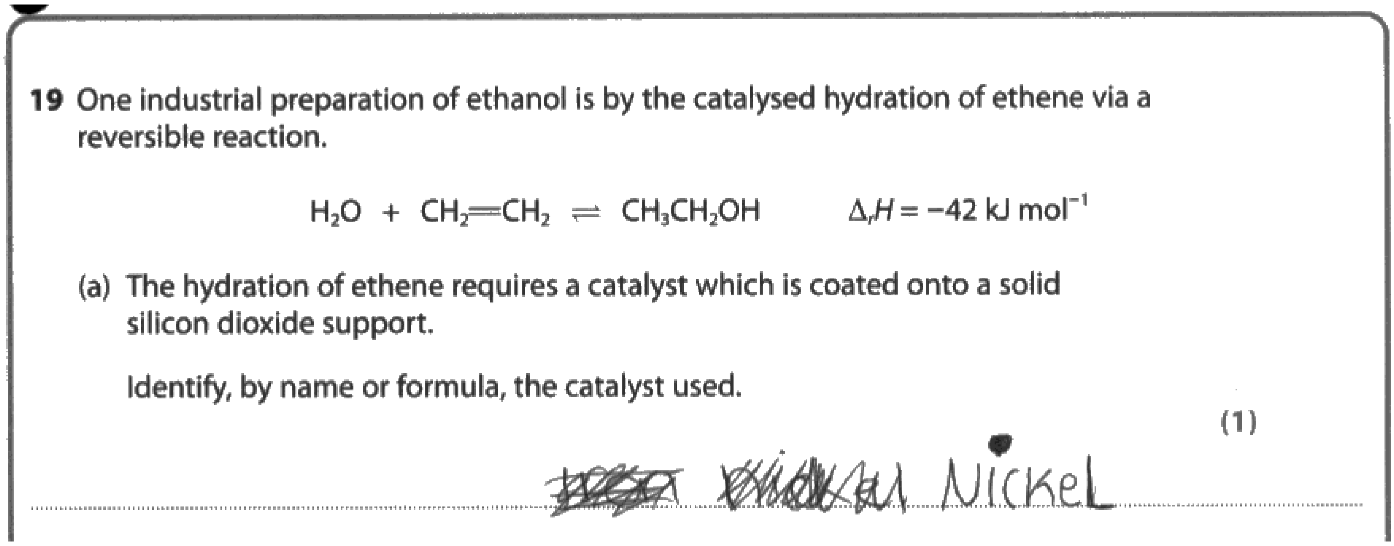
ResultsPlus
Examiner Comments

Both answers here are correct and would score on their own. Had either been incorrect, no mark would have been scored. The concentration was ignored.

ResultsPlus
Examiner Tip

It is usually best to only give one answer if the question requires only one. The mark may be lost if the second is incorrect.

Many different answers were seen including a range of substances, many of which are catalysts which candidates would be aware of.



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$$H_2O + CH_2{=}CH_2 \rightleftharpoons CH_3CH_2OH \qquad \Delta_r H = -42\ \text{kJ mol}^{-1}$$

(a) The hydration of ethene requires a catalyst which is coated onto a solid silicon dioxide support.

Identify, by name or formula, the catalyst used.

(1)

~~[illegible]~~ ~~[illegible]~~ Nickel

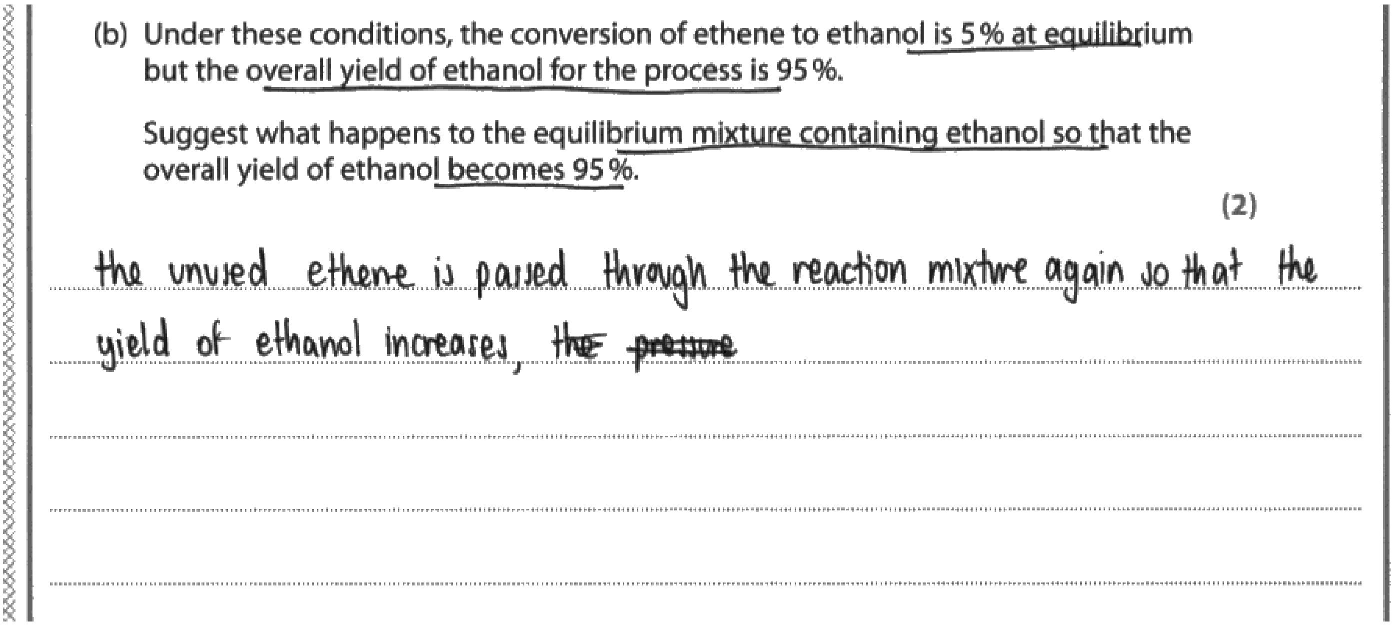
ResultsPlus
Examiner Comments

This was a very common incorrect answer, either on its own or stated as being under pressure. The incorrect spelling 'nickle' was also often seen.

Question 19 (b)

In many industrial syntheses the product yield is initially low. There are a number of reasons why reactions run at low yield, which appears quite contradictory to what is required. In this case, it is because the product can easily be obtained by cooling the mixture, at which point it liquifies, and the reactant ethene, which remains as a gas, can be recycled and used again. Each step yields only 5% ethanol, but continued cycling ultimately means that 95% of the ethene is successfully converted to ethanol.

The two correct parts to the answer, that the ethanol is removed from the mixture by cooling and that the ethene is recycled, were seen.



(b) Under these conditions, the conversion of ethene to ethanol is 5% at equilibrium but the overall yield of ethanol for the process is 95%.

Suggest what happens to the equilibrium mixture containing ethanol so that the overall yield of ethanol becomes 95%.

(2)

the unused ethene is passed through the reaction mixture again so that the yield of ethanol increases, ~~the pressure~~

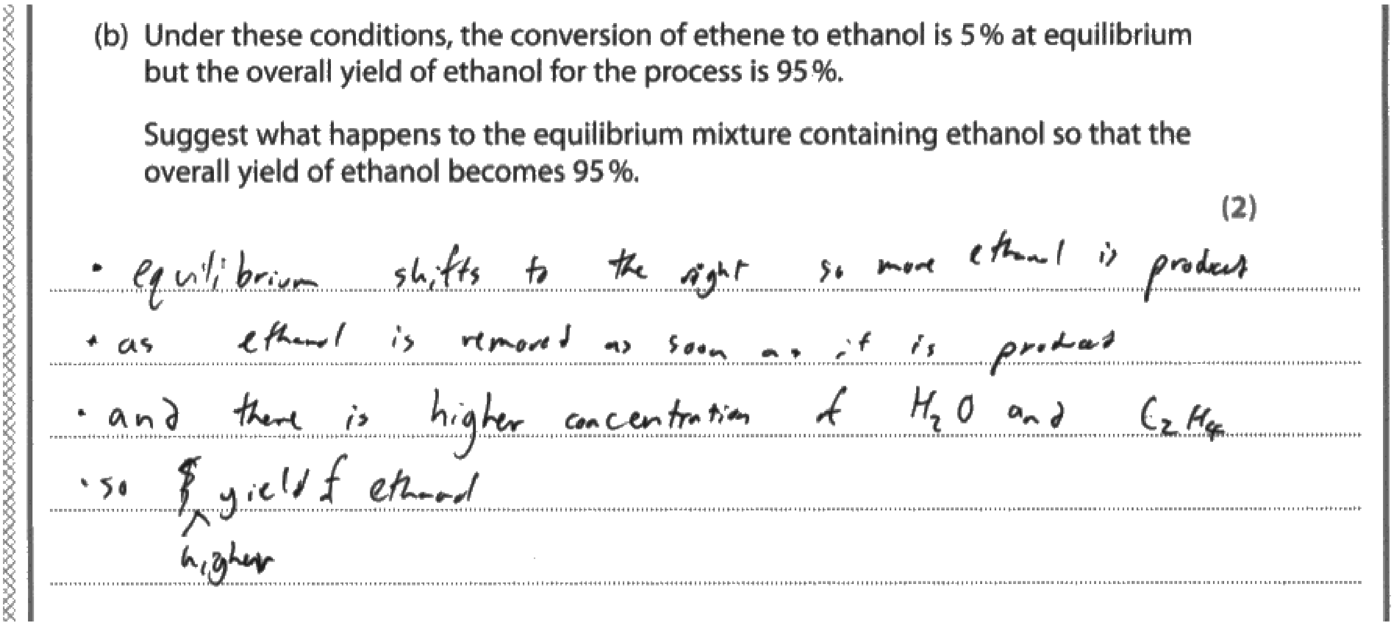
ResultsPlus Examiner Comments

This answer was the more common way of scoring 1 mark, for the recycling of the unreacted ethene.

ResultsPlus Examiner Tip

When 2 marks are available, two points need to be made.

The idea that the equilibrium would shift to the right was often suggested, but usually this was associated with changes in the temperature or pressure.



(b) Under these conditions, the conversion of ethene to ethanol is 5% at equilibrium but the overall yield of ethanol for the process is 95%.

Suggest what happens to the equilibrium mixture containing ethanol so that the overall yield of ethanol becomes 95%.

(2)

- equilibrium shifts to the right so more ethanol is produced
- as ethanol is removed as soon as it is produced
- and there is higher concentration of H_2O and C_2H_4
- so ~~[illegible]~~ yield of ethanol
  higher

ResultsPlus
Examiner Comments

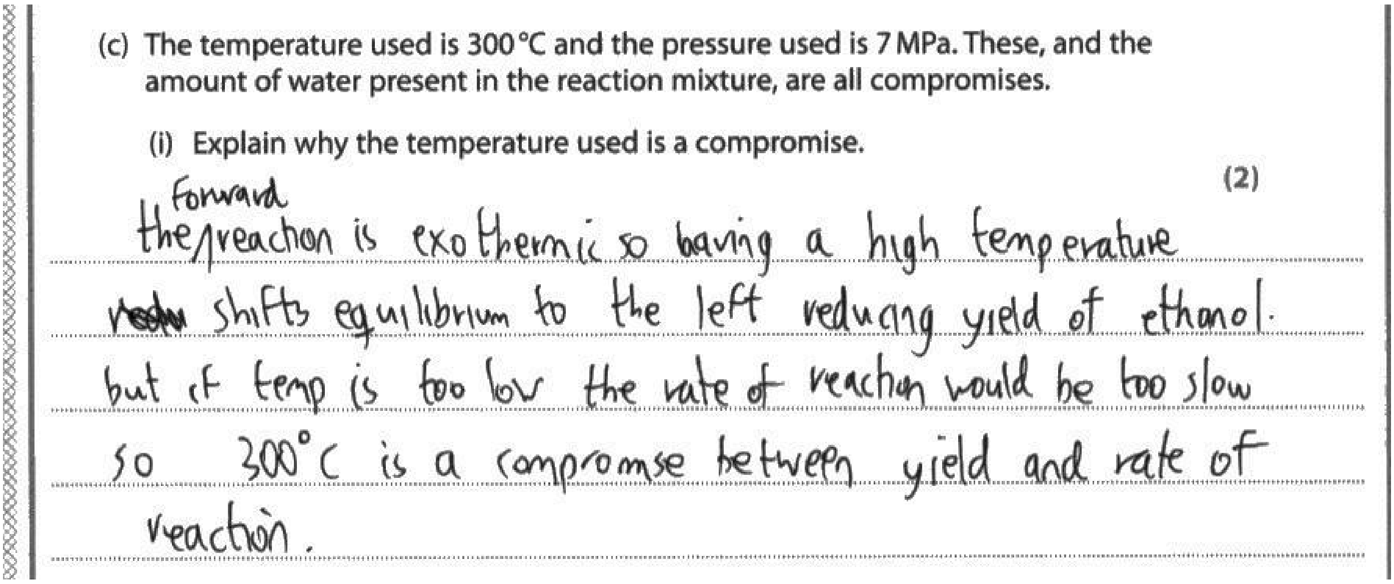
This example links the shift in the equilibrium to the removal of ethanol as it is formed scoring 1, and correctly identifies that water is also removed.

The removal of water does not score here, but is useful in later questions.

Question 19 (c)(i)

In most industrial processes, a compromise of the conditions is used. Question 19(c)(i) looked at the balance between the highest possible yield and the rate of reaction.

The shifting of an equilibrium to left or to the right is often used to describe the change in equilibrium. It is actually misunderstood by some candidates who think shifting the equilibrium to the left means that the left hand side of the reaction is dominant, and so there is more of the right hand side. This can be seen sometimes in the explanations given, but often it is unclear if this misconception is present. Shifting to the left means more of the left hand side is present.



(c) The temperature used is 300 °C and the pressure used is 7 MPa. These, and the amount of water present in the reaction mixture, are all compromises.

(i) Explain why the temperature used is a compromise.

(2)

the forward reaction is exothermic so having a high temperature ~~redu~~ shifts equilibrium to the left reducing yield of ethanol. but if temp is too low the rate of reaction would be too slow so 300°C is a compromise between yield and rate of reaction.

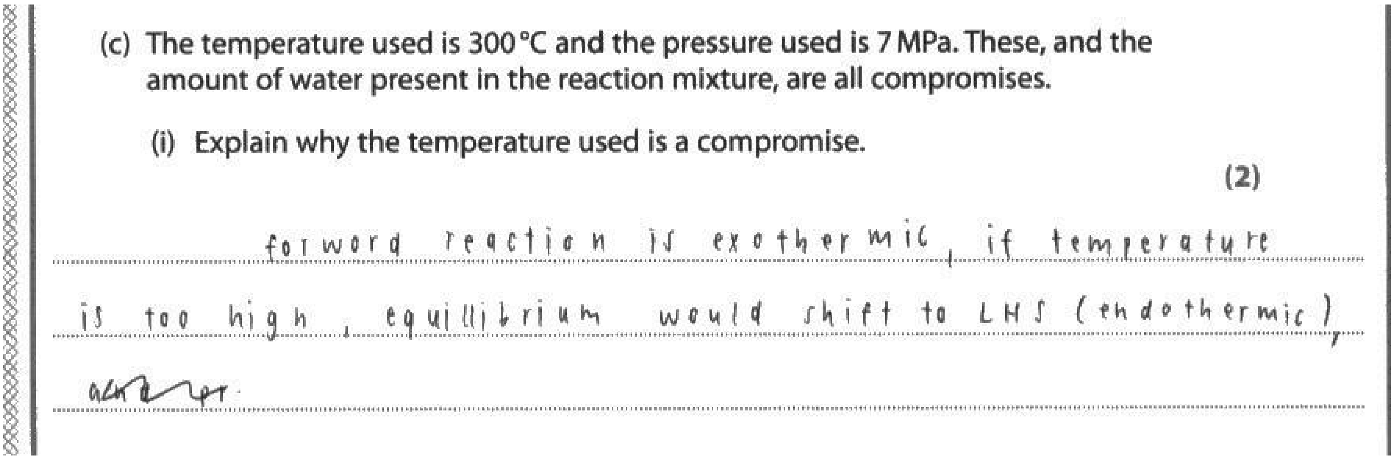
ResultsPlus
Examiner Comments

This candidate uses shifting to the left correctly as it is linked to a reduced yield of ethanol. The answer also correctly discusses the rate of reaction so this scores 2.

ResultsPlus
Examiner Tip

Always try to link shifting the equilibrium to what this means. As in this example, shifting to the left resulting in a lower yield of ethanol. This will avoid confusion.

The idea of compromise will require the answer to be in two parts, explain the two aspects of the compromise.



(c) The temperature used is 300 °C and the pressure used is 7 MPa. These, and the amount of water present in the reaction mixture, are all compromises.

(i) Explain why the temperature used is a compromise.

(2)

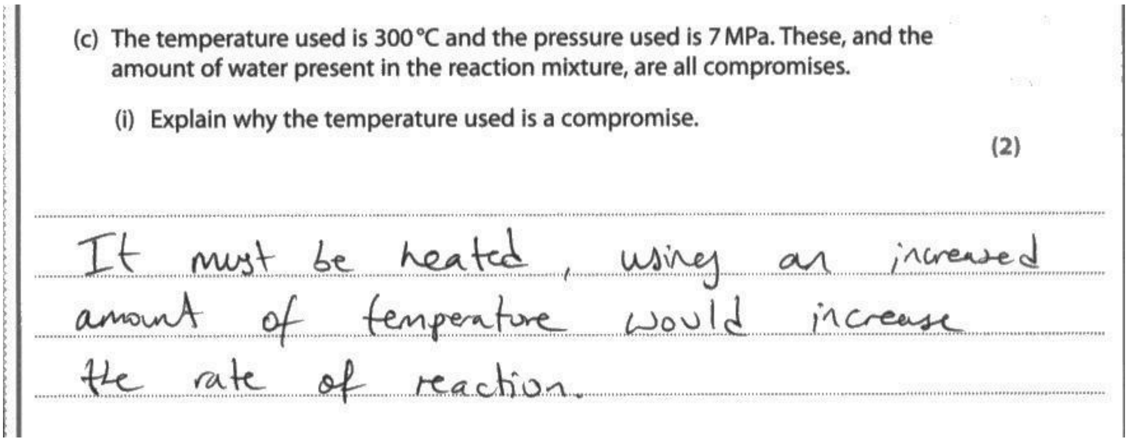
forword reaction is exothermic, if temperature is too high, equillibrium would shift to LHS (endothermic), [illegible].

ResultsPlus
Examiner Comments

This answer clearly explains why a temperature that is too high is not desirable, but does not explain why it needs to be as high as it is in terms of reaction rate, so this scores 1.

ResultsPlus
Examiner Tip

Consider both sides of an answer if it is required, for example a compromise like this.



(c) The temperature used is 300 °C and the pressure used is 7 MPa. These, and the amount of water present in the reaction mixture, are all compromises.

(i) Explain why the temperature used is a compromise.

(2)

It must be heated, using an increased amount of temperature would increase the rate of reaction.

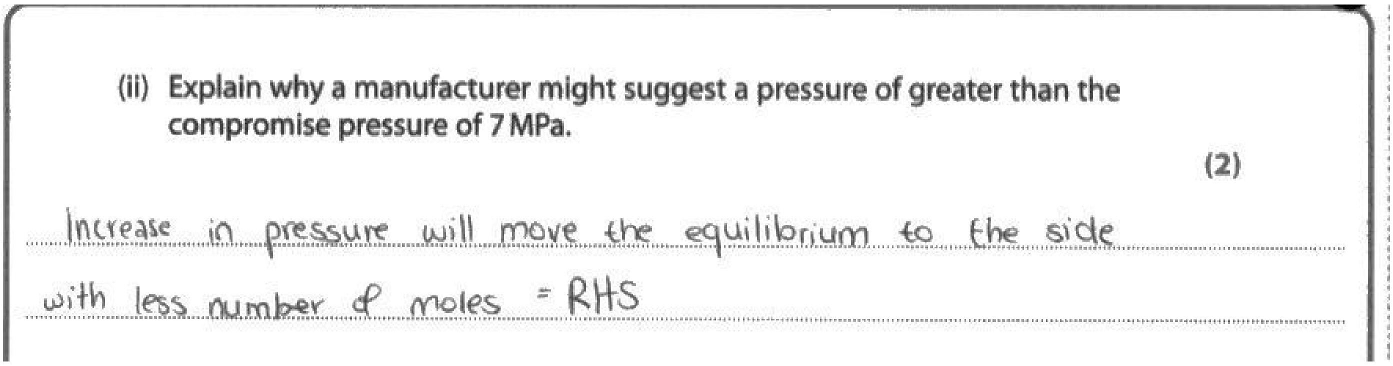
ResultsPlus
Examiner Comments

Similarly, this answer considers the effect of temperature on rate of reaction but not on yield, so scores 1.

Question 19 (c)(ii)

This question considered the effect of pressure on the equilibrium yield of product.

An increase in pressure results in a shift of the equilibrium to the side which has the fewer moles of gas, in this case the products side. This results in a higher yield of ethanol.



(ii) Explain why a manufacturer might suggest a pressure of greater than the compromise pressure of 7 MPa.

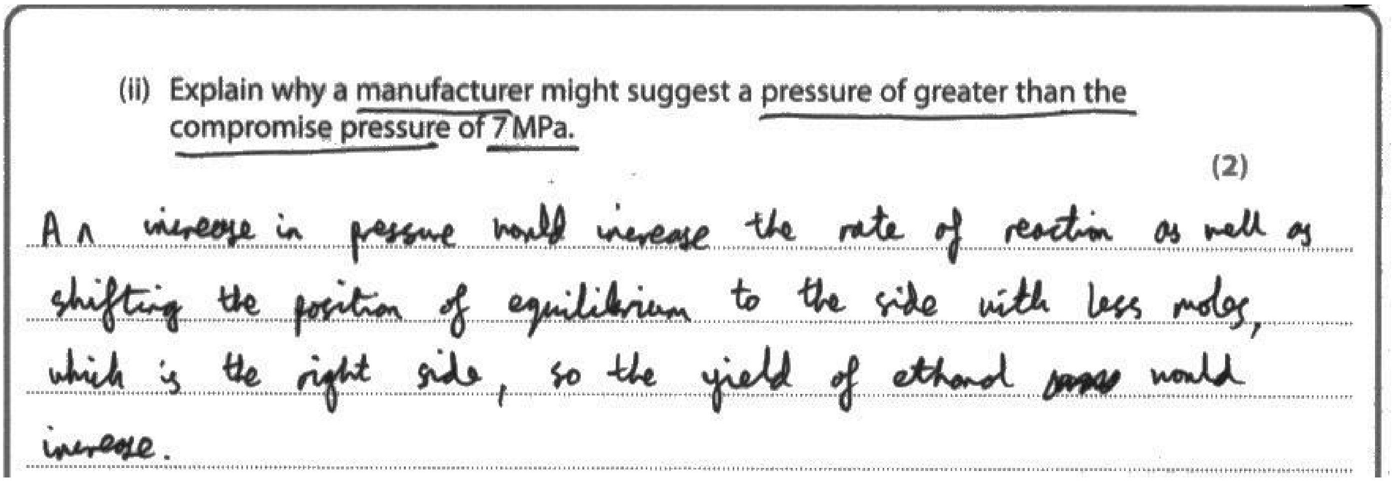
(2)

Increase in pressure will move the equilibrium to the side with less number of moles = RHS

ResultsPlus Examiner Comments

This answer gives the reason for the equilibrium shifting, but does not say which way, or that the yield of ethanol increases so this scores 1 mark.

The rate of reaction was mentioned often in answers.



(ii) Explain why a manufacturer might suggest a pressure of greater than the compromise pressure of 7 MPa.

(2)

An increase in pressure would increase the rate of reaction as well as shifting the position of equilibrium to the side with less moles, which is the right side, so the yield of ethanol ~~[illegible]~~ would increase.

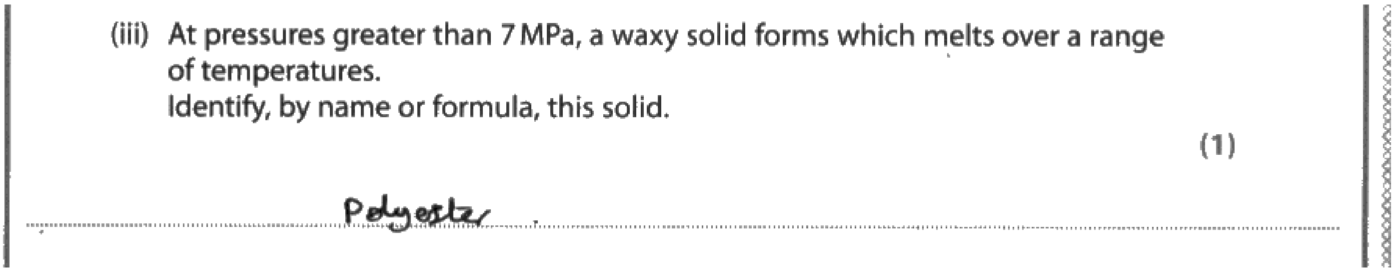
ResultsPlus Examiner Comments

A higher pressure will result in an increased rate of reaction at the beginning, but it does not score any marks here. The link here to the shifting of the equilibrium does, however, and both marks are scored.

Question 19 (c)(iii)

This question asked candidates to consider an unusual situation. The idea that a waxy solid might not have a single melting point required the recognition that this solid might be a polymer, which do melt over a range of temperatures.

Very few correct answers were seen. Polymers are one of very few things which melt over a range of temperatures.



(iii) At pressures greater than 7 MPa, a waxy solid forms which melts over a range of temperatures.
Identify, by name or formula, this solid.

(1)

Polyester

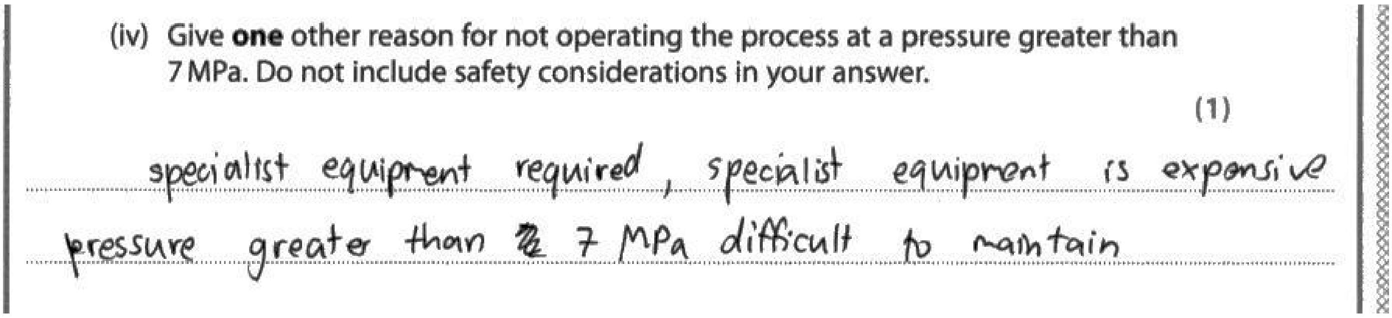
ResultsPlus
Examiner Comments

This candidate correctly identifies that the substances is a polymer, but has picked the wrong one. A good try, but unfortunately no marks.

Question 19 (c)(iv)

Higher pressures often favour an increased yield in industrial reactions, and this was the case here. This question requires candidates to realise why higher pressures are not always achievable.

The two major factors for not having higher pressures are safety considerations associated with plant failure primarily and the need for specialist equipment to contain these high pressures. Here, we were focusing on the second of these.



(iv) Give **one** other reason for not operating the process at a pressure greater than 7 MPa. Do not include safety considerations in your answer.

(1)

specialist equipment required, specialist equipment is expensive

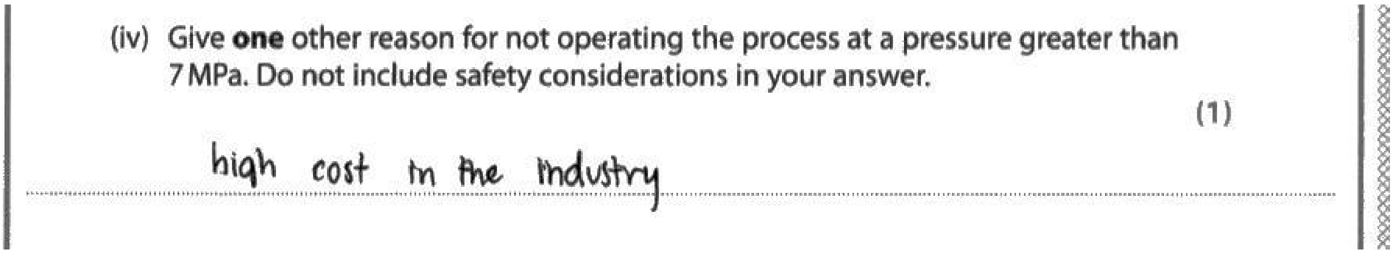
pressure greater than 7 MPa difficult to maintain

ResultsPlus
Examiner Comments

The cost on its own would not be enough, but this answer explains it is the cost of specialist equipment so scores the mark.

ResultsPlus
Examiner Tip

Cost without explanation is rarely enough to score a mark. Cost is important in industrial processes, but you must usually explain what the high price is for.



(iv) Give **one** other reason for not operating the process at a pressure greater than 7 MPa. Do not include safety considerations in your answer.

(1)

high cost in the industry

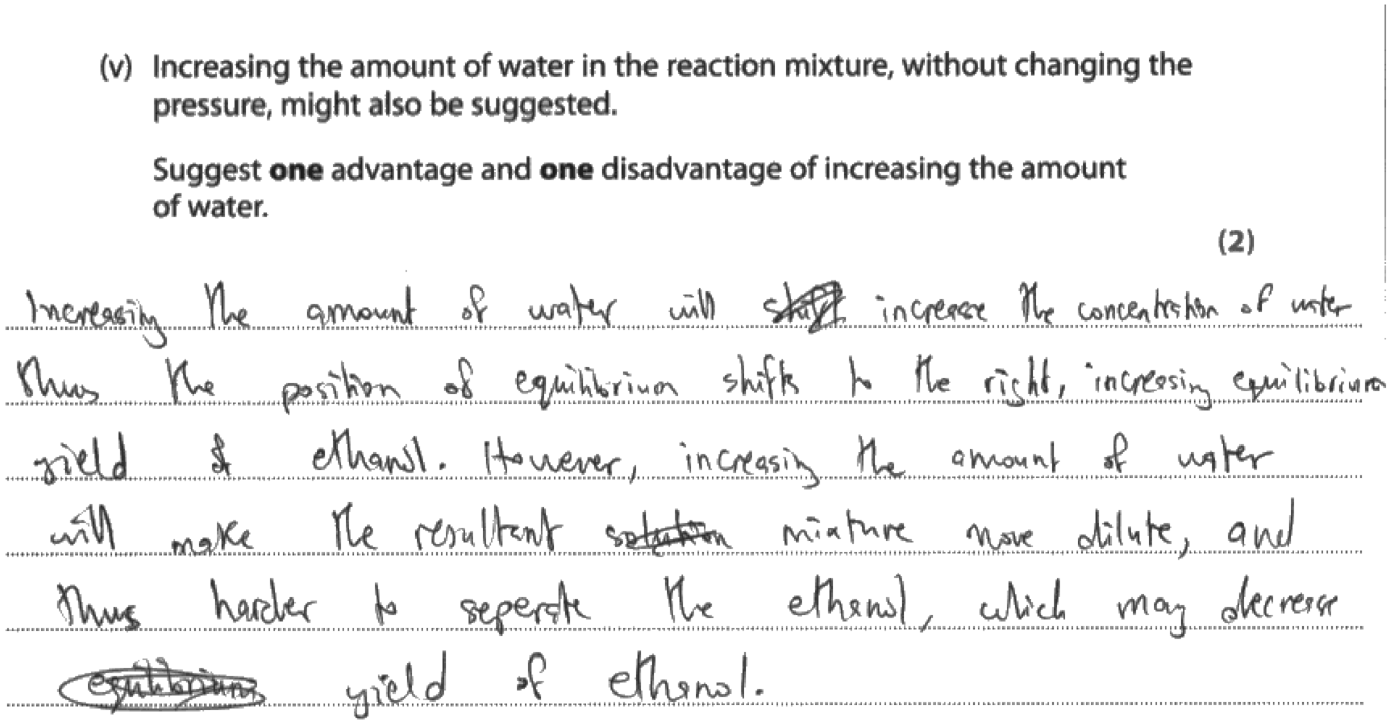
ResultsPlus
Examiner Comments

This example does not explain the high cost, so does not score.

Question 19 (c)(v)

The final part in Question 19 once again looked at equilibrium, but also how changing this equilibrium would change the equilibrium mixture.

This question was also about compromise. The two parts of this question were the increased yield as a result of water being added, but also the fact that this would increase the amount of water present in the reaction mixture at equilibrium and make it potentially more difficult to separate. The second problem associated with damage to the catalyst, though a very good answer, was not seen.



(v) Increasing the amount of water in the reaction mixture, without changing the pressure, might also be suggested.

Suggest **one** advantage and **one** disadvantage of increasing the amount of water.

(2)

Increasing the amount of water will ~~shift~~ increase the concentration of water thus the position of equilibrium shifts to the right, increasing equilibrium yield of ethanol. However, increasing the amount of water will make the resultant ~~solution~~ mixture more dilute, and thus harder to seperate the ethanol, which may decrease ~~equilibrium~~ yield of ethanol.

ResultsPlus
Examiner Comments

The response explains clearly the advantage and disadvantage and so scores 2.

Sometimes it is obvious that a question has a number of parts which must be addressed. This is one of these questions asking for one advantage and one disadvantage being required.

(v) Increasing the amount of water in the reaction mixture, without changing the pressure, might also be suggested.

Suggest **one** advantage and **one** disadvantage of increasing the amount of water.

(2)

advantage :

disadvantgge : will mix with product and form diluted product

ResultsPlus
Examiner Comments

This candidate recognises the need for the two parts, but is unsure of the advantage of adding water.

ResultsPlus
Examiner Tip

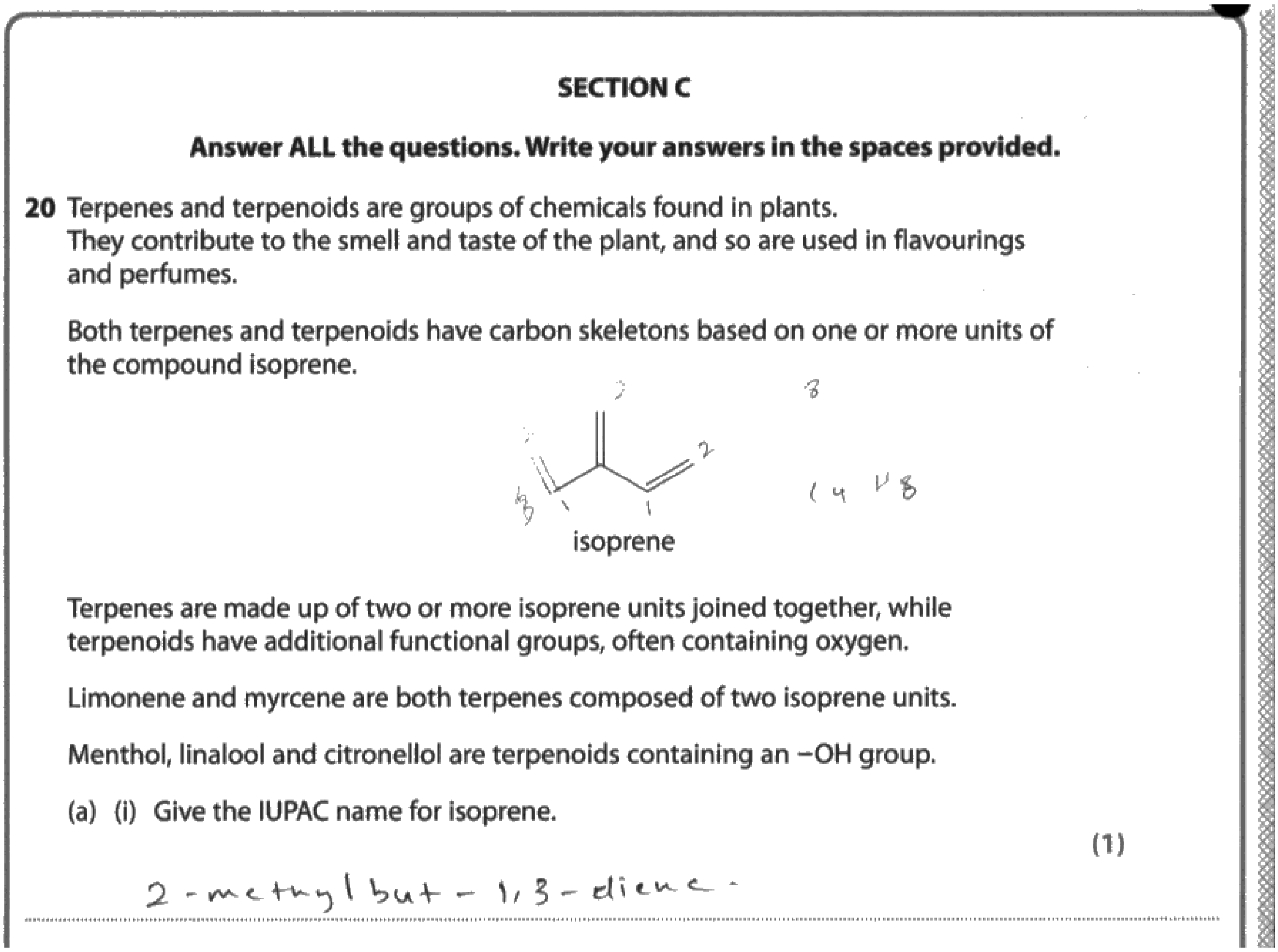
It is useful in questions such as this to make it clear what you are addressing in your answer. The labelling of advantage and disadvantage is useful!

Question 20 (a)(i)

The final question on the examination paper focused on groups of organic molecules called terpenes and terpenoids. These are an unfamiliar context for some familiar chemistry, the reactions of alkenes and alcohols.

These compounds are linked by their structure to a common basic component, the compound isoprene. The first question asked for the IUPAC name for isoprene.

The correct answer was 2-methylbuta-1,3-diene. There were a number of slight variations allowed.



SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

20 Terpenes and terpenoids are groups of chemicals found in plants.
They contribute to the smell and taste of the plant, and so are used in flavourings and perfumes.

Both terpenes and terpenoids have carbon skeletons based on one or more units of the compound isoprene.

isoprene

C_4H_8

Terpenes are made up of two or more isoprene units joined together, while terpenoids have additional functional groups, often containing oxygen.

Limonene and myrcene are both terpenes composed of two isoprene units.

Menthol, linalool and citronellol are terpenoids containing an –OH group.

(a) (i) Give the IUPAC name for isoprene.

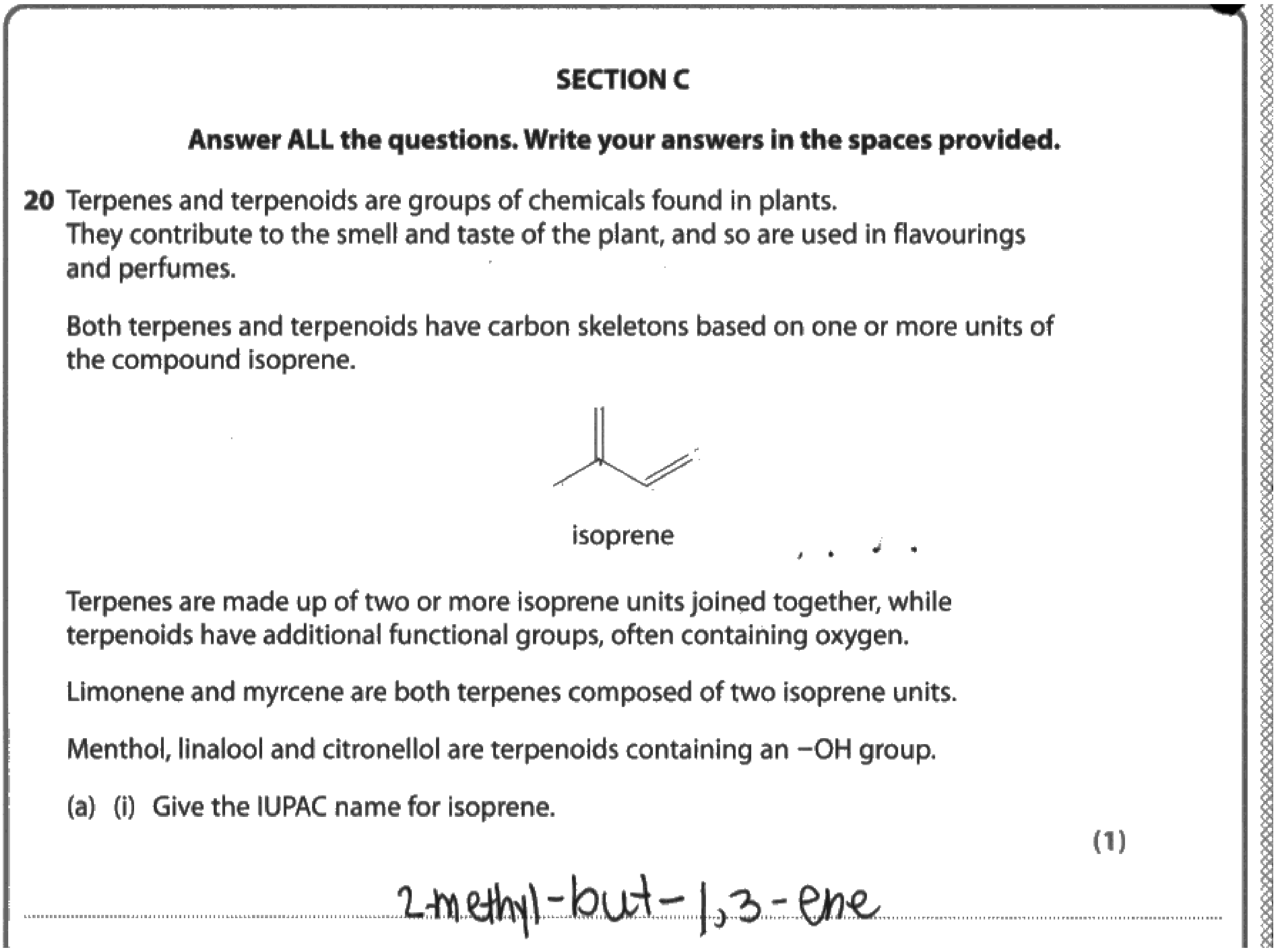
(1)

2-methylbut-1,3-diene.

ResultsPlus
Examiner Comments

This is correct and scores 1.

This response was a common one.



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isoprene

Terpenes are made up of two or more isoprene units joined together, while terpenoids have additional functional groups, often containing oxygen.

Limonene and myrcene are both terpenes composed of two isoprene units.

Menthol, linalool and citronellol are terpenoids containing an –OH group.

(a) (i) Give the IUPAC name for isoprene.

(1)

2-methyl-but-1,3-ene

ResultsPlus
Examiner Comments

The answer here is correct except for the absence of the 'di' in front of the – ene at the end of the name.

ResultsPlus
Examiner Tip

Practise the naming of organic compounds in the specification.

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

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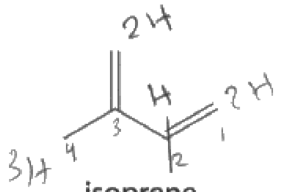


isoprene

~~5~~ 4 carbo.

Terpenes are made up of two or more isoprene units joined together, while terpenoids have additional functional groups, often containing oxygen.

Limonene and myrcene are both terpenes composed of two isoprene units.

Menthol, linalool and citronellol are terpenoids containing an –OH group.

(a) (i) Give the IUPAC name for isoprene.

(1)

but-~~2~~1,3-diene

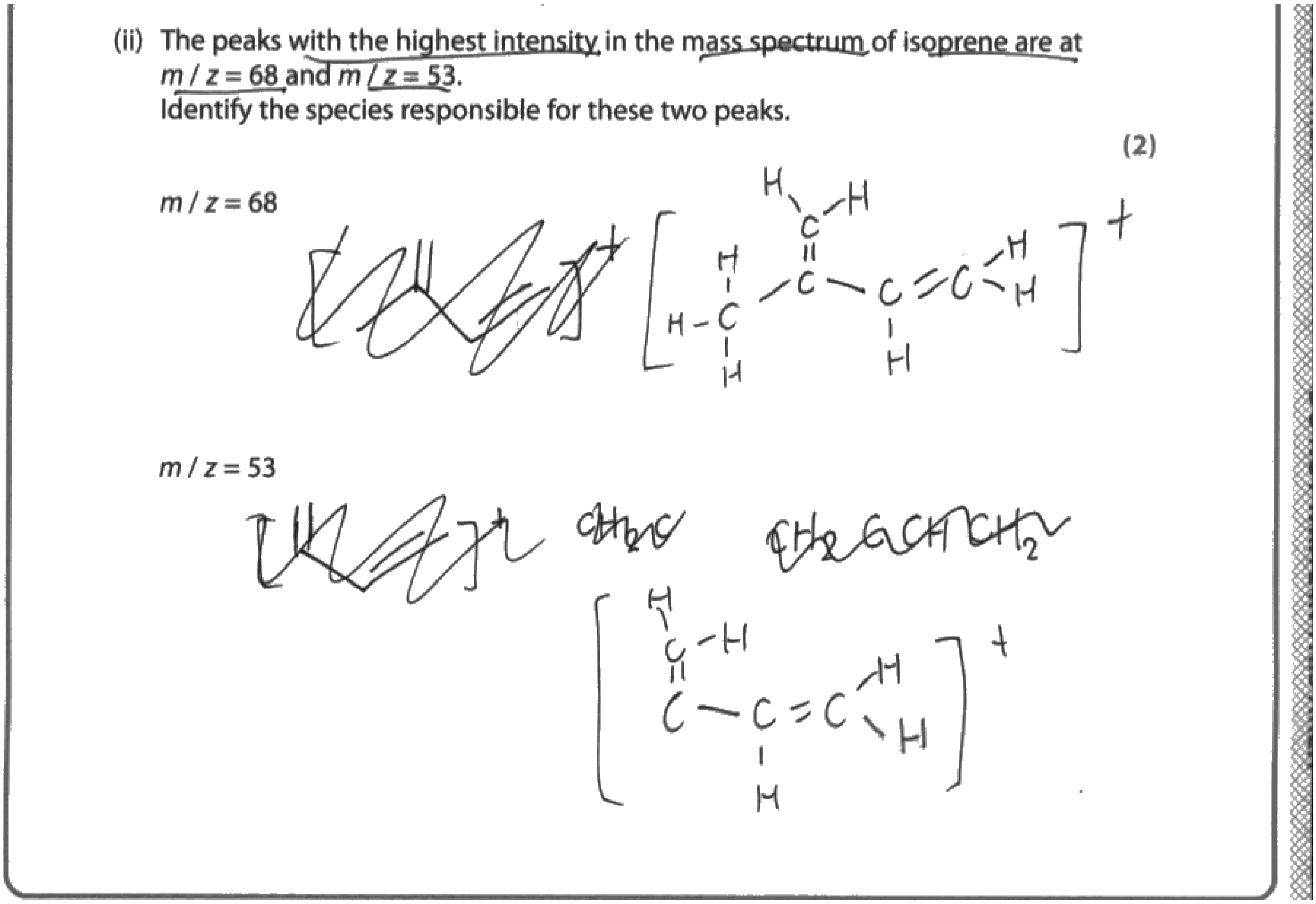
ResultsPlus
Examiner Comments

This has the correct name of the diene, but does not have the methyl side group identified in the name, so does not score.

Question 20 (a)(ii)

The next question focused on the mass spectrum of isoprene. Two peaks were required in the answer, one the molecular ion peak and one the result of removal by fragmentation of a methyl group. The candidates who used displayed formulae for the structures of the species were most likely to score the marks. Those using condensed structural formulae were much less likely to score the first mark as if they did not use brackets around side chains, this mark could not be scored.

This is a very clear example showing both structures correctly using displayed formulae.



(ii) The peaks with the highest intensity in the mass spectrum of isoprene are at $m / z = 68$ and $m / z = 53$.
Identify the species responsible for these two peaks.

(2)

$m / z = 68$

$m / z = 53$

CH_2CCHCH_2

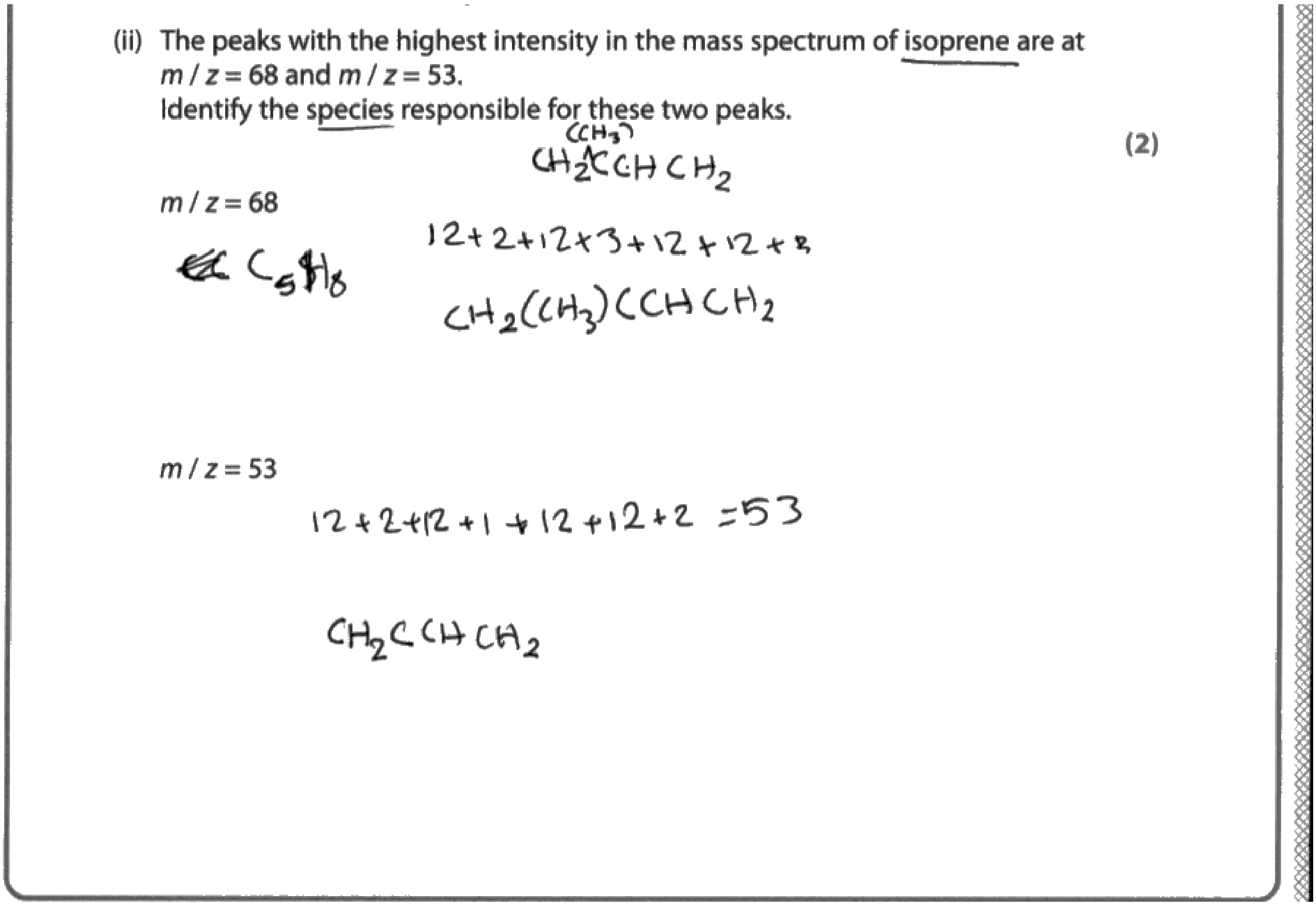
ResultsPlus Examiner Comments

Candidates using displayed formulae showing all the bonds were more likely to score 2 marks, as here.

ResultsPlus Examiner Tip

Drawing structures of organic fragments of ions as fully displayed formulae will help to get the correct structures. Drawing the structure of the molecule and then working out which bonds have broken will help, or using a structure on the paper if one has been given.

A common error on mass spectrometry questions is to forget to include the charge on the ion which is being detected.



(ii) The peaks with the highest intensity in the mass spectrum of isoprene are at $m/z = 68$ and $m/z = 53$.
Identify the species responsible for these two peaks.
(2)

$m/z = 68$

C_5H_8

$CH_2\overset{(CH_3)}{C}CHCH_2$

$12+2+12+3+12+12+8$

$CH_2(CH_3)CCHCH_2$

$m/z = 53$

$12+2+12+1+12+12+2 = 53$

CH_2CCHCH_2

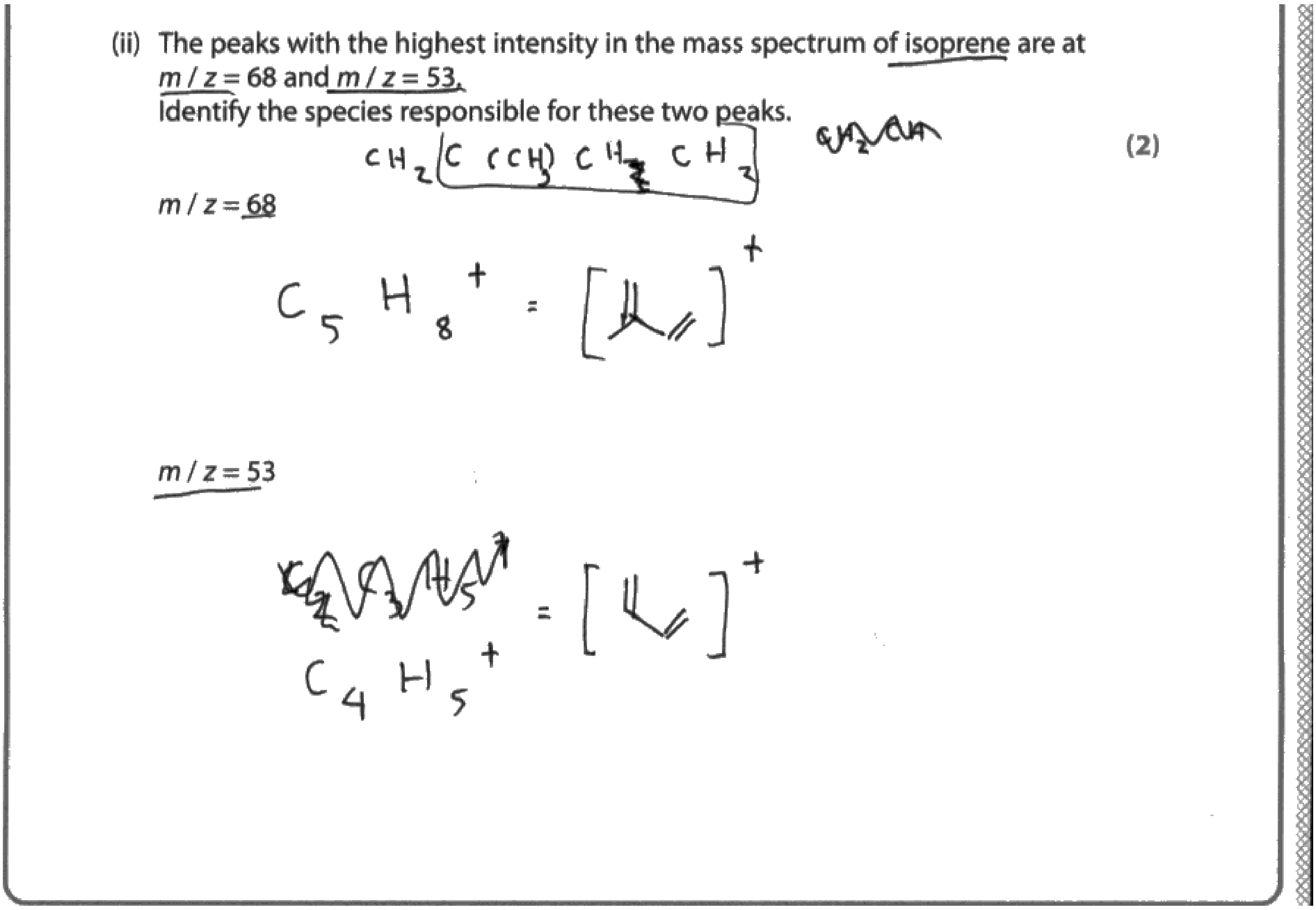
ResultsPlus
Examiner Comments

This example has the methyl side group in a bracket in the molecular ion so could score the first mark and has a correct structure for the fragment, but neither has a charge. This was penalised once so this scores 1.

ResultsPlus
Examiner Tip

Remember that the species detected in a mass spectrum are positively charged.

It was common to see molecular formulae for the ions. These were penalised once if seen.



(ii) The peaks with the highest intensity in the mass spectrum of isoprene are at $m / z = 68$ and $m / z = 53$.
Identify the species responsible for these two peaks.

(2)

$CH_2 \boxed{C(CH_3) CH_2 CH_3}$ CH_2CH

$m / z = 68$

$C_5H_8^+$ =

$m / z = 53$

=

$C_4H_5^+$

ResultsPlus
Examiner Comments

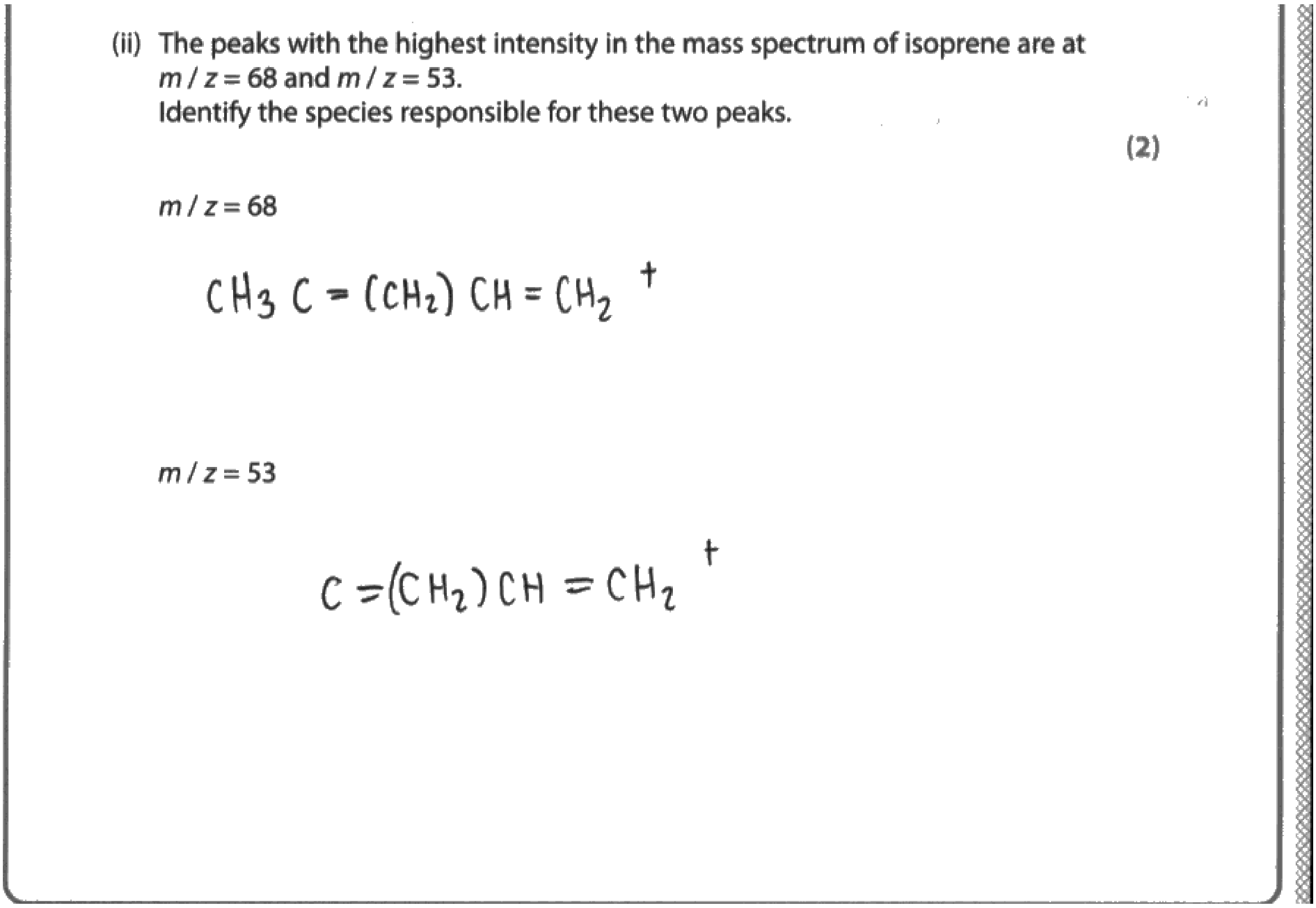
This example shows the molecular formulae of the species concerned, which on their own would have scored one mark, but here they are clearly being used as working to find the correct structures which then follow. Skeletal structures were perfectly acceptable, though perhaps harder to work out whether they are correct or not.

This scored 2 marks.

ResultsPlus
Examiner Tip

Unless you are very confident, displayed formulae are probably easier to work with than skeletal formulae for structures.

The use of condensed versions of displayed formulae which did not show all the bonds required use of brackets for the molecular ion fragment.



(ii) The peaks with the highest intensity in the mass spectrum of isoprene are at $m/z = 68$ and $m/z = 53$.
Identify the species responsible for these two peaks.

(2)

$m/z = 68$

$CH_3C=(CH_2)CH=CH_2{}^{+}$

$m/z = 53$

$C=(CH_2)CH=CH_2{}^{+}$

ResultsPlus
Examiner Comments

Here the brackets are not quite in the right place. The bracket should include the double bond in both species. Apart from that slip, both structures are correct.

This was awarded 1 mark since the mistake is the same in both ions.

ResultsPlus
Examiner Tip

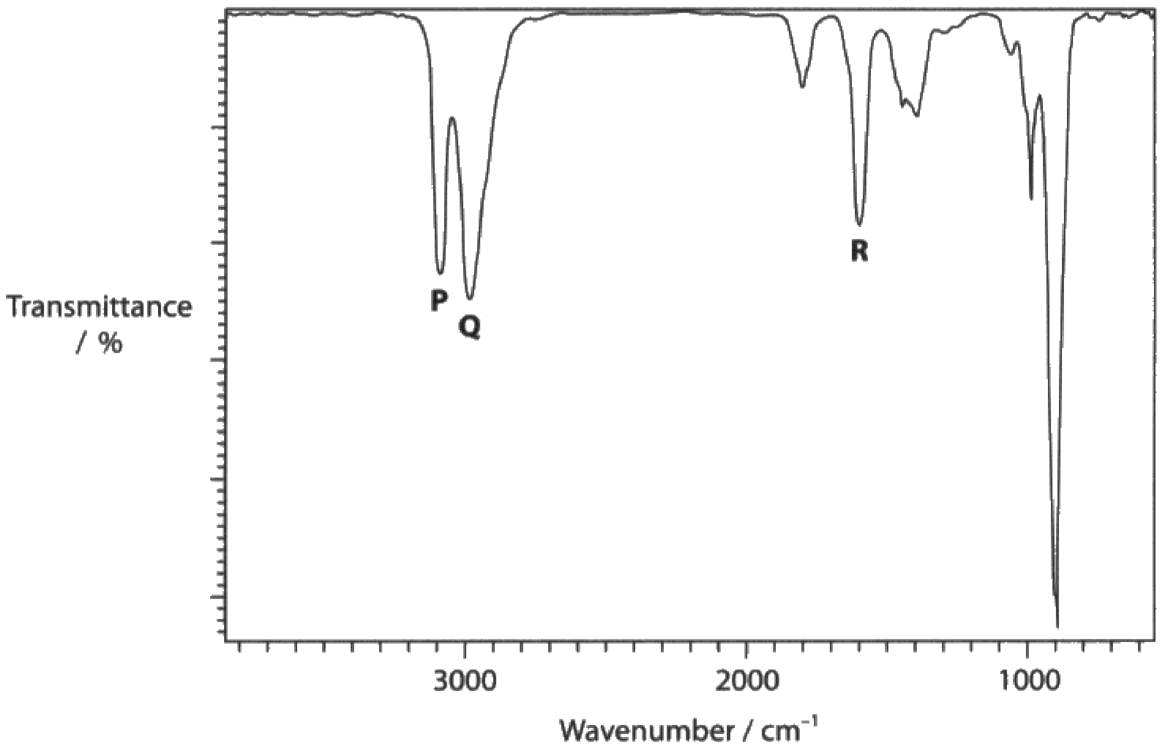
Multiple bonds should be included in the brackets for a side group.

Question 20 (a)(iii)

Question 20(a)(iii) considered the infra-red spectrum of isoprene and required the use of the Data Booklet. Despite being given the structure of this hydrocarbon, many candidates attributed the peaks to bonds containing atoms which could not be present, for example C=O bonds, when no oxygen was present in the molecule. These answers were surprisingly common. Diagrams, when seen, were very helpful and tended to score well, but few candidates used them. The question asked for the origins of the peak, and in infra-red spectroscopy the source of the peak is the presence of a particular bond. For all three answers, the bond responsible needed to be identified. These come from the Data Booklet. The answers needed the bond to be accurately described. The peak at P is for a C-H bond where the carbon is part of an alkene functional group, whereas the peak for Q is for a C-H bond where the carbon is single bonded to another. The expected responses were C-H in an alkene and C-H in an alkane respectively. Since the only C=C in the molecule is from an alkene, this was not required in the answer, so C=C was enough to score the mark for R.

The bond causing the peak and a description of its environment were expected in the answer. The candidates were expected to know the structure, since they were given it earlier in the question.

(iii) The infrared spectrum of isoprene is shown.



State the origins of the peaks labelled **P**, **Q** and **R**. You may use a labelled diagram.

Use the Data Booklet as a source of information.

(3)

P C−H stretching vibrations

Q C-H stretching vibrations

R C=C stretching vibrations

ResultsPlus
Examiner Comments

If both P and Q were identified as being due to C-H bonds, 1 mark could be scored if no environment was given.

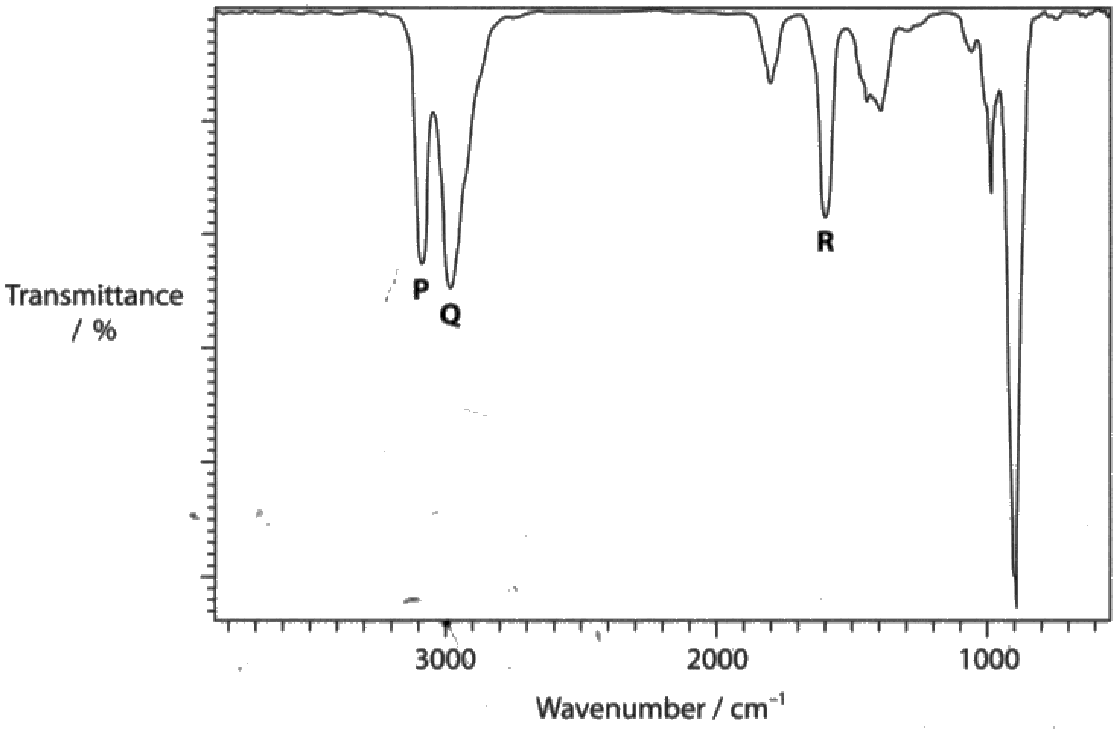
The peak for R needed only the bond, so this response scored 2.

ResultsPlus
Examiner Tip

The Data Booklet is helpful for identifying a peak, but is also very helpful for providing information about that peak.

This example shows one where a peak has been identified by use of the Data Booklet which is not possible for this structure. Amide was commonly given for peak P and carbonyl groups of various sorts identified as being responsible for peak R, but isoprene contains neither nitrogen or oxygen atoms. This candidate has clearly drawn the diagram of isoprene (with no nitrogen!) but, unfortunately, has not then used it.

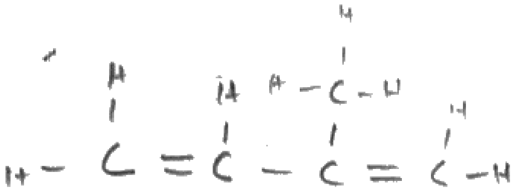
(iii) The infrared spectrum of isoprene is shown.



State the origins of the peaks labelled **P**, **Q** and **R**. You may use a labelled diagram.

Use the Data Booklet as a source of information.

(3)



P N – H stretching in amide at 3500 – 3140 cm^{-1} range

Q C – H stretching in alkenes at 3010 – 3095 cm^{-1} range

R ~~166~~ C = C stretching in alkenes at ~~166~~ 1669 – 1645 cm^{-1} range

ResultsPlus
Examiner Comments

Peak P does not score. Peak Q has the correct bond identified, but is not the correct environment, so does not score. Peak R is correctly identified. The fact that it is an alkene C=C was not required, but is correct. Arene C=C was commonly seen and this was not awarded the mark.

ResultsPlus
Examiner Tip

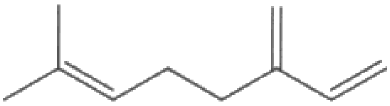
Where this is a large space with no lines this is because we are expecting either a calculation or, in this case, a diagram. If the question does not specifically ask for one then it is not necessary, but if a space has been left it is because we think it might be very helpful. Consider a diagram if you see a space like this.

Question 20 (b)(i)

The main target of this question was to test the ability of candidates to deduce a molecular formula, and hence the empirical formula, of a compound from a skeletal structure. This has been asked very commonly in recent years, but the presence of the double bonds appeared to confuse candidates who often had the wrong number of hydrogen atoms in their molecular formulae, or who had oxygens, presumably assuming the double bond was a carbonyl group, C=O. In either case, this proved more challenging than expected. Those that could correctly deduce the molecular formulae often scored the second mark for the deduction of the ratio between the formulae and that of isoprene.

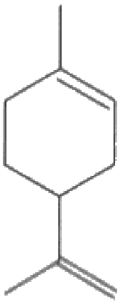
Candidates often wrote molecular and/or empirical formulae under the structures. This was a very sensible working area and they got credit if this happened.

(b) (i) Show that myrcene and limonene are terpenes by comparing the molecular and/or empirical formulae of myrcene, limonene and isoprene.



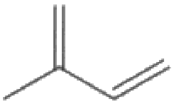
$C_{10}H_{16}$

myrcene



$C_{10}H_{16}$

limonene



C_5H_8

isoprene

(2)

both mycrene and limonene has moleculare formulae $C_{10}H_{16}$,

but limonene is cyclo 6, ~~mercene is [illegible] straight chain~~.

isoprene has moleculare formulae C_5H_8

However, all three has the same emperical formulae

of C_5H_8

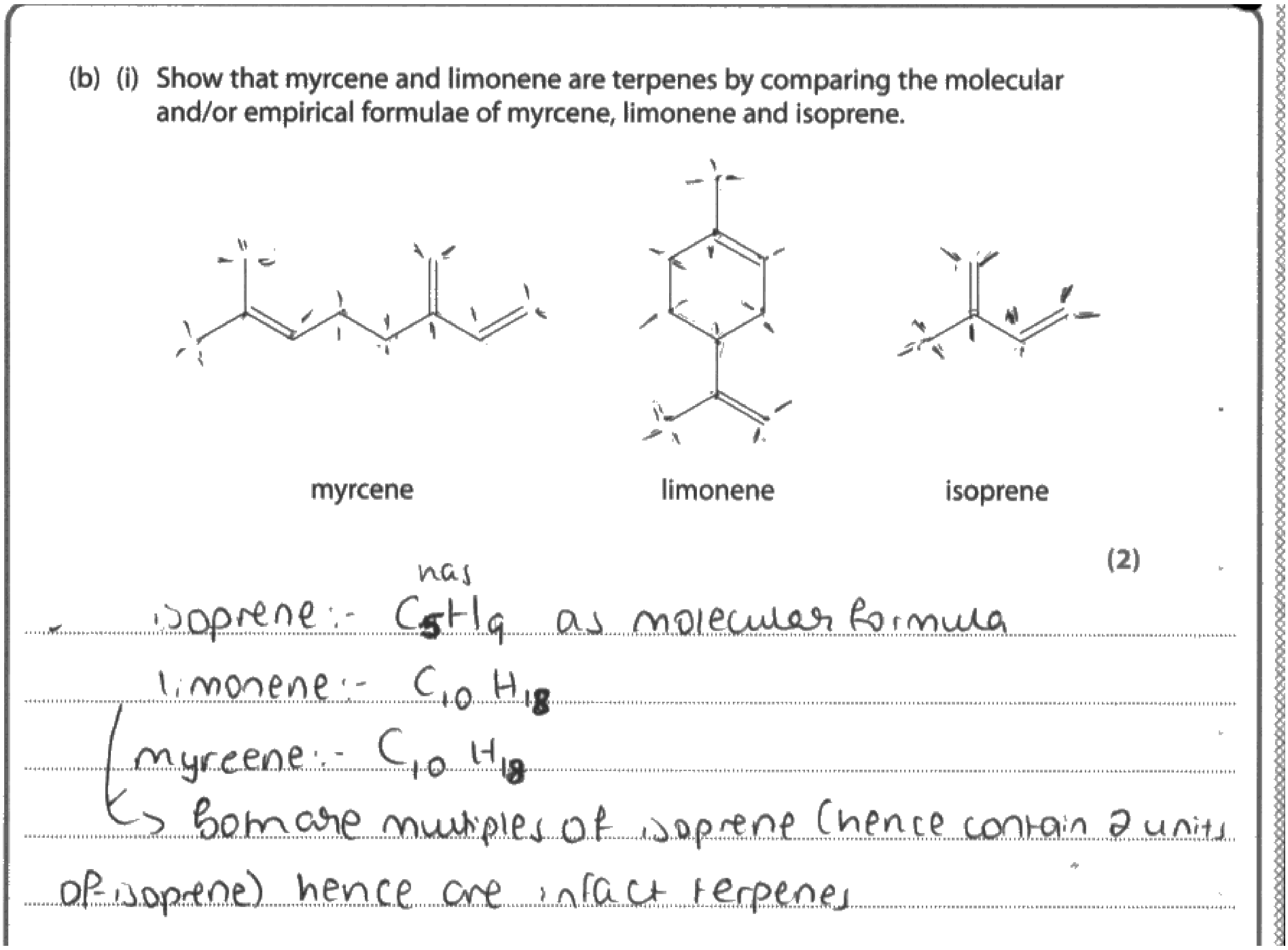
ResultsPlus

Examiner Comments

This candidate has used the method of identifying that the empirical formulae of all three is the same to score both marks. The molecular formulae of isoprene, myrcene and limonene are clearly given both below the diagrams and in the text.

Limonene is cyclo (presumably cyclic was intended) was ignored.

Some candidates had trouble deducing the molecular formulae. There was enough information in the question to deduce that the molecular formulae of both myrcene and limonene should be multiples of isoprene, and that they should be the same.



(b) (i) Show that myrcene and limonene are terpenes by comparing the molecular and/or empirical formulae of myrcene, limonene and isoprene.

myrcene limonene isoprene

(2)

isoprene :- C_5H_9 $\overset{\text{has}}{}$ as molecular formula

limonene :- $C_{10}H_{18}$

myrcene :- $C_{10}H_{18}$

↳ Both are multiples of isoprene (hence contain 2 units of isoprene) hence are infact terpenes

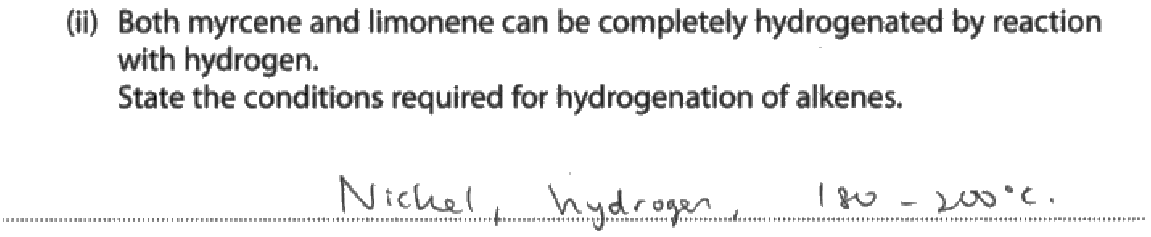
ResultsPlus
Examiner Comments

It looks as if this candidate may have used this information to refine their molecular formulae. Though they are actually incorrect, the method for the deduction of both limonene and myrcene being twice the molecular formula of isoprene is logical and can score the second mark.

Question 20 (b)(ii)

Question 20(b)(ii) required recall of the conditions for the hydrolysis of alkenes. Answers given included many conditions, but the correct answer was reasonably common.

This reaction requires a catalyst, which is usually nickel, and heat.



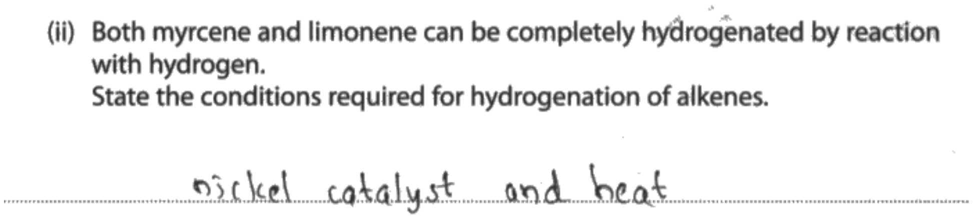
(ii) Both myrcene and limonene can be completely hydrogenated by reaction with hydrogen.
State the conditions required for hydrogenation of alkenes.

Nickel, hydrogen, 180 – 200°C.

ResultsPlus
Examiner Comments

This answer includes the hydrogen necessary for the hydrogenation, but this has been given in the question so was unnecessary.

Nevertheless, this scored the mark.



(ii) Both myrcene and limonene can be completely hydrogenated by reaction with hydrogen.
State the conditions required for hydrogenation of alkenes.

nickel catalyst and heat

ResultsPlus
Examiner Comments

This answer included the fact that the nickel was present acting as a catalyst. This is absolutely correct, but again was not required. No particular temperature was required with heat being the expected correct answer, so this scored the mark.

ResultsPlus
Examiner Tip

Learn the reagents and conditions for all the organic transformations.

Question 20 (b)(iii)

The final question was a relatively accessible calculation. Most candidates were able to make a start on this, though there was some confusion as the structure of the two terpenes, myrcene and limonene, which arose from misunderstandings in Question 20(b)(i). The candidates suffering from this were still able to score good marks, however, when their errors were transferred through the calculations. There were two common methods. One was to calculate the number of moles of hydrogen required to hydrogenate each terpene and hence the volume. The other was to find the volume of hydrogen required to hydrogenate one terpene double bond, and then multiply by the number of double bonds. Most candidates who found correct answers did all the steps for both terpenes, but considerable time could be saved by recognising that the volume required for limonene was 2/3 of that required for myrcene.

(iii) 5 g samples of myrcene and limonene were completely hydrogenated. Calculate the volume of hydrogen required to hydrogenate each sample. Include the unit with your answer.

Assume the volume of 1 mol of hydrogen = 24 000 cm^3

(4)

$$\underset{136}{\overset{5g}{C_{10}H_{16}}} + 3H_2 \longrightarrow C_{10}H_{22}$$

$(12 \times 10) + 16 = \boxed{136}$

$$\frac{1}{x} \times \frac{136}{5}$$

$x = \frac{5}{136} = 0.0368\,mol$

1 : 3

$\Rightarrow 3(0.0368) = 0.1103\,mol$

$$\frac{1}{0.1103} \times \frac{24\,000}{x}$$

$x = 24000 \times 0.1103 = 2647.05882$

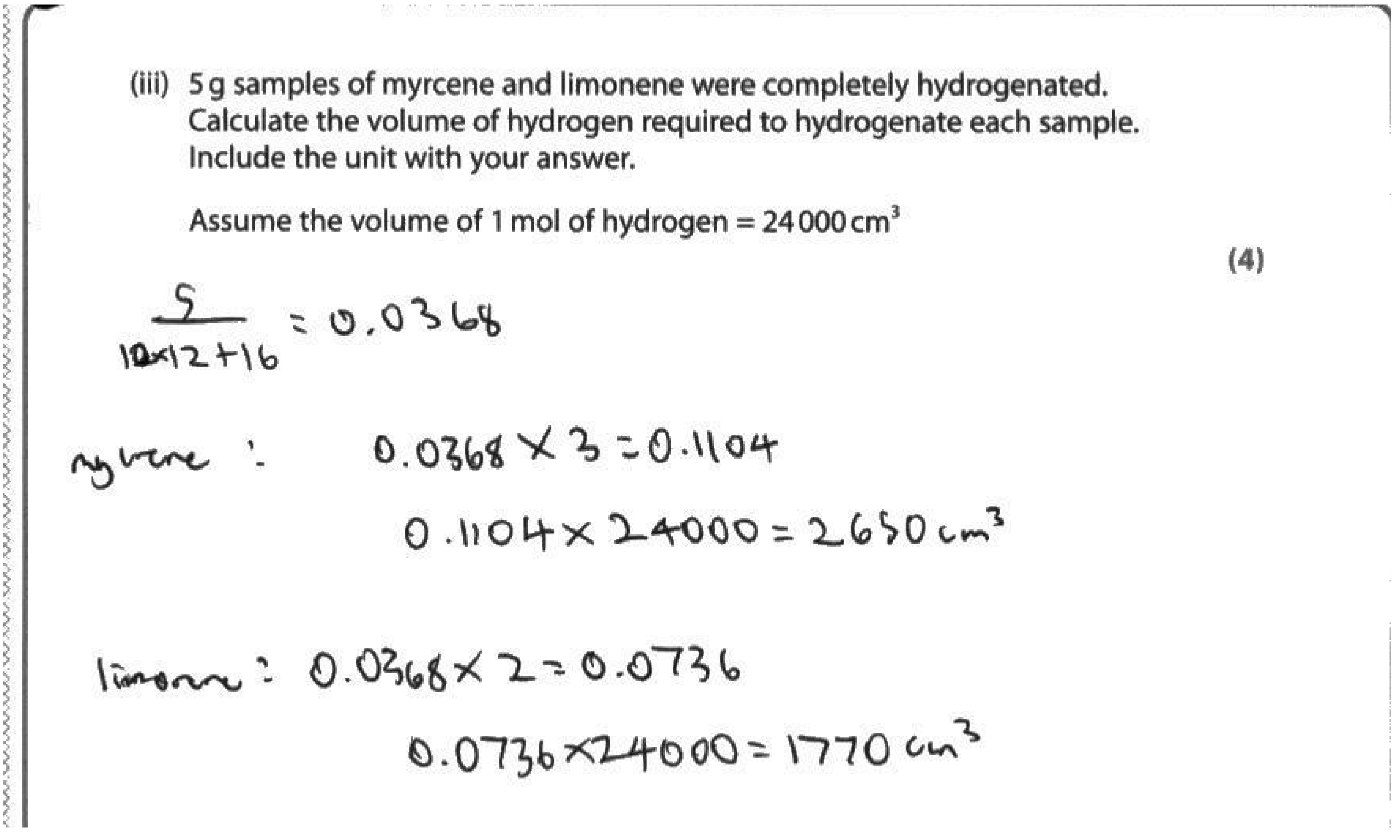
$= \boxed{2647\ cm^3}$

ResultsPlus
Examiner Comments

This method has correctly started by calculating the number of moles of hydrogen required to hydrogenate myrcene (though this has not been stated) and hence the volume of hydrogen required.

This scored 3 marks for the 3 correct calculation steps.

This candidate finds the number of moles of hydrogen required for each terpene and hence the volume of hydrogen, carrying out all the steps to calculate both volumes.



(iii) 5 g samples of myrcene and limonene were completely hydrogenated. Calculate the volume of hydrogen required to hydrogenate each sample. Include the unit with your answer.

Assume the volume of 1 mol of hydrogen = 24 000 cm^3

(4)

$\frac{5}{10 \times 12 + 16} = 0.0368$

myrcene : $0.0368 \times 3 = 0.1104$

$0.1104 \times 24000 = 2650\ cm^3$

limonene : $0.0368 \times 2 = 0.0736$

$0.0736 \times 24000 = 1770\ cm^3$

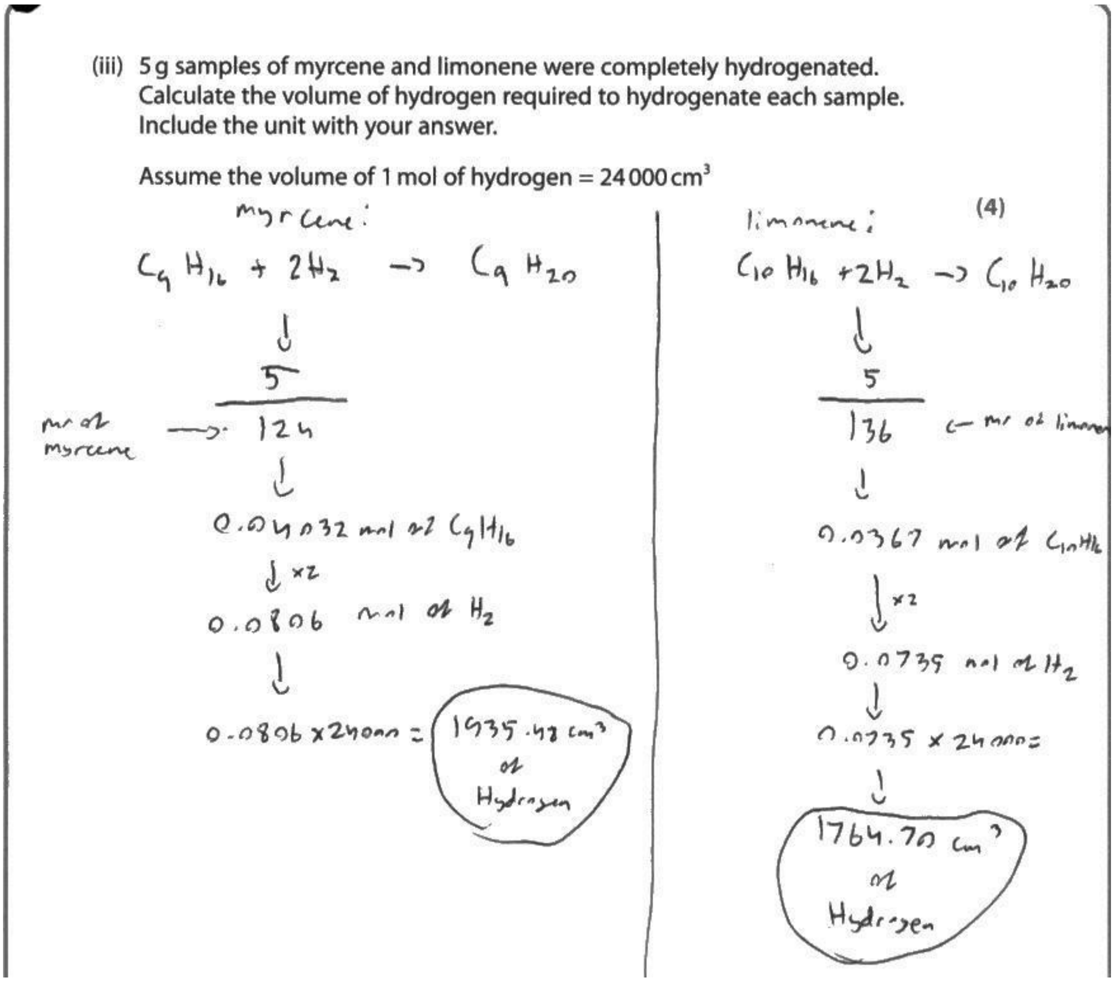
ResultsPlus
Examiner Comments

This example is very clearly laid out, but would have benefitted from explanation of each step in case an error was made. Everything here is correct, however, so full marks were scored.

ResultsPlus
Examiner Tip

Label each step of your calculations saying what is being calculated. This helps work through the calculation and makes seeing transferred errors when mistakes are made so marks can be awarded for the processes being carried out.

Candidates quite commonly did not recognise that limonene and myrcene were isomers so had the same molecular mass. In such cases, both calculations were considered and marks awarded on either of the two strands.



(iii) 5 g samples of myrcene and limonene were completely hydrogenated. Calculate the volume of hydrogen required to hydrogenate each sample. Include the unit with your answer.

Assume the volume of 1 mol of hydrogen = 24 000 cm^3

(4)

myrcene:

$C_9H_{16} + 2H_2 \rightarrow C_9H_{20}$

$\downarrow$

$\frac{5}{124}$ ← Mr of myrcene

$\downarrow$

0.04032 mol of C_9H_{16}

$\downarrow \times 2$

0.0806 mol of H_2

$\downarrow$

0.0806 × 24000 = 1935.42 cm^3 of Hydrogen

limonene:

$C_{10}H_{16} + 2H_2 \rightarrow C_{10}H_{20}$

$\downarrow$

$\frac{5}{136}$ ← Mr of limonen

$\downarrow$

0.0367 mol of $C_{10}H_{16}$

$\downarrow \times 2$

0.0735 mol of H_2

$\downarrow$

0.0735 × 24000 =

$\downarrow$

1764.70 cm^3 of Hydrogen

ResultsPlus

Examiner Comments

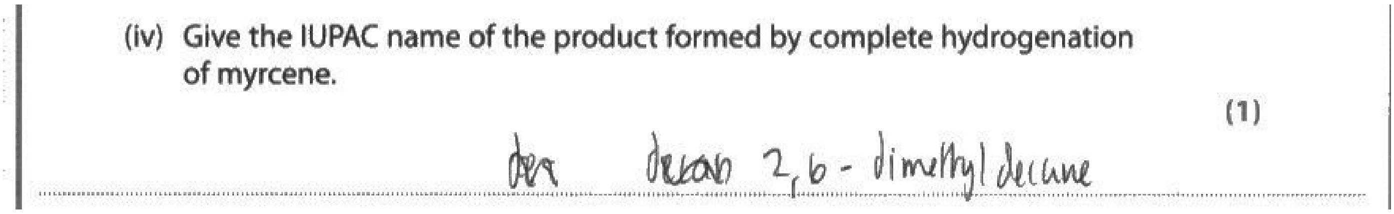
The calculation for limonene uses the correct molecular mass and finds the correct volume for limonene. This scores 3 marks for the three correct steps.

For myrcene there are two errors, the molecular mass and the multiplication by 2 instead of 3 to find the number of moles. On its own, this would have scored 1 mark for the final step, but that mark has already been awarded in the limonene strand. This scores 3.

Question 20 (b)(iv)

This question asked for the IUPAC name of the product of hydrogenation of myrcene.

The root of the name here, decane, possibly comes from the fact that there are 10 carbon atoms in the molecule, and the two methyl groups have not been taken from the 10, which would give the correct answer.



(iv) Give the IUPAC name of the product formed by complete hydrogenation of myrcene.

(1)

dec decan 2,6-dimethyl decane

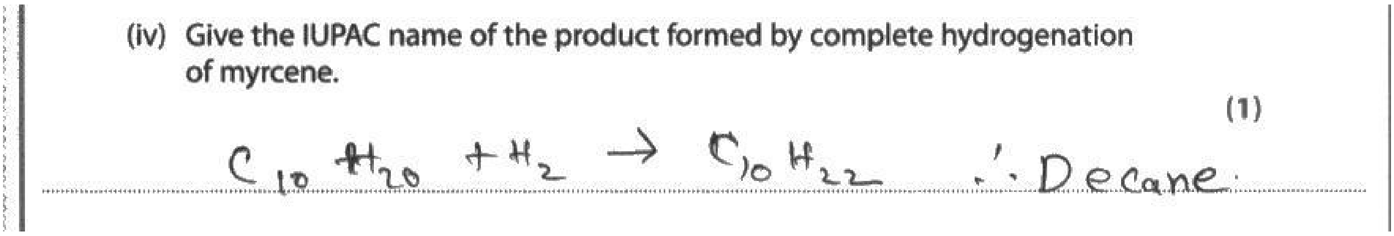
ResultsPlus
Examiner Comments

The methyl side chains have the correct numbers, only the main chain is wrongly named, so this does not score.

ResultsPlus
Examiner Tip

Learn how to name compounds from the specification. Most papers have marks available for this skill.

This response has found the molecular formula correctly and has used this to find the name, unfortunately incorrectly.



(iv) Give the IUPAC name of the product formed by complete hydrogenation of myrcene.

(1)

$C_{10}H_{20} + H_2 \rightarrow C_{10}H_{22}$ ∴ Decane.

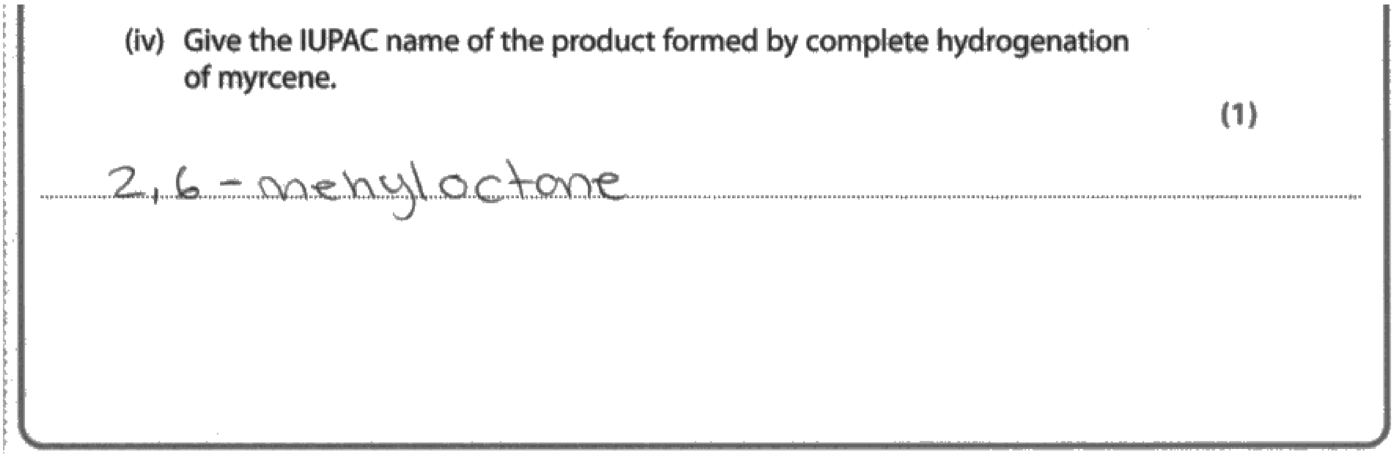
ResultsPlus
Examiner Comments

The straight chain molecule with this formula would indeed be decane, but this is an isomer of decane, so this does not score.

ResultsPlus
Examiner Tip

Remember that molecular formulae only tell you the number of each type of atom in a molecule, not the structure of that molecule.

The naming of multiple side chains or functional groups of the same type as di-, tri-, etc. is an important part of IUPAC nomenclature for larger molecules.



(iv) Give the IUPAC name of the product formed by complete hydrogenation of myrcene.

(1)

2,6-mehyloctane

ResultsPlus
Examiner Comments

This answer is correct but for the missing di – in front of the methyl so did not score.

Question 20 (c)

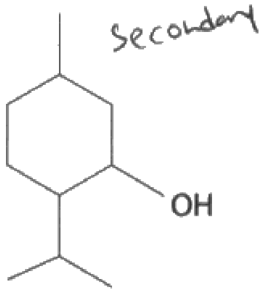
The final question was the 6-mark open response question. These questions need reading with even more care than usual, to ensure candidates understand what is being asked and so what is required. This centred on the context of three students using three different tests to identify the presence of an – OH group in three terpenoids. Each student carried out one test on all three compounds. The context was to identify which, if any, of the three tests would indicate correctly the presence of the – OH group. Indicative points were split between the tests, with one for each of the observations expected when getting a positive result with these tests and the second for how the observations related to the context.

For tests 1 and 2, many candidates recognised the importance of the structure of the alcohols played in the reaction with the two oxidising agents, potassium dichromate(VI) and potassium manganate(VII). Some, however, believed that menthol was a tertiary alcohol, whilst linalool was a secondary alcohol. These candidates were still able to score good marks despite this error. Many candidates either assumed that the potassium manganate(VII) would behave in exactly the same way as potassium dichromate(VI) or recognised that it would react with the double bonds to form diols, but few realised it could do both. The candidates who did not could still score for the correct observation. The most appropriate test was the use of phosphorous(V) chloride, PCl_5 which would react with all three giving misty fumes of HCl as the expected observation.

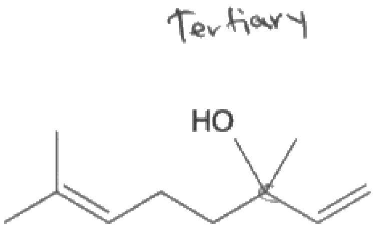
A common mistake was to misunderstand the question and have student 1 only testing compound 1, menthol, and student 2 only testing linalool with student 3 only testing citronellol. Some of these still scored good marks for the test results and often some background theory.

There were a number of very good responses which knew the importance of the structure of the terpenoids in the first test and that PCl5 was the reagent used to test for an – OH group and the expected results. Potassium manganate(VII), as expected, was the hardest of the tests to score well on.

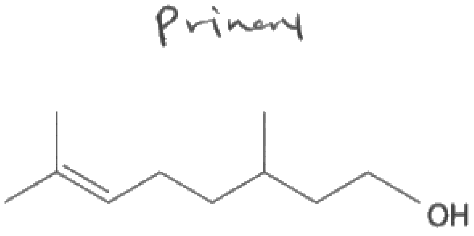
*(c) Three students were asked to carry out a single chemical test to unambiguously identify the presence of the —OH group in the three terpenoid compounds, menthol, linalool and citronellol.



menthol



linalool



citronellol

The first student tried using acidified potassium dichromate(VI) to oxidise the alcohols.

The second tried acidified potassium manganate(VII), an oxidising agent similar to potassium dichromate(VI).

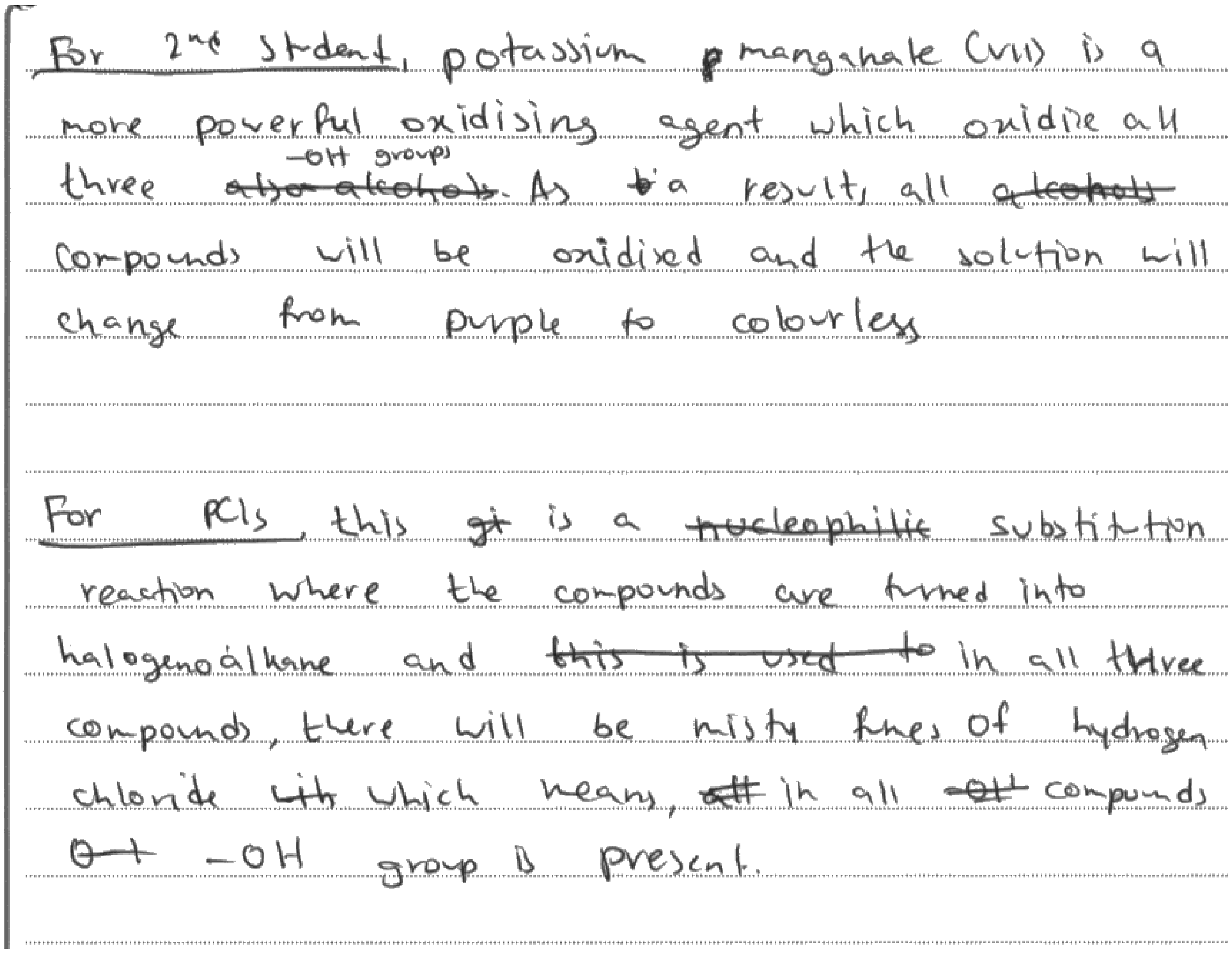
The third student tried using phosphorus(V) chloride.

Criticise the three students' suggestions by linking the expected results and the actual observations that would be made, for each test and the structures of the three alcohols.

(6)

Menthol is a secondary alcohol, linalool is a tertiary alcohol and citronellol is a primary alcohol

For the first student, potassium dichonate is an oxidising agent which only oxidise primary and secondary ~~alcohol~~ O-H groups and if result is positive then the colour changes from orange to green. So only menthol and citronellol will give positive result. To conclude this is not a suitable test for tertiary ~~alcohol~~ -OH group



For 2nd student, potassium ~~p~~ manganate (VII) is a more powerful oxidising agent which oxidise all three ~~also alcohols~~ -OH groups. As ~~t~~ a result, all ~~alcohols~~ compounds will be oxidised and the solution will change from purple to colourless

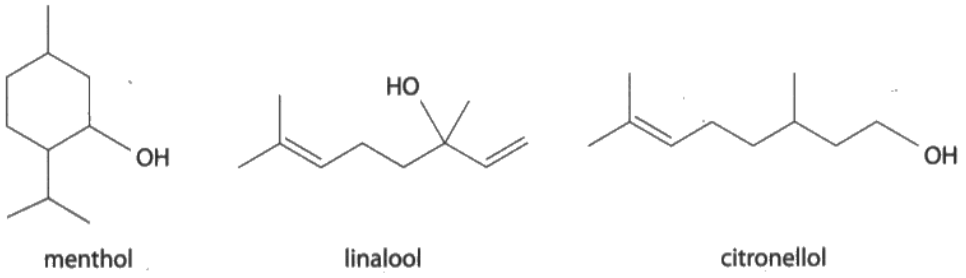
For PCl_5, this ~~gt~~ is a ~~nucleophilic~~ substitution reaction where the compounds are turned into halogenoalkane and ~~this is used to~~ in all three compounds, there will be misty fumes of hydrogen chloride ~~with~~ which means, ~~all~~ in all ~~-OH~~ compounds ~~O-t~~ -OH group is present.

ResultsPlus
Examiner Comments

This candidate scores 2 indicative points on each of the first and third tests. For potassium manganate(VII), they have identified the correct result but only concerned themselves with the oxidation reaction of the – OH group. Perhaps realising there must be some difference in this test and that with dichromate(VI) other than the different colour change, this candidate suggests all the alcohols are oxidised, which is not correct.

This is a well laid out answer, with sections for each of the students. Answers like this undoubtedly helped with the application of reasoning and logic between the tests.

*(c) Three students were asked to carry out a single chemical test to unambiguously identify the presence of the —OH group in the three terpenoid compounds, menthol, linalool and citronellol.



The first student tried using acidified potassium dichromate(VI) to oxidise the alcohols. X tertiary

The second tried acidified potassium manganate(VII), an oxidising agent similar to potassium dichromate(VI). X add OH groups

The third student tried using phosphorus(V) chloride. → HCl misty fumes..

Criticise the three students' suggestions by linking the expected results, and the actual observations that would be made, for each test and the structures of the three alcohols.

(6)

First student:

Acidified potassium dichromate(VI) can oxidise menthol and ~~linalool~~ citronellol as they are ~~pri~~ secondary and primary alcohols respectively but not linalool as it~~s~~ is a tertiary alcohol.

observation: ~~Misty fumes~~ Colour change from orange to green occurs for menthol and citronellol but linalool does not react.

Second ~~group~~ student:

Acidified $KMnO_4$ reacts with linalool and citronellol but not menthol as it does not have a C=C double bond. This test will also be invalid as the $KMnO_4$ oxidises the alcohols to a diol (when citronellol reacts) and triol (when linalool reacts) respectively so we are adding more OH groups, not confirming their presence.

Observation: Colour change from purple to colourless occurs for linalool and citronellol but not menthol.

Third student:

Adding PCl_5 to each of the three alcohols will cause a substitution reaction forming chloroalkanes, by ~~rem~~ substituting each of the OH groups with a Cl atom.

Observation: Misty fumes of HCl is produced which confirms the presence of OH groups.

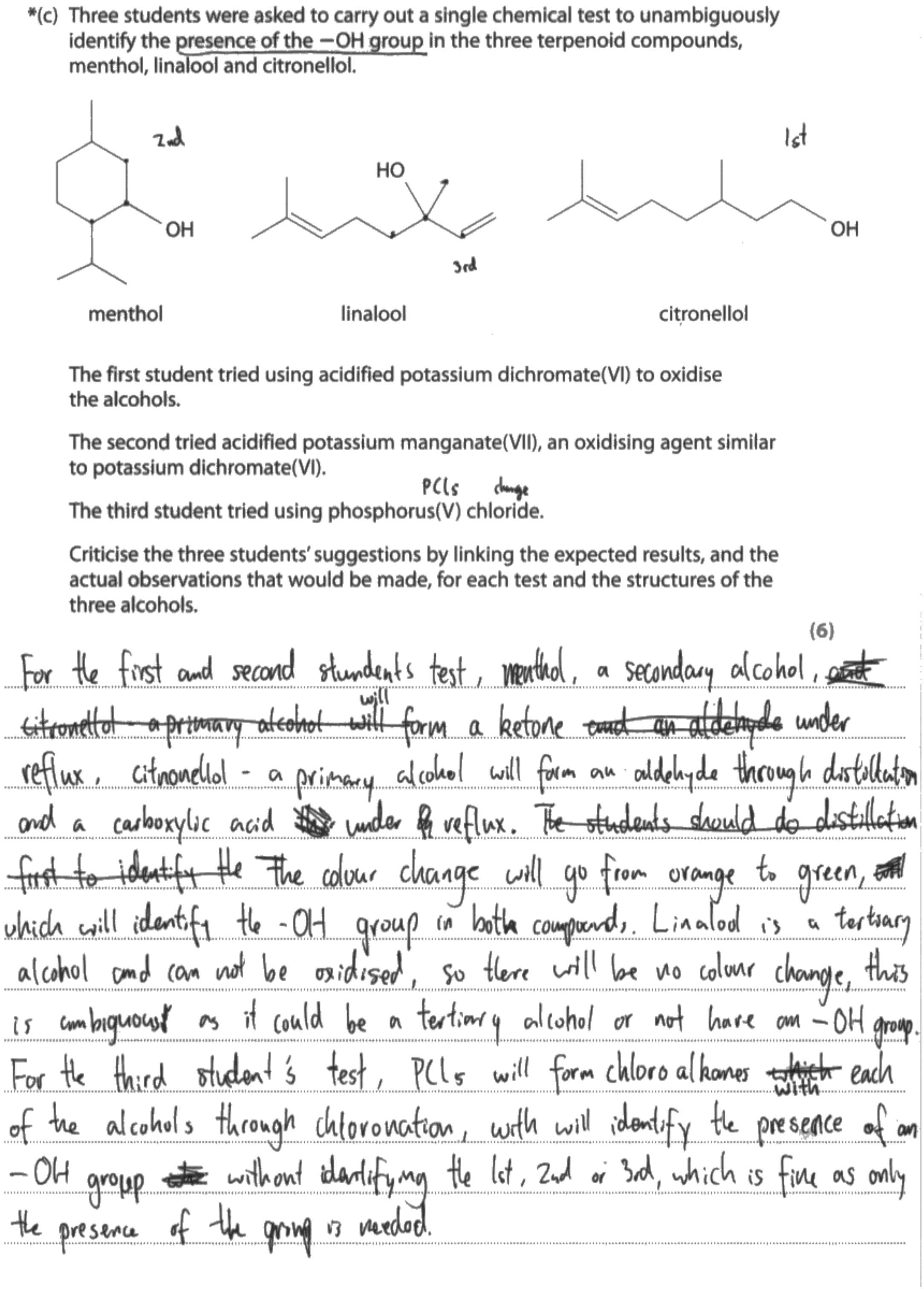
ResultsPlus
Examiner Comments

This candidates recognised that potassium manganate(VII) reacts with the double bonds to form a diol, but did not remember that it would also oxidise the – OH group. This response scored 5 marks having scored on 5 of the indicative points.

ResultsPlus
Examiner Tip

A structured answer will help to organise the ideas within the answer and lead to the best result.

Many candidates went into great detail about how oxidation of primary and secondary alcohols differed, which although usually quite correct, was not relevant to the context of testing for the presence of an – OH group and so did gain any credit. This may have led some candidates to believe they had written enough to score marks when actually they needed to more carefully address the question.



*(c) Three students were asked to carry out a single chemical test to unambiguously identify the presence of the –OH group in the three terpenoid compounds, menthol, linalool and citronellol.

menthol linalool citronellol

The first student tried using acidified potassium dichromate(VI) to oxidise the alcohols.

The second tried acidified potassium manganate(VII), an oxidising agent similar to potassium dichromate(VI).

PCl_5 change

The third student tried using phosphorus(V) chloride.

Criticise the three students' suggestions by linking the expected results, and the actual observations that would be made, for each test and the structures of the three alcohols.

(6)

For the first and second stundents test, menthol, a secondary alcohol, ~~and~~ ~~citronellol - a primary alcohol will~~ will form a ketone ~~and an aldehyde~~ under reflux, citronellol - a primary alcohol will form an aldehyde through distillation and a carboxylic acid under reflux. ~~The students should do distillation first to identify the~~ The colour change will go from orange to green, which will identify the -OH group in both compounds. Linalool is a tertiary alcohol and can not be oxidised, so there will be no colour change, this is ambiguous as it could be a tertiary alcohol or not have an –OH group. For the third student's test, PCl_5 will form chloroalkanes ~~which~~ with each of the alcohols through chloronation, with will identify the presence of an –OH group without idantifying the 1st, 2nd or 3rd, which is fine as only the presence of the group is needed.

ResultsPlus
Examiner Comments

This answer was extremely good at linking the tests and observations with the context of the tests and the identification of the – OH group and the significance of the structure of the alcohols. Unfortunately, the observation for test 3 was not mentioned (indicative point 5) and the test with potassium manganate(VII) was not mentioned at all.

ResultsPlus
Examiner Tip

Read the question carefully to make sure all parts have been addressed. This answer makes no reference to potassium manganate(VII) and provides more information than is necessary about oxidation products.

Paper Summary

Based on the performance seen in this paper candidates should:

- Take every opportunity to apply their knowledge of chemistry in unfamiliar situations.
- Remember to start their answers with basic information and work up to a conclusion which addresses the question, ensuring all the points are covered.
- Take time to learn these reagents and conditions as this paper almost always has some marks for knowing reagents and conditions required to complete particular organic chemistry reactions.
- Watch out for **bold** text. This usually indicates something important about the requirements for answer the question, for example, give **two** reasons why...
- Practise producing the different types of graphs associated with thermodynamic practicals, such as thermometric titrations, in this paper, or similar activities such as metal displacement reactions. The results of these different practicals are processed in different ways in the graphs.
- Express answers describing changes in equilibria by referring to increases in the concentrations of products or reactants rather than equilibrium shifting to the left or the right. The change in direction is easily misunderstood or badly expressed, and many candidates give answers which are contradictory. An answer like 'the equilibrium moves so that amount of product present increases and the amount of reactant decreases' is easily understood.
- Practise balancing ionic equations and half-equations, balancing the atoms present and the charge and oxidation state changes.
- Practise naming organic molecules including the use of di-, tri – etc. for molecules relevant to the specification.
- Read the questions with care to ensure they understand what is required rather than assuming the question will be the same as a question in a previous paper.