

Examiners' Report
June 2018

GCE Chemistry 9CH0 03

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Introduction

The paper tests understanding from across all parts of the specification and many of the questions are synoptic in nature. In addition, a central core of the paper covers the indirect assessment of practical skills. Questions in this context assess conceptual and theoretical understanding of experimental methods that will draw on candidates' experiences of the core practicals.

The main differences between this paper and the style of assessment used in the previous specification are:

- a much longer exam paper
- a wider breadth of content
- the indirect assessment of practical skills
- greater emphasis on extended writing questions
- greater emphasis on unstructured calculations
- no multiple-choice questions
- questions that target mathematical skills at Level 2 or above.

The paper counts as 40% of the total qualification and covers all three assessment objectives, AO1, AO2 and AO3 as outlined in the specification. It provides an opportunity for candidates to demonstrate knowledge of chemical principles and to apply them to a wide range of both familiar and unfamiliar contexts, both quantitatively and qualitatively. It also will challenge candidates to show that they can analyse, interpret and evaluate information, often data or observations from a practical context.

Question 1 (a) (i)

Nearly all candidates realised the involvement of electrons in the formation of London forces, though it was relatively commonplace to see answers represented only in terms of numbers of electrons, without considering how the electrons were involved in the process. Candidates who did this often went on to use the same argument, in the correct context of 1(a)(ii), essentially giving the same answer to the first two questions on the paper.

Those who focused on the formation of the forces, often realised that random movement of the electrons initiated the process. The terms 'instantaneous' and 'temporary' to describe the dipole formed were regularly seen; however a minority seemed to have learnt these phrases, but struggled to use them in a correct context. Similarly the use of the phrase 'induced dipole' was common, but to score the mark, it needed to be in the context of a second molecule.

1 This question is about some halogens and their compounds.

(a) The intermolecular attractions between halogen molecules are London forces.

(i) Describe how London forces form between halogen molecules.

(3)

In a particular time, electron density seems to be on the one side than the other in a molecule. the less electron density side would attract of one halogen with more surrounded electrons have stronger London force:
Therefore: $I_2 > Br_2 > Cl_2 > F_2$
As ~~an~~ going down the group, ^{more} electrons are added.



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Examiner Comments

Here the candidate realises that the uneven distribution of electrons is the key to the description. Although they know the trend in London force strength down the group, they don't attempt to link the electron movement to the formation of these forces.



When describing intermolecular forces make sure you think about how **a pair** of molecules interact, not just the changes in a single molecule.

Question 1 (a) (ii)

Candidates were on familiar ground with this question, nearly always linking the number of electrons to stronger London forces. Those who didn't manage to gain full credit generally focused only on the link between molar mass and London forces, or misinterpreted the question and discussed the attraction between the electrons and the nucleus.

(ii) The boiling temperatures of chlorine and bromine are shown in the table.

| Halogen | Boiling temperature / °C |
|----------|--------------------------|
| chlorine | -34 |
| bromine | 59 |

Explain why bromine has a higher boiling temperature than chlorine.

(2)

Bromine has a larger atomic radius, so has one more and stronger London forces. This requires more energy to be overcome these forces.



This example realises that larger halogens have stronger London forces, so scores 1 mark. To get the second mark, they needed to recognise that this is due to the greater number of electrons and not the size of the atoms or molecules.



Remember to always consider the number of electrons when comparing London forces.

Question 1 (b)

It was surprising to see how many candidates ignored the guidance in the stem of the question and as a result described inappropriate experiments using alternative reactants.

The most common of these was the use of silver nitrate solution in a similar manner to an experiment to determine the reactivity of halogenoalkanes. Another route, seen less often, was an attempt to compare the reactions of metal halides with concentrated sulfuric acid. Such attempts focused on the halide ions rather than the halogens and used reactants not provided to the student. It cannot be emphasised enough how important it is to read through the stem of a question with great care, as it can often help candidates structure a more appropriate response.

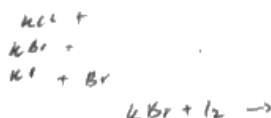
Of those who managed to describe displacement reactions, most were able to score two marks for testing Br_2 with KCl and Br_2 with KI or I_2 with KBr. A smaller proportion went on to correctly show the ionic equation, either because they wrote the full equation, or because they thought iodine would oxidise bromide ions.

The colours in cyclohexane were not often referenced, and even when described were often confused with the colours in aqueous solution. Frustratingly, some otherwise very good candidates missed a mark because they ignored the comment about the '**smallest** number of experiments' and were therefore wrong about all the possible combinations of halogen/halide.

(b) A student carries out experiments to determine the order of reactivity of three halogens: bromine, chlorine and iodine.

The student is provided with aqueous solutions of the following five substances:

- bromine
- iodine
- potassium chloride
- potassium bromide - brown gas
- potassium iodide - purple gas



The student has **no** access to chlorine gas or chlorine water.

The student uses cyclohexane, an organic solvent, to identify the halogen present at the end of each experiment.

The student carries out the **smallest** number of experiments required to determine the order of reactivity of the halogens.

Describe the experiments and the expected observations.

Include in your answer **ionic** equations for any reactions that occur.

State symbols are **not** required.

(5)

Experiments are displacement experiments - in that the more reactive halogens will displace less reactive halides. The first experiment would be to react ~~bromine~~^{iodine} with potassium bromide, ~~react~~
~~iodine will displace the bromide ions~~ and then with potassium chloride, where no displacement will take place as iodine is less reactive ~~than bromine~~. Using cyclohexane these mixtures should confirm there has been no displacement. Bromine should then be added to ~~the~~ potassium chloride.



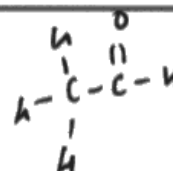
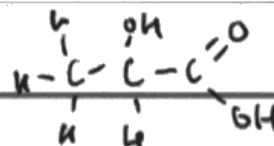
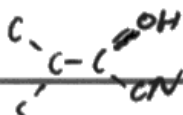
In this example, which scores two marks, the candidate correctly identifies two key reactions to attempt, but also suggests the unnecessary reaction between iodine and potassium chloride. Despite the guidance in the question there is no attempt to describe any observation or to write any equation.



Read each stem with great care and use it to help 'chunk' longer questions into a series of smaller parts.

Question 2 (a)

Nearly all students attempted to outline a synthetic route. However weaker responses got into difficulty at the first stage, either because they tried to synthesise a Grignard reagent from ethanal or they oxidised the ethanal into ethanoic acid. Those who recognised the need to extend the carbon chain via the formation of a hydroxynitrile often went on to successfully suggest how to form lactic acid. Otherwise good answers tended to lose credit by omission of the reaction type. Use of reaction schemes often made it difficult to award the balanced equation marks. The best answers used reaction schemes to highlight reagents and conditions, but then subsequently wrote separate balanced equations for the two reactions.



- 2 This question is about lactic acid (2-hydroxypropanoic acid), $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$. Lactic acid is used to make biodegradable polymers.

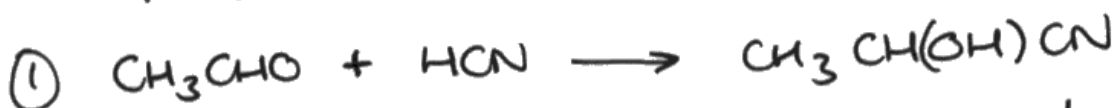
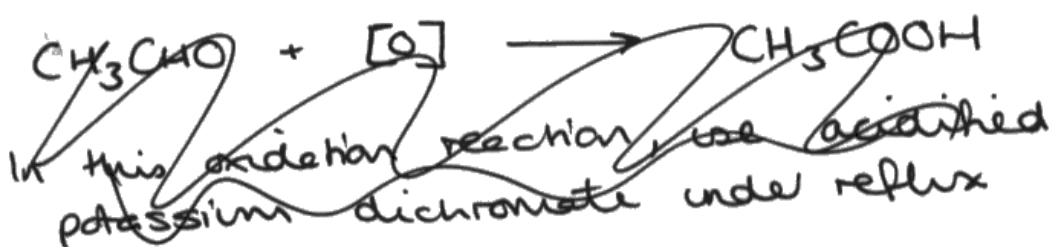
(a) Lactic acid can be made in a two-step synthesis starting from ethanal, CH_3CHO .

Devise a reaction scheme for a two-step synthesis.

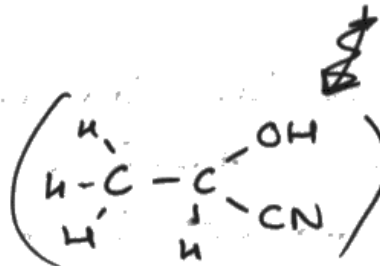
Include in your answer all reagents and conditions, the type of reaction occurring at each step, and a balanced equation for each reaction.

State symbols are **not** required.

(7)

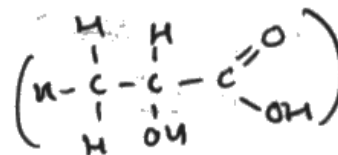


Reflux ethanal with HCN ions to form a hydroxynitrile.

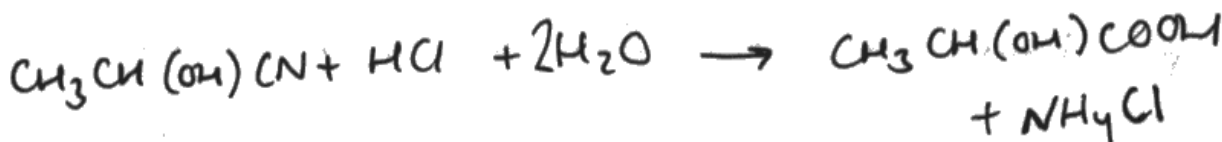


Reflux the hydroxynitrile with dilute HCl then distil off the lactic acid

(2-hydroxypropanoic acid)

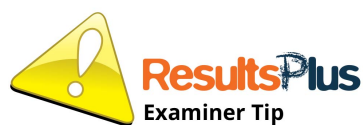


BALANCED EQUATION





This example shows all the reactants and conditions needed to synthesise lactic acid from ethanal in two steps. However neither type reaction is included, as requested, so scores 5 of the available marks.



Cross check longer answers against the requirement of the question, to check all information required is included.

Question 2 (b) (i)

The majority of candidates realised the type of polymerisation was condensation, though a significant minority suggested addition. Other candidates clouded their answers with additional information, possibly wasting time in the process.

(i) State the type of polymerisation occurring in this reaction.

(1)

addition polymerisation.



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Examiner Comments

The answer 'addition' was relatively common, suggesting for some candidates this question became a '50-50' between the two types of polymerisation studied at this level.



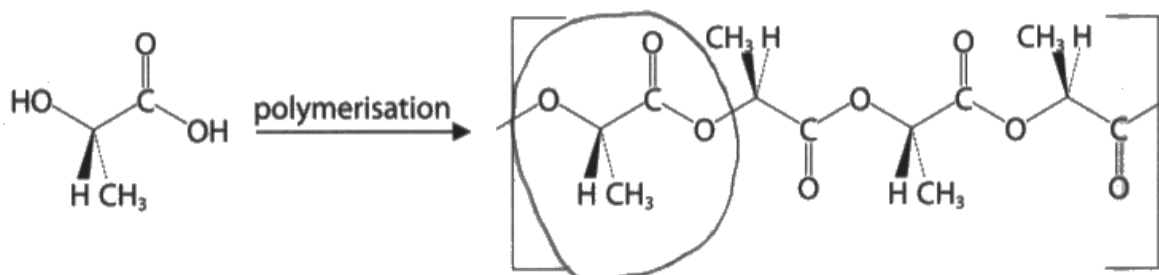
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Examiner Tip

Remember that addition polymerisation occurs when the monomers have a C=C bond, **not** a C=O bond.

Question 2 (b) (ii)

Over 60% of candidates could circle a repeat unit of the polymer. Those who did not score generally included three oxygen atoms in their responses. Others circled a section of the polymer covering more than one repeat unit.

(b) Polymerisation of lactic acid forms poly(lactic acid) as shown in the diagram.



(i) State the type of polymerisation occurring in this reaction.

(1)

condensation

(ii) On the diagram, draw a circle around the repeat unit of the polymer.

(1)

(Total for Question 2 = 9 marks)



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Examiner Comments

Most answers unworthy of credit included an additional oxygen in the repeat unit.



ResultsPlus
Examiner Tip

Remember the repeat unit of a polyester will have a carbonyl group (from the acid) at one end, and a 'bridging' oxygen (from the alcohol) at the other end.

Question 3 (a-c)

The calculations here provided a level of discrimination as virtually all candidates could score at least one or two marks in parts (a) and (b). Part (c) provided more of a challenge, but the most common way to miss a mark was to not give the molar mass of MCO_3 to an 'appropriate number of significant figures'. Others assumed their answer of 87 applied to the metal, not the carbonate, and so suggested M was strontium. A minority, often despite realising the acid is in excess in (d)(ii), tried to base their calculation on the amount of nitric acid, then linked this to the amount of carbonate. Such answers gained some credit via transferred errors.

| Measurement | | Value |
|---------------------------------------|------------------|--------|
| Mass of weighing bottle and carbonate | /g | 13.247 |
| Mass of empty weighing bottle | /g | 12.431 |
| Mass of carbonate used | /g | 0.816 |
| Volume of acid used | /cm ³ | 100 |
| Volume of gas collected | /cm ³ | 225 |

Table 1

(a) Complete Table 1 to show the mass of the carbonate used. (1)

(b) Calculate the amount, in moles, of carbon dioxide collected in the measuring cylinder at r.t.p. (1)

$$v = n \times 24000$$

$$n = \frac{225}{24000} = 9.375 \times 10^{-3} \text{ mol}$$

(c) Calculate the molar mass of the Group 2 carbonate to an appropriate number of significant figures and hence deduce the identity of the Group 2 metal. (4)

$$n \text{ Carbonate} = 9.375 \times 10^{-3} \text{ mol}$$

$$n = \frac{M}{M_r} \Rightarrow M_r = \frac{M}{n}$$

$$M_r = \frac{0.816}{9.375 \times 10^{-3}} = 87.04$$

$$XCO_3 = 87.04$$

$$X = 87.04 - (12 + 3(16))$$

$$= 27.04$$

$$M_r \text{ of } X \approx 27.0 \quad (3 \text{ s.f.})$$

X is probably magnesium.



This was a commonly seen response, which lost 1 mark in part (c), as the molar mass is given to an inappropriate number of significant figures used.



When deciding the number of appropriate significant figures for an answer in a calculation, look at the lowest number of significant figures in the data given in the question and use this as a guide.

Question 3 (d) (i)

Many responses seemed to focus on mistakes Student 2 may have made, rather than on the unavoidable issue with the procedure as described. Hence the idea of carbon dioxide escaping was commonly seen and scored one mark. However this was often linked to a failure to use the delivery tube properly, rather than the unavoidable time lag between adding the acid and replacing the bung.

(d) Student 2 carried out the same experiment as Student 1, using the same mass of the Group 2 carbonate.

Student 2 made no errors in their measurements or calculations but obtained a value for the molar mass which was 10 g mol^{-1} greater than the value obtained by Student 1.

(i) Explain **one** procedural error which could have resulted in Student 2 obtaining a molar mass greater than that of Student 1.

(2)

Taking too long to put the bung in the flask would result in gas escaping so less gas collected. Less moles are calculated so Molar mass is calculated to be larger.



This response shows evidence that the candidate has looked through the stem of the question with care to identify a procedural error and predict the effect it has on the final result.



When a question is in a practical context, read the procedure carefully and visualise the process. This will help you understand the method described, and so answer questions based on the experiment.

Question 3 (d) (ii)

Over 75% of candidates recognised that Student 2's result would not be affected due to the fact that the nitric acid was already in excess. A minority simply commented that 'all of the carbonate would react', which on its own, was insufficient to score.

- (ii) It was later discovered that Student 2 had used 110 cm^3 of 0.200 mol dm^{-3} dilute nitric acid, instead of 100 cm^3 of 0.200 mol dm^{-3} dilute nitric acid.

Give a reason why this mistake would **not** have affected Student 2's result.

No calculation is required.

(1)

The acid was in excess either way.



The stem of the question clearly states that the nitric acid is in excess and this candidate has noticed that fact so scores the mark. A small number of responses noted that the carbonate was the limiting reagent, which was also worth credit.



Information in the stem of a question is designed to help contextualise a question and provide candidates with required information or data. If you are struggling to give an answer, always re-read the stem for guidance. In a multi-part question, this may mean going back to the very start of the question.

Question 3 (d) (iii)

Examiners noted that the majority of candidates were able to link increase in surface area to an increase in rate. However, a sizeable number believed this would result in the production of a greater volume of gas. Even those who realised the final volume would remain the same, often stated that this volume would take less time to form and did not explain this outcome with reference to the constant amount of carbonate used.

(iii) The teacher noticed that Student 2 had used the Group 2 carbonate in powdered form rather than in lumps.

Explain how, if at all, this would affect the rate of reaction and the final volume of gas produced in the reaction.

(2)

It would increase reaction rate as there is a larger total surface area of carbonate to react on. This wouldn't change final volume of gas produced, only produce it faster.



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Examiner Comments

In this example the candidate has explained the effect of the use of the powder on the rate. However, although they have stated the effect on the final volume, they haven't given a reason, so only scored 1 of the 2 marks available.



ResultsPlus
Examiner Tip

Remember in an 'explain' question any answers must be backed up with a reason, to score full credit.

Question 3 (e) (i)

Over 75% of candidates successfully wrote a correct equation, with some giving a specific example based on a group 2 carbonate, which was allowed. Of those who failed to score the overwhelming reason was the omission of state symbols, despite the guidance in the question. A small number believed elemental oxygen was involved in the reaction, either as a reactant or a product.

(e) Student 3 suggested a different experiment.

Student 3 realised that, by heating the carbonate, carbon dioxide would be lost and an oxide would remain.

Student 3 decided to measure the change in mass of the carbonate and to use this information to calculate its molar mass.

- Student 3 weighed an empty test tube.
- Using a spatula, Student 3 added some of the carbonate to the test tube.
- The test tube containing the carbonate was then weighed.
- The test tube and its contents were heated to constant mass.
- The results obtained by Student 3 are shown in Table 2.

| Measurement | Value |
|-----------------------------------|--------|
| Mass of carbonate + test tube / g | 20.447 |
| Mass of oxide + test tube / g | 20.205 |
| Mass of empty test tube / g | 19.996 |

Table 2

(i) Write an equation, including state symbols, for the thermal decomposition of a Group 2 carbonate, MCO_3 , where M represents the metal.

(1)



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Examiner Comments

This candidate is able to construct the equation but has not included state symbols, so does not score the mark.

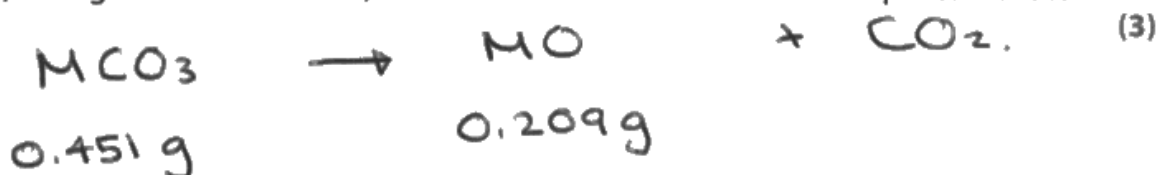


Always check in the stem of a question to see if state symbols are required. If you cannot recall the states of the species involved, re-read the stem, as information there can sometimes help.

Question 3 (e) (ii)

Over 65% of candidates managed to score at least 2 marks in this question, and in general examiners found that the performance in calculations was slightly better than in 2017. The majority of successful responses followed the method outlined in the mark scheme, though several elegant alternative approaches were seen and credited. Occasionally such approaches focused on the calculation of the atomic mass of M and did not subsequently determine the molar mass of the carbonate.

(ii) Using Student 3's results, calculate the molar mass of the Group 2 carbonate. (3)



$$\frac{0.451}{M + 60} = \frac{0.209}{M + 16}$$

$$0.451M + 7.216 = 0.209M + 12.54.$$

$$0.242M = 5.324$$

$$M = 22$$

$$22 + 12 + 16 \times 3 = 82$$



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Examiner Comments

In this example the candidate uses the idea that the number of moles of MCO_3 that reacts is the same as the number of moles of MO that forms. They then construct an expression to determine the atomic mass of M and remember to add 60, to calculate the final answer required.



It is always helpful for both examiners and candidates, when working is shown clearly. Lay out each part of a calculation separately and in an ordered way across the answer space.

Question 3 (f)

Although nearly 50% of the answers seen were correct, examiners saw many answers that focused on the total number of masses recorded in each experiment, rather than the percentage uncertainty in the mass of the carbonate. Such answers tended to discuss the effect of multiple measurements rather than the idea that student 3 used a smaller mass of carbonate.

(f) Student 3 used the same balance as Student 1.

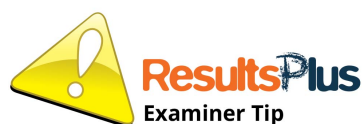
Give a reason why the mass of the carbonate measured by Student 3 has a greater percentage uncertainty than that measured by Student 1.

(1)

Student 3 has a smaller mass of carbonate than student 1



This is a succinct, correct response, where the student has focused on the specific percentage uncertainty framed by the question.



Read each question twice to ensure you answer what is asked.

Question 3 (g)

This question proved to be a useful discriminator as, in general, only better candidates could link the loss of solid to the apparent increase in the amount of carbon dioxide produced. Even those who realised this, could not always go on to deduce the effect on the molar mass.

There were many examples that talked about losing or gaining mass but never specifying which substance their comment applied to and consequently were often unable to access any marks.

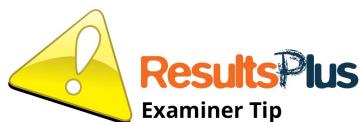
- (g) Student 3 noticed that on heating the test tube some solid was lost.
Explain how this would affect the calculated value for the molar mass of the Group 2 carbonate.

(2)

This would mean that the M_r was lower than it should have been. As $\frac{\text{mass}}{M_r} = \text{moles}$.
If moles were same and mass decreased M_r would have decreased also.



This type of response was often seen. The candidate has not managed to make it clear which substance is being discussed and as the 2nd mark was dependent on the first in the mark scheme, did not score.



When discussing changes in a reaction in any context, make sure you refer specifically to the substances involved.

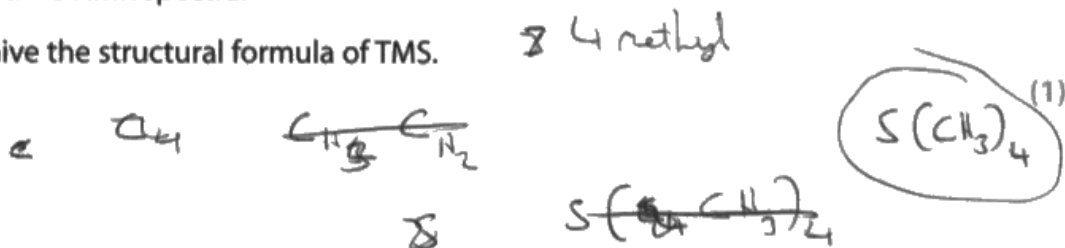
Question 4 (a) (i)

A surprisingly significant minority used the symbol 'S' for silicon in this question, so despite knowing the outline structure, did not score. A few lost the mark as they struggled to construct the structural formula, presenting their answer as though the silicon atom was at the end of a hydrocarbon chain.

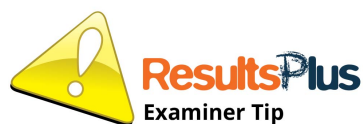
4 This question is about the use of NMR spectroscopy to distinguish between isomers of $C_6H_{12}O_2$.

(a) Tetramethylsilane (TMS) is a compound used as a standard when recording both 1H and ^{13}C NMR spectra.

(i) Give the structural formula of TMS.



Here the candidate has assumed the S in 'TMS' means sulfur, despite the use of 'silane' in the name.



Practice using brackets in structural formulae to emphasise groups that are attached to the same atom.

Question 4 (a) (ii)

Examiners were a little frustrated to see lots of examples here that referred to the fact that TMS is inert and non-toxic, despite the request in the question for 'two other reasons'. Over 50% scored at least one mark, and this was most commonly for the idea that all the hydrogen atoms are in the same environment. Many candidates concentrated on the idea that TMS has a chemical shift at 0ppm, without appreciating the significance of the position of the TMS peak in relation to other possible peaks.

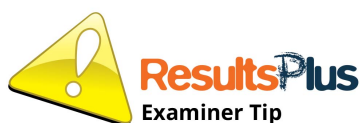
- (ii) TMS is an inert and non-toxic compound. State **two** other reasons why TMS is suitable for use as a standard when recording NMR spectra.

(2)

TMS has a low boiling point so easily vaporises from the organic compound being analysed. TMS has 12 equivalent protons & produces a tall sharp peak for ^1H NMR and its peak due to its carbon atom can easily be removed for eg. ^{13}C NMR as well as ^1H NMR



This answer scores two marks, for the ideas that TMS has a low boiling point/is easily removed, and that it has 12 hydrogen atoms in the same environment.



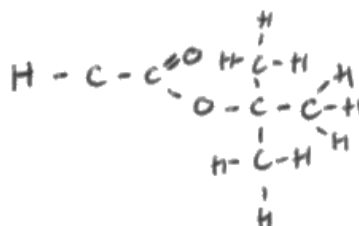
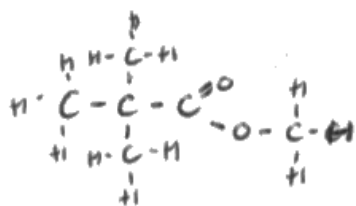
When a question asks for 'other reasons' check your answer to make sure you are not simply repeating the reasons in the question.

Question 4 (b) (i)

This question polarized answers in the sense that most candidates who could work out one structure with only two hydrogen environments, could then easily deduce a second. Many answers that failed to score did so because they could not draw the structure of an ester, often suggesting carboxylic acids. Others did show esters but focused on showing two isomers rather than considering the hydrogen environments.

- (b) (i) Draw the structural formulae of the **two** esters with formula $C_6H_{12}O_2$ that each have only **two** peaks, both singlets, in their high resolution **proton** NMR spectra. The relative peak areas are 3:1 for both esters.

(2)



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Examiner Comments

Most candidates who scored 1 mark, did so because of this type of error. In the second structure, having realised the need to 'flip' the position of the three methyl groups, the candidate has not shown all the hydrogens on the single methyl group attached to the carbonyl carbon.



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Examiner Tip

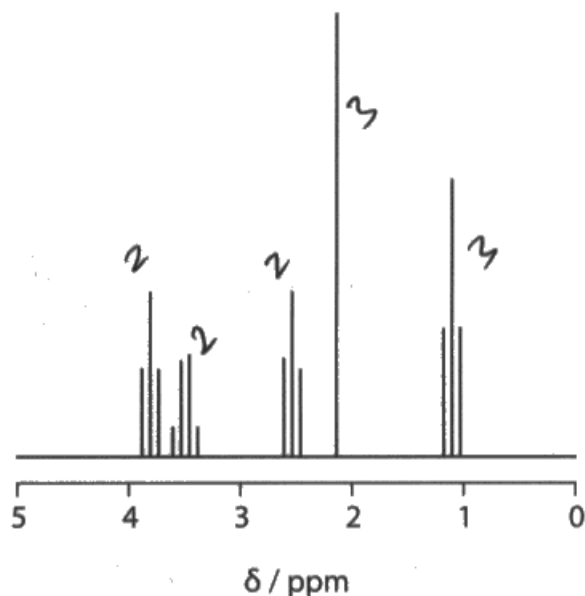
If you have time, double check that each carbon atom has four bonds in any displayed structures.

Question 4 (b) (ii)

This question discriminated successfully, with able candidates able to score four or five marks. The best answers annotated the displayed formula in the question to link hydrogen environments to the chemical shift data. Others carefully described the position of the groups to ensure the examiner could clearly see which part of the molecule the candidate was referring to. This was often achieved using phrases such as 'the methyl group on the far left of the molecule.'

Weaker responses lacked clarity, for instance discussing methyl groups without making it clear which of the two possible such groups they were discussing. Other common issues included answers which stated that carbon atoms had caused the peaks, and answers that when trying to justify splitting patterns talked about 'neighbouring hydrogens' without always making it clear that such atoms were on an adjacent carbon.

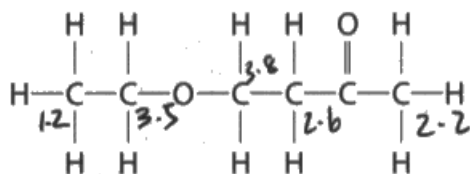
(ii) The high resolution **proton** NMR spectrum of another isomer of $C_6H_{12}O_2$ is shown.



The ratios of the number of protons for the five sets peaks in the spectrum are given in the table.

| | | | | | |
|--------------------------------|-----|-----|-----|-----|-----|
| δ / ppm | 3.8 | 3.5 | 2.6 | 2.2 | 1.2 |
| Ratio of the number of protons | 2 | 2 | 2 | 3 | 3 |

Show that **all** these data are consistent with the displayed formula shown. Refer to the five chemical shifts and explain **two** of the splitting patterns.



(5)

5 different peaks due to five different proton environments.

~~3.8 ppm = CH₂ adjacent to C=O~~

3.8 ppm = O-CH₂, ratio 2 as only 2H in same environment.

3.5 ppm = CH₂-O, ratio 2 as only 2H in same environment.

2.6 ppm = CH₂-C=O, ratio 2 as only 2H in same environment.

2.2 ppm = O=C-CH₃, ratio 3 as 3H in same environment.

1.2 ppm = CH₃-CH₂, ratio 3 as 3H in same environment.

splitting at 3.5 ppm due to $\text{CH}_2\text{-O}$ adjacent to carbon with 3H attached. $(n+1)$ rule means $(3+1) = 4$ splits produced.

splitting at 1.2 ppm to form triplets due to CH_3 bonded to CH_2 . $(2H+1) = \text{triplet}$.



This example shows how the candidate has sensibly annotated the structure to clearly reference how the chemical shift data is consistent with the structure. Notice how they also lay out the pieces of structural information from the data book. They ensure the groups are shown in the correct orientation as well as showing the number of hydrogens in that environment.



Don't be afraid to clearly annotate diagrams to make your point clear in questions based on NMR.

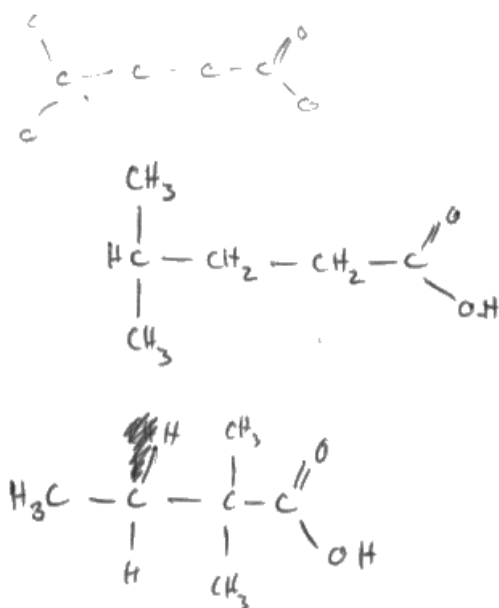
Question 4 (c)

Part (i) proved a significant level of challenge for many. In a similar way to (b)(i), answers that gave two structural isomers rather than considering the carbon environments were common. Others, concentrating on the five environments, ignored the need for the structures to be carboxylic acids, so lost both marks. Several otherwise good answers missed out because they made a mistake when drawing a structural formula, having correctly shown a displayed formula. Most students were able to score in (c)(ii). The most common mistakes were the inclusion of a benzene ring, or showing OH groups in the 1,2- positions.

- (c) (i) There are three other isomers of $C_6H_{12}O_2$ which are carboxylic acids with five peaks in their carbon-13 NMR spectra.

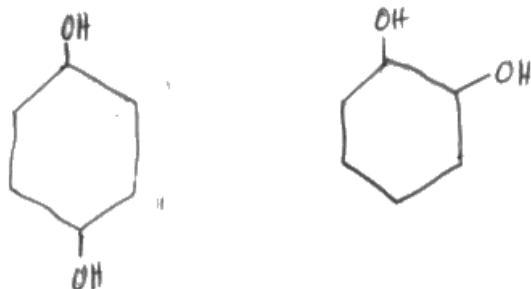
Draw the structural formula of **two** of these isomers.

(2)



- (ii) Draw the **skeletal** formula of a cyclic diol isomer of $C_6H_{12}O_2$ that has only **two** peaks in its **carbon-13 NMR spectrum**.

(1)





This example shows two correct structures in (i). Note that the structure with missing hydrogens was ignored as it is clearly working out. However in (ii), this response did not score. Despite including the correct structure, they also included an incorrect structure.



In general, when a single formula is required, the inclusion of a second incorrect formula will lose the mark.

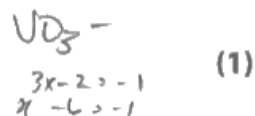
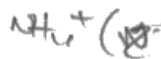
Question 5 (a)

Nearly 85% of candidates correctly calculated the oxidation state of vanadium in NH_4VO_3 . The incorrect answers struggled to assign a value to the ammonium ion, and no pattern was seen in wrong values. Many answers showed no evidence of working, suggesting some answered this question using recall.

5 This question is about the properties of transition elements, their ions and their complexes.

(a) Give the oxidation state of vanadium in the compound NH_4VO_3 .

8 +V



ResultsPlus
Examiner Comments

Due to the use of Roman numerals in Stock notation, +V was an allowed response in this question, although rarely seen.



ResultsPlus
Examiner Tip

Candidates should remember that the best strategy is to use Arabic numerals when calculating oxidation states, to avoid potential confusion with chemical symbols.

Question 5 (b)

This extended response-style question also discriminated well, with the marks spread evenly across the range. Many candidates gave detailed and logical accounts of the changes, with correct equations and E_{cell} values.

However weaker responses, although recognising the four colours involved, confused the order of the colour changes. Others struggled to determine the direction of the reaction, or even if they realised that reactions involved zinc as a reducing agent, could not construct an overall equation. A second level of discrimination was evident due to 'unforced errors' in equations. The most common of these was a failure to balance water and/or hydrogen ions or confusion between the ions VO^{2+} and VO_2^+

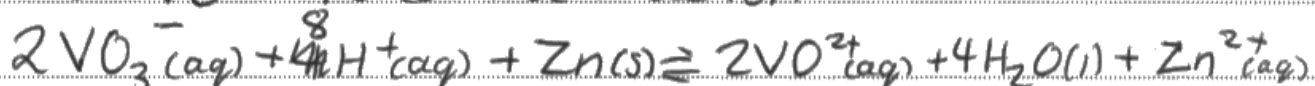
(b) Excess zinc powder is added to an acidified solution of the compound NH_4VO_3 . Using the data in the table, explain the sequence of reactions that takes place.

In your answer, include a description of what you would **see**, and the relevant ionic equations with their calculated E_{cell}^\ominus values. State symbols are not required.

$\text{V} \quad \begin{matrix} +5 & +4 & +3 & +2 \\ \text{yellow} & \text{green} & \text{blue} & \text{violet} \end{matrix}$
(7)

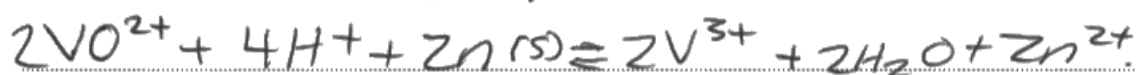
| Electrode system | E^\ominus / V |
|---|------------------------|
| $\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$ | -1.18 |
| $\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$ | -0.26 |
| $\text{VO}^{2+}(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ | +0.34 |
| $\text{VO}_3^-(\text{aq}) + 4\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ | +1.00 |
| $\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$ | -0.76 |

Zinc reduces the VO_3^- ions in the NH_4VO_3 to VO^{2+} ions via reaction



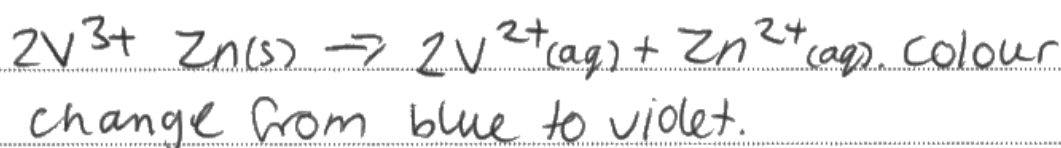
colour change from yellow to green as $\text{VO}^{2+}(\text{aq})$ ions are produced.

Zinc then further reduces the $\text{VO}^{2+}(\text{aq})$ ions to $\text{V}^{3+}(\text{aq})$ ions, decreasing oxidation number from +4 to +3 via reaction.



colour change from green to blue as $\text{V}^{3+}(\text{aq})$ ions are produced.

The $\text{V}^{3+}(\text{aq})$ ions are then further reduced to $\text{V}^{2+}(\text{aq})$ ions via the reaction





This example clearly understands the chemistry involved and has correctly written three equations for the redox reactions that take place. These are accompanied with accurate descriptions of each colour change. Unfortunately, the response does not score full marks as they have neglected to include E_{cell} values, as requested by the question. In addition, they did not use the data to show that the reduction stops at $V^{2+}(\text{aq})$, so scores five marks out of seven.



In extended response questions, go through the stem and use it to help break down your response into sections, covering all the required information. For instance, in this question, given the stem, a systematic approach would essentially split the question into sub-sections. Each sub-section would then cover:

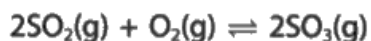
- An equation for the reaction
- E_{cell} values for each reaction
- Observations for each reaction

This style of approach should minimise the risk of omitting information you actually know.

Question 5 (c)

A large number of responses gave generic answers that were either based on alternative mechanisms of lower activation energy, or absorption onto a solid surface. Even those which attempted to discuss the specific role of vanadium(V) oxide, tended to discuss weakening of the sulfur dioxide bonds rather than consider the changes in oxidation number. The best answers were often the straightforward ones, that used equations to illustrate the role of the catalyst in the reaction.

(c) Explain how vanadium(V) oxide acts as a catalyst in one step of the contact process. The equation for this step is



(2)
 $\text{V}_2\text{O}_5 + \text{SO}_2 \rightarrow \text{V}_2\text{O}_4 + \text{SO}_3$. The SO_2 molecules are adsorbed onto the surface of the vanadium, its active site. It weakens the bonds within the molecules and places it in the right orientation so collisions can happen on the surface. The vanadium (V) oxide reduces the activation energy.



ResultsPlus
Examiner Comments

Here the equation is enough to show the role of the vanadium(V) oxide in the initial oxidation of sulfur dioxide. Unfortunately the response did not go on to explain how the catalyst was regenerated, so scored just one mark.



ResultsPlus
Examiner Tip

Using balanced equations in questions is often a very effective way to explain what is happening in any chemical change.

Question 5 (d)

The examination team found that the responses to this question showed that many candidates had seen and done these reactions. Certainly, the ability to describe and write equations for these reaction of copper complexes was an improvement on questions involving similar reactions using chromium complexes in 2017. The full range of marks was seen, with some or all the descriptions proving most accessible. Often candidates provided additional information, especially regarding the dropwise addition of ammonia. Pleasingly, this was often correct. Errors though were often unforced. These commonly included incorrect or missing state symbols in the reaction with sodium hydroxide solution, or unbalanced equations. A very small number of candidates lost marks because they insisted on describing the reaction types but made mistakes, for instance stating that the reaction with sodium hydroxide solution was a ligand exchange.

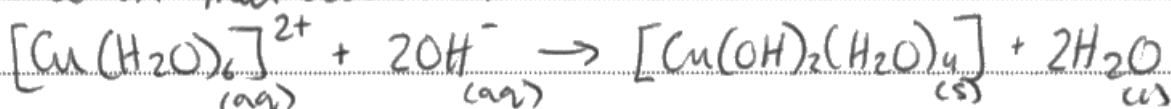
*d) Describe the reactions of separate portions of aqueous copper(II) ions with aqueous sodium hydroxide solution, with excess aqueous ammonia solution and with concentrated hydrochloric acid.

In your answer you should link observations with equations which include the formulae of any copper-containing complex ions. Include state symbols.

(6)

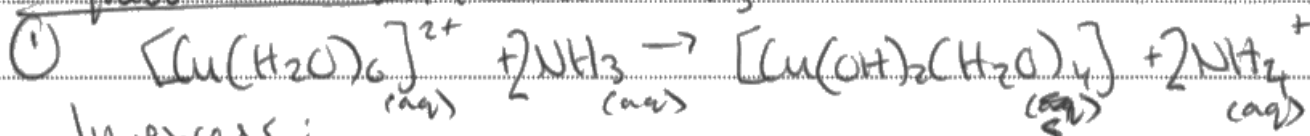
Aqueous Cu^{2+} with NaOH :

The reaction that occurs is:

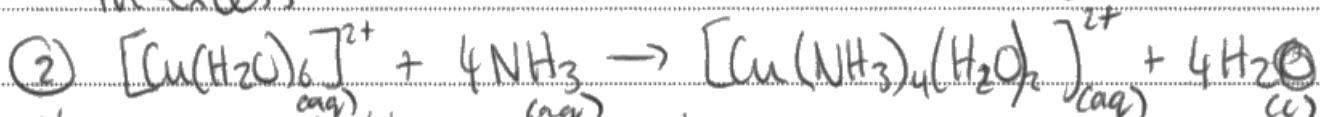


Observations: blue solution (Cu^{2+}) becomes a pale blue precipitate ($\text{Cu}(\text{OH})_2$). It is insoluble in excess NaOH . This is a ~~typ~~ acid-base reaction, NOT a ligand exchange. The OH^- is protonated to form water.

Aqueous Cu^{2+} with excess NH_3 :



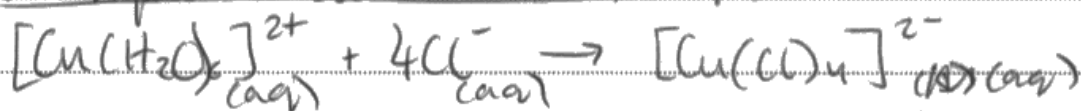
In excess:



Observations: blue solution becomes pale blue precipitate, and in excess, precipitate dissolves to give a dark blue solution ($[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$).

Reaction $\textcircled{1}$ is an acid-base reaction, but ~~the~~ reaction $\textcircled{2}$ (with excess) is a ligand exchange reaction, where NH_3 replaces H_2O .

Cu^{2+} Aqueous Cu^{2+} with conc. HCl



Observations: a blue solution turns into a yellow solution.

This is a ligand exchange reaction where Cl^- replaces H_2O . The coordination number changes from 6 to 4 as Cl^- are larger charged ligands, and so fewer of them can fit around the Cu^{2+} than H_2O .



ResultsPlus
Examiner Comments

The answer adopts a systematic approach similar to that suggested in the 'examiner tip' for 5(b). The candidate has made life more straightforward for themselves, by splitting a 6-mark extended response into three smaller questions. This helps prevent an answer drifting off from what has been asked, giving the candidate a keen focus in the requirements of the question. As a result, the answer was given 5 out of 6 marks. The only mistake was not balancing the equation for the reaction with concentrated hydrochloric acid.



ResultsPlus
Examiner Tip

Check equations for ligand exchange reactions to make sure that **both** ligands balance.

Question 6 (a) (i)

This question proved to be straightforward for most, with over 80% scoring both marks. Incorrect answers tended to name functional groups involved rather than show the bonds or quote an incorrect range.

6 This question is about the analysis of an unknown carboxylic acid **X** by three students.

The students analyse the mass spectrum of **X** and find that it has a molecular ion peak at $m/z = 116$.

The three students each propose a different structural formula for compound **X**.

Structure 1 $\text{HOOCCH}=\text{CHCOOH}$

Structure 2 $\text{HOCH}_2\text{CH}=\text{CHCH}_2\text{COOH}$

Structure 3 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$

(a) The students are given the infrared spectrum of **X**.

- (i) State **two** wavenumber ranges of the infrared absorptions providing evidence that compound **X** is a carboxylic acid. Include the bonds responsible.

(2)

3300 - 2500 — due to O-H bond

1700 - 1680 — due to C=O bond.



ResultsPlus
Examiner Comments

This example scored one out of two as the candidate has quoted an incorrect range for the carbonyl group. They have used $1725\text{-}1680\text{ cm}^{-1}$, which is for an aryl carboxylic acid.



ResultsPlus
Examiner Tip

Check when using the data book that any infrared wavenumber ranges you quote match the environment of the bond. Take particular care with the bonds in alkyl or aryl compounds. The same type of bond in each environment can have similar, but not exactly, the same range.

Question 6 (a) (ii)

In this question many candidates struggled with the subtlety of the problem and thought they should mention every bond and corresponding IR absorptions for each structure. Many achieved two marks regardless but then found it difficult to make it clear how the differences in the absorptions could be used to categorically distinguish between each structure. A common mistake was to assume the absorption at around 3010 cm^{-1} was due to a C=C bond.

However nearly 30% of candidates scored all three marks with succinct responses that discussed the differences in bonds and consequently absorptions meaning not every bond is present in each structure. A small number confused IR with mass spectrometry, discussing the molar mass of the structures.

- (ii) One of the students suggests that this infrared spectrum and the data in the Data Booklet **alone** could be used to identify which of the three proposed structures is **X**.

Show that this student's suggestion is correct. Include relevant infrared data in your answer.

(3)

The student is correct as the two molecules containing a C=C double bond would show a C=C stretching vibrations peak at $1669 - 1645$ (Structure 1 and 2). Also, Structure 2 would be distinguishable as there would be a wide O-H stretching vibrations peak at $3750 - 3200\text{ cm}^{-1}$.



ResultsPlus
Examiner Comments

Here the candidate has used appropriate data to distinguish between structures 1 and 2, but has made no attempt to consider structure 3, so loses a mark.



When distinguishing between structures using IR, focus on the differences not the similarities.

Question 6 (b)

As expected this was a very straightforward calculation with over 85% of candidates able to score both marks. Of the 15% who didn't achieve full credit, most were able to score 1 mark for the amount in moles, which they then multiplied by an incorrect molar mass.

- (b) The students decide to carry out an acid-base titration to obtain further information about compound X.

Each student uses solid sodium hydroxide, NaOH, to prepare a solution of concentration $0.140 \text{ mol dm}^{-3}$.

Calculate the mass, in grams, of solid sodium hydroxide that each student should weigh out to prepare 250.0 cm^3 of a $0.140 \text{ mol dm}^{-3}$ solution.

(2)

$$n = c v$$

$$n = 0.140 \times \frac{250}{1000}$$

$$n = 0.035$$

$$g = n \times \text{RFM}$$

$$g = 0.035 \times 116$$

$$g = 4.06 \text{ g}$$



ResultsPlus
Examiner Comments

This was by far the most common way to lose a mark. The value of 116 is the relative molecular mass of compound X, not sodium hydroxide.



Double check values of relative molecular mass used in your answer match the substance in the question.

Question 6 (c) (i)

In general questions that tested the ability of candidates to deduce the effect of an experimental mistake on final outcome of a process was better than in 2017, especially amongst candidates likely to achieve the higher grades. However, this may in part be due to the familiarity of acid-base titrations. In this case nearly all candidates realised that Student B's mistake would lead to fewer moles of sodium hydroxide, so could score at least 1 mark. However, a significant minority of these thought this would result in a greater value for the titre.

- (c) Each of the students makes up 250.0 cm^3 of 0.140 mol dm^{-3} sodium hydroxide solution in a volumetric flask and titrates this solution with the same solution of **X** of known concentration.

Student A

- correctly prepares the 0.140 mol dm^{-3} sodium hydroxide solution and pipettes a volume of 10.0 cm^3 of the solution into a conical flask
- fills a burette with the solution of **X** and carries out a titration
- repeats the procedure until obtaining concordant results
- obtains a mean titre of 10.20 cm^3 .

Student B

- dissolves the sodium hydroxide in distilled water and transfers the solution to a volumetric flask
- adds more distilled water to the volumetric flask and mixes the solution
- notices that the volumetric flask has been filled with distilled water several cm^3 beyond the graduation mark
- realises the mistake, removes the extra solution and discards it $\downarrow [\text{NaOH}]$
- pipettes 10.0 cm^3 of the sodium hydroxide solution into a conical flask and titrates this with the solution of **X**.

Student C

- correctly prepares the 0.140 mol dm^{-3} sodium hydroxide solution
- washes a conical flask thoroughly with distilled water and pipettes 10.0 cm^3 of the sodium hydroxide solution into the wet conical flask
- titrates the contents of the conical flask with the solution of **X**.

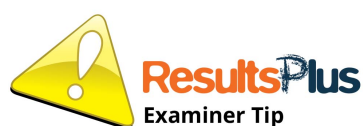
- (i) Explain how, if at all, Student B's mistake affects the value of the titre.

(2)

~~By removing extra solution:~~ By over diluting the solution, the student lowers the concentration of the NaOH solution. This means a larger titre will be needed to react with X.



The candidate has noticed that the removal of the excess solution has produced a lower concentration of alkali. However they then suggest this would result in a larger titre. This suggests they believe the sodium hydroxide solution is being added from the burette, and the volume of the solution of X is staying constant.



Read procedural details for titrations twice, to make sure you realise which solution is in the burette, and which is in the conical flask.

Question 6 (c) (ii)

Here 10% fewer candidates managed full marks compared to part (c)(i). In general, this was because they made the familiar error of believing that dilution of the solution in the conical flask would affect the outcome of the titre. In one sense, this mistake is entirely predictable, but seems incongruous when one considers their likely laboratory experience, where it seems unlikely they will use a clean, dry conical flask for each titre.

Some answers started with the promising statement that the titre would not be affected much, but went on to make it clear that they believed the reason for this was because the dilution effect of the water was so small.

(ii) Explain how, if at all, Student C's use of a wet conical flask affects the value of the titre.

(2)

~~Water in conical flask dilutes~~
Water in conical flask dilutes
NaOH solution. This means ^{less} ~~more~~ solution in burette required to
neutralise NaOH. This decreases titre value.



This response highlights the very common misconception that a wet flask has an impact on a final titre, by diluting the alkali, so less acid is required. It did not score any marks.



Remember during practical work to explain each part of the procedure in your reports. This will help you to realise why certain parts of a process may lead to significant errors if not followed with care, whereas others, such as the use of a wet flask due to distilled water, have no impact on the final outcome.

Question 6 (c) (iii)

Most candidates understood how to calculate a percentage uncertainty, with over 80% of candidates scoring at least two marks. The most common error was a failure to recognise the burette is read twice in each titre, so using 0.05 cm^3 as the uncertainty, not 0.10 cm^3 . A small number used an incorrect denominator in the calculation.

(iii) Student A uses three pieces of apparatus to measure volumes in this experiment.

- The burette has an uncertainty of $\pm 0.05 \text{ cm}^3$ for each volume reading
- The volumetric flask has an uncertainty of $\pm 0.30 \text{ cm}^3$ for the volume
- The pipette has an uncertainty of $\pm 0.04 \text{ cm}^3$ for the volume

Show by calculation which volume measurement has the lowest percentage uncertainty. (3)

$$\text{Burette} = \frac{0.05}{50} \times 100 = 0.1\%$$

$$\text{Volumetric flask} = \frac{0.30}{250} \times 100 = 0.12\%$$

$$\text{Pipette} = \frac{0.04}{10} \times 100 = 0.4\%$$

This shows the Burette has the lowest percentage uncertainty.



Here the candidate scored two marks, as they have calculated the percentage uncertainty correctly for the pipette and volumetric flask, and make a correct judgement based on their data, as to the instrument with the lowest percentage uncertainty. They have actually made two mistakes in the burette calculation, using 0.05 cm^3 as the uncertainty, not 0.10 cm^3 , as well as using the maximum volume of the burette, not the titre of 10.10 cm^3 .



Remember to check the denominator in a percentage uncertainty problem. It should be measurement recorded, and not necessarily the maximum amount an instrument can measure.

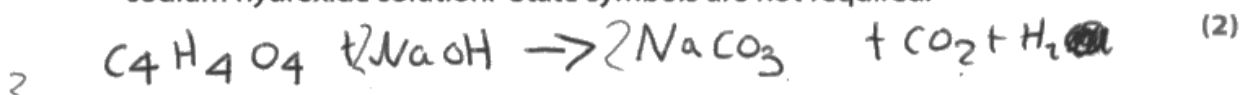
Question 6 (d) (i)

An equation for a simple acid-base reaction proved quite challenging for around 50% of candidates. A common error was to fail to transcribe the formula of structure 1 correctly from the question, normally by omitting a carbon atom. Other mistakes included treating the acid as monoprotic, and in some cases not realising the products would simply be a salt and water.

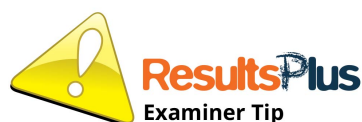
- (d) Student **A** calculates the correct value for the molar mass of compound **X**, using the mean titre of 10.20 cm³. The results indicate that **X** has **structure 1**.



- (i) Write the equation for the reaction between **structure 1** and sodium hydroxide solution. State symbols are not required.



In this example the candidate has the correct molecular formula for structure 1, and two moles of sodium hydroxide on the left-hand side. However, the products are incorrect on the right-hand side, so only 1 out of 2 marks were obtained.



Practice writing equations for standard reactions of acids, e.g. with metals, alkalis and carbonates. Use unfamiliar carboxylic acids to check you understand the reaction and are not just memorising common equations.

Question 6 (d) (ii)

Over 50% of candidates realised that the reaction with structure 2 would only involve 1 carboxyl group, but less than 20% realised this would double the titre. By far the most common value suggested was 5.1 cm^3 . This suggests, as in part (c)(i), that a number believed the acid to be in the conical flask, with the sodium hydroxide solution in the burette. A smaller number stated that the volume would be unchanged, either because both structures had the same molar mass, or because they believed that the hydroxyl group in structure 2 would behave in the same way as the carboxyl group.

- (ii) Deduce the value that would have been obtained for the mean titre if the structural formula of X had been **structure 2**.
Justify your answer.

(2)

5.1 cm^3 would have been obtained as it would have only required 1 mole of NaOH not 2 as on structure 2 there is only one carboxylic acid group.



This example scored 1 mark for realising that structure 2 possesses a single carboxyl group.



Read procedural details for titrations twice, to make sure you realise which solution is in the burette, and which is in the conical flask.

Question 6 (e)

This was a clear-cut test of the ability to apply knowledge of organic qualitative tests and nearly 70% of responses were fully correct. The bromine test for the C=C double bond was especially well known. The test for the alcohol group was slightly more challenging, with a number thinking that the -OH group in the -COOH group would also react.

(e) The students could have identified the three structures using chemical tests.

Complete the table to show whether or not the suggested structures react with bromine water and when heated with acidified potassium dichromate(VI).

Use a tick (✓) if a reaction occurs.

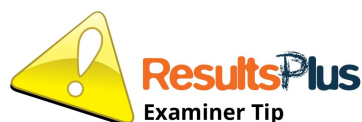
Use a cross (✗) if no reaction occurs.

(2)

| Structure | Test with bromine water | Test with acidified potassium dichromate(VI) |
|--|-------------------------|--|
| $\text{HOOCCH}=\text{CHCOOH}$ | ✓ | ✗ |
| $\text{HOCH}_2\text{CH}=\text{CHCH}_2\text{COOH}$ | ✓ | ✗ |
| $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$ | ✗ | ✗ |



This candidate clearly recalls the test for a C=C bond but seems less familiar with the reaction with acidified potassium dichromate(VII), perhaps not realising it could be used in this context to identify structure 2.



Practice looking at the structures of unfamiliar organic compounds and check which qualitative functional group tests would give a positive result. In addition make sure you can describe the positive result.

Question 6 (f) (i)

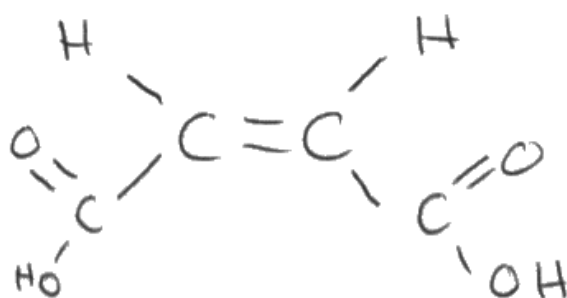
This presented little difficulty for the vast majority of candidates who were clearly well-taught in the drawing of *E*-/*Z*-isomers. Only a small minority needed to rely on the rescue mark, available for those who labelled the isomers the wrong way round. A small number presented diagrams with incorrect connectivity to the -COOH group, generally through careless drawing rather than a belief that the group bonded via an atom other than the carbon. In this context they were still awarded marks if the isomers were otherwise correct.

(f) The structure $\text{HOOCCH}=\text{CHCOOH}$ has two stereoisomers.

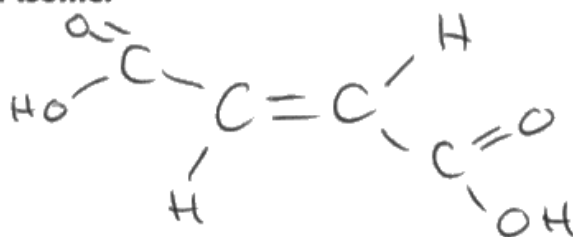
(i) Draw the structures of these stereoisomers.

(2)

E-isomer



Z-isomer



ResultsPlus
Examiner Comments

This example scored the 'rescue mark' of 1 out of 2, for the correct structures, incorrectly classified.



Use mnemonics to help you remember the idea of the positions of the groups in *E/Z* isomers. For instance, you can link the '*E*' to 'enemies' which are on opposite sides. In the *E*-isomer the two highest priority groups are on opposite sides of the C=C bond.

Question 6 (f) (ii)

Over 80% of candidates successfully explained that there was restricted rotation about the double bond. Many of these candidates, whilst not required by the question, explained why the rotation was restricted, by considering orbital overlap. Far fewer candidates managed to explain the other key criteria required for *E/Z* to occur, namely the **different** groups on each carbon of the double bond.

(ii) State why $\text{HOOCCH}=\text{CHCOOH}$ has *E/Z* isomers.

(2)

The space π bond in the C=C double bond restricts rotation of the groups either side of the bond so you get 2 isomers!



ResultsPlus
Examiner Comments

This example was routinely seen, with no attempt to go beyond the idea of 'restricted rotation'. Of those who did attempt to give further details, many used ambiguous statements such as 'they have the same group on either side', which, without further clarification, was not worth additional credit.



ResultsPlus
Examiner Tip

Make models of two different alkenes, one that can form *E/Z* isomers, and one that cannot. But-1-ene and but-2-ene, would make good examples. Look at each structure and compare the groups attached to the carbon atoms in the double bond, to help your explanation.

Question 7 (a)

Candidates who recognised this was a buffer calculation generally performed well on this question and 20% of the cohort achieved full marks. The award of the marks was spread relatively evenly, suggesting the problem discriminated effectively.

The most common errors were:

- not calculating the amount of HX remaining
- calculating the moles of HX remaining but then failing to consider the amount of X⁻ formed
- not noting the inclusion of sodium hydroxide and treating the problem as if the solution just contained a weak acid

A small number of candidates tried to use a version of the Henderson-Hasselbalch Equation. This is a perfectly acceptable strategy, but mistakes in recall led to errors. Perhaps use of the K_a expression leads to a better understanding of what is happening when a buffer solution forms.

7 This question is about weak acids.

- (a) A weak acid, HX, has a K_a value of $5.25 \times 10^{-5} \text{ mol dm}^{-3}$. A solution was formed by mixing 10.5 cm^3 of $0.800 \text{ mol dm}^{-3}$ dilute sodium hydroxide with 25.0 cm^3 of $0.920 \text{ mol dm}^{-3}$ HX(aq).

Calculate the pH of the solution formed, showing all your working.

(5)

$$[\text{H}^+] = 5.25 \times \frac{0.023}{6.034}$$

$$[\text{H}^+] = \del{5.25} 0.00014375$$

$$-\log[\text{H}^+] = \text{pH}$$

$$\text{pH} = 3.84 \text{ (3 s.f.)}$$

moles of NaOH:

$$\frac{10.5}{1000} \times 0.8 = 0.0084$$

moles of HX:

$$\frac{25}{1000} \times 0.92 = 0.023$$



ResultsPlus
Examiner Comments

Here the candidate has realised they need to consider both HX and X⁻ when determining the final pH. However, they have not realised that some of the HX will be neutralised by the acid, and have used the total amount of acid present initially to find pH, rather than the amount remaining after the addition of sodium hydroxide solution. Having made just this mistake they scored 4 marks.



Look out for questions where a weak acid and a strong alkali are mixed together. If the acid is in excess, the resultant mixture will be a buffer solution.

Question 7 (b)

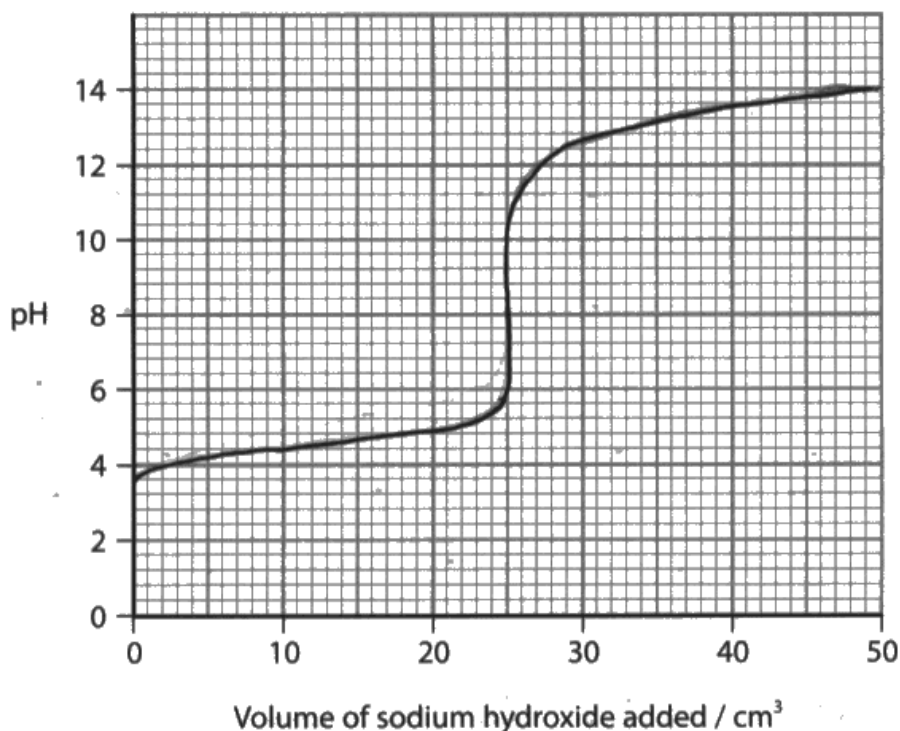
The examination team felt that many candidates knew the general shape of the titration curve in (b)(i) but struggled to incorporate the finer details required by this specific example. The two straightforward marks were use of an appropriate starting pH and showing a vertical section at the end point of 25 cm³. However the vertical section often covered a pH range more suitable to a strong-acid/strong alkali titration and the final pH tended to either stop short of 50 cm³, or was at a pH value of greater than 13.

In part (b) (ii), those who realised the significance of half-equivalence nearly always went on to make the link between pH and pK_a at this volume. A significant minority mistakenly thought that the pH should be determined at the equivalence point.

(b) (i) Propanoic acid, CH₃CH₂COOH, is a weak acid.

On the grid below, sketch the change in pH during the addition of 50.0 cm³ of 0.100 mol dm⁻³ sodium hydroxide solution to 25.0 cm³ of 0.100 mol dm⁻³ propanoic acid solution.

(4)



- X (ii) Explain how you would use the graph in (b)(i) to obtain the value of the acid dissociation constant, K_a, for propanoic acid. You are **not** expected to calculate this value.

(2)

At half the when half the volume added at the steep steep region is added, this is called the half equivalence point. The pH at this point is pK_a so ~~10~~ 10^{-pK_a} = K_a. ~~Rest~~



This candidate has shown the general shape required in (b)(i), with an appropriate starting pH and equivalence point. Unfortunately, the final pH is too high, so 1 mark was lost. The response in (b)(ii), correctly links the pH at half-equivalence to pK_a , so scores both marks.



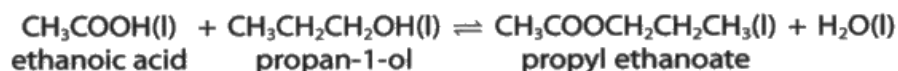
Learn the general shape of titration curves but be ready to use data in the question if necessary to help determine fine detail, such as the volume at equivalence, or starting and finishing values of pH.

Question 8 (a)

Over 70% of candidates appreciated the catalytic role of the acid in the esterification reaction. Those who didn't score nearly always stated its presence was solely to make the mixture acidic.

- 8 This question is about an experiment to determine the equilibrium constant, K_c , for an esterification reaction producing propyl ethanoate.

The equation for the reaction is



In an experiment to determine the equilibrium constant, K_c , the following steps were carried out.

- 6.0 cm^3 of ethanoic acid (0.105 mol), 6.0 cm^3 of propan-1-ol (0.080 mol) and 2.0 cm^3 of dilute hydrochloric acid were mixed together in a sealed boiling tube. In this pre-equilibrium mixture, there is 0.111 mol of water.
- The mixture was left for one week, at room temperature and pressure, to reach equilibrium
- The equilibrium mixture and washings were transferred to a volumetric flask and the solution made up to exactly 250.0 cm^3 using distilled water
- 25.0 cm^3 samples of the **diluted** equilibrium mixture were titrated with a solution of sodium hydroxide, concentration 0.200 mol dm^{-3} , using phenolphthalein as the indicator
- The mean titre was 23.60 cm^3 of 0.200 mol dm^{-3} sodium hydroxide solution.

(a) State the role of the hydrochloric acid in the esterification reaction.

(1)

To make it more acidic



ResultsPlus
Examiner Comments

This type of answer, as well as suggestions that the acid was simply there 'to add hydrogen ions', was the most common uncreditworthy response.



ResultsPlus
Examiner Tip

You do not need to be able to describe the mechanism of esterification reactions, so just remember the acid behaves as a catalyst.

- (ii) The 2.0 cm^3 of dilute hydrochloric acid contained 0.00400 mol of $\text{H}^+(\text{aq})$ ions. Use this and your answer to part (b)(i) to calculate the amount, in moles, of ethanoic acid present in the equilibrium mixture.

(1)

$$0.0472 - 0.0040 = 0.0432 \text{ moles}$$

- (c) (i) The initial mixture in the boiling tube contained 0.105 mol of ethanoic acid. Use your answer to (b)(ii) to calculate the amount, in moles, of ethanoic acid that reacted to form the ester in the equilibrium mixture.

(1)

$$0.105 - 0.0432 = 0.0618 \text{ moles}$$

- (ii) Use information given in the method, and your answer to (c)(i), to calculate the amounts, in moles, of propan-1-ol, propyl ethanoate and water that are present in the equilibrium mixture.

(3)

For acid - 0.0618 reacted

propam-1-ol ~~that~~ ^{in eqm} ~~was~~ = $0.08 - 0.0618$
eth = 0.0182

Moles of propan-1-ol at equilibrium 0.0182

Moles of propyl ethanoate at equilibrium 0.0618

Moles of water at equilibrium 0.0618



This example illustrates the most common error amongst more able candidates. The only error evident is in (c)(ii), where they have forgotten to take into account the 0.111 moles of water present from the catalyst in the equilibrium mixture.



Practice as wide a range of similar calculations as possible to improve your ability to see a route through this type of problem.

Question 8 (d)

Most candidates could construct the expression in (d)(i). Errors tended to either be the omission of a CH_2 group from either the ester or the acid or leaving out water completely from the numerator. The idea of 'volume cancels out' was prevalent in (d)(ii). A common idea was to state that all substances were in the same state, which was not worth credit on its own. Candidates found it much more difficult to get across the idea of the same number of molecules on both sides of the equation, with the result that sometimes it was difficult to judge whether they were describing an equal number of moles of each substance in the equilibrium mixture. The best answers often used mathematical manipulation of the units in the expression to make their point.

A wide variety of transferred errors were credited in (d)(iii), although a pleasing number got the precise answer as per the mark scheme.

The expression is correct in (d)(i) and both marks in (d)(iii) are obtained through transferred errors. However in (d)(ii) only the volume has been considered when explaining why the use of amount in moles is acceptable.

(d) (i) Write the expression for the equilibrium constant, K_c , for this reaction.



$$K_c = \frac{[\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}]}$$

(ii) Explain why it is possible, in this case, to calculate K_c using equilibrium amounts in moles, rather than equilibrium concentrations.

(2)

Because the equilibrium ~~const~~ ratio is equimolar, so the volumes cancel out

(iii) Calculate the value of K_c .

Give your answer to an appropriate number of significant figures.

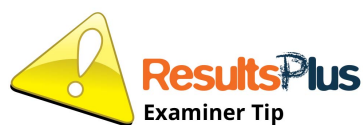
(2)

$$K_c = \frac{(4.72 \times 10^{-3})^2}{0.07528 \times 0.021}$$

$$K_c = 0.01407$$
$$= 14.1 \times 10^{-3}$$



The expression is correct in (d)(i) and both marks in (d)(iii) are obtained through transferred errors. However in (d)(ii) only the volume has been considered when explaining why the use of amount in moles is acceptable.



Where appropriate don't be afraid to use annotated mathematical expressions to make your point in an explanation.

Question 8 (e)

Although many candidates may have noticed this observation in their own experimental work, only a minority were able to suggest a reason why. Many seemed to get the two colours of phenolphthalein the wrong way round, and suggested that excess alkali caused the change to colourless. Relatively basic answers were able to score a mark for a realisation that the solution had become more acidic, although only 13% of candidates were able to link this to either the equilibrium mixture or absorption of carbon dioxide.

- (e) The pink colour of the phenolphthalein fades after the end-point of the titration has been reached.

Give a possible explanation for this observation.

(2)

Because it is an equilibrium reaction, so some of the propanoate and H_2O reacts to produce more ethanoic acid, making it acidic. With ethanoic acid removed, the backwards reaction is favoured.



This example, were the candidate has realised that mixture has become more acidic due to the backwards reaction between the ester and water, scored both marks.



Whenever you carry out any experimental work, keep careful notes not only of data but also any unusual observations, and subsequent deductions.

Question 8 (f)

Whilst a substantial minority appreciated the need to study the equilibrium over an extended time period, answers tended to lack precision and it was not always clear whether candidates wanted to leave the initial experiment running or begin collecting an entirely new set of data. Equally when considering how to use their findings, vague suggestions such as 'see if the results are the same' were common.

(f) Explain what you could do to confirm that one week is sufficient time for the mixture to reach equilibrium.

(2)

you can leave it for 1, 2, 3 weeks and compare the results to each other, if the results are the same (really close to each other) you know 1 week is sufficient or not.



ResultsPlus
Examiner Comments

This example scored 1 mark for the idea of leaving the experiment for a longer period of time. However to score the second a reference was needed to a measurable quantity, not just a generic reference to results.



ResultsPlus
Examiner Tip

After lab work, evaluate the procedure, to see if the method or data could be improved. This is especially important if you have planned part or all of the process yourself.

Question 8 (g)

This proved a successful end to the paper for many, with over 70% scoring at least 1 mark. Those who did not score nearly always suggested that K_c would decrease, and so were unable to justify their incorrect deduction.

- (g) A student repeated the experiment, but left the mixture in a water bath at 40 °C until equilibrium was reached.



Deduce the effect, if any, on this student's value for K_c compared with that obtained in part (d)(iii).

The equilibrium reaction would shift to the right-hand side and the value for K_c would be greater (2)



ResultsPlus
Examiner Comments

Here the candidate has correctly deduced the effect of the temperature change on the equilibrium constant, but has not linked the change to the endothermic nature of the forward reaction. One mark was awarded.



ResultsPlus
Examiner Tip

When justifying a change in K_c , remember to say why an equilibrium has moved in a particular direction.

Paper Summary

Based on their performance on this paper, candidates are offered the following advice:

- Read the stem of each question carefully to ensure you focus your response more precisely on what the question is asking.
- Take care to revise all the reactions of organic functional groups highlighted in the specification and practise using these in multi-step synthetic routes.
- When revising, work together with peers to evaluate experimental work. Consider the reasons for any unusual or unexpected observations.
- Label each step clearly, when you practice unstructured calculations. This will help embed approaches that you can then try to apply to unfamiliar questions.
- Make sure you can recognise when a buffer solution is formed, so you can tailor your approach to a problem appropriately.
- Don't be afraid to use balanced equations or annotated diagrams to support your answers.
- Use data given in a question to help draw more detailed titration curves.
- Practice processing data from experiments to determine equilibrium constants.

Grade Boundaries

Grade boundaries for this, and all other papers, can be found on the website on this link:

<http://www.edexcel.com/iwantto/Pages/grade-boundaries.aspx>

