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Examiners' report

CHEMISTRY A

H432

For first teaching in 2015

H432/03 Summer 2023 series

Version 1

Contents

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Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers is also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

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Paper 3 series overview

H432/03 is one of the three examination components for GCE Chemistry A. This largely synoptic component links together different areas of chemistry within different contexts, some practical, some familiar and some novel. To do well on this paper, candidates need to be comfortable applying their knowledge and understanding to unfamiliar contexts and be familiar with a range of practical techniques.

H432/03 is much more application based that the other two A Level Chemistry components, H432/01 and H432/02, which have a greater emphasis on knowledge and understanding of the assessment outcomes from the specification. H432/03 also contains more questions set in a practical context than H432/01 and H432/02.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• Displayed knowledge and understanding of important chemistry concepts, e.g.: ○ Question 2 (a) (ii): direct enthalpy calculation ○ Question 3: reactions of functional groups. • Performed standard calculations following a set method, e.g.: ○ Question 2 (a) (ii): calculation of an energy change using $mc\Delta T$ and subsequent ΔH determination ○ Question 5 (a): analysis of titration results ○ Question 6 (d): calculation of K_c using provided data ○ Question 6 (e): formula determination from percentage composition.	• Found it difficult to apply knowledge and understanding to unfamiliar situations, e.g.: ○ Questions 1 (d) (i), 2 (a) (ii) and 2 (c): writing equations for unfamiliar reactions using provided information ○ All parts of Question 4. • Found it difficult to use provided information and clues within the questions, especially within Question 4. • Showed unclear setting out of unstructured calculations, sometimes with unlabelled numbers scattered across the page, e.g.: ○ Questions 5(a) and 6 (d): calculation of titration results and K_c. • Showed a lack of basic knowledge and understanding of elements in the periodic table (Question 1).

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Question 1 (a)

1 This question is about the first 36 elements in the periodic table:

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

From these 36 elements **only**, write the symbol for the element(s) that fit each description.

(a) The **three** elements that, when in a molecule, can form hydrogen bonds with other suitable molecules.

.... **[1]**

Most candidates selected N, O and F, with other responses choosing other elements seemingly at random.

Question 1 (b)

(b) The element in Period 2 with the successive ionisation energies shown below.

Ionisation number	1st	2nd	3rd	4th	5th	6th	7th	8th
Ionisation energy / kJ mol^{-1}	1000	2251	3361	4564	7012	8496	27 107	31 671

.... **[1]**

Most successful candidates looked for the large difference between successive ionisation, usually shown by annotations below the table. The commonest incorrect response was F, the element after the large difference. Other incorrect responses were random.

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Question 1 (c)

(c) An element that is a solid at RTP with a simple molecular lattice structure.

.... **[1]**

Candidates found this question harder than Questions 1 (a) and (b) with S and P being the most common correct elements seen. As and Se were also allowed. Si was a common incorrect response.

Question 1 (d)

(d) The **two** elements with atoms containing five unpaired electrons.

.... **[2]**

Most candidates chose at least one of the two elements Cr and Mn, with Mn being the most common. Incorrect elements were usually other d block elements.

Erratum

Turn to **page 3** of the **question paper** and look at **question 1(d).**

At the end of the sentence insert the word "d" between the words "unpaired" and "electrons".

The end of the sentence should now read:

"…. containing five unpaired d electrons."

Question 1 (e)

(e) The element in Period 3 that exists in the solid state as a network of atoms bonded by strong covalent bonds.

.... **[1]**

Most candidates correctly chose Si. As with earlier questions, there seemed to be little pattern with incorrect elements.

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Question 1 (f)

(f) The p-block element in Period 3 that forms a compound with fluorine with octahedral molecules.

.... **[1]**

The answer S was well known, with SF_6 being the specification example of a compound with octahedral molecules.

Question 1 (g)

(g) The element that forms 1– ions most readily.

.... **[1]**

Although most candidates did choose F, a substantial number chose Br (most common), K and H, seemingly confused between gaining and losing electrons in forming ions.

Question 1 (h)

(h) The element with an average atomic mass of 1.244×10^{-22} g.

.... **[1]**

This question was a good discriminator. Candidates who scored the mark usually showed their mathematical working which led to As being chosen as the correct element. Other elements were seen randomly. More candidates omitted this part of Question 1 than other parts. With questions such as this, it is always better to guess as there is no penalty for an incorrect response.

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Question 2 (a) (i)

2 These questions are from different areas of chemistry.

(a) This question is about two salts of rubidium (atomic number 37): $RbClO_3$ and $RbClO_4$.

(i) The oxidation number of chlorine is different in the two rubidium salts, $RbClO_3$ and $RbClO_4$.

What is the name of $RbClO_4$?

.... **[1]**

Candidates had difficulty in naming a compound using Roman numerals for an element which can have different oxidation numbers. For the name of $RbClO_4$, many omitted the number entirely, showing just rubidium chlorate. Many inventive names such as rubidium chlorotetraoxide were seen. Some candidates wrote the correct VII before chlorate and many different Roman oxidation numbers were seen. Roman numerals' use in naming compounds is part of chemical nomenclature, included in the specification.

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Question 2 (a) (ii)

(ii) A student carries out an experiment to determine the enthalpy change of solution of $RbClO_3$ using the method below.

- A 2.00 g sample of solid $RbClO_3$ is added to water in a well-insulated container. The initial temperature is 23.0 °C.
- The mixture is stirred until all the $RbClO_3$ has dissolved. The final temperature is 21.5 °C. The final solution has a mass of 102 g.

Determine the enthalpy change of solution, $\Delta_{sol}H$, of $RbClO_3$ in $kJ\,mol^{-1}$.

Assume that the specific heat capacity of the solution is the same as that of pure water.

$\Delta_{sol}H$ ($RbClO_3$) = ... $kJ\,mol^{-1}$ **[3]**

This question was a good discriminator, producing marks across the whole 3 mark range. More successful candidates correctly calculated the energy change, moles of $RbClO_3$ and enthalpy change of solution. However, there were pitfalls for many including the following:

- calculating the energy change using the mass of water rather than the mass of the solution. This was despite the suppled information that the specific heat capacity of the solution is the same as for water. Candidates should understand that *m* in $mc\Delta T$ is the mass of the substance that produces ΔT
- calculating an incorrect value for the molar mass of $RbClO_3$. Instead of 169, this was often seen as 120.5 (using the atomic number of 37 for Rb, rather than the mass number of 85.5) and 185 (for $RbClO_4$)
- using values of *m* at the wrong stages in the calculation. e.g. 2 g with the energy change and 102 g or 100 g with the moles calculation
- calculating the correct numerical value for the enthalpy change of solution, but then placing a '–' sign in front of the value, despite ΔT being for a decrease in temperature.

Finally, as with all multi-step calculations, candidates are advised to use calculator values throughout. Any intermediate rounding introduces rounding errors in the final value. The final value can be rounded either to the significant figures demanded by the question or to the lowest number of significant figures used in the provided data.

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Question 2 (b)

(b) A student investigates the rate of a reaction that is 1st order with respect to hydrochloric acid, HCl(aq).

- The student carries out a reaction using 0.680 mol dm^{-3} HCl(aq). The initial rate is 9.52×10^{-4} mol dm^{-3} s^{-1}.
- The student dilutes a different sample of 0.680 mol dm^{-3} HCl(aq) with water. The pH of this diluted acid is 1.50.
- The student repeats the reaction using the same volume of this diluted acid.

Determine the initial rate using this diluted acid.

initial rate = ... mol dm^{-3} s^{-1} **[3]**

The marks for this calculation were much more polarised than the calculation in Question 2 (a).

Many candidates worked through the problem methodically to get an answer for the initial rate between 4.4×10^{-5} and 4.5×10^{-5} mol dm^{-3} s^{-1}. A substantial number of candidates worked out [H$^+$] using 10^{-pH} for 1 mark but were then unable to progress any further. This was a novel calculation, requiring candidates to develop their own strategy for its solution. Candidates who found this question difficult often attempted a solution based on stock weak acid calculation, using $[H^+]^2/[HA]$.

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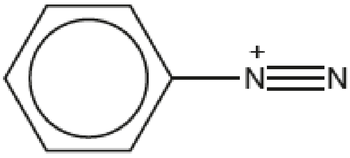
Question 2 (c)

(c) The benzenediazonium ion, shown below, is stable at temperatures below 10 °C.



Benzenediazonium

Above 10 °C, the benzenediazonium ion reacts with water to form phenol.

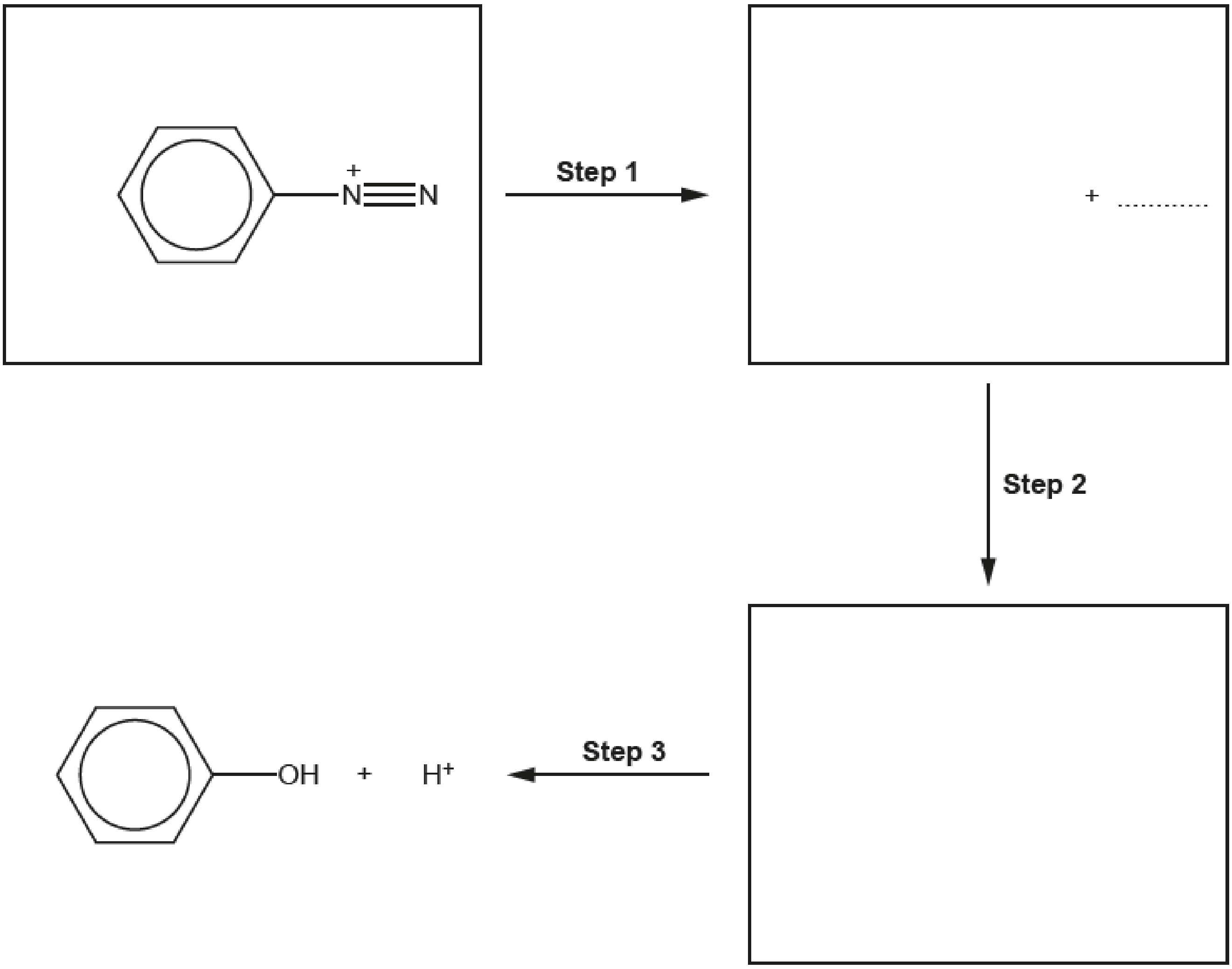
The reaction proceeds in a three-step mechanism.

Step 1 Elimination of nitrogen gas to form a carbocation.

Step 2 Nucleophilic attack by water.

Step 3 Proton loss to form the organic product.

Complete the boxes below with intermediates and curly arrows to show the mechanism for this reaction.



[4]

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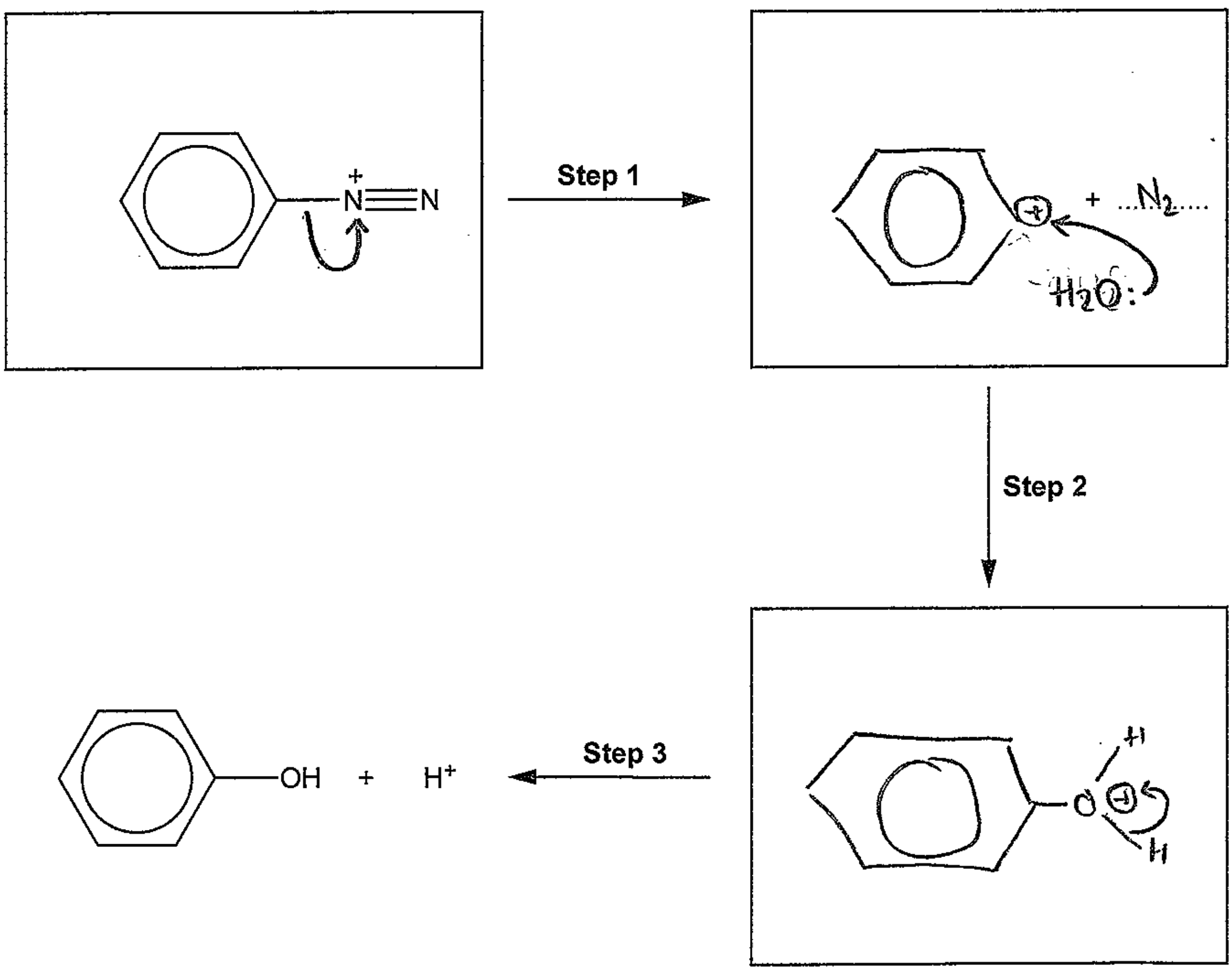
This question required candidates to apply their understanding of organic mechanisms to an unfamiliar reaction. The stem to the question includes important information and clues that should have guided candidates towards this unfamiliar mechanism, with the prompts for the three steps being critical. Many responses fell back to the familiar mechanism for electrophilic substitution, an approach that could not be credited.

This question discriminated very well but many candidates scored few marks.

Exemplar 1



This response has been included to show a candidate with an excellent understanding of the meaning of curly arrows and the importance of charges and dipoles. The prompts in the question are followed and the candidate has been given all four marks.

Notice how the curly arrows start either from a bond or from a lone pair. The candidate has also realised that the addition of H_2O produces a positively charged oxonium ion. Many candidates omitted the '+' charge or showed the curly arrow for loss of a proton going to a H atom rather than the O atom of water.

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Assessment for learning

In organic chemistry mechanisms, a curly arrow shows the movement of an electron pair and demonstrates the direction of electron flow in organic reactions.

A curly arrow must start from:

- A lone pair or negative charge and go to an atom to show where a bond **forms**
- A bond to show where a bond **breaks**.

In Question 2 (c), curly arrows:

- start from a C–N bond to form the intermediate carbocation by elimination of N_2
- go from a lone pair on the water O atom to the + charge of the carbocation
- go from an O–H bond to the + charge on the oxonium ion, losing a proton H^+ in the process.

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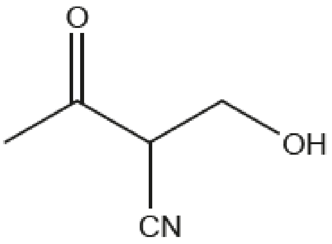
Question 3*

3* A chemist is investigating compound **A**, shown below, as a potential organic intermediate.



Compound A

Describe the type of stereoisomerism shown by compound **A** and suggest **three** reactions of compound **A**, one for each of the three functional groups using reagents of your choice.

In your answer, show stereoisomers of compound **A**, your chosen reactants and conditions, and the structures for the organic products produced.

Mechanisms and equations are **not** required. **[6]**

Overall, candidates performed well when answering this question. They were required to identify that compound **A** shows optical isomerism and to choose a reaction for each of the three functional groups. Candidates were also expected to use structures for the organic products.

To achieve the highest level of response, a description of optical isomerism should be accompanied by 3D diagrams of the optical isomers.

Optical isomerism was usually identified, with associated diagrams with almost all candidates identifying the chiral centre. Most attempted 3D diagrams but candidates do need to take care that the groups attached to the chiral C atom are those in compound A and that no parts of chains are omitted. Optical isomers do also require use bold and dashed wedges to be used.

Most candidates showed good knowledge and understanding of reactions for the three functional groups.

- For the primary alcohol, most chose $H^+/Cr_2O_7^{2-}$, with distil (→ aldehyde) or reflux (→ carboxylic acid); a significant number chose a concentrated acid (→ alkene) or Br^-/H^+ (→ haloalkane)
- For the ketone, most chose $NaBH_4$ (→ secondary alcohol)
- For the nitrile, most chose either H_2/Ni (→ amine) or H^+(aq) (→ carboxylic acid).

Clear diagrams of the products were usually seen although many omitted a CH_2 from the amine branch for hydrolysis of the nitrile or an extra CH_2 in the aldehyde or carboxylic acid branch from oxidation of the primary alcohol.

Some candidates chose 2,4-DNP for a reaction of the ketone and treated the question as one requiring tests, and then proving that the compound was a ketone from no reaction with Tollens' reagent. The question asked for the organic product and the 2,4- DNP product is beyond the demands of this specification (although this was seen very rarely). Candidates adopting this reaction were limiting the extent of their response and candidate should have considered this requirement before selecting 2.4-DNP.

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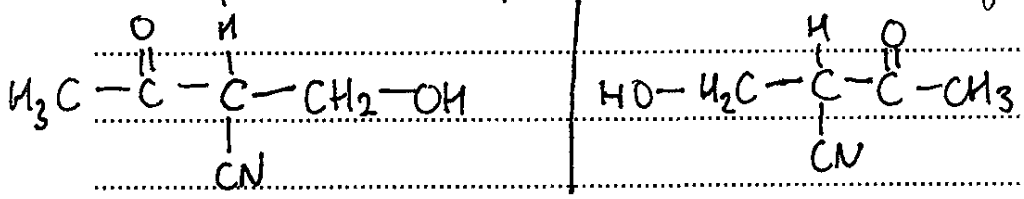
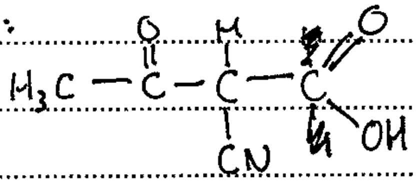
Exemplar 2

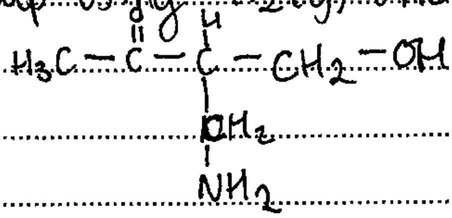
The type of stereoisomerism shown by A is optical isomerism as it has a chiral centre with 4 different groups attached, so it forms non-superimposable mirror images.



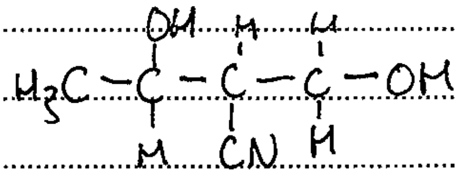
The first reaction of A is oxidation of the primary alcohol group under reflux to form a carboxylic acid, using the reagents $K_2Cr_2O_7$ / H_2SO_4. The organic product formed is:



The second reaction of A is hydrogenation of the nitrile to form an amine group using H_2(g) and a Nickel catalyst. This forms:



A third reaction of A is the reduction of the ketone group using $NaBH_4$ to form a secondary alcohol. This forms:



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This exemplar shows a good response that lacks 3D diagrams for the optical isomers. The candidate has clearly given reagents and conditions and has shown the organic products. In the response, you can see that the candidate initially showed an extra CH_2 in the –COOH branch, and a mistake in the amine branch.

The absence of 3D structures limits the response to Level 2 and 4 marks have been awarded for choosing correct and relevant reagents and conditions, and for the clear communication of the structures.

Question 4 (a)

4 Tutton's salts are 'double salts' with the formula $\mathbf{X}_2\mathbf{Y}(\mathbf{Z}O_4)_2 \cdot 6H_2O$.

A Tutton's salt contains two cations: $\mathbf{X}^+$ and $\mathbf{Y}^{2+}$.

- $\mathbf{X}^+$ can be an ion of the Group 1 elements K, Rb, Cs or Fr, or an ammonium ion.
- $\mathbf{Y}^{2+}$ can be a 2+ ion of magnesium or an ion of most of the transition elements in Period 4.
- **Z** can be S or Cr.

$(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$ is an example of a Tutton's salt.

(a) Predict the formula of a Tutton's salt containing different ions from $(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$.

.... **[1]**

Question 4 assesses candidates' ability to apply their chemical knowledge and understanding from different parts of the specification in a novel context. Information is supplied throughout the question, and clues are sometimes presented to candidates.

In part (a), candidates are introduced to Tutton's salts and are given an example of a Tutton's salt that forms the context of the whole question. A candidate needs to apply the information in the bullet points to predict the formula of a different Tutton's salt.

This question discriminated extremely well across different abilities and highlighted that some candidates struggled to use supplied information. This was repeated in other parts of Question 4.

Just over half the candidates gave a correct formula from the information. Some candidates did not choose one of the acceptable ions shown in the first and second bullet points, and many chose S rather than Cr, despite S being in the supplied Tutton's salt; a significant number omitted the $\cdot 6H_2O$.

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Question 4 (b) (i)

(b) A student prepares a sample of the Tutton's salt, $(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$ using the method shown below.

Step 1 Dissolve 0.025 mol of ammonium sulfate and 0.025 mol of hydrated copper(II) sulfate, $CuSO_4 \cdot 5H_2O$, in water and make up to 50 cm^3.

Step 2 Boil the resulting mixture for 2 minutes and allow to cool.

Step 3 Allow the solvent to evaporate slowly. Pale blue crystals of the Tutton's salt form.

(i) What masses are needed of ammonium sulfate and $CuSO_4 \cdot 5H_2O$?

mass of ammonium sulfate .... g

mass of $CuSO_4 \cdot 5H_2O$ .... g
[2]

This question required candidates to calculate the masses of two reactants that could be used to prepare a sample of the Tutton's salt. Candidates were supplied with the formula of hydrated copper(II) sulfate but not the formula of ammonium sulfate, so candidates needed to work out its formula from ions that candidates are expected to be able to recall from the specification.

Just over half the candidates obtained both correct masses but many obtained just one correct mass, usually that of $CuSO_4 \cdot 6H_2O$.

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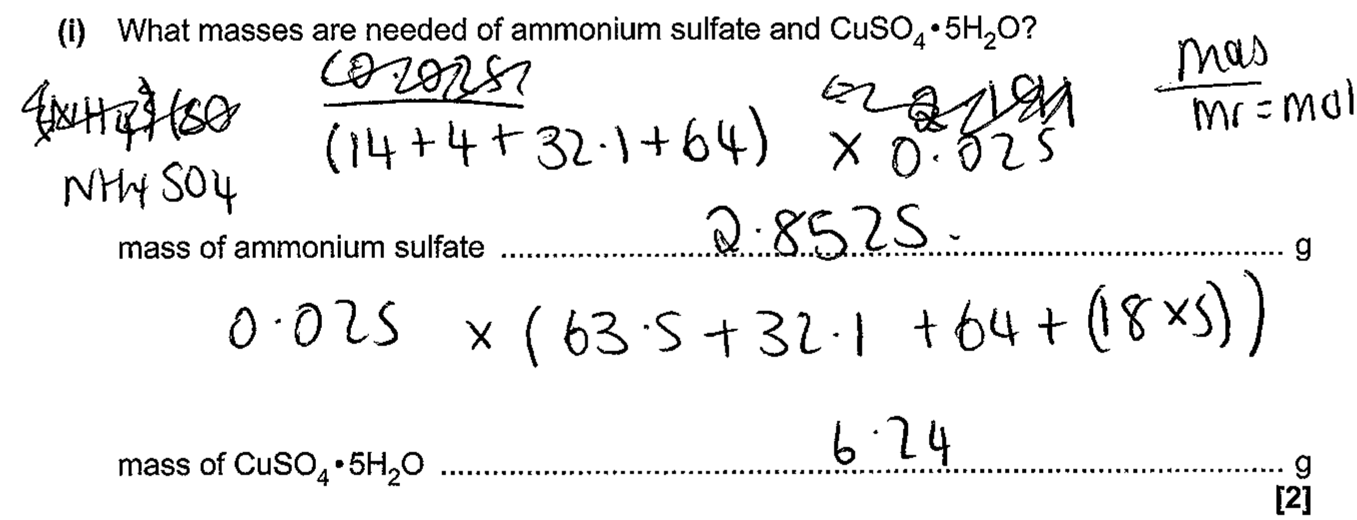
Exemplar 3



(i) What masses are needed of ammonium sulfate and $CuSO_4 \cdot 5H_2O$?

NH4 SO4 — $\frac{mass}{Mr} = mol$ — $(14 + 4 + 32.1 + 64) \times 0.025$

mass of ammonium sulfate .... 2.8525 .... g

$0.025 \times (63.5 + 32.1 + 64 + (18 \times 5))$

mass of $CuSO_4 \cdot 5H_2O$ .... 6.24 .... g

[2]

This exemplar shows a typical response with the incorrect formula of ammonium sulfate clear shown by the candidate, resulting in the incorrect mass of 2.8525 g. This incorrect formula and mass were seen in many responses and, from the initial crossings out, this candidate is clearly confused about how to tackle this simple mole calculation. The incorrect answer of 2.85 g was seen on almost as many scripts as the correct answer of 3.30 g.

The moral is that candidates need to learn the formula and charges of the common ions encountered in chemistry. The comments here apply also to Question 6 (b) (i), where formulae need to be written using ions listed in the specification.

Question 4 (b) (ii)

(ii) In **Step 3**, why does the student allow the solvent to evaporate and **not** boil off all the solvent in **Step 2**?

....

....

.... **[1]**

The majority of candidates did not answer this question correctly. Candidates were expected to refer back to the formula of the Tutton's salt, spot that there was water of crystallisation present, and that this would be lost if all the solvent was boiled off. Many responded vaguely in terms of decomposition or formation of larger crystals but a mark was only awarded if there was a definite link to the water contained within the crystals.

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Assessment for learning

In the specification, Section 2.1.2a states the following:

(a) the writing of formulae of ionic compounds from ionic charges, including:

(i) prediction of ionic charge from the position of an element in the periodic table

(ii) recall of the names and formulae for the following ions: NO_3^{-}, CO_3^{2-}, SO_4^{2-}, OH^{-}, NH_4^{+}, Zn^{2+} and Ag^{+u}.

This section will be studied at the start of the 2 year course. Candidates need to be confident with using these common formulae. For success in chemistry, these ions must be learnt.

Question 4 (c) (i)

(c) The student dissolves their Tutton's salt in water. A pale blue solution forms.

The student carries out two tests on this aqueous solution.

(i) The student adds an excess of aqueous ammonia to their aqueous solution of Tutton's salt. A deep blue solution forms.

The complex ion responsible for the deep blue solution has a molar mass of $167.5\,g\,mol^{-1}$.

Suggest the formula of this complex ion.

.... **[1]**

This reaction of copper(II) ions with aqueous ammonia and the formula of the complex ion formed are part of the specification. Within this novel context, the molar mass had been provided as a clue.

Less than half the candidates correctly gave the correct formula and it was noticeable how well this part discriminated across abilities. This was another example of many candidates being unable to apply their knowledge and understanding to a novel context.

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Question 4 (c) (ii)

(ii) The student adds NaOH(aq) to the aqueous solution of Tutton's salt and warms the mixture.

A precipitate and a gas are formed.

Write the formulae of the precipitate and gas and suggest a test that could confirm the identity of the gas.

Formula of precipitate ....

Formula of gas ....

Test to confirm the identity of the gas ....

....

.... **[3]**

Addition of NaOH(aq) to the Tutton's salt results in two reactions: precipitation of copper(II) hydroxide and a reaction of an ammonium ion, used to show its presence as a qualitative test. As with Question 4 (c) (i), this part discriminated very well with many candidates able to be rewarded with some of the marks.

The formula of copper(II) hydroxide, as $Cu(OH)_2$ or $Cu(OH)_2(H_2O)_2$ were both acceptable. This was correct more often than the responses related to the ammonium ion.

The formula of the gas formed in the reaction of NaOH(aq) with the ammonium ion caused problems, with NH_3 and its subsequent test with moist indicator turning blue seen much less than the reaction of Cu^{2+}(aq) ions. Hydrogen (the 'squeaky pop test) and oxygen (relighting a glowing split) were common incorrect responses.

This was another question in which referring back to the formula of the Tutton's salt would have revealed important clues.

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Question 4 (c) (iii)

(iii) How could the student carry out a test-tube test to confirm the anion in the Tutton's salt?

....

....

....

.... **[2]**

Th final part of Question 4 required candidates to identify the anion in the Tutton's salt as sulfate, and to recall that Ba^{2+} ions is used for the sulfate test to form a white precipitate. Any soluble barium compound was credited with barium chloride and nitrate being the commonest seen.

As with earlier parts, this part discriminated very well. Most candidates who knew that barium ions were needed also collected the mark for the white precipitate observation. Over half the candidates did not score here, the most common errors being to repeat the test for the ammonium ion, or to use silver nitrate, clear confusion with the halide test.

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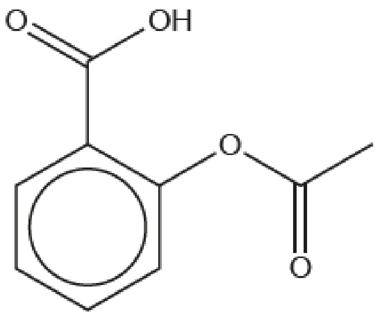
Question 5 (a)

5 Aspirin tablets are used for pain relief.

The structure of aspirin is shown below.



Aspirin

(a) A student uses the reaction of aspirin with cold NaOH(aq) to determine the mass of aspirin in **one** tablet.

In this reaction, 1 mol of aspirin reacts with 1 mol of cold NaOH(aq).

The student's method is outlined below.

Step 1 The student reacts **three** aspirin tablets with 100 cm^3 of 0.500 mol dm^{-3} NaOH(aq). The NaOH is in excess. A colourless solution forms.

Step 2 The colourless solution from **Step 1** is made up to 250.0 cm^3 with distilled water.

Step 3 A 25.00 cm^3 sample of the diluted solution from **Step 2** is titrated with 0.200 mol dm^{-3} HC*l*(aq) in the burette.

The HC*l*(aq) reacts with excess NaOH(aq) that remains in **Step 1**:

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

The student repeats the titration to obtain concordant (consistent) titres.

Titration results
The trial titre has been omitted.

The burette readings have been read to the nearest 0.05 cm^3.

	1	2	3
Final reading / cm^3	23.10	45.40	27.40
Initial reading / cm^3	0.00	23.10	5.00

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Analysis of results
From the results, the student can determine the following.

1. The amount, in mol, of excess NaOH(aq) that remains after the reaction of aspirin with NaOH(aq).

2. The amount, in mol, of NaOH(aq) that reacted with the aspirin.

Use the results to determine the mass, in mg, of aspirin in **one** aspirin tablet.

mass of aspirin in **one** tablet = ... mg **[6]**

Compared with the application based Question 4, candidates answered this stock titration calculation well. Almost all candidates determined that the mean titre was 22.35 cm^3 and went on to calculate the number of moles of HCl as 4.47×10^{-3} mol. Most scaled this value by 10 to determine the moles in 250 cm^3.

Most candidates then used the initial moles of HCl to determine the moles of aspirin in the 3 tablets as 5.30×10^{-3} moles. A significant number omitted this stage but they were able to be credited for the next stage of calculation using a correct method. Consequently over half the candidates were awarded 5 or 6 marks for this stock calculation.

Question 5 (b) (i)

(b) Aspirin reacts with hot NaOH(aq), under reflux.

(i) Draw a labelled diagram of suitable apparatus for reflux.

[2]

Most candidates drew a diagram that looked like a vertical condenser above a flask. The quality of the diagrams was not very good. Candidates then needed to label their diagram.

Errors included a bung or thermometer inserted at the top of the condenser and water flowing the wrong way in the condenser. For labelling, candidates were expected to use scientific terminology. Responses such as 'condensation tube' and vague terms such as 'flask' were not credited. These labels were often omitted.

A significant number drew a set up for distillation instead of reflux.

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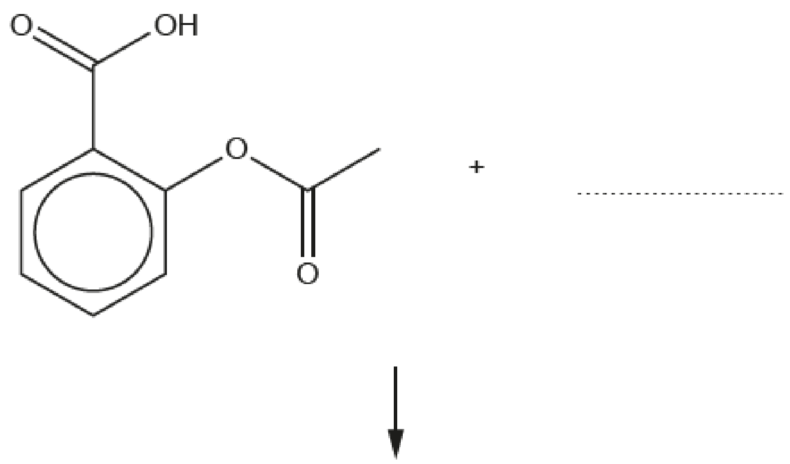
Question 5 (b) (ii)

(ii) In this reaction, 1 mol of aspirin reacts with 3 mol of hot NaOH(aq).

Complete the equation for the reaction of aspirin with an excess of hot NaOH(aq).

Show structures for organic compounds.



[3]

This question was the hardest part of Question 5 and about half the candidates were not given any marks. Some drew the sodium carboxylate salt of aspirin structure, leaving the ester link intact.

A large number of candidates realised that the ester would be hydrolysed. Sometimes the sodium salts were often not shown and, even they were shown, the phenol group was often shown intact.

The hardest mark was the formation of $2H_2O$ and a large number of candidates showed the more intuitive but incorrect '$3H_2O$' instead.

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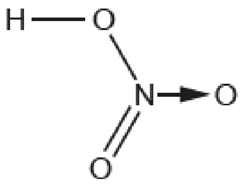
Question 6 (a)

6 This question is about nitric acid, hydrochloric acid and sulfuric acid.

(a) Nitric acid has 2 single covalent bonds, 1 double covalent bond and 1 dative covalent bond as shown below.



Nitric acid

Predict the H–O–N and O–N–O bond angles in nitric acid.

Explain your reasoning.

....

....

....

....

....

.... **[4]**

This question required candidates to apply their knowledge and understanding of bond angles and electron pair repulsion in a novel context. The best candidates rose to this challenge, securing all four marks for correct bond angles and explanations in terms of the numbers of bonded and lone pairs.

The 104.5º and 120º were commonly seen and high scoring candidates provided excellent reasoning. The best explanation for 120º was in terms of three bonding regions and no lone pairs.

Lower scoring responses often reasoned that bond angles are determined by lone pairs repelling the atoms, with the role of bonding pairs often being ignored.

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Question 6 (b) (i)

(b) Dilute nitric acid reacts with aluminium oxide to form a solution of aluminium nitrate.

(i) Write an equation for this reaction.

.... **[2]**

Candidates were required to write a balanced equation for an acid–base reaction. As with Question 4 (b) (ii), candidates needed to write formulae from what should have been common ions, but the formulae for aluminium oxide and aluminium nitrate were often incorrect.

In the equation, the reactants and products were sometimes unbalanced, or incorrectly balanced. A common error was H_2 instead of H_2O as the second product.

The question was an excellent discriminator.

Question 6 (b) (ii)

(ii) The solution contains nitrate ions, NO_3^-.

Draw a 'dot-and-cross' diagram for the NO_3^- ion.

Use a different symbol for the extra electron.

[2]

Candidates were expected to use the displayed formula of nitric acid to identify that the central N atom had one double bond, one covalent bond and one dative covalent bond. This information then gave the strategy for the dot and cross diagram.

Although virtually all candidates attempted the dot and cross diagram, only about a quarter of candidates could be credited with a meaningful response. The key was to use nitrogen's 5 outer shell electrons and to combine these with 3 oxygen electrons or 2 oxygen electrons and the extra electron. Then the remaining oxygen electrons could be added, taking care that there were 6 around out O atom. Finally the extra electron would need to be placed in an octet gap.

Many candidates showed just 4 nitrogen electrons and this approach resulted in no marks. Other common errors included 3 double bonds around the N atom, and a lone pair on the N atom.

This dot and cross diagram discriminated between higher scoring candidates extremely well.

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Question 6 (c) (i)

(c) A mixture of concentrated nitric and hydrochloric acid is called 'aqua regia'. Aqua regia can dissolve gold.

The reaction of aqua regia with gold is a redox reaction which forms chlorauric acid, $HAuCl_4$.

(i) Balance the half-equation for the oxidation process in this reaction.

Au + ...HC*l* ⟶ ....H^+ + $AuCl_4^-$ + ...e^-

[1]

Most candidates added '4' before HC*l* and H^+, and 3 before e^- to gain this mark. Where an error was made, it invariably was with the number of electrons, usually $4e^-$.

Question 6 (c) (ii)

(ii) In the reduction process in this reaction, HNO_3 and H^+ react together to form 2 oxides: **X** (M_r = 30) and **Z** (M_r = 18).

Determine the formulae of **X** and **Z** and write the half-equation for this reduction.

X = ...

Z = ...

half-equation .... **[3]**

Almost all candidates identified **X** and **Y** as NO and H_2O respectively, but the equation proved to be much more testing. Some candidates were careless, showing NO and H_2O the wrong way round (credited with 1 out of these 2 marks) or with charges.

For the equation, candidates needed to consider the oxidation number change of N from +5 to +2, This should have naturally led to $3e^-$ being added on the left-hand side. Many candidates omitted the electrons entirely. Some did add $3e^-$ but on the right. This suggests that candidates would benefit with practising the construction of half equations.

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Question 6 (d)

(d) In the UK, most sulfuric acid, H_2SO_4, is manufactured by the Contact process.

One stage in the Contact process involves the equilibrium between sulfur dioxide, oxygen and sulfur trioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

This equilibrium is investigated:

Step 1 5.82×10^{-2} mol of SO_2 is mixed with 7.40×10^{-2} mol of O_2 in a $2.00\,dm^3$ container.

Step 2 The container is sealed and allowed to reach equilibrium at constant temperature.

Step 3 At equilibrium, 5.20×10^{-2} mol of SO_3 is formed.

Determine the equilibrium concentrations and calculate K_c, including units.

K_c = ... units .... **[5]**

As with the stock titration calculation in Question 5 (a), candidates were much more comfortable in tackling a stock K_c calculation. These have been assessed in several previous H432/01 exams and many excellent responses were seen, gaining all 5 marks. Error carried forwards allowed for an early slip in the calculation to be credited subsequently for a correct method.

The hardest part of the calculation was the initial determination of the equilibrium moles and concentrations. The equilibrium moles of O_2 was the main error, presumably from the 2:1:2 stoichiometry. Some candidates multiplied by 2 instead of dividing by 2 for the concentration. A common error was for candidates to use a partial pressure approach. These errors lost intermediate marks by credit could then be awarded for using the correct K_c expression to generate a K_c value with correct units. Very few candidates did not gain any marks.

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Question 6 (e)*

(e)* Three reactions involving sulfuric acid are shown below.

Reaction 1
Dilute sulfuric acid is reacted with nickel(II) hydroxide to form a green solution.

The solvent is allowed to evaporate leaving hydrated crystals of compound **D**, with the percentage composition by mass: Ni, 22.33%; S, 12.20%; O, 60.87%; H, 4.60%.

Reaction 2
Concentrated sulfuric acid is reacted with hydrogen bromide, HBr, to form three products:

- an element which exists as diatomic molecules
- a gaseous compound **E**
- a liquid.

At RTP, 1.00 dm^3 of compound **E** has a mass of 2.67 g.

Reaction 3
Concentrated sulfuric acid acts as a catalyst when 2-hydroxypropanoic acid reacts to form compound **F** (M_r = 144).

In this reaction, 2 mol of 2-hydroxypropanoic acid forms 1 mol of compound **F** and 2 mol of water.

Identify compounds **D**, **E** and **F** and construct equations for the reactions.

Show structures for any organic compounds. **[6]**

This level of response question required candidates to interpret three pieces of information to identify 3 unknown chemicals, linked by three reactions of sulfuric acid. Levels were assigned based on identifying the three unknowns and writing equations for the reactions. The 3 reactions were tiered in difficulty with the cyclic structure for compound **F** being the most difficult.

The question discriminated extremely well, with comparatively few candidates not scoring any marks.

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Exemplar 4

Show structures for any organic compounds. [6]

1: Ni S O H

$\frac{22.33}{58.7}$ $\frac{12.2}{32.1}$ $\frac{60.87}{16}$ $\frac{4.6}{1}$

= 0.3804 = 0.38006 = 3.804375 = 4.6

1 : 1 : 10 : 12

$NiSO_{10}H_{12}$ $Ni(SO_4) \cdot 6H_2O$

$4H_2O + H_2SO_4 + Ni(OH)_2 \rightarrow NiSO_4 \cdot 6H_2O$

D

2: $H_2SO_4 + 2HBr \rightarrow Br_2 + SO_2 + 2H_2O$

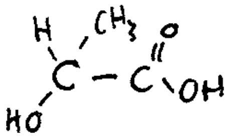
$1 dm^3$ vol = mol × 24

$\frac{1}{24}$ = mol

mol = 0.04167

Mr = $\frac{2.67}{0.04167}$ = 64.08

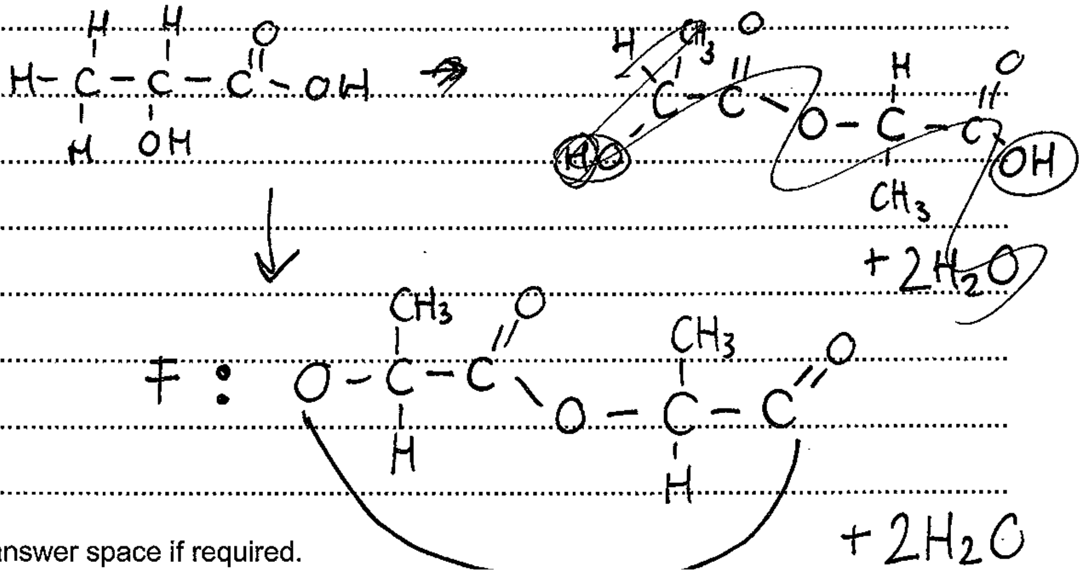
SO_2 = 64.1 E = $SO_{2(g)}$



C

21

3: 2



Additional answer space if required.

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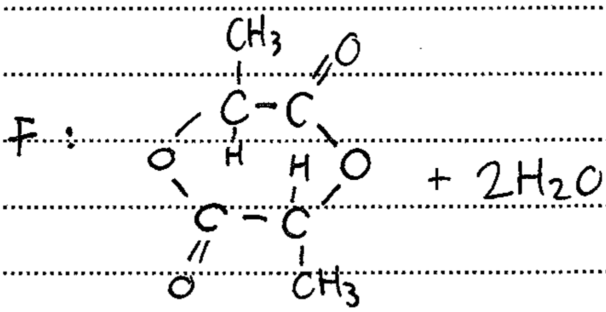

This exemplar shows an excellent response which was awarded Level 3 and 6 marks.

The crossing out shows how the candidate progressively solved the problem. Despite the crossing out, working is shown throughout, and the presentation of the response is very clear.

For reaction 1, the candidate initially made an error in the stock formula determination calculation. Notice that the candidate crossed out their initial values and wrote them afresh. This approach is recommended. as changing incorrect numbers can lead to ambiguous numbers.

In reaction 2, the candidate comfortably identified compound **E** from its molar mass and wrote a balanced equation for this reaction.

For reaction 3, you can see how the candidate's thought developed during the solve. They initially went for a straight chain structure and then worked out that there must be a cyclic structure. They finally show the cyclic diester as a conventional structural (based on glucose?), and with a balanced equation.

This was an excellent response of a high-ability candidate and shows what a well-prepared candidate is capable of achieving.

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