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Examiners' report

CHEMISTRY A

H432

For first teaching in 2015

H432/03 Summer 2018 series

Version 1

www.ocr.org.uk/chemistry

Contents

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. 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 can be downloaded from OCR.

Subject information update

Candidates sitting their A Level Chemistry examinations this summer may have noticed they had additional line space to write their answers to level of response questions. We made this change having noticed in previous examination series that some candidates were writing answers that were longer than could fit in the space provided. The extra line space was clearly labelled as additional, and was only there should candidates have required it. There is not an expectation that candidates will necessarily need to use the extra space and we would encourage teachers to continue reminding candidates about the importance of writing concise answers to questions. We will continue to make the extra line space available for level of response questions in future exam series too.

Paper H432/03 series overview

- H432/03 is one of the three examination components for the new revised A Level examination 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.

Candidate performance

Candidates who did well on this paper generally did the following:

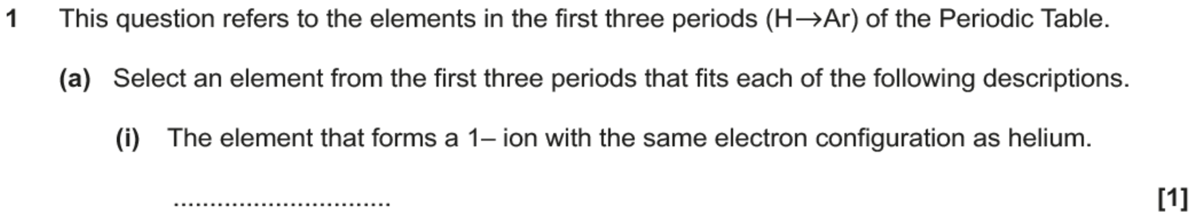
- Performed standard calculations following the required rubric (e.g. clear working, units, significant figures) relating to rate from a volume/time graph (2a(i)), gas and solution volumes and stoichiometry (2a(ii)), an unstructured titration calculation (3b(ii)), enthalpy changes (5a), equilibrium quantities and K_c calculation (5b(v)).
- Produced clear and concise responses for Level of Response questions: 4(b)(ii), 6(b).
- Drew clear diagrams for structures: 3a, 5b(iii), 6b(iv).
- Constructed and balanced equations for unfamiliar reactions: 2b, 2c(i).
- Drew clear mechanisms with good use of curly arrows, lone pairs and charges: 4a(ii), 6b.
- Applied knowledge and understanding to questions set in a novel context.

Candidates who did less well on this paper generally did the following:

- Found it difficult to apply what they had learnt to unfamiliar situations.
- Produced responses that lacked depth, and were often rambling and peripheral to what had been asked, sometimes simply repeating information provided. e.g. 1b, 2c, 4b(ii), 6b.
- Showed poor setting out of unstructured calculations, e.g. 2a(i), 3b(ii), 5a, 5b(v).
- Lacked precision in balancing equations, particularly charges on either side of the equation, e.g. 2b, 2c(i), 5b(ii).

There was no evidence that any time constraints had led to a candidate underperforming or of scripts where there were no responses to many questions.

Question 1(a)(i)



1 This question refers to the elements in the first three periods (H→Ar) of the Periodic Table.

(a) Select an element from the first three periods that fits each of the following descriptions.

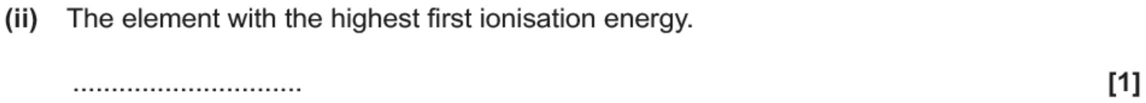
(i) The element that forms a 1– ion with the same electron configuration as helium.

.... **[1]**

Most candidates were credited this straightforward mark and identified that hydrogen would gain an electron to form a 1– ion. Some candidates opted for lithium, able to form an ion with the same electron configuration as helium, but with a 1+ rather than a 1– charge.

Candidates are recommended to look closely at the requirements of the question set.

Question 1(a)(ii)



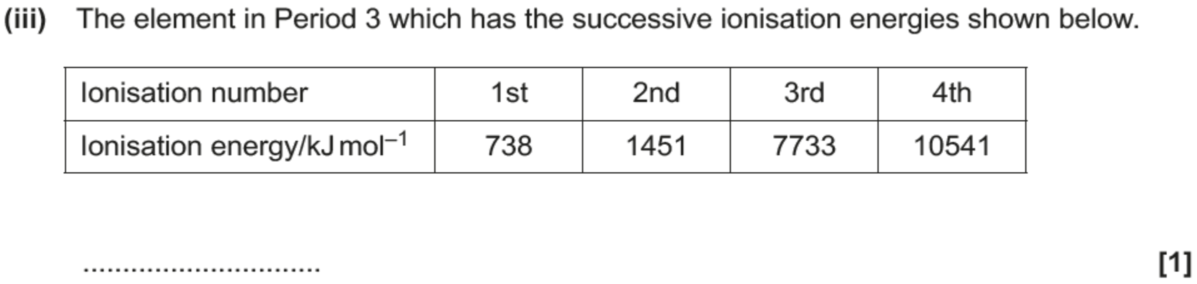
(ii) The element with the highest first ionisation energy.

.... **[1]**

This part required candidates to recall their knowledge of trends in first ionisation energy. Candidates found this part harder than 1(a)(i) with only the higher ability candidates choosing the correct response of 'helium'.

Many candidates instead chose another noble gas, with neon and argon commonly seen. Other common incorrect responses were hydrogen and fluorine.

Question 1(a)(iii)



(iii) The element in Period 3 which has the successive ionisation energies shown below.

Ionisation number	1st	2nd	3rd	4th
Ionisation energy/kJ mol^{-1}	738	1451	7733	10541

.... **[1]**

Most candidates did correctly select magnesium, but many other elements were seen, especially aluminium, silicon, beryllium and calcium.

To identify the element's group, candidates needed to analyse the data to find the large increase in ionisation energy corresponding to a change in shell. From the responses, some candidates did not make use of 'Period 3' in the stem.

Question 1(a)(iv)

(iv) The element which forms a compound with fluorine that has octahedral molecules.

.... **[1]**

Most candidates selected sulfur as the correct response, recalling their knowledge of molecular shapes encountered early in the course. There was no real pattern for incorrect responses, suggesting that they were guesses.

Question 1(a)(v)

(v) An element which reacts with water to form an acidic solution.

.... **[1]**

Most candidates chose the correct response of chlorine, although hydrogen was a common incorrect response, presumably by linking to the acidic properties of H^+ ions. Other candidates focused on 'reacts with water' and chose sodium (which does form a solution with water, but on that is alkaline rather than acidic).

Question 1(a)(vi)

(vi) The element **X**, which forms a compound with hydrogen, $\mathbf{X}H_3$, with a molar mass of $34.0\,g\,mol^{-1}$.

.... **[1]**

Almost all candidates correctly responded with phosphorus and this was the easiest part of 1(a).

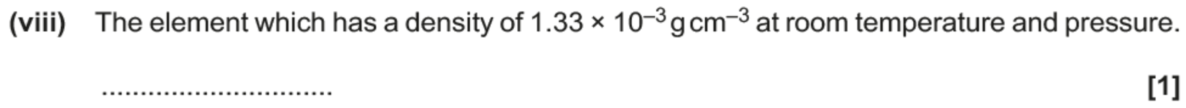
Question 1(a)(vii)

(vii) An element which forms a compound with hydrogen in which the element has an oxidation number of –4.

.... **[1]**

Most candidates correctly selected carbon. From their A Level studies, candidates would expect hydrogen to have an oxidation number of +1 and to form compounds with carbon (CH_4) and silicon (SiH_4) in which the element has an oxidation number of –4. Although hydrogen is actually slightly less electronegative than carbon, hydrogen is slightly more electronegative than silicon. Therefore, in the case of SiH_4, silicon has an oxidation number of +4. A response of silicon still indicates a correct understanding of oxidation number rules and was also credited

Question 1(a)(viii)

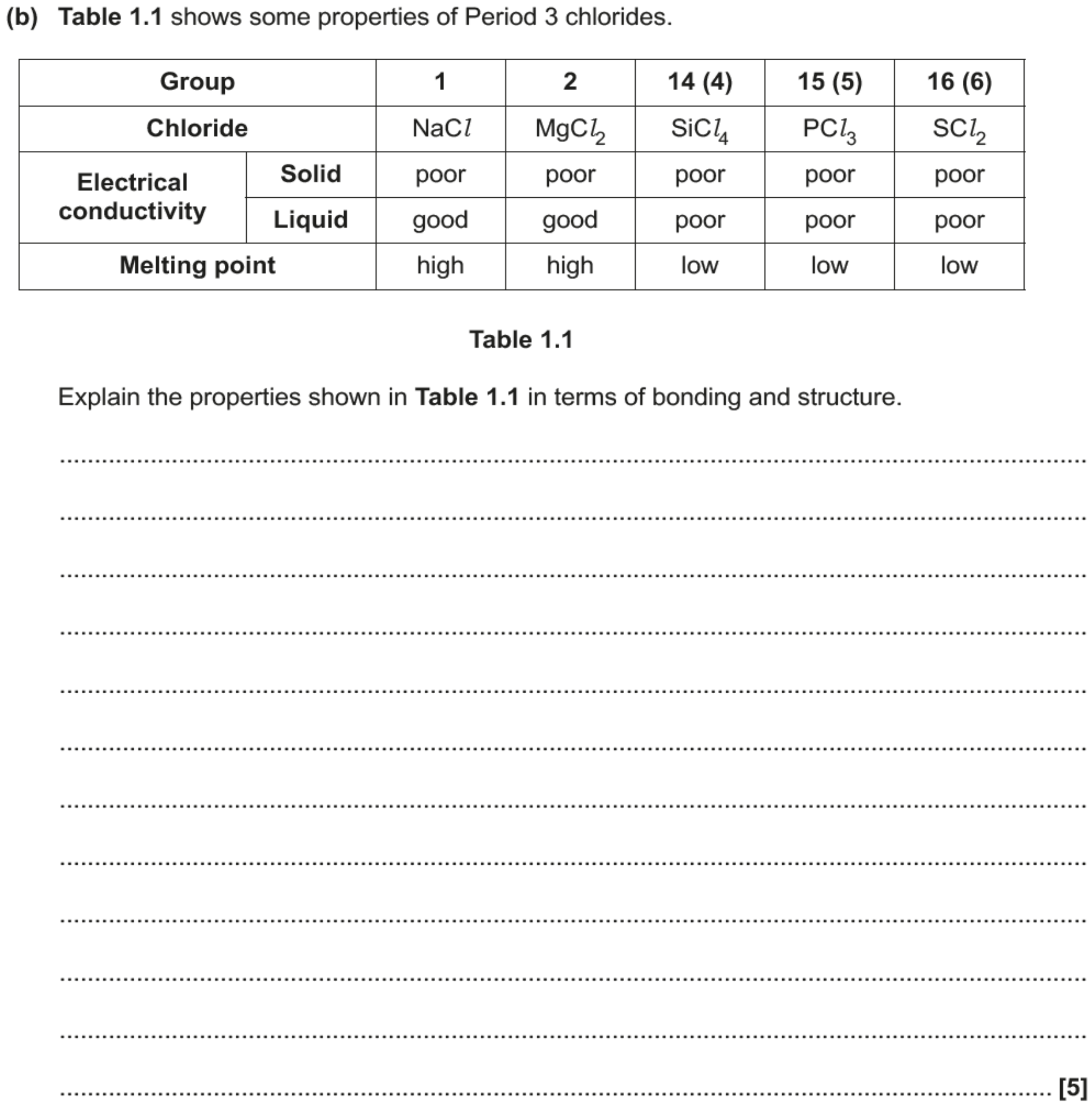


(viii) The element which has a density of 1.33 × 10^{-3} g cm^{-3} at room temperature and pressure.

.... **[1]**

This proved to be the hardest part of 1(a) with only the higher ability candidates selecting oxygen. Sulfur proved to be the key distractor, having the same molar mass as O_2. Most candidates did not consider that the element was gaseous and could not be sulfur.

Question 1(b)



(b) **Table 1.1** shows some properties of Period 3 chlorides.

Group		**1**	**2**	**14 (4)**	**15 (5)**	**16 (6)**
Chloride		NaCl	$MgCl_2$	$SiCl_4$	PCl_3	SCl_2
Electrical conductivity	**Solid**	poor	poor	poor	poor	poor
	Liquid	good	good	poor	poor	poor
Melting point		high	high	low	low	low

Table 1.1

Explain the properties shown in **Table 1.1** in terms of bonding and structure.

.... **[5]**

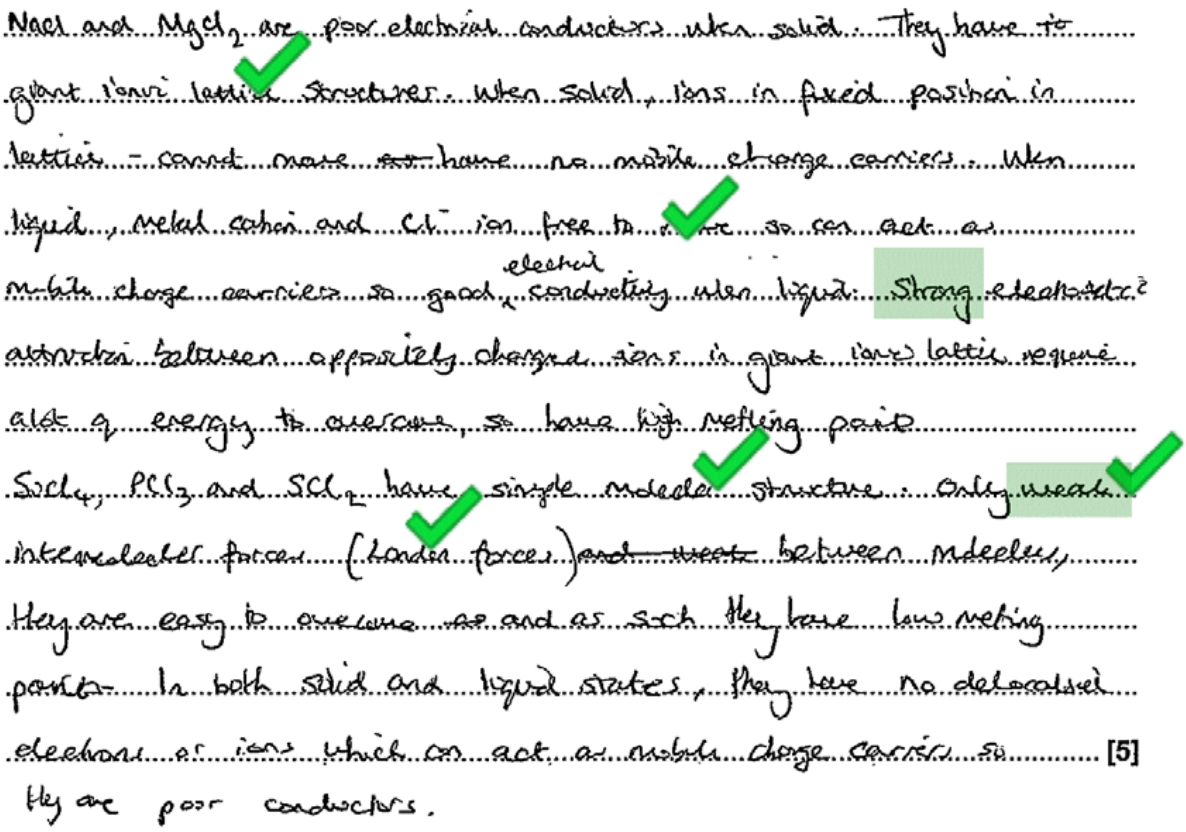
This part required candidates to determine the structure and bonding of unfamiliar compounds from their melting points and electrical conductivities.

This part discriminated very well. Candidates with a good knowledge and understanding of structure and bonding, often produced concise, clear responses which were credited with a high mark, as shown in the Exemplar 1.

Poor understanding often showed up with contradictions and it was common to see ionic lattices with strong intermolecular forces and able to release mobile electrons (rather than mobile ions) in the liquid state. Weaker candidates often wrote extensive answers, although the extra length did not lead to more marks as correct responses were then often contradicted. Exemplar 2 shows part of a very muddled and rambling response in which NaCl is described as having both ionic bonding and London forces.

The best responses identified NaCl and $MgCl_2$ as having giant ionic lattices with strong forces between their ions. This structure was then compared with the simple molecular structures of $SiCl_4$, PCl_3 and SCl_2 with weak London forces between their molecules. A common error was for $SiCl_4$ to have a giant covalent lattice, presumably linking with the structure of elemental silicon and not using the low boiling point in the supplied data.

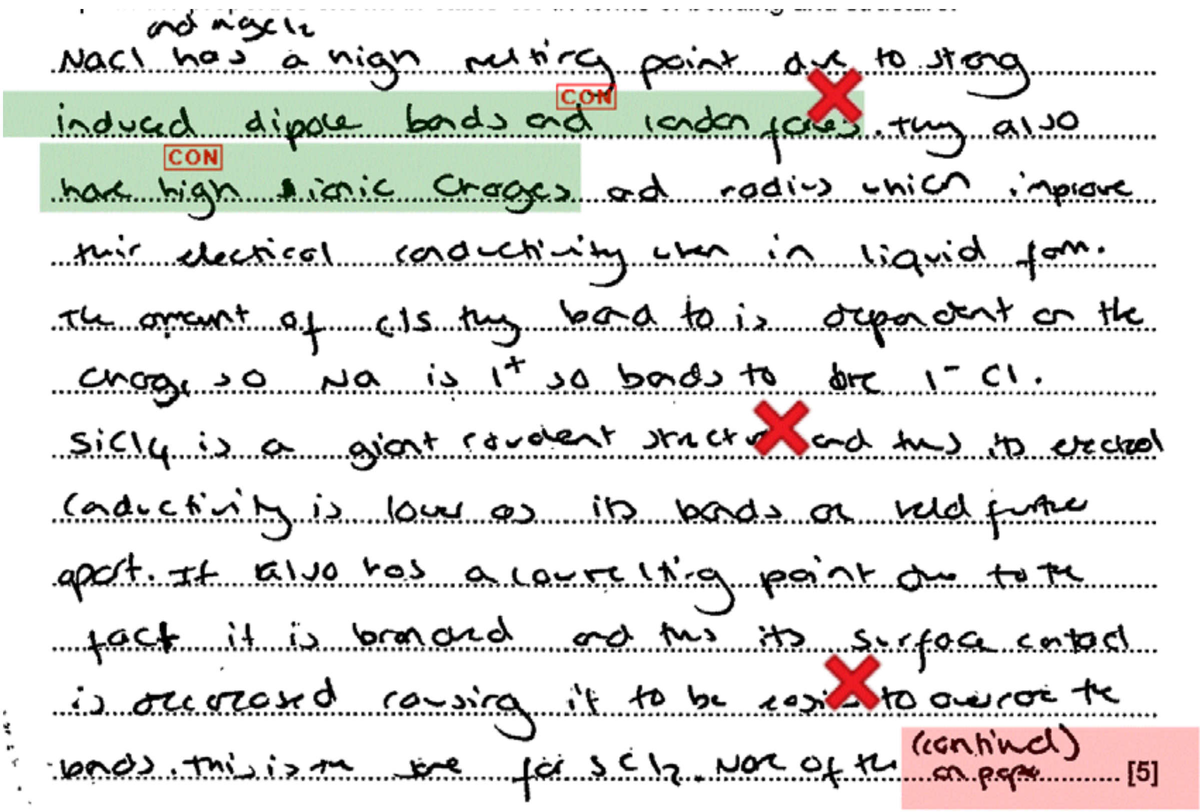
Exemplar 1



NaCl and $MgCl_2$ are poor electrical conductors when solid. They have ~~to~~ giant ionic lattice ✓ structures. When solid, ions in fixed position in lattice - cannot move ~~or~~ have no mobile charge carriers. When liquid, metal cation and Cl^- ion free to move ✓ so can act as mobile charge carriers so good electrical conductivity when liquid. Strong electrostatic attraction between oppositely charged ions in giant ionic lattice require a lot of energy to overcome, so have high melting point.

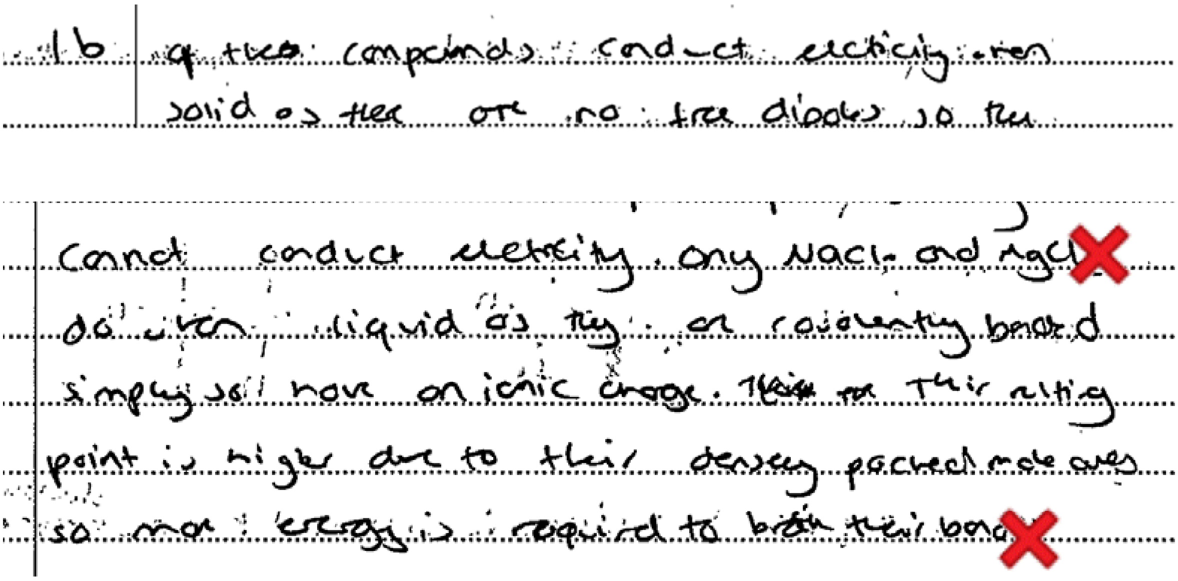
$SiCl_4$, PCl_3 and SCl_2 have ✓ simple molecular ✓ structure. Only weak ✓ intermolecular forces (London forces) ~~and weak~~ between molecules. They are easy to overcome ~~as~~ and as such they have low melting points. In both solid and liquid states, they have no delocalised electrons or ions which can act as mobile charge carriers so **[5]** they are poor conductors.

Exemplar 2



and MgCl2

NaCl has a high melting point due to strong induced dipole bonds and london forces. they also have high ionic charges and radius which improve their electrical conductivity when in liquid form. The amount of Cls they bond to is dependent on the charge so Na is 1+ so bonds to one 1− Cl. SiCl4 is a giant covalent structure and thus its electrical conductivity is lower as its bonds are held further apart. It also has a lower melting point due to the fact it is branched and thus its surface contact is decreased causing it to be easier to overcome the bonds. this is the same for SCl2. None of the (continued on paper) [5]



1b 4 these compounds conduct electricity when solid as there are no free electrons so they

cannot conduct electricity. only NaCl and MgCl2 do when liquid as they are covalently bonded simply still have an ionic charge. ~~Their~~ ~~me~~ Their melting point is higher due to their densely packed molecules so more energy is required to break their bonds

Question 2(a)(i)

2 This question looks at reactions of hydrogen peroxide and of cobalt(II) ions.

(a) Aqueous hydrogen peroxide decomposes as shown in **equation 2.1**.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ **Equation 2.1**

The reaction is catalysed by manganese(IV) oxide, MnO_2.

A student investigates the decomposition of a hydrogen peroxide solution as outlined below.

- The student adds 50.00 cm^3 of $H_2O_2(aq)$ to a conical flask.
- The student adds a small spatula measure of MnO_2 and quickly connects the flask to a gas syringe.
- The student measures the volume of oxygen every 200 seconds.

Results

Time/s	Volume of O_2/cm^3
0	0
200	15
400	28
600	36
800	41
1000	46
1200	48
1400	50

(i) Process the results as outlined below.

- On page 5, plot a graph of **volume of O_2** against **time**.
- Use your graph to find the rate of the reaction, in $cm^3 s^{-1}$, at t = 500 s.

Show your working on the graph and in the space below.

rate = ... $cm^3 s^{-1}$ **[5]**

The graph was generally well drawn although many didn't realise that a tangent needed to be drawn. A few tried to draw a straight line of best fit, rather than a curve.

Most candidates were able to construct a correct graph, assigning the axes correctly and making good use of the graph paper. Points were usually plotted correctly and most candidates made a good attempt to draw a curved line of best fit. Candidates then needed to draw a tangent at 500 seconds and to measure its gradient to calculate the rate. Lower ability candidates did not draw a tangent to their curve and just calculated the volume formed at 500 seconds.

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Question 2(a)(ii)

(ii) The student allows the reaction in **equation 2.1** to proceed until no more gas is evolved. The volume of O_2 in the syringe is now 55 cm^3, measured at RTP.

Calculate the initial concentration of the H_2O_2.

Give your answer to **two** significant figures.

initial concentration of H_2O_2 = ... mol dm^{-3} **[3]**

Most candidates calculated the initial concentration of 0.092 mol dm^{-3}, although many ignored the two significant figures requirement with 0.0916 and 0.09 being seen commonly.

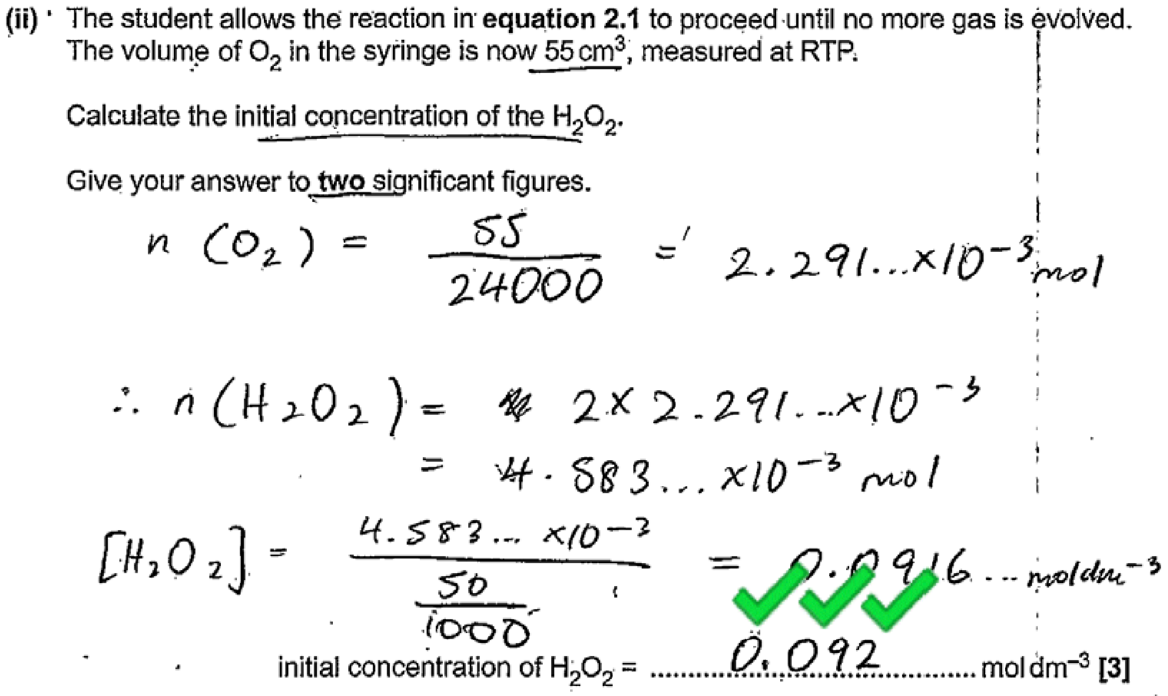
Almost all candidates corrected calculated that 55 cm^3 O_2 contains 2.29×10^{-3} mol $O_2(g)$ and multiplied this value by 2 to obtain 4.58×10^{-3} mol H_2O_2 in 50 cm^3 of solution.

Fewer candidates scaled up this value to 1 dm^3 with many dividing by 20 (instead of × 20) or using 55 cm^3, the initial volume of $O_2(g)$ rather than the volume of the H_2O_2 solution.

Exemplar 3 shows a clear response where each step in the calculation can be clearly seen.

Exemplar 4 is more difficult to follow as the candidate has not indicated what the moles apply to. It is possible though to see that the scaling up by 2 for H_2O_2 has been omitted and the final answer (0.046) is half of the correct answer (0.092). It is then possible to award the final mark by error carried forward.

Exemplar 3



(ii) The student allows the reaction in **equation 2.1** to proceed until no more gas is evolved. The volume of O_2 in the syringe is now 55 cm^3, measured at RTP.

Calculate the initial concentration of the H_2O_2.

Give your answer to **two** significant figures.

$n(O_2) = \frac{55}{24000} = 2.291\ldots \times 10^{-3}$ mol

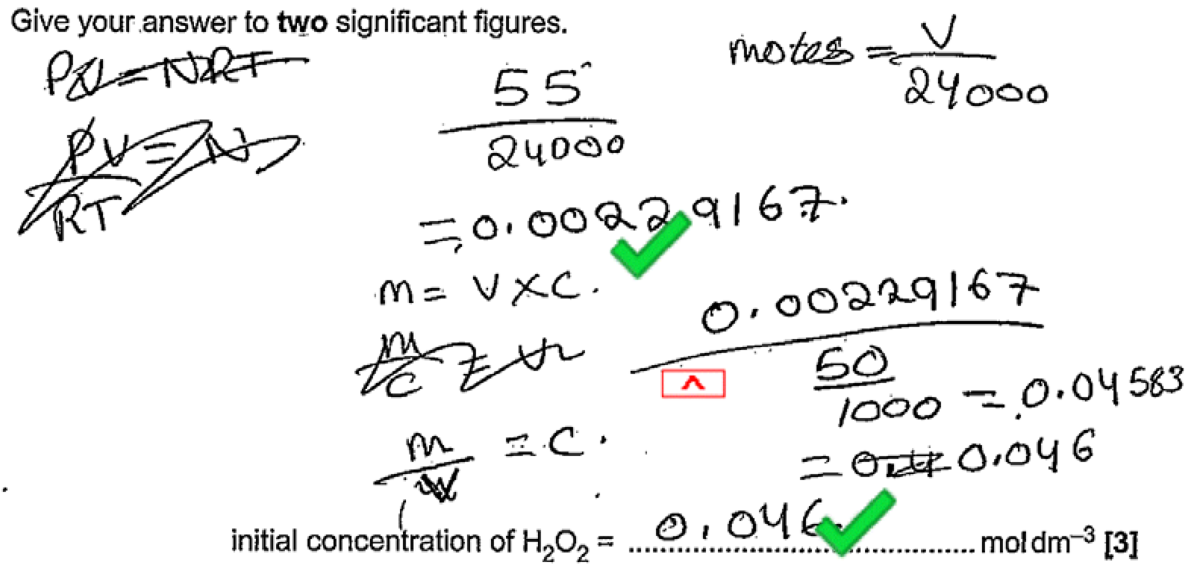
$\therefore n(H_2O_2) = 2 \times 2.291\ldots \times 10^{-3}$

$= 4.583\ldots \times 10^{-3}$ mol

$[H_2O_2] = \frac{4.583\ldots \times 10^{-3}}{\frac{50}{1000}} = 0.0916\ldots$ mol dm^{-3} ✓✓✓

initial concentration of H_2O_2 = 0.092 mol dm^{-3} **[3]**

Exemplar 4



Give your answer to **two** significant figures.

~~PV = NRT~~

~~$\frac{PV}{RT} = N$~~

moles $= \frac{V}{24000}$

$\frac{55}{24000}$

$= 0.00229167$ ✓

$m = V \times C$

~~$\frac{m}{C} = V$~~

$\frac{m}{V} = C$

$\frac{0.00229167}{\frac{50}{1000}} = 0.04583$ ^

$=$ ~~0.04~~ 0.046

initial concentration of H_2O_2 = 0.046 ✓ mol dm^{-3} **[3]**

Question 2(b)

(b) Hydrogen peroxide can act as an oxidising agent or as a reducing agent.

Some standard electrode potentials are shown below.

$2H^+(aq) + O_2(g) + 2e^- \rightleftharpoons H_2O_2(aq) \quad E^{\ominus} = +0.68\,V$
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l) \quad E^{\ominus} = +1.77\,V$

$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l) \quad E^{\ominus} = +0.34\,V$
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l) \quad E^{\ominus} = +1.51\,V$

Use this information to write an equation for a reaction in which hydrogen peroxide acts as a reducing agent.

.... **[2]**

This part discriminated extremely well with many candidates obtaining either both marks or zero marks.

Candidates needed to select the correct redox pairs, combine them and cancel H^+ and H_2O.

Many otherwise correct equations did not receive credit as they contained basic balancing errors. As a final step in constructing an equation, candidates are recommended to check the formulae of their species and that the equation is balanced.

Question 2(c)(i)

(c) Cobalt(II) forms complex ions with water ligands and with chloride ligands.

- With water ligands, cobalt(II) forms a pink octahedral complex ion, $[Co(H_2O)_6]^{2+}$.
- With chloride ligands, cobalt(II) forms a blue tetrahedral complex ion.

A student dissolves cobalt(II) sulfate in water in a boiling tube. A pink solution forms.

Experiment 1
The student places the boiling tube in a water bath at 100 °C.
Concentrated hydrochloric acid is added dropwise.
The colour of the solution changes from pink to blue.

Experiment 2
The student places the boiling tube from **experiment 1** in an ice/water bath at 0 °C.
The colour of the solution changes from blue to pink.

(i) Write the equilibrium equation for the reaction that takes place when the colour of the solution changes.

.... **[1]**

In this part, candidates needed to apply their knowledge and understanding of ligand substitution and equilibrium to a novel situation.

The best equations used Cl^- ions to form $CoCl_4^{2-}$. Some candidates used HCl instead and then H+ was often omitted in the equation.

As with 2b, candidates are recommended to check that their completed equations are balanced.

Question 2(c)(ii)

(ii) Explain the observations and predict whether the formation of the blue colour is exothermic or endothermic.

....

....

....

....

.... **[2]**

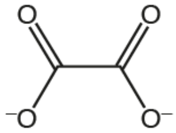
Candidates were expected to determine the type of energy change by linking their equilibrium equation in 2b(i) with the colour changes at different temperatures.

Most candidates correctly concluded that the formation of a blue colour is endothermic. Many candidates did not explain this in terms of a shift in equilibrium position, considering bond breaking and bond making instead.

Question 3(a)

3 This question is about ethanedioic acid, $(COOH)_2$, and ethanedioate ions, $(COO^-)_2$.

(a) The ethanedioate ion, shown below, can act as a bidentate ligand.



Fe^{3+} forms a complex ion with three ethanedioate ions.
The complex ion has two optical isomers.

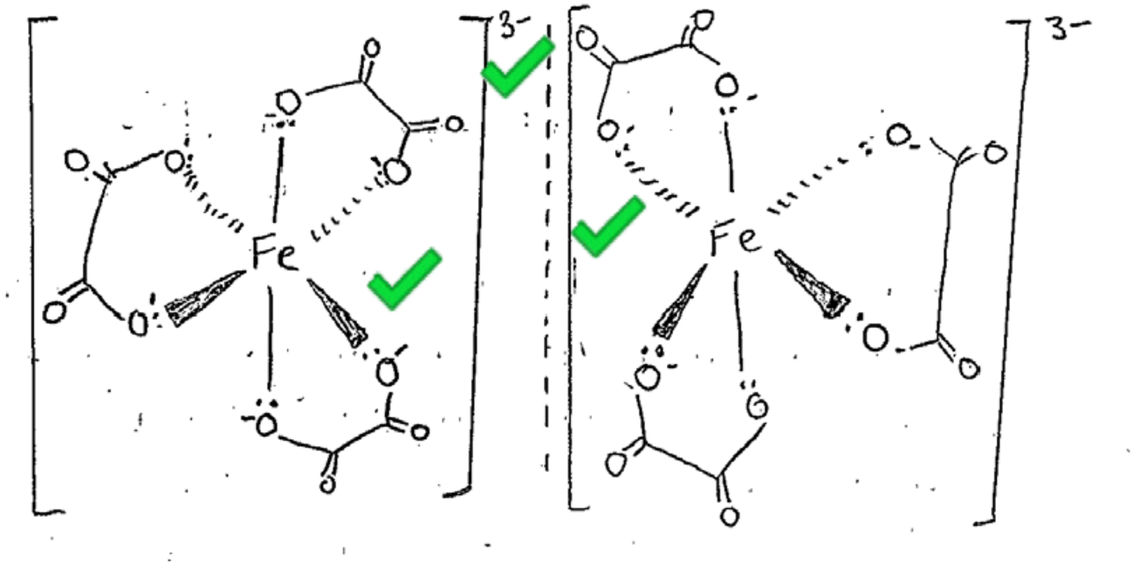
Draw the 3D shapes of the optical isomers.

In your diagrams, show the structure of the ethanedioate ligands and any overall charge.

[3]

Most candidates were able to draw clear octahedral 3D shapes of the optical isomers, with good use made of wedges. The best candidates showed an overall 3– charge on each isomer but lower ability candidates did not always cancel down the charges in the Fe^{3+} and $(COO^-)_2$ ions, showing a 3+ charge instead of the overall charge of 3–. (See Exemplar 5)

Exemplar 5



[3]

Question 3(b)(i)

(b) Ethanedioic acid, $(COOH)_2$, is present in rhubarb leaves.

A student carries out a redox titration using aqueous cerium(IV) sulfate, $Ce(SO_4)_2(aq)$, to determine the percentage, by mass, of ethanedioic acid in rhubarb leaves.

In the titration, $Ce^{4+}(aq)$ ions oxidise ethanedioic acid in hot acid conditions:

$$2Ce^{4+}(aq) + (COOH)_2(aq) \rightarrow 2Ce^{3+}(aq) + 2CO_2(g) + 2H^+(aq)$$

$Ce^{4+}(aq)$ ions have a yellow colour. $Ce^{3+}(aq)$ ions are colourless.

The student weighs 82.68 g of rhubarb leaves and extracts ethanedioic acid from the leaves.

The ethanedioic acid is added to dilute sulfuric acid to form a colourless solution which is made up to 250.0 cm^3 with distilled water.

The student heats 25.00 cm^3 of this solution to 70 °C and titrates this volume with 0.0500 $mol\,dm^{-3}$ $Ce(SO_4)_2$ from the burette.

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

Titration results
The trial titre has been omitted.

	1	**2**	**3**
Final reading/cm^3	24.30	47.80	23.65
Initial reading/cm^3	1.05	24.30	0.50

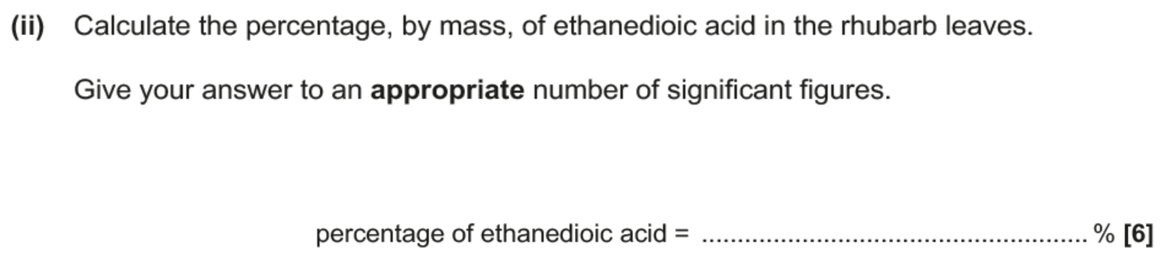
(i) This titration is self-indicating and the student does not need to add an indicator.

What colour change would the student observe at the end point?

Colour change from .... to .... **[1]**

Candidates were expected to apply their knowledge of the colour change in a manganate(VII) titration to this novel situation. Most candidates incorrectly showed the inverse colour change of yellow → colourless.

Question 3(b)(ii)



(ii) Calculate the percentage, by mass, of ethanedioic acid in the rhubarb leaves.

Give your answer to an **appropriate** number of significant figures.

percentage of ethanedioic acid = ... % **[6]**

Most candidates answered this unstructured titration calculation well, with almost all responses gaining some credit. Most coped well with the 1:2 reaction stoichiometry and the need to scale up to 250 cm^3.

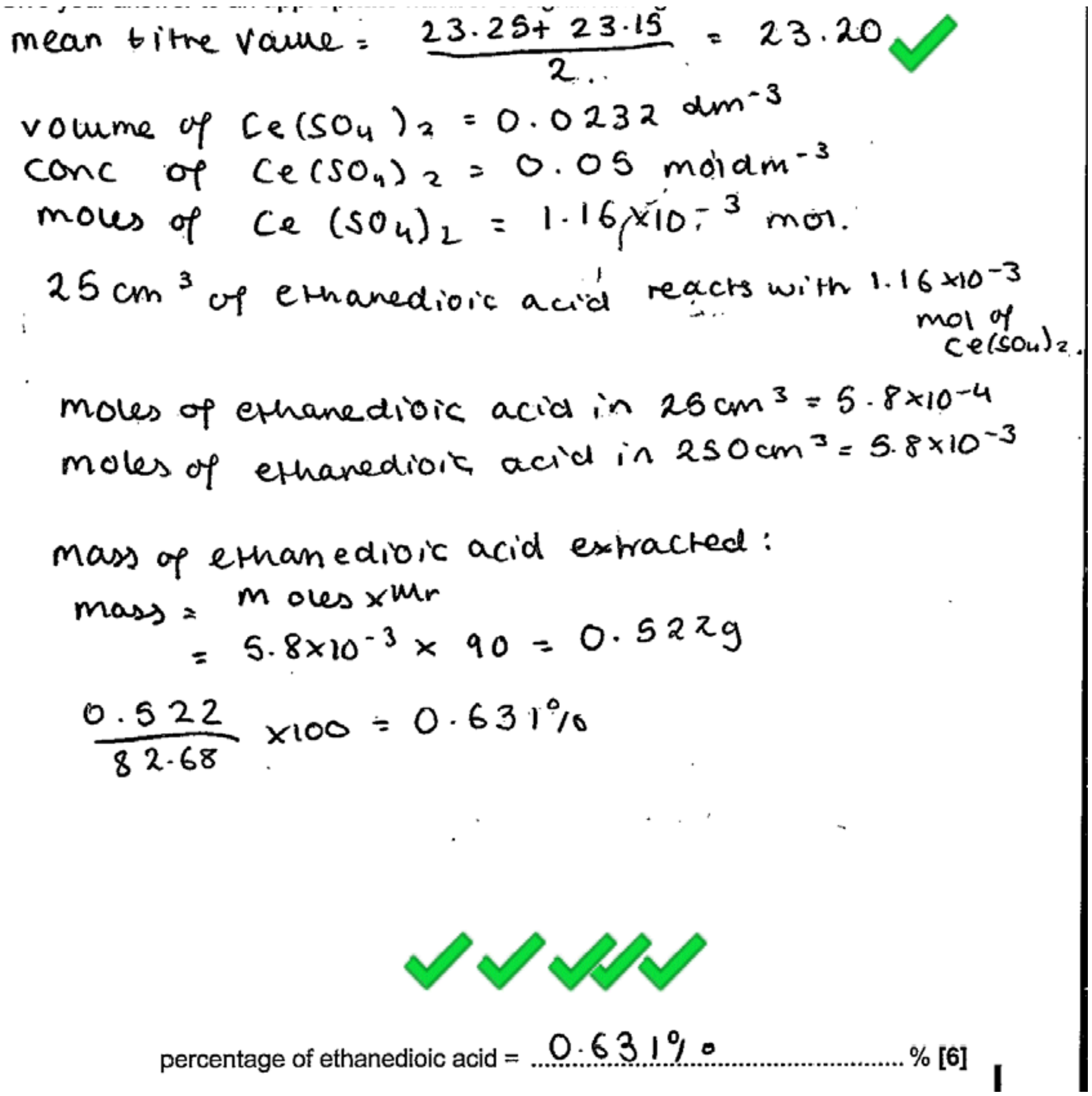
Common errors included the following.

- Taking the mean of all three titres (23.30 cm^3) instead of the closest titres (23.20 cm^3).
- Not considering the 1:2 stoichiometry.
- Not scaling up to 250 cm^3.
- Giving the final answer to two rather than three significant figures; this was the most common error.

The question required the final answer to be given to an appropriate number of significant figures. Many candidates seemed to be unaware that this reflects the least significant figures provided in the data, in this case three significant figures. Candidates are also advised to only round at the end of a multi-step calculation. Rounding of intermediate values introduces rounding errors in the final answer.

The example shows a perfect response with each step clearly described, leading to the correct concentration of ethanedioic acid. Candidates should present their calculations clearly. If there is a mistake at any stage, this can be easily identified, allowing for error carried forward to be applied for any subsequent good method.

Exemplar 6



mean titre value = $\frac{23.25+23.15}{2}$ = 23.20 ✓

volume of $Ce(SO_4)_2$ = 0.0232 dm^{-3}

conc of $Ce(SO_4)_2$ = 0.05 $mol dm^{-3}$

moles of $Ce(SO_4)_2$ = 1.16×10^{-3} mol.

25 cm^3 of ethanedioic acid reacts with 1.16×10^{-3} mol of $Ce(SO_4)_2$.

moles of ethanedioic acid in 25 cm^3 = 5.8×10^{-4}

moles of ethanedioic acid in 250 cm^3 = 5.8×10^{-3}

mass of ethanedioic acid extracted:

mass = moles × Mr

= $5.8 \times 10^{-3} \times 90$ = 0.522g

$\frac{0.522}{82.68} \times 100$ = 0.631%

✓✓✓✓✓

percentage of ethanedioic acid = 0.631% .... % [6]

Question 4(a)(i)

4 This question is about two compounds used in medicine.

(a) *Cis*-platin, $PtCl_2(NH_3)_2$, is a complex of platinum which is used in cancer treatment.

(i) What is the oxidation number of platinum in *cis*-platin?

.... **[1]**

Almost all candidates responded with the correct oxidation number of +2. Incorrect responses were 0 (the overall charge of the complex), +4 or 2 (with no sign).

Candidates are reminded on the importance of the sign in assigning oxidation numbers.

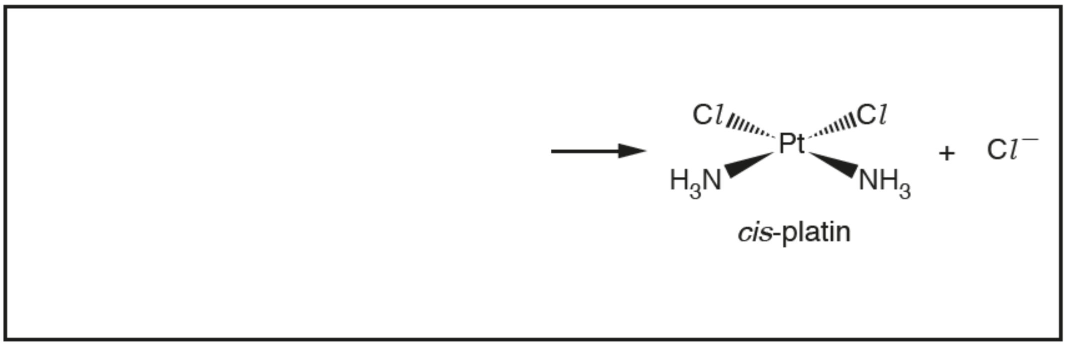
Question 4(a)(ii)

(ii) *Cis*-platin is prepared in a ligand substitution reaction which takes place in multiple steps.

The equation for the final step forming *cis*-platin is shown below.

$[PtCl_3(NH_3)]^- + NH_3 \rightarrow \underset{cis\text{-platin}}{PtCl_2(NH_3)_2} + Cl^-$

In the box, outline the mechanism for the formation of *cis*-platin from $[PtCl_3(NH_3)]^-$.
Use curly arrows and lone pairs where appropriate.



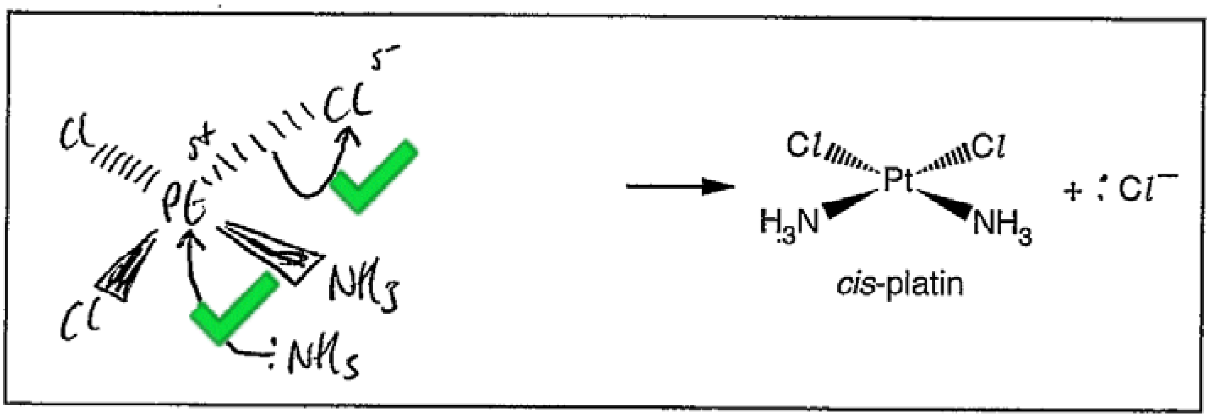
[2]

This part required candidates to apply their knowledge and understanding of the nucleophilic substitution mechanism in a novel context.

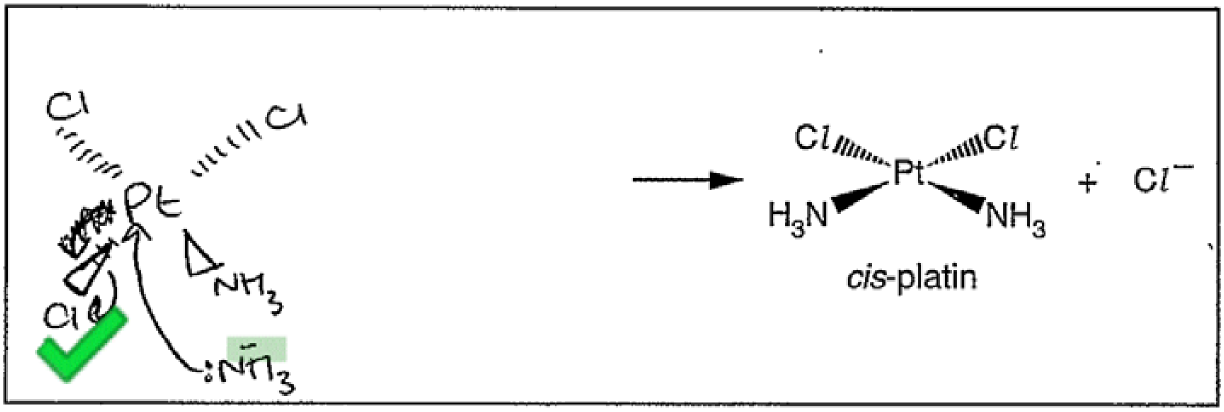
This part discriminated extremely well with able candidates drawing the correct initial complex and showing precisely positioned curly arrows, dipoles and the role of the NH_3 lone pair, as shown in Exemplar 7.

Lower ability candidates often showed imprecise curly arrows or placed a negative charge on NH_3, as shown in Exemplar 8.

Exemplar 7

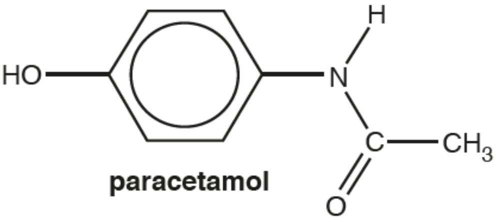


Exemplar 8



Question 4(b)(i)

(b) Paracetamol is a solid organic compound used in tablets as a painkiller.



paracetamol

(i) Name the functional groups present in paracetamol.

....

.... **[2]**

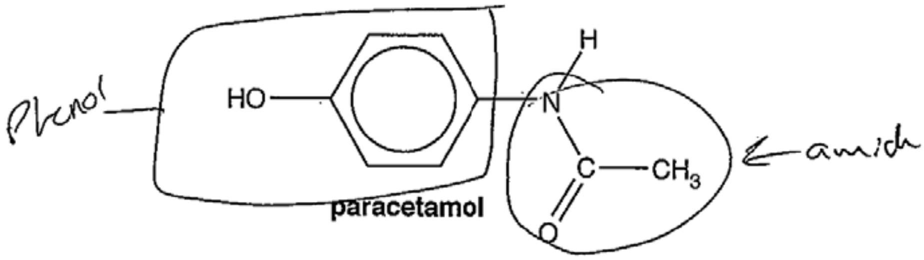
This part assessed knowledge of functional groups and proved to be a very good discriminator. Able candidates usually identified the phenol and amide functional groups, with 'secondary amide' also seen.

In Exemplar 9, the candidate has identified the correct functional groups. The candidate's working by circling the functional groups in the structure shows good examination technique, helping the candidate to arrive at the correct conclusion.

The phenol group was often incorrectly identified as an alcohol and the amide group as a combination of 'amine', 'ketone', 'keytone' or 'carbonyl'. Neutral responses such as 'hydroxyl' and 'benzene' were ignored.

Candidates need to be careful that they do not present an extensive list of many functional groups in the hope that the correct groups are amongst them, as shown in Exemplar 10. Incorrect groups are marked first.

Exemplar 9



(i) Name the functional groups present in paracetamol.

phenol ✓

amide ✓ **[2]**

Exemplar 10

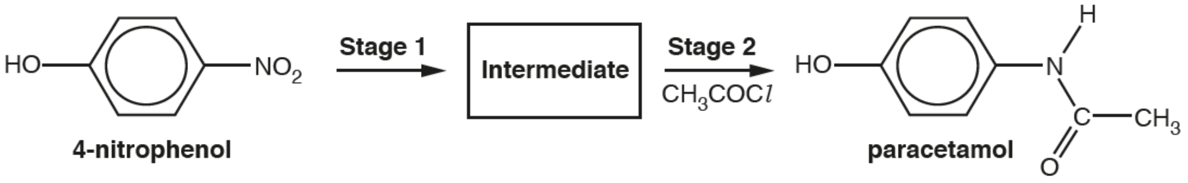
Name the functional groups present in paracetamol.

Phenol, ketone ✗, benzene,

Alkyl, Amine ✗ **[2]**

Question 4(b)(ii)*

(ii)* A chemist prepares a pure solid sample of paracetamol from 4-nitrophenol in two stages:



Describe a two-stage synthesis of 5.00 g of pure paracetamol from 4-nitrophenol. The overall percentage yield of paracetamol from 4-nitrophenol is 40.0%.

In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol. **[6]**

This part assessed practical aspects of a two-stage organic synthesis. Overall, candidates responded well, and this part was discriminating. Many candidates produced well-structured responses although lower ability candidates do have problems with constructing a cohesive response.

Most candidates identified the correct reagents (Sn and concentrated HCl) and the intermediate (4-aminophenol), which was usually shown as its structure.

Able candidates usually showed that 11.5 g of 4-nitrophenol is needed for the synthesis. A common error used the 'inverse percentage' ratio of 40/100, resulting in an incorrect mass of 1.84 g. Candidates are recommended to check whether a calculated answer looks sensible. Looking at the structures and with a percentage yield of 40%, 1.84 g does not look to be enough of the starting chemical.

Some lower ability candidate responses assumed that 5.00 g was 40% of the required mass and responded with 5.00 × 100/40 = 12.5 g.

There were some good descriptions of purification, although finer details such as using a minimum volume of hot solvent, washing with cold solvent, and drying) were often omitted. Candidates needed to respond with more than just 'recrystallisation'.

In the purification, common errors were showing the correct steps but in the wrong order and use of a drying agent such as $CaCl_2$ (confusion with part of the purification of an organic liquid). These candidates seemed unaware that adding a solid drying agent to an organic solid would result in impure paracetamol rather than purifying.

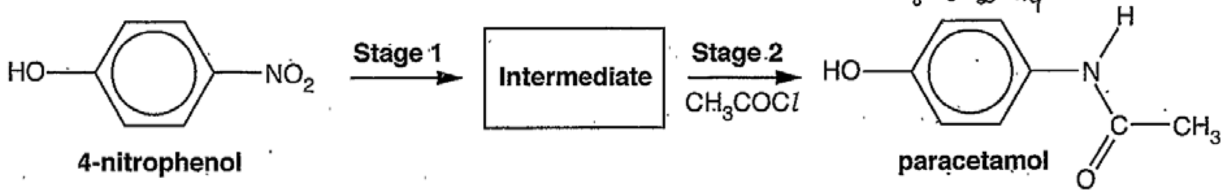
Exemplar 11 shows an excellent response that addresses all aspects of the problem.

In comparison, Exemplar 12 is much less detailed: concentrated HCl has not been shown as a reagent for step 1, the candidate has not shown that they know how to carry out a percentage yield calculation, and the purification is confused, and lacks detail.

Exemplar 11

(ii)* A chemist prepares a pure solid sample of paracetamol from 4-nitrophenol in two stages:

$C_8NO_2H_9$

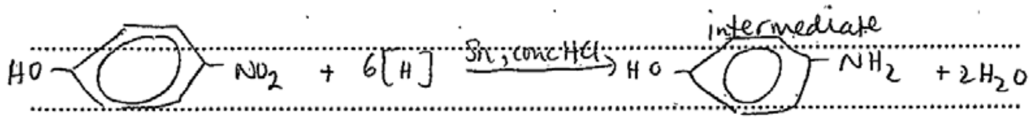


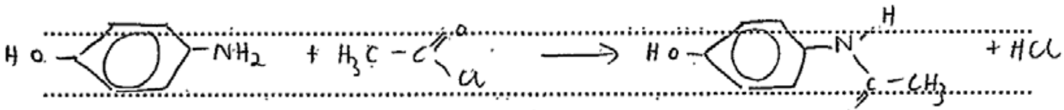
$C_6NO_3H_5$ =

Describe a two-stage synthesis of 5.00 g of pure paracetamol ~~from~~ 4-nitrophenol. The overall percentage yield of paracetamol from 4-nitrophenol is 40.0%.

In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol. **[6]**

L3





molar mass of paracetamol = 151 g mol^{-1}

moles in 5g : $\frac{5}{151}$ = 0.0331 mol

moles required = 0.0331 ÷ 0.4 = 0.08278 mol

moles of 4-nitrophenol required = 0.08278 mol

mass of 4-nitrophenol required = 0.08278 × 139 = 11.5g

To purify the paracetamol, filter the remaining solution under reduced pressure using Buchner apparatus. Dissolve the remaining solid in the ~~[illegible]~~ minimum amount of hot solvent and filter again. Cool the remaining ~~[illegible]~~ solution and filter ~~[illegible]~~ in an ice bath. Wash the remaining solid with cold solvent

Additional answer space if required.

and leave to dry.

Exemplar 12

In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol. **[6]** ^ L2

4-nitrophenol is ~~reacted with~~ reduced with (Sn) tin in presence of and acid and forms ~~4-phy~~ 4-phenylamide under high temperature

$400/160 \times 5.00 = 12.5$g from the begining is required

A pure sample of paracetamol was obtained by crystallisation. The impure solution was heated with a busen burner and stirred until crystals start forming. ~~on~~ After formation in was left to cool and and oven was used to evaporate any water left

Question 5(a)

5 A student carries out two experiments in the laboratory based on succinic acid (butanedioic acid), $(CH_2COOH)_2$.

(a) Aqueous succinic acid can be neutralised by aqueous sodium hydroxide, NaOH(aq):

$$(CH_2COOH)_2(aq) + 2NaOH(aq) \rightarrow (CH_2COONa)_2(aq) + 2H_2O(l)$$

This reaction can be used to determine a value for the enthalpy change of neutralisation, $\Delta_{neut}H$.

The student follows this method:

- Add 50.0 cm^3 of 0.400 mol dm^{-3} succinic acid to a polystyrene cup.
- Measure out 50.0 cm^3 of 1.00 mol dm^{-3} NaOH(aq), which is in excess.
- Measure the temperature of both solutions.
- Add the NaOH(aq) to the aqueous succinic acid in the polystyrene cup, stir the mixture, and record the maximum temperature.

Temperature readings

Maximum temperature of mixture/°C	26.5
Initial temperature of both solutions/°C	21.5

Calculate a value for the enthalpy change of neutralisation, $\Delta_{neut}H$, in kJ mol^{-1}.

Assume that the density of all solutions and the specific heat capacity, c, of the reaction mixture are the same as for water.

$\Delta_{neut}H$ = ... kJ mol^{-1} **[4]**

The direct determination of an enthalpy change is a common practical procedure.

Most candidates were able to calculate the energy change in the reaction as 2.09 kJ, with comparatively few not adding the two 50 cm^3 volumes in their calculation. Common errors were using the mass or moles of succinic acid in the $mc\Delta T$ calculation or to use 278 K, rather than 5ºC for ΔT.

Most candidates calculated that 0.02 mol of succinic acid had reacted.

The best responses recognised that the enthalpy change of neutralisation (i.e. formation of 1 mol of H_2O) was required and that 0.02 mol succinic acid produced 2 × 0.02 = 0.04 mol H_2O. 2.09 kJ was then scaled up to give the correct ΔH value of –52.25 kJ mol^{-1}. Example 1 follows this approach and each stage in the working can be followed easily.

Most candidates scaled up using 0.02 mol to obtain –104.6 kJ mol^{-1} and then thought that this was the final answer.

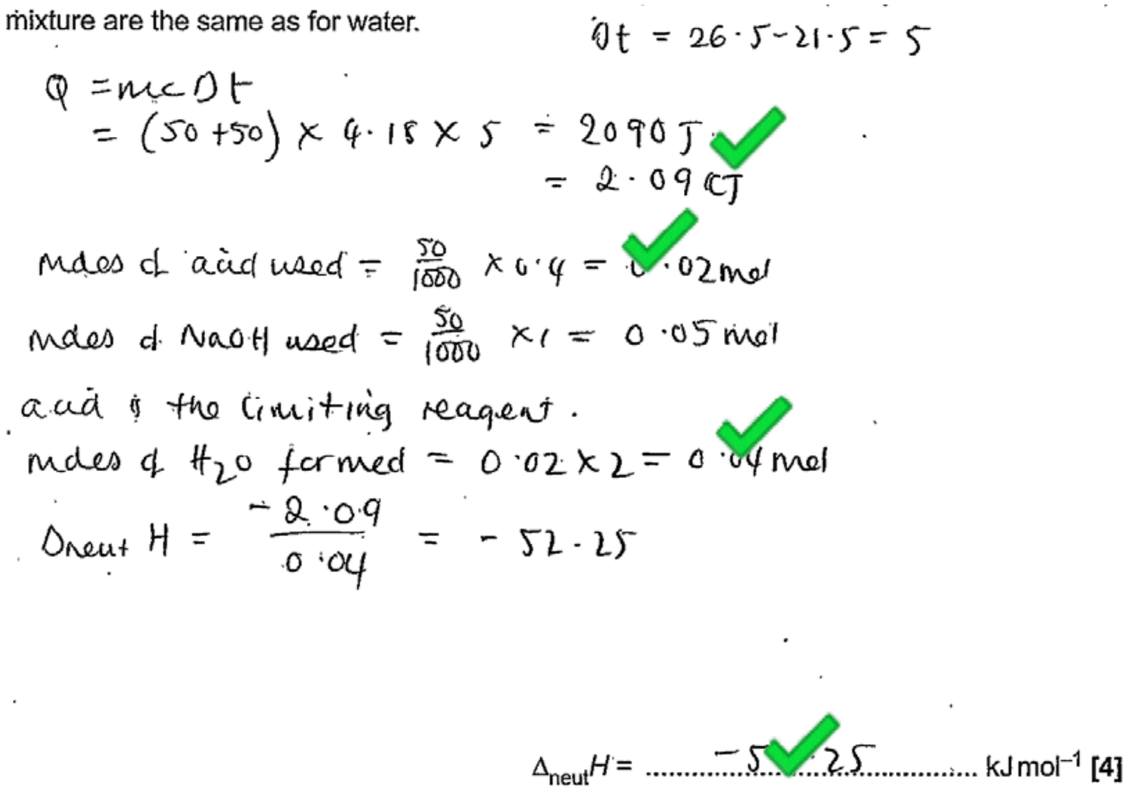
Lower ability candidates often calculated the moles of succinic acid as 0.02 but also calculated the moles of NaOH as 0.05 mol. They often then went on to scale up their energy change by 0.05 or 0.07.

Many responses were disorganised and poorly presented with unsubstantiated numbers across the answer space. Imperfect calculations may be partially credited by applying error carried forward but this is only possible if sense can be made of the response.

Compare the responses in Exemplar 13 and Exemplar 14. In Exemplar 14, there is no labelling to show what each stage refers to. It looks as if the candidate has calculated the moles of NaOH rather than succinic acid and has used this in the subsequent stage. Error carried forward has been applied generously on this assumption.

Answer = –52.25 kJ mol^{-1}.

Exemplar 13



mixture are the same as for water.

$\Delta t = 26{\cdot}5 - 21{\cdot}5 = 5$

$Q = mc\Delta t$

$= (50+50) \times 4{\cdot}18 \times 5 = 2090\ J$ ✓

$= 2{\cdot}09\ kJ$

moles of acid used $= \frac{50}{1000} \times 0{\cdot}4 = 0{\cdot}02$ mol ✓

moles of NaOH used $= \frac{50}{1000} \times 1 = 0{\cdot}05$ mol

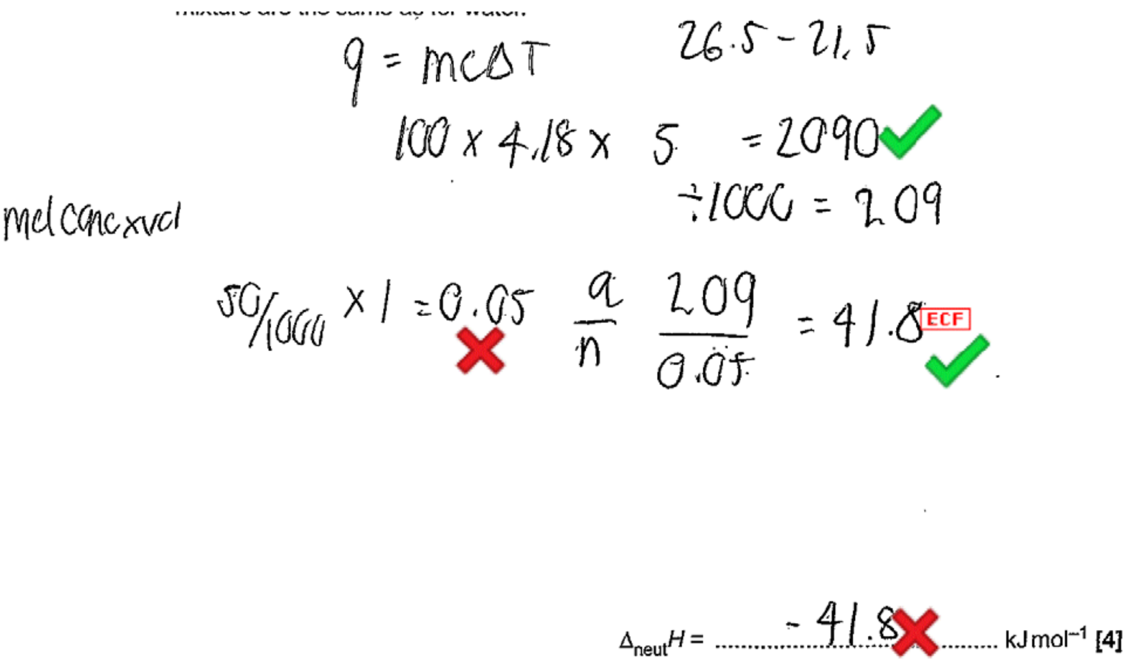
acid is the limiting reagent.

moles of H_2O formed $= 0{\cdot}02 \times 2 = 0{\cdot}04$ mol ✓

$\Delta_{neut} H = \frac{-2{\cdot}09}{0{\cdot}04} = -52{\cdot}25$

$\Delta_{neut}H$ = ... −52.25 ✓ .... kJ mol^{-1} **[4]**

Exemplar 14



$q = mc\Delta T$ $26.5 - 21.5$

$100 \times 4.18 \times 5 = 2090$ ✓

$\div 1000 = 2.09$

mol conc × vol

$50/1000 \times 1 = 0.05$ ✗ $\frac{q}{n}$ $\frac{2.09}{0.05} = 41.8$ ECF ✓

$\Delta_{neut}H$ = ... −41.8 ✗ .... kJ mol^{-1} **[4]**

Question 5(b)(i)

(b) Succinic acid is esterified by ethanol, C_2H_5OH, in the presence of an acid catalyst to form an equilibrium mixture.

The equilibrium constant, K_c, for this equilibrium can be calculated using the amounts, in moles, of the components in the equilibrium mixture, using **expression 5.1**.

$$K_c = \frac{n((CH_2COOC_2H_5)_2) \times n(H_2O)^2}{n((CH_2COOH)_2) \times n(C_2H_5OH)^2} \qquad \textbf{Expression 5.1}$$

A student carries out an experiment to determine the value of K_c for this equilibrium.

- The student mixes together 0.0500 mol of succinic acid and 0.150 mol of ethanol, with a small amount of an acid catalyst.
- The mixture is allowed to reach equilibrium.
- The student determines that 0.0200 mol of succinic acid are present in the equilibrium mixture.

(i) Which technique could be used to determine the equilibrium amount of succinic acid?

.... **[1]**

Candidates found this part difficult and only higher ability candidates identified that a titration could easily determine the concentration of succinic acid.

The answers seen covered most of the techniques encountered in the course. Candidates should consider the information provided in a practical context to arrive at an informed response rather than what sometimes seemed to be a guess.

Question 5(b)(ii)

(ii) Write the equation for the equilibrium reaction that takes place.

.... **[1]**

Candidates were required to derive the equation from which the supplied K_c expression had been written.

Overall, this part was answered well but some candidates struggled with the brackets or used CH_2COOH_2 for succinic acid.

Question 5(b)(iii)

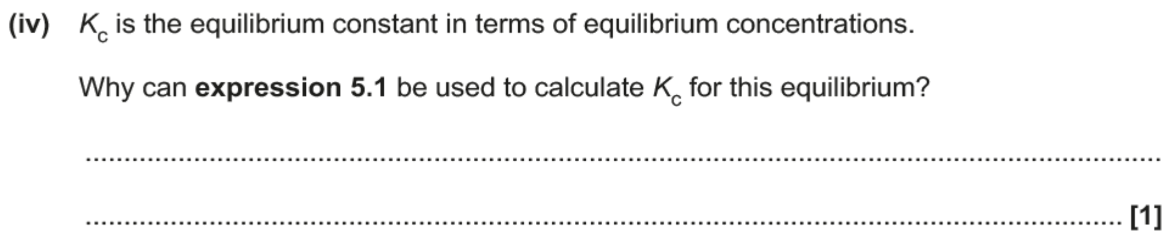
(iii) Draw the skeletal formula of the ester present in the equilibrium mixture.

[1]

This part discriminated extremely well with many candidates finding it difficult to convert the bracketed structural formula into a skeletal formula. Common errors were drawing of the mono-ester or omitting a carbon atom in the centre of the structure.

Even when incorrect, most attempted answers were skeletal formulae.

Question 5(b)(iv)



(iv) K_c is the equilibrium constant in terms of equilibrium concentrations.

Why can **expression 5.1** be used to calculate K_c for this equilibrium?

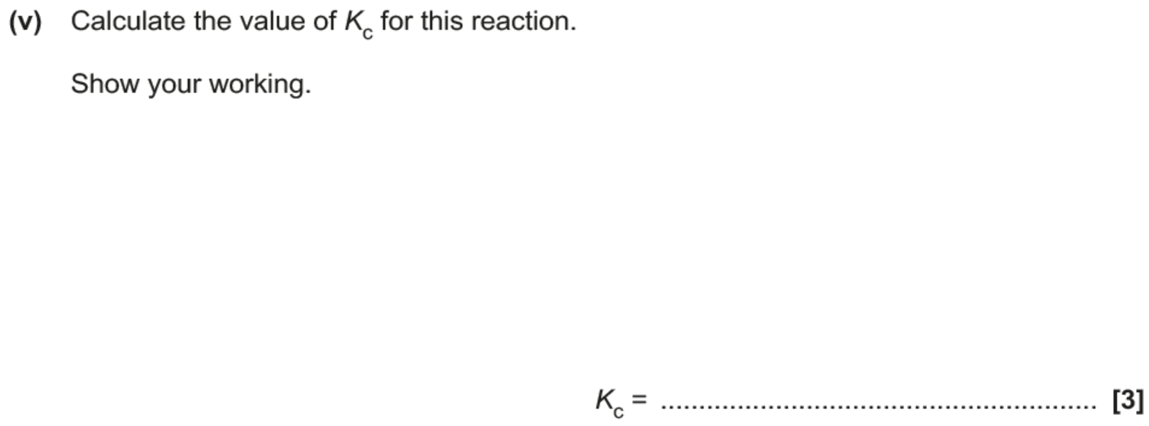
....

.... **[1]**

Many candidates did not seem to realise that the supplied equation used moles, not concentrations. Those who did often stated that the mole representation could be used because the volume was the same for all. Of those who went on to state that the volume would cancel, only a few explained why that was true in this particular case.

This challenging part discriminated very well. The best responses showed the units as n/V in the expression and showed that the volumes cancel.

Question 5b(v)



(v) Calculate the value of K_c for this reaction.

Show your working.

K_c = ... **[3]**

Overall, this part discriminated well with many candidates obtaining the correct answer of 0.67. Common errors included a one significant figure answer of 0.6 or 0.7 and 0.375, by using 0.12 mol instead of 0.09 mol for the moles of ethanol.

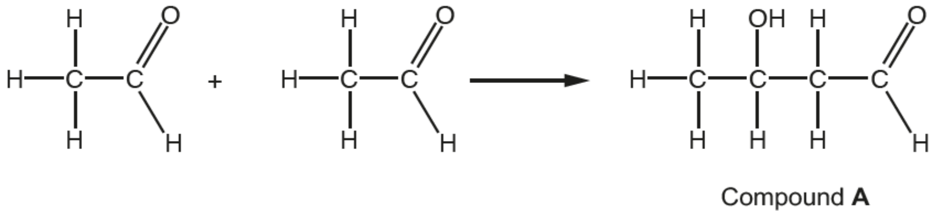
Many successful answers were well-presented and included a table of initial and final values. This gave a systematic way of deriving the equilibrium moles.

Question 6(a)(i)

6 This question is about organic reactions.

(a) Compound **A** is formed when ethanal is mixed with $OH^-(aq)$ ions, which act as a catalyst.

The balanced equation is shown in **reaction 6.1** below.



Reaction 6.1

(i) Give the systematic name for compound **A**.

.... **[1]**

Most candidates made good attempts at the name, the difficulty being that hydroxyl group needed to be shown as a hydroxy- prefix, rather than the suffix -ol.

Common errors included 2-hydroxybutanal (counting the carbon chain from the wrong end) and 2- or 3-hydroxybutanoic acid (reading the aldehyde group as a carboxylic acid).

Question 6(a)(ii)

(ii) What type of reaction has taken place?

.... **[1]**

This part was answered well with most choosing nucleophilic addition. Credit was given just for 'addition'.

Question 6(a)(iii)

(iii) **Reaction 6.1** takes place in two steps. OH^- ions act as a catalyst.

In **step 1**, ethanal reacts with OH^- ions to set up an acid–base equilibrium.
In **step 2**, compound **A** is formed.

- Complete the equilibrium for **step 1** and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

  CH_3CHO + OH^- ⇌ .... + ...

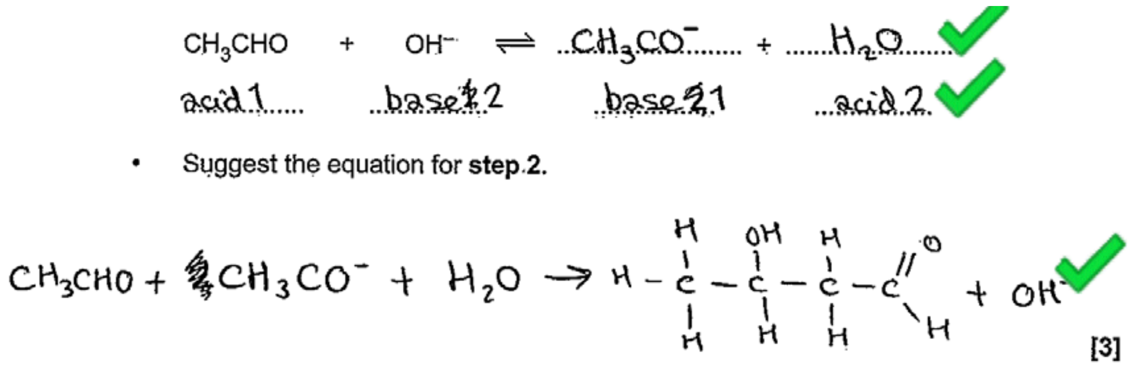
  ....

- Suggest the equation for **step 2**.

[3]

This novel question linked together acid–base equilibria with a multi-step process. Many candidates completed an equation to generate acid–base pairs, which were then usually assigned correctly. The final equation was challenging but the highest ability candidates were able to combine together all the information with their earlier responses to arrive at the correct equation. See Exemplar 15.

Exemplar 15



CH_3CHO + OH^- ⇌ CH_3CO^- + H_2O ✓

acid 1 base 2 base 1 acid 2 ✓

- Suggest the equation for **step 2**.

$$CH_3CHO + CH_3CO^- + H_2O \rightarrow H-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-C\overset{\displaystyle O}{\underset{\displaystyle H}{\lessgtr}} + OH^-$$ ✓

[3]

Question 6(a)(iv)

(iv) A similar reaction takes place when propanone, $(CH_3)_2CO$, is mixed with $OH^-(aq)$ ions.

Draw the structure of the organic product of this reaction.

[1]

This part was one of the most challenging on the paper.

Candidates needed to link the earlier information for combining two ethanal molecules to derive the product for combining two propanone molecules. Despite the challenge, the highest ability candidates were able to come up with the correct structure.

Question 6(b)*

(b)* Many organic reactions use electrophiles as reagents.

Explain the role of electrophiles in organic chemistry.

Your answer should include **one** reaction of an aliphatic compound and **one** reaction of an aromatic compound, including relevant mechanisms. **[6]**

Overall, this part was answered well.

Good answers were well organised, showing clear mechanisms with precisely positioned curly arrows.

Most candidates included a clear definition of an electrophile and were able to select appropriate reactions. Most candidates were familiar with the mechanisms for electrophilic addition and electrophilic substitution. Mechanisms of an alkene with HBr or Br_2 and benzene with NO_2^+ or Br^+ were the most commonly seen. Most candidates showed the role of a catalyst in electrophilic substitution.

Common errors/omissions were the direction of the curly arrow from the aromatic ring to the electrophile, the position of the curly arrow when H^+ is lost from an aromatic intermediate, and not showing the lone pair when Br^- attacks a carbocation.

Some answers lacked detail and gave only two mechanisms with minimal supporting words.

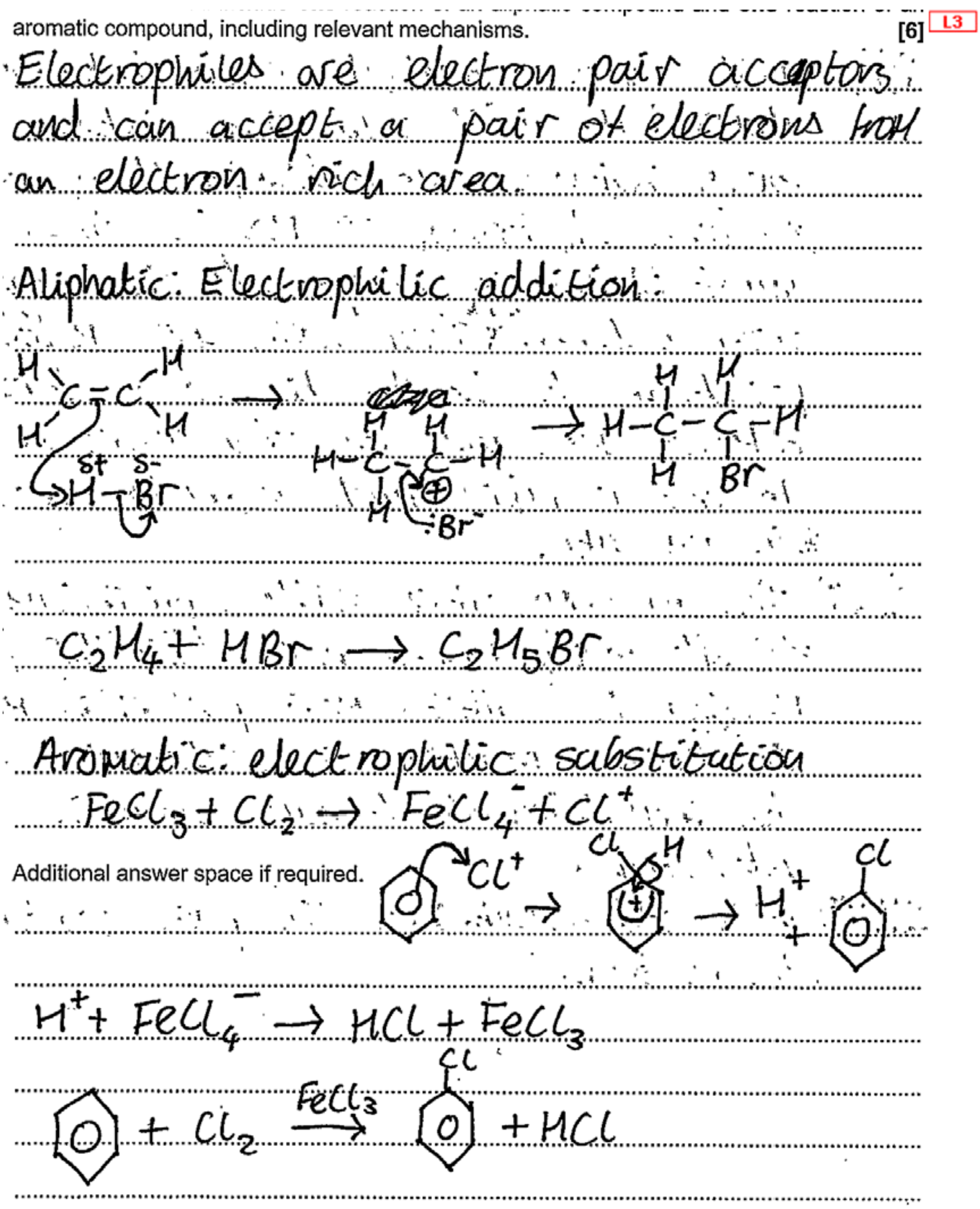
Lower ability candidates described nucleophilic addition or substitution as one of their mechanisms or had curly arrows going in the wrong direction.

A few candidates answered in prose without including equations or diagrams. Candidates are advised that mechanisms must always be communicated in the usual diagrammatic way.

Exemplar 16 is a very clear and concise response showing all the key features of electrophilic addition and electrophilic substitution, including the role of the $FeCl_3$ catalyst. Curly arrows are precisely positioned, with correct use of lone pairs and charges. The candidate has demonstrated excellent knowledge and understanding.

The response in Exemplar 17 is clearly at a different level. The candidate has chosen an alkane rather than an alkene and has used curly arrows and charges incorrectly. This candidate appears to have been poorly prepared.

Exemplar 16



aromatic compound, including relevant mechanisms. **[6]** L3

Electrophiles are electron pair acceptors and can accept a pair of electrons from an electron rich area.

Aliphatic: Electrophilic addition:

$C_2H_4 + HBr \longrightarrow C_2H_5Br$

Aromatic: electrophilic substitution

$FeCl_3 + Cl_2 \rightarrow FeCl_4^- + Cl^+$

Additional answer space if required.

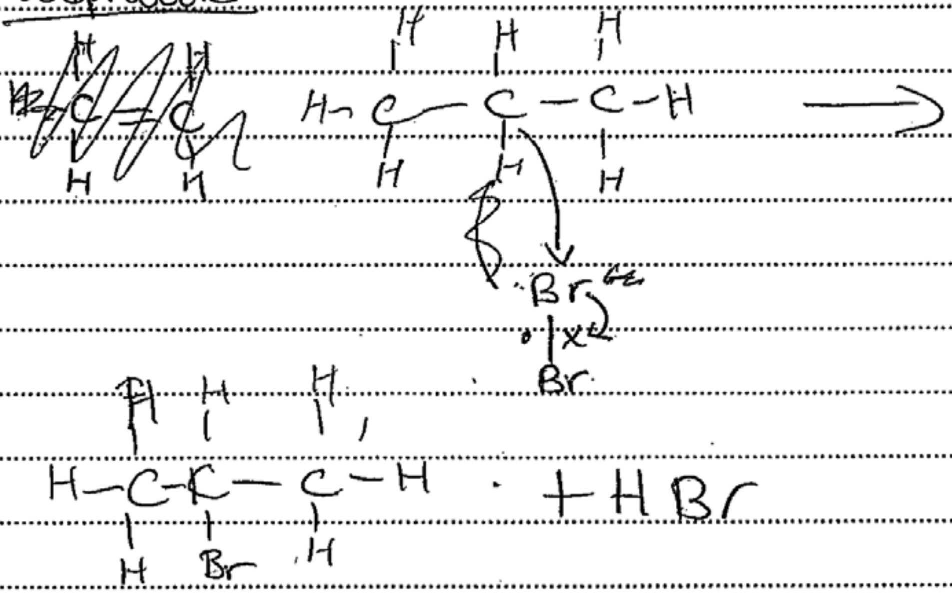
$H^+ + FeCl_4^- \rightarrow HCl + FeCl_3$

Exemplar 17

Your answer should include **one** reaction of an aliphatic compound and **one** reaction of an aromatic compound, including relevant mechanisms. **[6]** L1

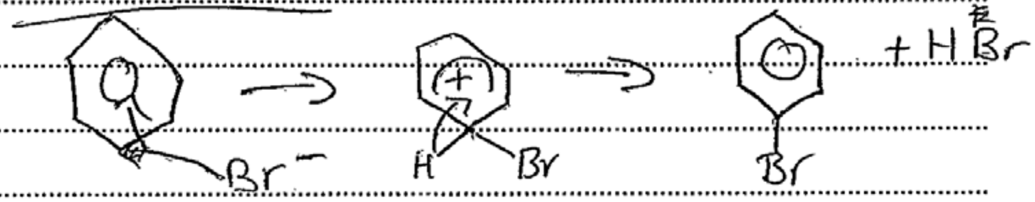
electrophiles ~~donate~~ accepts a pair of electrons and attack an organic molecule.

aliphatic



Additional answer space if required.

aromatic



$AlBr_3 + Br_2 \rightarrow AlBr_4^- + Br^-$

$AlBr_4^- +$ ~~Br~~ $H^+ \rightarrow AlBr_3 + HBr$

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