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Examiners' report

CHEMISTRY A

H432

For first teaching in 2015

H432/03 Summer 2022 series

Version 1

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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. A selection of candidate answers are 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.

Advance Information for Summer 2022 assessments

To support student revision, advance information was published about the focus of exams for Summer 2022 assessments. Advance information was available for most GCSE, AS and A Level subjects, Core Maths, FSMQ, and Cambridge Nationals Information Technologies. You can find more information on our website.

Paper 3 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.

Candidates who did well on this paper generally did the following:	Candidates who did less well on this paper generally did the following:
Displayed knowledge and understanding of important chemistry concepts, e.g. • Question 1 (c): Proton NMR splitting • Question 1 (d) (i): Bond angles • Question 1 (d) (ii): Square planar complexes Performed standard calculations following a set method, e.g. • Question (1) (b): Determination of relative atomic mass • Question (2) (a) (i): Stoichiometry and reacting quantities • Question (3) (a): Calculation of percentage yield • Question 5 (a): Calculation of an energy change using $mc\Delta T$ and subsequent ΔH determination • Question 6 (b): Calculation of pH for a weak acid • Question 6 (c): Analysis of titration results Used electrode potentials of redox systems to construct overall equations and to explain the rationale for the reactions (Question 2 (b)).	Showed poor setting out of unstructured calculations, sometimes with unlabelled numbers scattered across the page, e.g. • Question 5 (a): Calculation of energy and enthalpy changes. Showed lack of basic knowledge and understanding of structure and bonding • (Question 1 (a) (i)). Found it difficult to apply knowledge and understanding to unfamiliar situations, e.g. • Questions 1 (d) (i), (a) (ii) and 2 (c): Writing equations for unfamiliar reactions using provided information • Question 2 (a) (ii): Disproportionation using oxidation numbers for an unfamiliar reaction. Showed limited knowledge and understanding of practical scenarios and drawing labelled diagrams of apparatus, e.g. • Question 3 (a): Diagram of reflux • Question 3 (a): Purification of an organic liquid

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.

Note

Candidates have been provided with a fixed number of answer lines and an extra answer space. The extra answer space will be clearly labelled as additional and is only to be used when required. Teachers are encouraged to keep reminding candidates about the importance of conciseness in their answers.

Question 1 (a) (i)

1 These questions are from different areas of chemistry.

(a) Ammonia, NH_3, and ammonium nitrate, NH_4NO_3, are compounds of nitrogen.

(i) The boiling point of NH_3 is –33 °C.

The boiling point of NH_4NO_3 is 210 °C.

Explain why there is a large difference in boiling points.

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..... **[2]**

Candidates found the explanation difficult, and the responses showed some misconceptions. For example, many suggested that NH_3 and NH_4NO_3 both have hydrogen bonds. Those identifying that NH_4NO_3 has ionic bonding usually compared the greater strength of ionic bonding over intermolecular forces in NH_3. Unfortunately, many candidates described the ionic bonds as acting between molecules.

This question proved to be one of the most difficult on the paper.

Misconception

A good understanding of structure and bonding continues to be difficult for candidates, demonstrated by many incorrect explanations for the different boiling points. This is a key misconception.

Understanding could be improved by first considering the following.

- What is the type of bonding?
- What are particles in the structure?

Candidates need to be very careful when describing the two types of structure containing covalent bonds:

- Simple molecular with strong covalent bonds within the molecules and weaker intermolecular bonds between the molecules in the structure
  Giant covalent with strong covalent bonds between the atoms in the structure.

Exemplar 1

NH_3 and NH_4NO_3 both have hydrogen bonding. however NH_4NO_3 has many more H bonds due to size of compound. This means more energy is required to break bonds.

Exemplar 1 is typical of many, suggesting that NH_4NO_3 has hydrogen bonding, which is either stronger than in NH_3, or that NH_4NO_3 has more hydrogen bonds. This response was given 0 marks.

Question 1 (a) (ii)

(ii) Two students discuss the oxidation numbers in ammonium nitrate, NH_4NO_3.

One student claims that the two nitrogen atoms have the same oxidation number. The other student disagrees and claims that the nitrogen atoms have different oxidation numbers.

Explain with reasons which student is correct.

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..... **[1]**

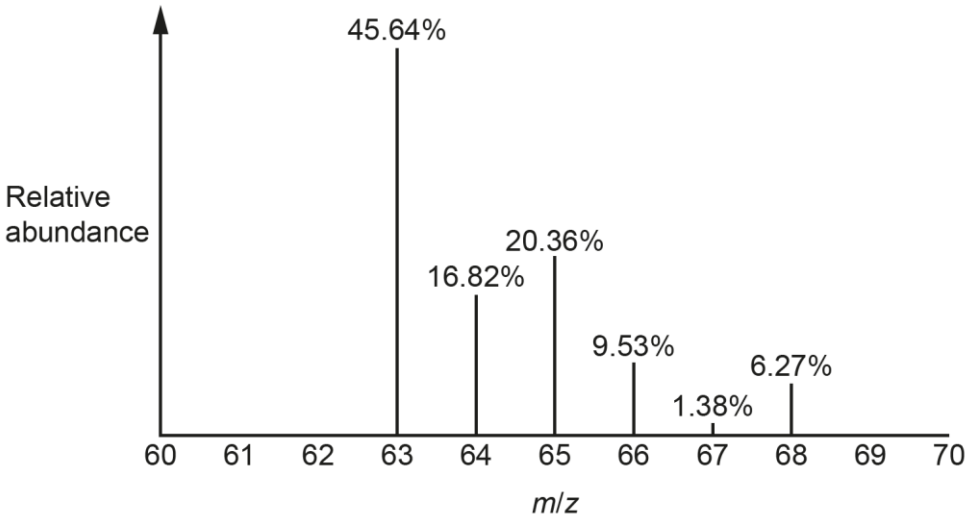
Considering the large number of candidates describing NH_4NO_3 as molecular in Question 1 (a) (i), most candidates identified here that NH_4NO_3 contains NH_4^+ and NO_3^- ions. Most then went on to show that the nitrogen atoms in the ions have different oxidation numbers: –3 and +5 respectively.

Candidates were only given marks if **both** signs had been included and this was usually the case. –4 and +6 were common incorrect responses, presumably by ignoring the charges on the ions. Comparatively few candidates grouped the nitrogen atoms together and suggested that they had the same oxidation number.

Question 1 (b) (i)

(b) Brass is an alloy of copper and zinc.

The mass spectrum of a sample of brass is shown below.



The peaks at $m/z = 63$ and $m/z = 65$ are from the ^{63}Cu and ^{65}Cu isotopes of copper.

The remaining four peaks are from isotopes of zinc.

(i) What are the percentage compositions of copper and zinc in the brass sample?

Cu = ... % Zn = ... % **[1]**

Question 1 (b) presented candidates with a mass spectrum of two elements in an alloy. This novel question was answered well, and the introductory part (i) provided candidates with a hint of how to approach the harder part (ii). Almost all candidates analysed the percentages to show that the brass sample contains 66% Cu and 34% Zn, the 34 being required in Question 1 (b) (ii).

Question 1 (b) (ii)

(ii) Calculate the relative atomic mass of zinc in the sample of brass.

Give your answer to **2** decimal places.

relative atomic mass = ... **[2]**

Most candidates produced a stock expression for a relative atomic mass calculation with the numerator comprising the four zinc isotopes with their respective percentage abundances, equating to 2224.28.

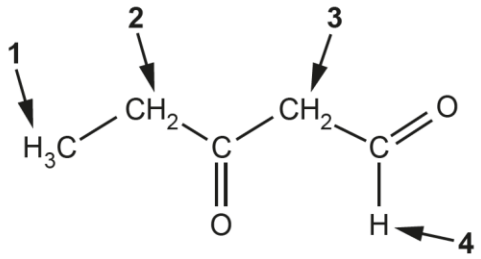
The second mark required candidates to realise that the numerator needed to be divided by the total zinc percentage abundance of 34% to produce a value of 65.42. Less successful responses divided by 100% to obtain a value of 22.24. Almost all candidates gave their answers to the required two decimal places.

The second mark proved to be a very good discriminator, with some candidates usually obtaining both marks with less successful responses still able to obtain the first mark for the numerator.

Question 1 (c) (i)

(c) The structure of an organic compound is shown below.

The protons are in four different environments, which are labelled **1**–**4**.



(i) Fill in the table to predict the splitting patterns in the **proton** NMR spectrum of the organic compound.

Proton environment	Splitting pattern
1	
2	
3	
4	

[2]

This question tested candidates' ability to predict splitting patterns of an organic compound in a proton NMR spectrum. The 2 marks were given for the interacting protons in environments 1 and 2, and in environments 3 and 4.

Most candidates predicted the correct triplet/quartet splitting pattern for the common CH_3CH_2 group. The splitting pattern for the less common CH_2CHO was more difficult with many predicting at least one singlet. As with Question 1 (b) (ii), the second mark proved to be a very good discriminator.

Question 1 (c) (ii)

(ii) The table shows the chemical shifts for the peaks in the **proton** NMR spectrum at proton environments **2** and **3**.

Proton environment	**2**	**3**
Chemical shift, δ	2.5 ppm	3.6 ppm

Suggest why the peaks for proton environments **2** and **3** have the chemical shifts which are shown in the table.

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..... **[2]**

This novel question required candidates to apply their knowledge and understanding of proton NMR spectroscopy to explain different chemical shifts. Most candidates used the *Data Sheet* in their answers, and most were then able to relate the chemical shift at δ = 2.5 ppm to an adjacent C=O group. Fewer candidates were then able to interpret the unexpected chemical shift at δ = 3.6 ppm to the presence of two adjacent C=O groups. Less successful responses often resorted to the *Data Sheet* a second time, suggesting the presence of an adjacent HC–O group, despite none being present in the structure.

It was encouraging to see how many candidates were able to explain the two chemical shifts correctly, suggesting that most candidates are comfortable with this concept.

Question 1 (d) (i)

(d) Glycine, H_2NCH_2COOH, is an α-amino acid.

(i) Glycine reacts with NaOH to form the salt H_2NCH_2COONa.

Glycine reacts with HCl to form the salt $HOOCCH_2NH_3Cl$.

The salts have different H–N–H bond angles.

State the different H–N–H bond angles and explain why they are different.

H_2NCH_2COONa H–N–H bond angle = ...°

$HOOCCH_2NH_3Cl$ H–N–H bond angle = ...°

explanation .....

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..... **[3]**

This question required candidates to apply their knowledge and understanding of bond angles and electron pair repulsion of NH_3 and NH_4^+ to amino acid salts. The best candidates rose to this challenge and secured all 3 marks for correct bond angles and explanations in terms of the numbers of bonded and lone pairs around the N atoms.

Overall, candidates found this question quite difficult. Many different bond angles were predicted, with 120º being the commonest incorrect H–N–H bond angle in H_2NCH_2COONa. The explanation for 120º was in terms of three bonding pairs and no lone pairs. 104.5º was also seen, presumably relating H_2N to H_2O. The 109.5º bond angle was correct more often, as was its explanation in terms of 4 bonding pairs.

Many successful responses showed working on diagrams in which bonded and lone pairs had been included. This strategy will have helped candidates in their conclusions.

Question 1 (d) (ii)

(ii) Glycine reacts with aqueous copper(II) ethanoate to form copper(II) glycinate, $Cu(H_2NCH_2COO)_2$, and ethanoic acid. Copper(II) glycinate is a complex which exists as two square planar isomers.

Write an equation for this reaction and draw the structures of the two square planar isomers of the complex $Cu(H_2NCH_2COO)_2$.

equation

.....

structures

[3]

Candidates were asked to predict an unfamiliar equation from provided information and to draw structures of square planar complexes containing an amino acid. Candidates found the structures easier than the equation, with many drawing 3D structures with 2 out-wedges and 2 in-wedges and attaching the NH_2 and COO groups correctly. It was also common to see a 'criss-cross' orientation, looking down on the complex, which is easier to draw. Many candidates connected the NH_2 and COO groups next to, and across from, each another in the isomers. A common error was for candidates to rotate their first structure, to produce a second drawing of the first structure. Less successful responses often tried to attach NH_2 and COO groups but with no CH_2 between the groups to produce a cyclic attachment. A minority of candidates ignored 'square planar' and drew tetrahedral structures instead.

The equation proved to be very difficult, the commonest error being omission of the '2' balancing numbers for H_2NCH_2COOH and CH_3COOH. The formulae for ethanol or propanoic acid were also often seen for ethanoic acid. Candidates are advised to check all formulae and then to check balancing, the golden rules for successfully constructing all equations.

Question 2 (a) (i)

2 This question is about redox reactions.

(a) 'Calcium hypochlorite', $Ca(Cl O)_2$, is an ionic compound used in 'bleaching powder'.

The ClO^- ion in $Ca(ClO)_2$ is the active ingredient that kills bacteria.

Calcium hypochlorite is prepared by reacting chlorine gas with calcium hydroxide.

$$2Cl_2(g) + 2Ca(OH)_2(s) \rightarrow Ca(ClO)_2(s) + CaCl_2(s) + 2H_2O(l) \quad \textbf{Equation 2.1}$$

(i) 420 dm^3 of chlorine, measured at RTP, is reacted with an excess of $Ca(OH)_2$.

The solid products are dissolved in water to form 4.00 m^3 of solution.

Calculate the concentration of $Ca(ClO)_2(aq)$ in this solution, in mol dm^{-3}.

Give your answer to an **appropriate** number of significant figures and in standard form.

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

Most candidates calculated the amounts of Cl_2 and $Ca(ClO)_2$ correctly as 17.5 mol and 8.75 mol respectively. Only the least successful did not use the equation's stoichiometry to halve 17.5 to 8.75. For the final step in the calculation, candidates needed to convert 4.00 m^3 into 4000 dm^3 and to then determine the concentration to an appropriate number of significant figures and standard form. As all the data had been provided to 3 significant figures, the final answer was also required to 3 significant figures, as 2.09×10^{-3} mol dm^{-3}. Answers such as 2.2×10^{-3}, 2.1875×10^{-3} and 2.19×10^{-6} and 0.00219 illustrate errors in these areas.

Question 2 (a) (ii)

(ii) Calcium hypochlorite, $Ca(ClO)_2$, is heated. The $Ca(ClO)_2$ decomposes to form $CaCl_2$ and $Ca(ClO_3)_2$. This is a disproportionation reaction.

Write an equation for this decomposition and explain, using oxidation numbers, why this is a disproportionation reaction.

equation .....

explanation .....

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..... **[3]**

Candidates were required to write a balanced equation from provided reactants and products and to use oxidation numbers to illustrate disproportionation.

In the equation, the reactants and products were sometimes unbalanced, or incorrectly balanced. A common error was to balance the equation after first adding O_2 as an extra reactant.

Illustrating disproportionation proved to be easier with the oxidation number changes from the initial +1 being required. Otherwise, more successful responses sometimes missed out on marks if they omitted detail. For example, the oxidation number changes were stated but the candidate omitted to state which change was oxidation and which was reduction. The best responses identified $Ca(ClO_3)_2$ as the oxidation product and $CaCl_2$ as the reduction product.

One unexpected error on many scripts was for calcium to be identified as the element undergoing disproportionation, with oxidation number changes from +6 to +14 and +2. It was difficult to see why this happened, with Ca forming +2 compounds, but the error was common.

Question 2 (b)

(b) A student analyses the redox reactions shown below. State symbols have been omitted.

$CH_3CHO + 2H^+ + 2e^- \rightleftharpoons C_2H_5OH \quad E^\ominus = -0.197\,V$

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \quad E^\ominus = +1.33\,V$

$FeO_4^{2-} + 8H^+ + 3e^- \rightleftharpoons Fe^{3+} + 4H_2O \quad E^\ominus = +2.20\,V$

The student concludes that different ions containing chromium can act as oxidising or reducing agents.

Using the terms oxidising agent and reducing agent, and ideas about electrode potentials and equilibrium, explain how the student is correct.

Include overall equations.

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..... **[5]**

Most candidates were able to obtain some credit for this problem. The equations proved to be among the easier marks, and it was encouraging to see how many candidates were able to use the E data to help them combine the half equations correctly. Most then cancelled down the common species present on both sides of the equation: H+, H2O and e–.

Explanations were generally sound, either by comparing the E values, stating the direction of equilibrium shift, or by using cell potentials.

The hardest marks proved to be the identification of the chromium ions that were the oxidising and reduction agents. Many candidates just referred to 'chromium' despite the chromium half equation containing two chromium ions, Cr2O72– and Cr3+. Candidates who had written correct equations sometimes assigned the wrong chromium ion as the oxidising or reducing agent. Mores successful responses constructed correct equations and stated that Cr2O72– was the oxidising agent as it oxidised C_2H_5OH and that Cr^{3+} was the reducing agent as it reduced FeO_4^{2-}.

Question 2 (c)

(c) A student bubbles hydrogen sulfide gas, $H_2S(g)$, through an acidified solution containing manganate(VII) ions, $MnO_4^-(aq)$.

A redox reaction takes place, forming aqueous manganese(II) ions, a yellow precipitate and one other product.

Construct the equation for this reaction. State symbols are not required.

..... **[2]**

Candidates needed to interpret the information provided and to use this as the basis for their redox equation.

The clue of a yellow product proved to be very difficult to interpret as being sulphur. The equation then required H^+ to be added as a reactant ('acidified' in the information) and H_2O as the other product. Balancing required use of oxidation numbers.

Candidates found this equation very difficult and relatively few correct equations were seen. The mark scheme did allow 1 mark for any correct five species but the correct equation proved to be challenging in demand.

Question 3 (a*)

3 Information about 1-bromobutane and butan-1-ol is shown in the table.

Compound	Melting point / °C	Boiling point / °C	Density / g cm^{-3}
1-bromobutane	–113	102	1.268
butan-1-ol	–90	118	0.810

A student prepares a sample of 1-bromobutane by refluxing 9.25 g of butan-1-ol with sodium bromide and sulfuric acid.

After reflux, the reaction mixture is purified.

The student obtains 6.10 cm^3 of pure 1-bromobutane.

(a)* Draw a diagram to show how the student would have carried out the reflux and calculate the percentage yield of 1-bromobutane that the student obtains.

Describe how the student could have obtained pure 1-bromobutane from the reaction mixture obtained after reflux. **[6]**

This question was assessed by level of response (LoR). Candidates were required to describe key features in a procedure to prepare a pure organic liquid, including a labelled diagram for reflux, a calculation of the percentage yield and the procedural steps for purification. Levels were determined using these three features. Marks within a level were determined by communication. This question discriminated extremely well.

Level 3 candidates would draw a clear diagram with all key items labelled and the set up being capable of being used safely. The percentage yield calculation would be correct, producing a percentage yield close to 45.2%. The steps for the purification: use of a separating funnel, drying and redistillation would be described in the correct order and with some detail.

Level 2 candidates would have obtained some of the features required for Level 3 but there would be some key omissions or errors. The diagram may have been drawn clearly but labelling may have been incomplete or a thermometer with bung may have been inserted into the top of the condenser, a very hazardous arrangement. The calculation would be attempted but with some errors, such as omitting to use the density, or using a mixture of moles and masses. The purification steps may have been described but in the wrong order. Purification steps would be incomplete, perhaps only including distillation.

Level 1 candidates often drew a diagram resembling a tube above a flask, with water often flowing in the wrong direction. The percentage yield may have been a simple mass ratio with no moles being used.

A significant number of candidates described the purification steps for an organic solid, including recrystallisation. The preparation of an organic liquid is a key practical procedure that will have been experienced by students during their A Level studies (PAG 5). The overall standard of drawing diagrams was poor, an area that needs improvement.

Question 3 (b)

(b) Butan-1-ol reacts with sodium bromide and sulfuric acid to form 1-bromobutane by nucleophilic substitution.

The mechanism for this reaction takes place by two steps.

Step 1 The oxygen atom of the alcohol group accepts a proton to form a positively-charged intermediate.

Step 2 Bromide ions react with the intermediate from **Step 1** by nucleophilic substitution to form 1-bromobutane.

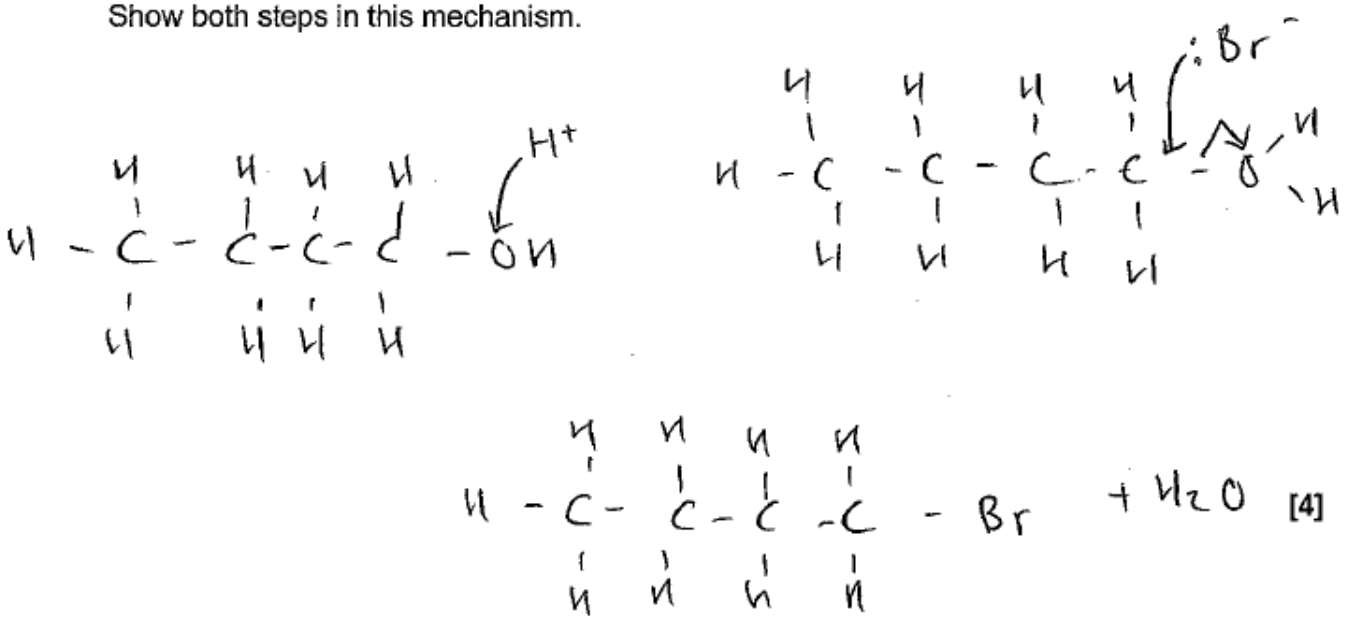
Show both steps in this mechanism.

[4]

This question is one of two on this paper assessing understanding of unfamiliar organic reaction mechanisms. The stem to the question includes important information and clues that should have then guided candidates towards this unfamiliar mechanism (which is related to the familiar nucleophilic substitution of haloalkanes). The two prompts for Step 1 and Step 2 are critical but many candidates did not use these, instead inventing their own mechanisms. However, there were many successful responses seen that gained the full 4 marks.

Exemplar 2

Show both steps in this mechanism.



Exemplar 2 illustrates a limited appreciation of what curly arrows mean and the importance of charges and dipoles. Step 1 is an attempt to show the alcohol OH group accepting a proton, but a curly arrow shows the movement of an electron pair. It cannot travel from a + charge to a lone pair. The intermediate shown does contain the correct atoms but the + charge has been omitted from the O atom.

Marks were given for the curly arrow from the Br^- lone pair and from the C–O bond. However, the candidate has drawn the bonds with very short lines making it all too easy for a curly arrow to be shown imprecisely. This response was given 2/4 marks.

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 Q3b, curly arrows start

- from a lone pair on the alcohol OH and a Br^- ion
- from a C–O bond

A curly arrow will **not** originate from a + charge.

Question 4 (a)

4 Two students plan to investigate **Equilibrium 4.1**, shown below.

$CoCl_4^{2-}(aq) + 6H_2O(l) \rightleftharpoons [Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$ **Equilibrium 4.1**

blue pink

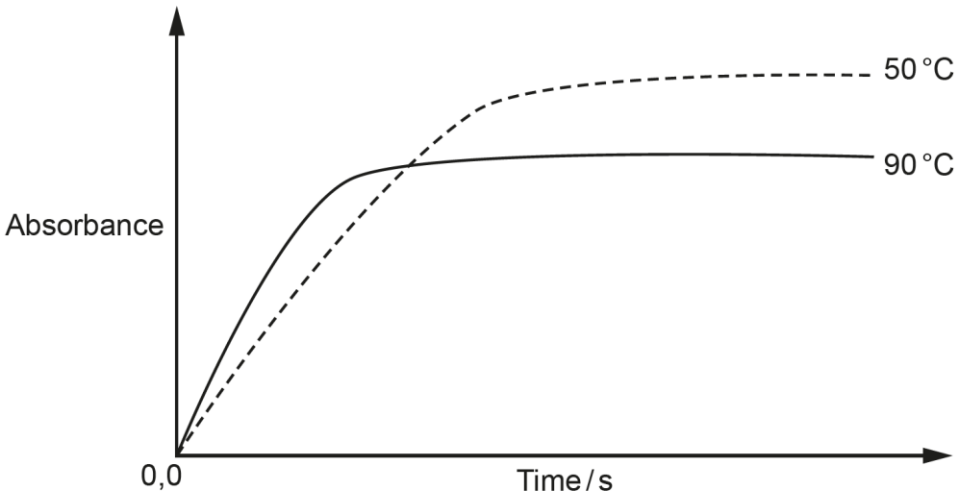
(a) The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- One student heats 20 cm^3 of the mixture to 50 °C.
- The other student heats 20 cm^3 of the mixture to 90 °C.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[Co(H_2O)_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.



Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at 50 °C and 90 °C.
- Predict the sign of ΔH for the forward reaction in **Equilibrium 4.1**.

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..... **[4]**

This question asked candidates to explain the different rates from a novel experiment carried out at 50ºC and 90ºC, and to predict the ΔH sign for the forward reaction. Candidate explanations for the rates were often superficial, solely in terms of greater energy at 90ºC. Many responses referred neither to the different frequency of collisions nor the greater number of particles exceeding the activation energy at 90ºC. Most candidates predicted that ΔH would have a negative sign.

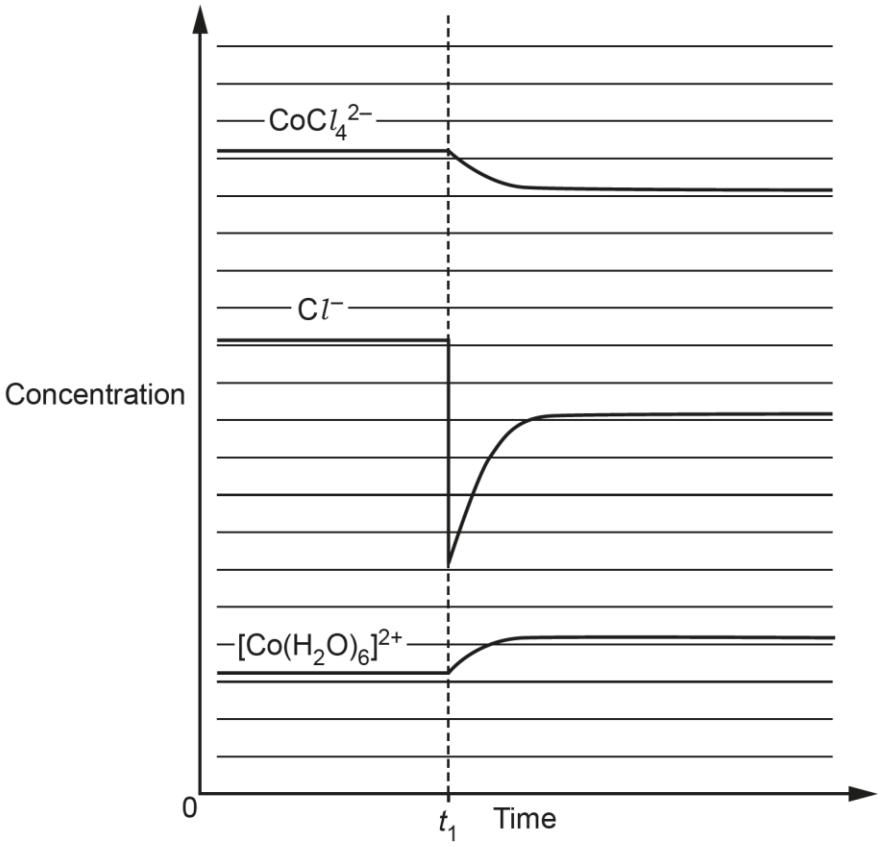
Candidates were expected to link the evidence from the absorbance data in the graph to less $[Co(H_2O)_6]^{2+}$ being present at 90ºC. When experimental information has been presented, candidates are advised to look for the evidence responsible in their explanations.

Question 4 (b) (i)

(b) The students investigate how addition of aqueous silver nitrate, $AgNO_3(aq)$, affects the equilibrium position in **Equilibrium 4.1**.

The graph shows the changes in the equilibrium concentrations of $CoCl_4^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after addition of the $AgNO_3(aq)$.

The $AgNO_3(aq)$ is added at time = t_1.



(i) Explain why the Cl^- concentration drops sharply at time = t_1.

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..... **[1]**

Almost all candidates realised that Cl^- ions would react with the added $AgNO_3$ at time = t_1.

Question 4 (b) (ii)

(ii) Explain the changes in concentration of $CoCl_4^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after time = t_1. Refer to **Equilibrium 4.1** in your answer.

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..... **[3]**

In contrast with Question 4 (a), most candidates did interpret the graphical information provided and related this to the reduced concentration of $CoCl_4^{2-}$ ions and the increased concentration of $[Co(H_2O)_6]^{2+}$ ions. Most candidates also referred to Equilibrium 4.1 to conclude that the equilibrium shifts to the right. Only the very best candidates recognised that the increase in Cl^- concentration following the initial addition of $AgNO_3$ was 4 times greater than the increase in the concentration of $Co(H_2O)_6]^{2+}$, arising from the 4 : 1 ratio in the stoichiometry in the equation.

Question 5 (a)*

5 This question is about energy changes.

(a)* A student plans to determine the enthalpy change of hydration of calcium ions.

The student finds the information below from data tables.

Enthalpy change	**ΔH / kJ mol^{-1}**
Lattice enthalpy of calcium chloride	–2223
Enthalpy change of hydration of chloride ions	–378

The student carries out an experiment to find the enthalpy change of solution of calcium chloride.

Student's method:

- Weigh a bottle containing calcium chloride and weigh a polystyrene cup.
- Add water from a measuring cylinder to the polystyrene cup and measure its temperature.
- Add the calcium chloride, stir the mixture, and measure the maximum temperature of the final solution.
- Weigh the empty bottle and weigh the polystyrene cup with the final solution.

Mass readings

Mass of bottle + calcium chloride / g	27.45
Mass of empty bottle / g	18.17
Mass of polystyrene cup / g	21.24
Mass of polystyrene cup + final solution / g	127.84

Temperature readings

Initial temperature of water / °C	21.0
Maximum temperature of final solution / °C	39.5

Calculate the enthalpy change of solution of calcium chloride and determine the enthalpy change of hydration of calcium ions.

Show your working, including an energy cycle linking the energy changes.

Assume that the density and specific heat capacity, *c*, of the solution are the same as for water. **[6]**

This question was assessed by level of response (LoR). Candidates were required to process raw experimental results to determine one enthalpy change, and then to determine a second enthalpy change by using an energy cycle. Levels were determined by the accuracy of the candidates' processing of the results, calculations and use of the energy cycle. Marks within a level were determined by communication. This question discriminated extremely well.

Level 3 candidates used the mass of solution as 106.6 g with $mc\Delta T$ to obtain an energy change of 8.24 kJ. They then divided this value by the moles of $CaCl_2$ that reacted (0.0835 mol) to obtain the enthalpy change of –98.7 kJ mol^{-1}. Finally, they constructed an energy cycle which they then used to obtain the second enthalpy change of –1566 kJ mol^{-1}.

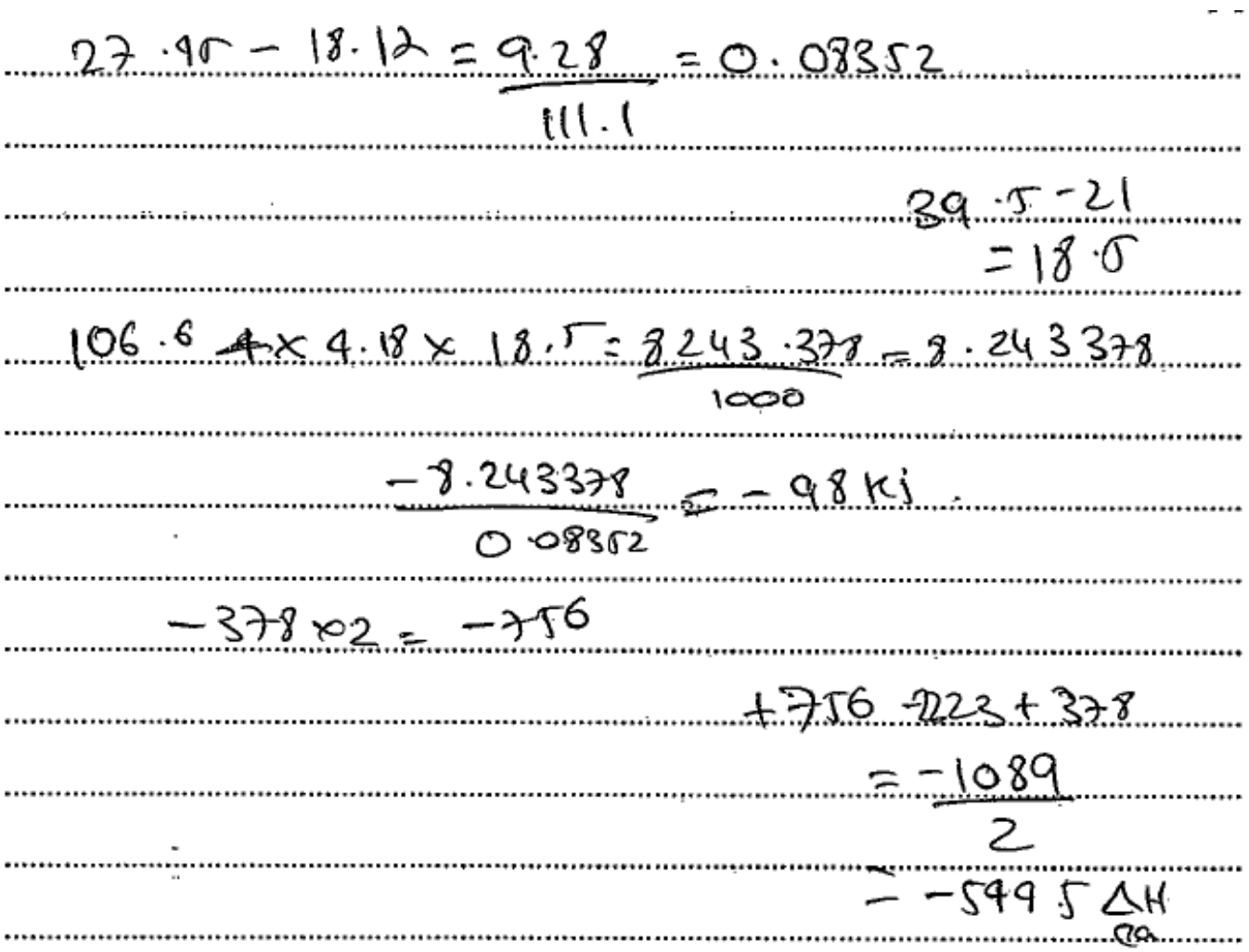
Level 2 candidates determined the first enthalpy change but may have used the approximate mass of 100 g for the mass of solution from the experimental method. Their energy cycle was often incorrect or absent, with the second enthalpy change calculated incorrectly.

Level 1 candidates often calculated the initial energy change using $mc\Delta T$ but made little further correct progress.

Less successful responses used the solid mass of calcium chloride (9.28 g) instead of the mass of the solution in their $mc\Delta T$ calculation.

Overall, mathematical skills were displayed well but some basic errors were made, particularly with subtractions. This may have been the result of mis-keying values into a calculator and believing the answer displayed.

Exemplar 3



Exemplar 3 is a Level 2 response. The candidate has calculated the initial energy change, the moles of calcium chloride and the first enthalpy change using a correct method. This response has not been given marks for the communication strand of Level 3 because there is nothing to indicate what the numbers refer to. The response could be summarised as a mass of numbers scrawled across the page. Unfortunately, this is the pattern of many responses. So, this response was given 3/6 marks.

Question 5 (b) (i)

(b) Internal combustion engines have historically used fuels obtained from crude oil as a source of power.

The environmental effects of fossil fuel use can be reduced by blending petrol with biofuels such as ethanol.

A fuel is being developed using a 1:1 molar ratio of octane and ethanol.

(i) Write the equation for the complete combustion of this fuel.

..... **[1]**

Most candidates attempted to write an equation for the combustion of the 1:1 molar mixture of octane and ethanol. The formulae of C_8H_{18} and C_2H_5OH were usually seen although some candidates combined these as a 'mixture formula' of $C_{10}H_{24}O$ (which was accepted).

The balancing of the equation using $15½O_2$ was the hardest part of the equation and many different balancing numbers for O_2 were seen ($10CO_2$ and $12H_2O$ where usually correct). Less successful responses often attempted a combustion equation using octane OR ethanol, but not both.

This is not an easy equation to construct, and the context was novel. Overall candidates made a good attempt at this question.

Question 5 (b) (ii)

(ii) Calculate the energy released, in kJ, by the complete combustion of 8.00 kg of this fuel.

$\Delta_c H(C_8H_{18}) = -5470\,kJ\,mol^{-1}$; $\Delta_c H(C_2H_5OH) = -1367\,kJ\,mol^{-1}$.

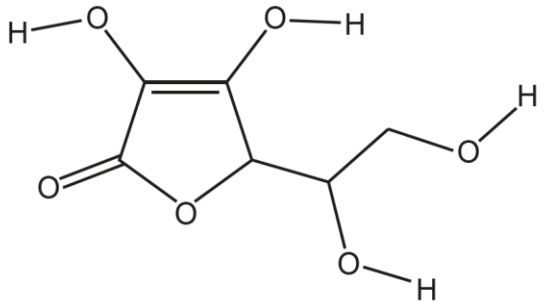
energy released = ... kJ **[3]**

This question took the novel context introduced in 5b a stage further by considering the energy released during the combustion of this fuel. Most candidates were able to obtain some credit, and many obtained the correct energy of 341,850 kJ. The commonest error was for candidates to assume that the 8 kg mixture would contain 4 kg of octane and 4 kg of ethanol, rather than an equal moles of each. Such an approach could still be partly given marks by ECF, provided that the method was sound and clear.

Question 6 (a)

6 A student carries out an investigation on vitamin C, $C_6H_8O_6$.

(a) The structure of vitamin C is shown below. Vitamin C is an optical isomer.



Vitamin C

What is the total number of optical isomers with the structure of vitamin C?

total number of optical isomers = ... **[1]**

Most candidates added two asterisks to the diagram of vitamin C for the possible chiral centres. More successful responses usually realised that two chiral centres would give rise to $2^2 = 4$ optical isomers, with 2 optical isomers being the commonest error.

Question 6 (b) (i)

(b) Vitamin C is extremely soluble in water. This means that vitamin C is removed rapidly from the body. 'Vitamin C ester' is available in tablet form as a less soluble source of vitamin C which stays in the body for longer.

(i) Suggest why vitamin C is extremely soluble in water.

.....

.....

..... **[1]**

Most candidates realise that hydrogen bonds would be formed from the OH groups in vitamin C to water. Candidates are advised to read the question carefully as the word 'extremely' was a hint that 'many' OH groups would be needed in the explanation. The most successful responses quoted that hydrogen bonds would form between the 4 OH groups in vitamin C and water. Some candidates stated that O atoms in vitamin C would be involved. This was not given marks as not all O atoms in vitamin C are a part of OH groups and capable of hydrogen bonding.

Question 6 (b) (ii)

(ii) A 'vitamin C ester' tablet contains an ester with the molecular formula $C_{22}H_{38}O_7$.

This ester can be prepared by reacting vitamin C with a long chain carboxylic acid, C_xH_yCOOH, in the presence of an acid catalyst.

Vitamin C and the long chain carboxylic acid react in a 1:1 molar ratio.

Determine *x* and *y* in the formula of this carboxylic acid.

x = ... *y* = ... **[2]**

More successful responses determined that *x* = 15 and *y* = 31.

The key to success here was to subtract the formula of vitamin C from the formula of the ester and to add the formula of water: $C_{22}H_{38}O_7 - C_6H_8O_6 + H_2O \rightarrow C_{16}H_{32}O_2 \rightarrow C_{15}H_{31}COOH$.

A significant number of candidates did obtain one of these values, with 15/16 and 29/30/32 being common incorrect answers. Omitting part(s) of sequence above would result in these incorrect numbers.

Question 6 (c) (i)

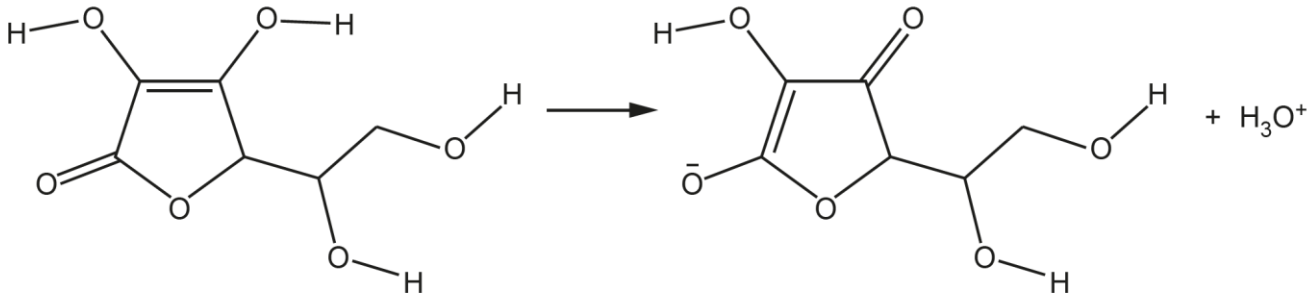
(c) Vitamin C, $C_6H_8O_6$, is a weak acid (K_a = 7.94 x 10^{-5} (mol dm^{-3})), which is often referred to as ascorbic acid.

(i) In aqueous solution, vitamin C donates a proton to water:

$C_6H_8O_6 + H_2O \rightleftharpoons C_6H_7O_6^- + H_3O^+$

Add curly arrows to the diagram to suggest the mechanism for this process.

H_2O:



[2]

This novel mechanism assessed a candidate's understanding of curly arrows, and four curly arrows were needed. One mark was available for one correct curly arrow, usually from the H_2O: or from the C=O. 2 marks were given for three or four correct curly arrows. The two curly arrows within the ring structure proved to be the most difficult.

The question discriminated extremely well: many candidates were able to secure one mark with the most able being given both marks. A candidate showing all four curly arrows correctly demonstrated an excellent understanding of curly arrows.

Question 6 (c) (ii)

(ii) The student dissolves 0.150 mol of vitamin C in water and makes the solution up to 250 cm^3 in a volumetric flask.

Calculate the pH of this solution of vitamin C.

Give your answer to **2** decimal places.

pH = ... **[3]**

Most candidates had learnt a standard method for calculating the pH of a weak acid. with the correct answer of 2.16 being seen on very many scripts. Success required conversion of 0.150 moles of vitamin C in 250 cm^3 to its concentration as 0.600 mol^{-3}, calculation of $[H^+]$ using $[H^+] = \sqrt{(K_a \times [HA])}$ and determination of pH using $-\log[H^+]$.

Common errors usually resulted from one mistake and could still be rewarded with 2 of the available 3 marks. Examples are shown below.

- pH = 4.32 *No square root of* $(7.94 \times 10^{-5} \times 0.600)$
- pH = 2.46 *No conversion of 0.150 mol to 0.600 mol* dm^{-3} $\sqrt{(7.94 \times 10^{-5} \times 0.150)}$
- pH = 2.76 ÷ 4 instead of × 4 for concentration $\sqrt{(7.94 \times 10^{-5} \times 0.0375)}$

Assessment for learning

pH calculations are common in A Level Chemistry

There are four different types, and it is essential that the standard methods for determination of $[H^+]$ in the calculations are **learnt**:

- pH of strong acids
- pH of weak acids, using K_a and [HA]
- pH of strong bases, using K_w and $[OH^-]$
- pH of buffers, using K_a and $[HA]/[A^-]$

It is extremely likely that at least one of these types of pH calculation will feature in at least one of the A Level units.

Question 6 (c) (ii)

(d) The label on a carton of orange juice lists the mass of vitamin C, in mg, in a typical serving of 150 cm^3.

The student carries out an investigation to check the vitamin C content in the orange juice.

Vitamin C can be oxidised by iodine:

$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2I^-(aq) + 2H^+(aq)$

The student dilutes 150 cm^3 of the orange juice with water to 250.0 cm^3 in a volumetric flask.

The student then titrates 25.0 cm^3 volume of this solution with 9.60×10^{-4} mol dm^{-3} iodine solution, $I_2(aq)$.

The mean titre of $I_2(aq)$ is 22.50 cm^3.

Determine the mass, in mg, of vitamin C in a 150 cm^3 serving of the orange juice.

mass of vitamin C in the 150 cm^3 serving of orange juice = ... mg **[4]**

This question was a standard titration calculation, set in a practical context. As with Question 6 (c) (i), this assessed one of the important principles encountered in A Level Chemistry.

Success required three main stages:

- Calculation of the amount, in mol, of I_2 used in the titration of 25.0 cm^3 of the diluted orange juice.
- Determination of the amount in mol of vitamin C in the 250 cm^3 solution (effectively scaling by $\times 10$)
- Use of this value with the molar mass of vitamin C to determination of the mass of vitamin C, in mg, in the 150 cm^3 serving of the orange juice.

Most candidates calculated the amount of I_2 (and vitamin C) in the titre as 2.16×10^{-5} mol. The next scaling stage by $\times 10$ to 2.16×10^{-4} mol introduced a problem. Many candidates were distracted by the '150 cm^3' serving of orange juice and they scaled further by a factor of 150/250 to give 1.296×10^{-4} mol.

Candidates scaling corrected by $\times 10$ usually used the vitamin C molar mass of 176 g mol^{-1} to determine the correct mass of 38 mg in the orange juice serving.

The common incorrect mass of 22.8 mg resulted from the extra scaling by 150/250 described above. This could still be given 3 of the available 4 marks as only one error had been made.

Some candidates worked out an incorrect molar mass for vitamin C, with 174 often seen. Provided that this value was used with a correct method, ECF could still be applied for the final mass.

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