Qualification Accredited

A LEVEL

Examiners' report

CHEMISTRY A

H432
For first teaching in 2015

H432/03 Summer 2019 series

Version 1

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.

Paper 3 series overview

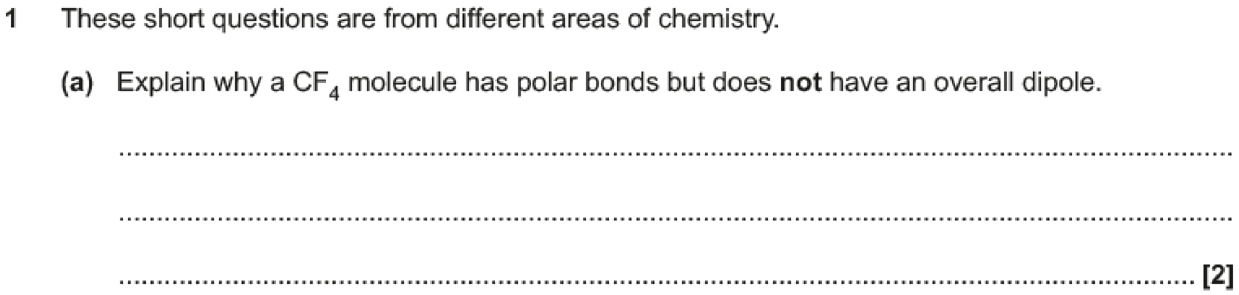
- H432/03 is one of the three examination components for the new revised A Level examination for GCE Chemistry A. This largely synoptic component links together different areas of chemistry within different contexts, some practical, some familiar and some novel. To do well on this paper, candidates need 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:***
• Performed standard calculations showing clear working, units, and using an appropriate number of significant figures, e.g. 1(c), 1(e): stoichiometry 2(d): percentage yield calculation 4(a)(iv): concentration and K_a calculation 5(a)(i), 5(b): enthalpy, entropy and free energy. • Produced clear and concise responses for Level of Response questions: 5(a)(i), 6(b). • Applied knowledge and understanding to questions set in a novel context, e.g. 5(b), 6(b). • Displayed knowledge and understanding of important practical techniques and interpretation of raw practical results, e.g. 2(e): recrystallisation 5(a)(i): determination of enthalpy changes 6(b): interpretation of a novel practical scenario.	• Showed unclear setting out of unstructured calculations, sometimes with unlabelled numbers scattered across the page, e.g. 3(a)(v), 4(a)(iv), 5(a)(i), 5(b). • Showed lack of knowledge and understanding of important chemical concepts, e.g. 1(b): isotopes and M_r 1(c): partial pressure 2(a): writing an ionic equation 3(b): structure and bonding 4(b)(iii): functional groups and their reactions. • Had difficulty in converting units, e.g. 1(d): m^3 to cm^3 5(b): kJ to J. • Found it difficult to apply what they had learnt to unfamiliar situations, e.g. 6(a): interpretation of a flowchart 6(b): identifying relevant information from a novel practical scenario.

Note

From this series students have been provided with a fixed number of answer lines and an additional answer space. The additional answer space will be clearly labelled as additional, and is only to be used when required. Teachers are encouraged to keep reminding students about the importance of conciseness in their answers. Please follow this link to our SIU (https://www.ocr.org.uk/administration/support-and-tools/siu/alevel-science-538595/)

Question 1 (a)



1 These short questions are from different areas of chemistry.

(a) Explain why a CF_4 molecule has polar bonds but does **not** have an overall dipole.

....

....

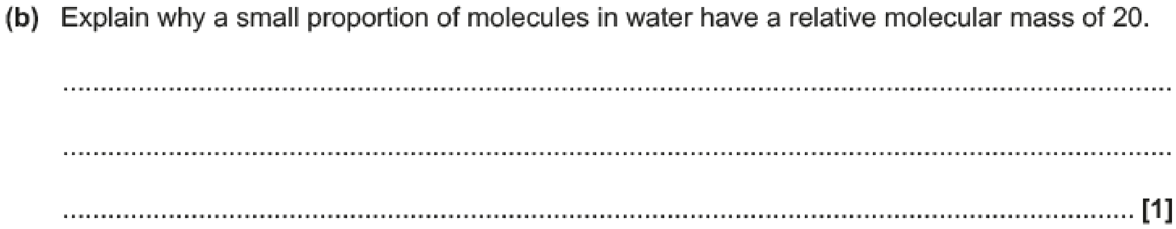
.... [2]

The best candidates explained that bond polarity results from fluorine being more electron negative than carbon.

Most candidates were able to explain why a CF_4 molecule has no overall dipole in terms of the symmetry of the molecule or dipoles cancelling. Some candidates confused dipoles cancelling with polar bonds cancelling.

A significant number of candidates did not attempt to explain bond polarity at all. Candidates are recommended to look closely at the requirements of the question set and to look at the total marks for a short answer question to gauge how many points they need to make.

Question 1 (b)



(b) Explain why a small proportion of molecules in water have a relative molecular mass of 20.

....

....

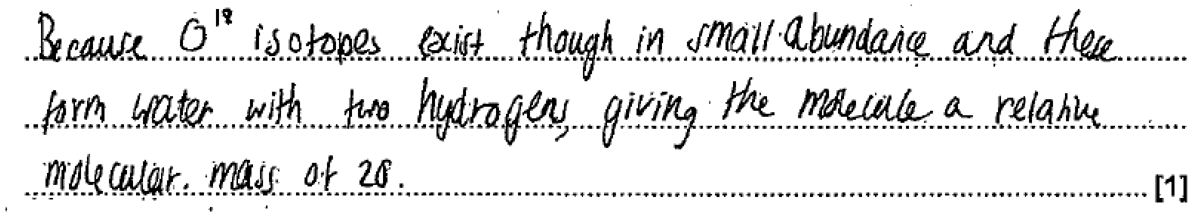
.... [1]

Many candidates recognised that the presence of hydrogen or oxygen isotopes could explain the high relative molecular mass of water. The best responses discussed D_2O or molecules with other combinations of isotopes including ^{18}O and even ^{3}H. Exemplar 1 shows a good response which explains the relative molecular mass of 20 in terms of the presence of ^{18}O.

Many candidates claimed that some water molecules had the formula of H_4O, often bringing lone pairs and hydrogen bonds into their explanations, as shown in Exemplar 2.

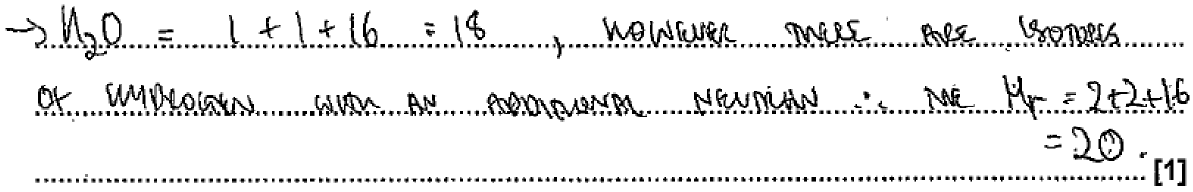
D_2O is encountered in proton NMR spectroscopy, so candidates will have encountered it during their studies, but many candidates were unable to link this to the relative molecular mass of 20.

Exemplar 1



Because O^{18} isotopes exist though in small abundance and these form water with two hydrogens, giving the molecule a relative molecular mass of 20. [1]

Exemplar 2



→ H_2O = 1 + 1 + 16 = 18, HOWEVER THERE ARE ISOTOPES OF HYDROGEN WITH AN ADDITIONAL NEUTRON ∴ THE M_r = 2+2+16 = 20. **[1]**

Question 1 (c)

(c) What is the partial pressure of O_2 (in Pa) in a gas mixture containing 21% O_2 by volume and with a total pressure of 1.0×10^5 Pa?

partial pressure of O_2 = ... Pa **[1]**

This question tested an understanding of 'partial pressure' as a concept. Most candidates obtained the correct response of 21,000 Pa or 2.1×10^4 Pa. Scaling proved to be a common error with 2.1×10^{-4} Pa being seen, presumably from dividing, instead of multiplying, 0.21 by 1×10^4.

In calculations, candidates are advised to think about whether their answer is sensible, rather than relying just on the answer displayed on the calculator.

Question 1 (d)

(d) What mass of carbon dioxide (in g) is formed by the complete combustion of 42.0 m^3 (measured at RTP) of propane?

mass = ... g **[2]**

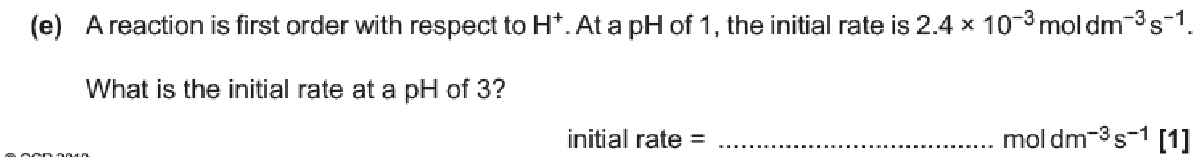
This part required candidates to work out the amount in moles of propane that combusted, followed by a calculation of the volume of CO_2.

The initial mole calculation required candidates to first convert the volume of 42.0 m^3 into dm^3 or cm^3. A correct calculation shows that 1750 mol of propane was combusted. Many struggled with the unit conversion, with 0.175 and 1.75×10^{-3} often being seen. This value then needed to be multiplied by 3 (from the stoichiometry of the equation) and 44 to produce 231,000 g. Here, ×3 was sometimes omitted.

Some candidates ignored RTP in the question and used the ideal gas equation to calculate the moles of propane. This approach was acceptable provided that sensible values had been chosen for the conditions at room temperature and pressure (e.g. 298K, 293K, 100 kPa,101 kPa).

Candidates are advised to practice volume unit conversions – important for any calculation involving gases.

Question 1 (e)



(e) A reaction is first order with respect to H^+. At a pH of 1, the initial rate is 2.4×10^{-3} mol dm^{-3} s^{-1}.

What is the initial rate at a pH of 3?

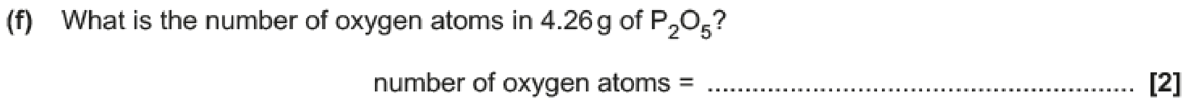
initial rate = ... mol dm^{-3} s^{-1} **[1]**

This part tested an understanding of pH as a logarithmic scale and the relationship between rates and order. This part discriminated extremely well. A pH of 3 meant that the H^+ concentration would be 100 times less than at a pH of 1. Being a first order reaction with respect to H^+, the initial rate is simply 100 times less than at a pH of 1: 2.4×10^{-5} mol dm^{-3} s^{-1}.

The higher-ability candidates identified the relationships and often wrote the correct answer on the answer line with no visible working (presumably doing the calculation in their head). Others used their well-learnt equations to calculate the same correct answer.

Many candidates found the calculation difficult and 7.2×10^{-3} ($3 \times (2.4 \times 10^{-3})$) was a very common incorrect answer. If candidates had fully scrutinised this answer, they may have realised that a more dilute solution cannot produce a faster rate.

Question 1 (f)



(f) What is the number of oxygen atoms in 4.26 g of P_2O_5?

number of oxygen atoms = ... **[2]**

This part required candidates to initially work out the amount in moles of P_2O_5 in 4.26 g of P_2O_5, followed by multiplication by 5 (for O) and the Avogadro constant to produce 9.03×10^{22} atoms.

The initial moles calculation proved to be a relatively easy mark which most candidates were awarded. Many then struggled, sometimes omitting the ×5 factor to account for the O atoms, producing the common incorrect answer of 1.806×10^{22}.

Question 2 (a)

2 Benzoic acid, C_6H_5COOH, is added to some foods as a preservative.

A student prepares benzoic acid as outlined below.

Step 1 The student mixes 4.00 cm^3 of phenylmethanol, $C_6H_5CH_2OH$, (density = 1.04 g cm^{-3}) with sodium carbonate and aqueous potassium manganate(VII), as an oxidising agent. The mixture is heated under reflux.

Step 2 The resulting mixture is cooled and then acidified with concentrated HC*l*. Impure crystals of benzoic acid appear.

Step 3 The student recrystallises the impure crystals to obtain 1.59 g of pure benzoic acid.

(a) In **Step 1**, sodium carbonate, Na_2CO_3, makes the reaction mixture alkaline.

Write an ionic equation to show how carbonate ions form an alkaline solution in water.

.... **[1]**

This equation presented problems for many candidates, despite the question asking for an equation between carbonate ions and water. An acceptable equation had to be ionic and needed to produce OH^- (for the alkaline solution) and either HCO_3^- or CO_2.

Many candidates wrote an equation with H^+ instead of H_2O, with lower ability candidates showing the carbonate ion with the wrong charge as CO_3^-.

Many candidates wrote full equations despite the question asking for an ionic equation. Candidates do need to read the instructions in the question.

Question 2 (b)

(b) In **Step 2**, explain why the mixture must be acidified so that crystals of benzoic acid appear.

....

....

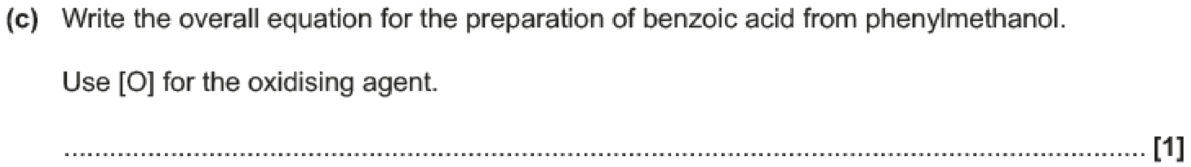
....

.... **[1]**

Candidates found this part extremely difficult. The question was aimed to stretch and challenge.

Many candidates followed on directly from part (a), stating in simple terms that the alkaline solution needed to be neutralised to remove hydroxide ions. However, candidates were expected to recognise that the alkaline conditions would lead to benzoate ions rather than benzoic acid being present in the mixture. The mixture is acidified to protonate the benzoate. The hint in the question was about making the benzoic acid appearing when acid is added.

Question 2 (c)



(c) Write the overall equation for the preparation of benzoic acid from phenylmethanol.

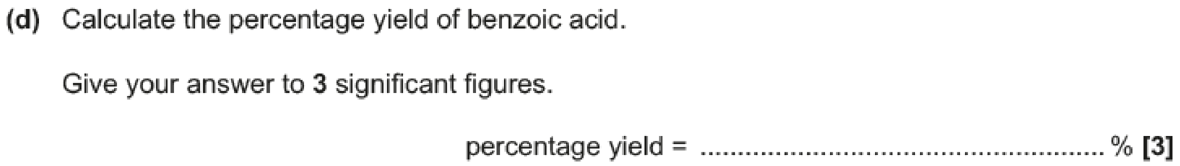
Use [O] for the oxidising agent.

.... **[1]**

This part discriminated well with many candidates being able to write a correct equation using their knowledge of the oxidation of alcohols. Mistakes usually resulted in the balancing with either [O] instead of 2[O] or $2H_2O$ instead of H_2O.

Written equations always need to be checked for the atoms balancing.

Question 2 (d)



(d) Calculate the percentage yield of benzoic acid.

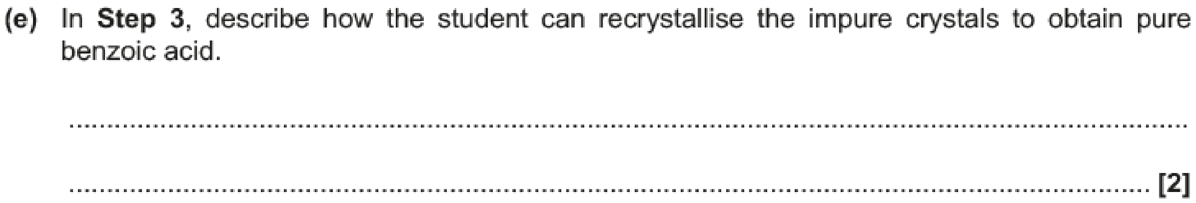
Give your answer to **3** significant figures.

percentage yield = ... % **[3]**

Candidates are well practised with percentage yield calculations with about half obtaining the correct percentage yield of 33.8 or 33.9% to secure all 3 marks. Many were able to secure partial credit for incorrect answers, provided that the working was laid out clearly.

Some responses showed a simple percentage of the two masses with no consideration of moles or molar masses. Such a response received no credit.

Question 2 (e)



(e) In **Step 3**, describe how the student can recrystallise the impure crystals to obtain pure benzoic acid.

....

.... **[2]**

Many candidates produced thorough responses, showing that they had encountered recrystallisation as a technique in their practical work.

Most candidates were aware that the impure product is dissolved in a minimum volume of hot solvent, although 'minimum' was sometimes omitted.

The subsequent stages were sometimes incomplete or in the wrong order. Many were aware that the hot solution can be passed through fluted filter paper to remove solid impurities. (This is beyond the specification requirements for A Level but good practice).

Most candidates were aware of the need to filter (usually under reduced pressure) but the necessary cooling stage to form the crystals was sometimes omitted.

Finally, many responses omitted the need to dry the crystals. Candidates did sometimes dry the crystals by adding an anhydrous salt (e.g. $CaCl_2$ or $MgSO_4$), a clear confusion with drying an organic liquid. Others described the purification of an organic liquid for their response, including use of a separating funnel, drying and distillation.

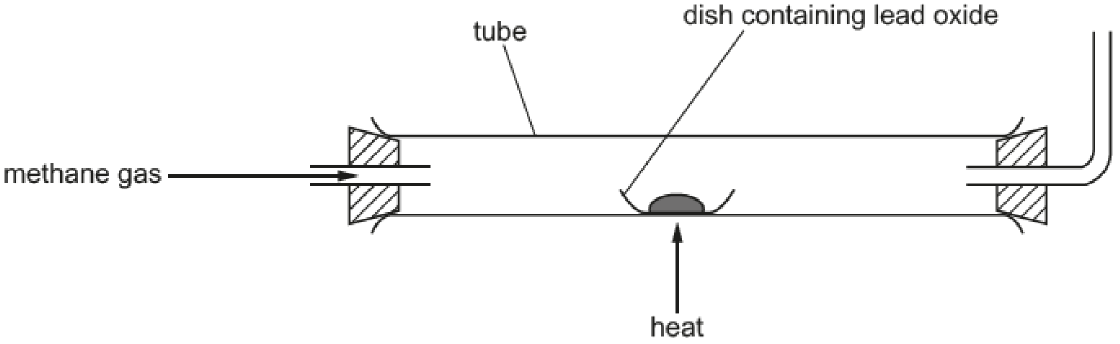
Question 3 (a) (i)

3 This question is about elements and compounds in Group 14 (Group 4) of the periodic table.

(a) There are four oxides of lead: PbO, PbO_2, Pb_2O_3 and Pb_3O_4.

A student carries out an experiment to identify an unknown lead oxide, which is one of the four oxides of lead shown above.

The student plans to reduce the unknown lead oxide to lead by heating the lead oxide in a stream of methane gas, CH_4. The apparatus is shown below.



Student's method

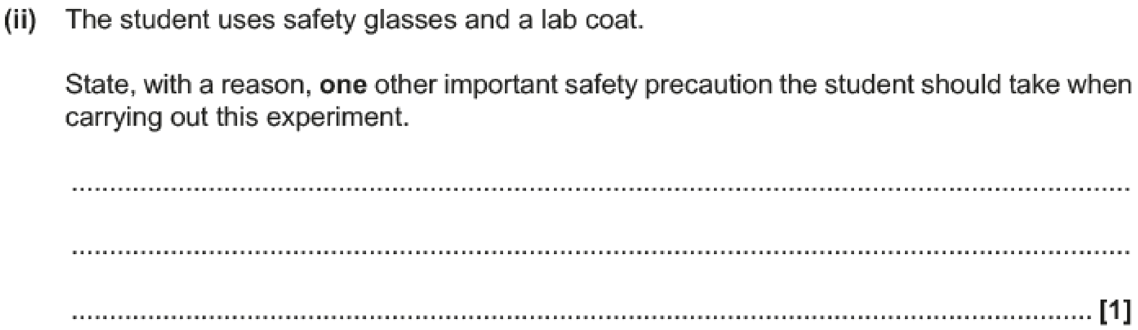
- Weigh an empty dish.
  Add the lead oxide to the dish and reweigh.
- Set up the apparatus and pass methane gas through the tube as shown.
  Heat the dish for 10 minutes.
- Pass cold air through the tube to cool the dish and contents.
- Weigh the dish and contents.

(i) Write the equation for the reduction of Pb_2O_3 with CH_4.

.... **[1]**

This equation proved to be very testing and only a minority of candidates were able to write a balanced equation for this reaction forming Pb, CO_2 and H_2O. Many different and implausible products were seen such as O_2, H_2, and CH_3OH.

Question 3 (a) (ii)



(ii) The student uses safety glasses and a lab coat.

State, with a reason, **one** other important safety precaution the student should take when carrying out this experiment.

....

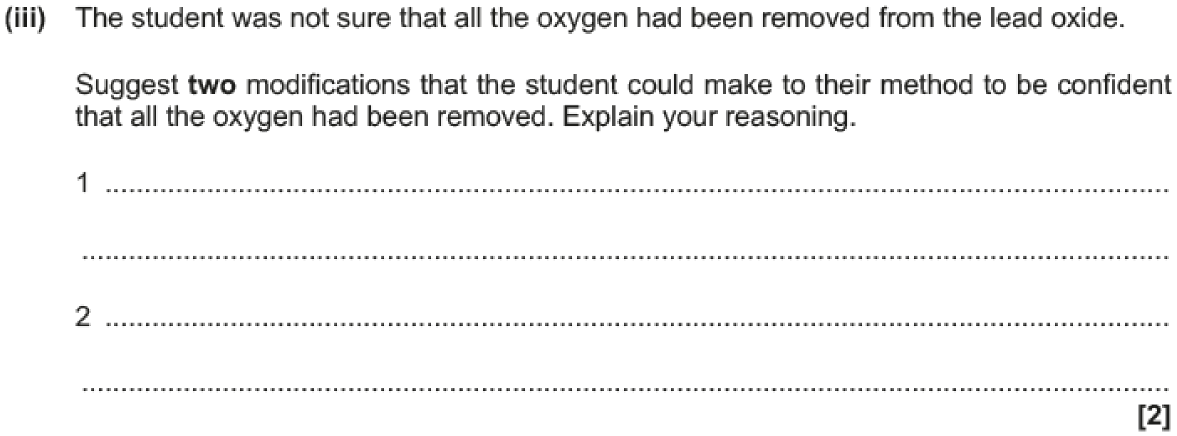
....

.... **[1]**

The mark scheme catered for a wide range of responses that were judged to be worthy of credit. Responses that form part of normal safe laboratory practice, such as keeping bags under benches, tying hair back, etc., were not given.

Candidates were expected to identify a precaution for a chemical hazard. As with GCSE, general words to describe hazards, such as harmful and dangerous, were not given. Acceptable chemical hazards would include those encountered in hazard signs such as flammable (for methane) or toxic (for lead or lead compounds). The best responses suggested that naked flames should be kept away from flammable methane or that gloves should be worn when using toxic lead. Other suggested use of a fume cupboard or good ventilation when using flammable or toxic materials. Responses such as 'face masks' gained no credit.

Question 3 (a) (iii)



(iii) The student was not sure that all the oxygen had been removed from the lead oxide.

Suggest **two** modifications that the student could make to their method to be confident that all the oxygen had been removed. Explain your reasoning.

1 ....

....

2 ....

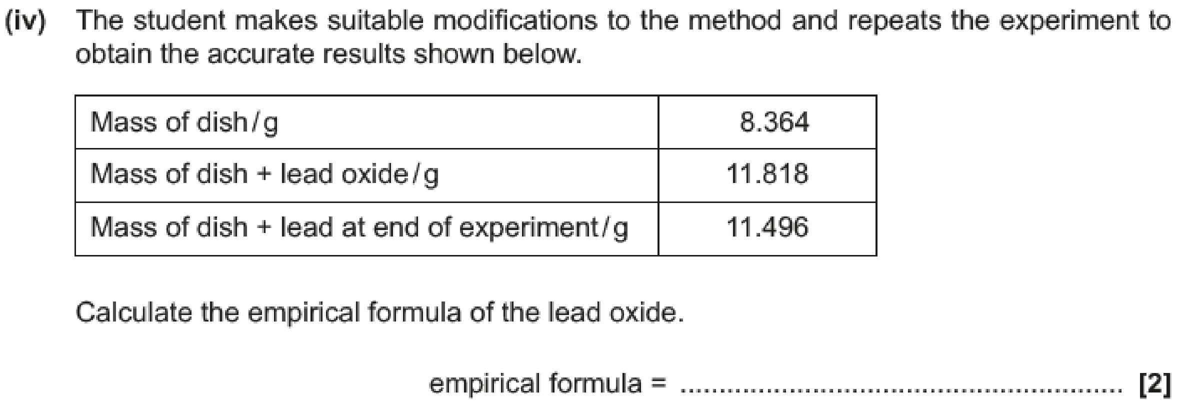
....

[2]

For one modification, many candidates suggested heating to constant mass. A second modification proved to be elusive for many. Other acceptable modifications included using powdered lead oxide to increase the surface area, bubbling the escape gases through lime water to identify when no more CO_2 was being produced in the reaction, and passing an inert gas through the apparatus during cooling to prevent re-oxidation of the lead from oxygen in the air.

Some suggestions would have created safety issues, such as working in a closed system. A significant number of candidates suggested collecting the gases evolved and that the reaction was complete when the gas volume no longer increased. Presumably the suggestion came from practical experience of rates experiments involving gas collection. This is unfeasible though when there is a constant flow of methane gas.

Question 3 (a) (iv)



(iv) The student makes suitable modifications to the method and repeats the experiment to obtain the accurate results shown below.

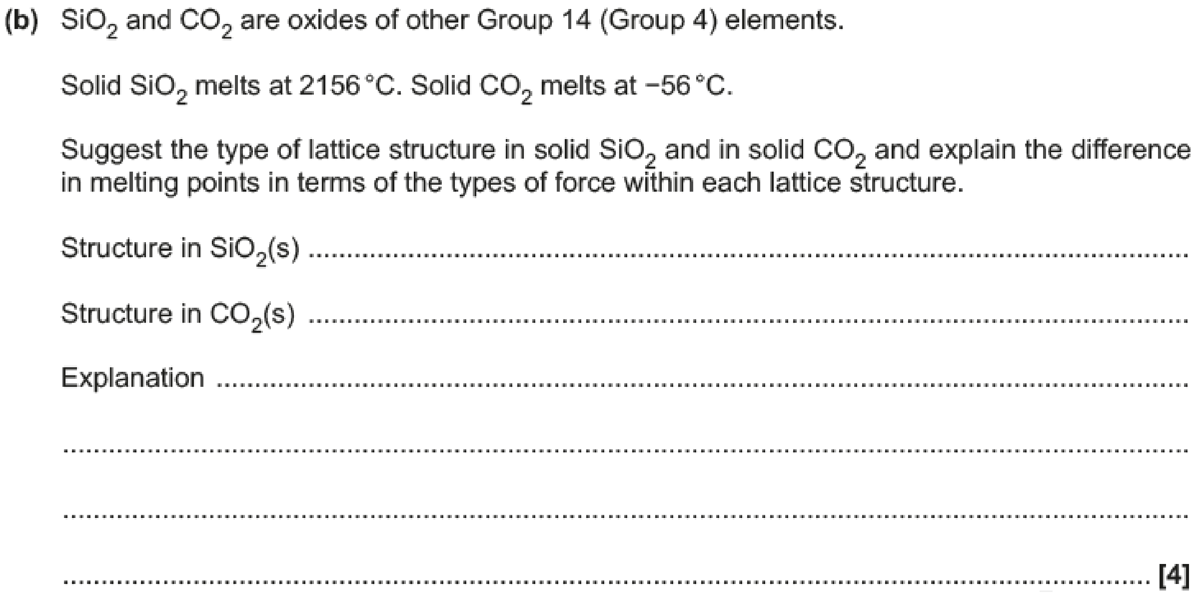
Mass of dish / g	8.364
Mass of dish + lead oxide / g	11.818
Mass of dish + lead at end of experiment / g	11.496

Calculate the empirical formula of the lead oxide.

empirical formula = ... **[2]**

Most candidates were able to work out the masses of Pb and O atoms in the lead oxide from the supplied experimental results, and to then attempt to find the molar ratio of Pb : O. The 1 : 1.33 ratio was not always identified and a significant number of candidates approximated this to PbO or Pb_2O_3 instead of scaling up the ratio to 3 : 4 to show that the formula is Pb_3O_4 .

Question 3 (b)



(b) SiO_2 and CO_2 are oxides of other Group 14 (Group 4) elements.

Solid SiO_2 melts at 2156 °C. Solid CO_2 melts at −56 °C.

Suggest the type of lattice structure in solid SiO_2 and in solid CO_2 and explain the difference in melting points in terms of the types of force within each lattice structure.

Structure in SiO_2(s) ....

Structure in CO_2(s) ....

Explanation ....

....

....

.... **[4]**

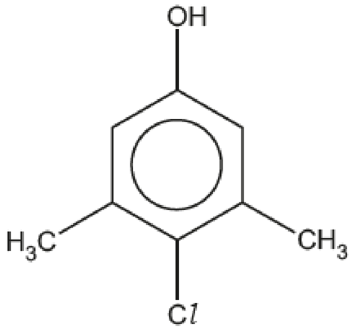
A good understanding of structure and bonding continues to be difficult for candidates, demonstrated by many explanations seen for the different melting points.

Most candidates obtained two relatively easy marks for identifying the giant and simple molecular/covalent structures of SiO_2 and CO_2 respectively.

The explanation proved to be much more difficult as candidates showed some misconceptions. Many identified that CO_2 had London forces but their action between molecules was often omitted. Many candidates realised that the forces broken on melting are much stronger in SiO_2 than in CO_2, but then went on to erroneously compare the strength of London forces or intermolecular forces in **both** SiO_2 and CO_2.

Question 4 (a) (i)

4 Dettol® is a disinfectant containing the antiseptic chloroxylenol, shown below.



chloroxylenol

(a) Chloroxylenol is a weak Brønsted–Lowry acid.

(i) What is the systematic name of chloroxylenol?

.... **[1]**

Most candidates correctly named the organic compound as 4-chloro-3,5-dimethylphenol.

The numbers caused candidates less issues than the need for the 'di' prefix to signify two methyl groups in the name.

Question 4 (a) (ii)

(ii) Predict the number of peaks in a ^{13}C NMR spectrum of chloroxylenol.

.... **[1]**

Most candidates predicted that there would be 5 peaks in the ^{13}C NMR spectrum. The common incorrect responses were 3 or 4 peaks, presumably from omitting the C–OH or C–Cl carbon atoms.

Question 4 (a) (iii)

(iii) Name the functional group responsible for the acidity of chloroxylenol and describe a simple test which would confirm the presence of this group.

Functional group ....

Test ....

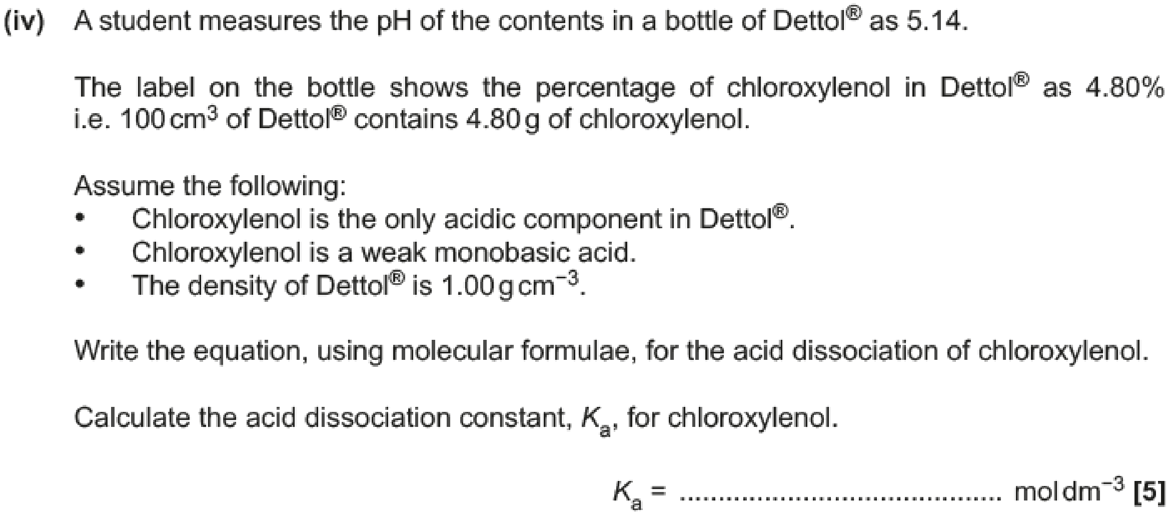
....

.... **[2]**

Most candidates identified the phenol functional group but a satisfactory test proved to be far more difficult. Many candidates identified that there would be no effervescence with sodium carbonate but it was common that the pH being less than 7 was often not seen. Neutralisation with sodium hydroxide was often seen but with no observation.

Although not in the specification, the reaction with bromine to produce a white precipitate was often seen as an acceptable alternative test for the phenol group.

Question 4 (a) (iv)



(iv) A student measures the pH of the contents in a bottle of Dettol® as 5.14.

The label on the bottle shows the percentage of chloroxylenol in Dettol® as 4.80% i.e. 100 cm^3 of Dettol® contains 4.80 g of chloroxylenol.

Assume the following:

- Chloroxylenol is the only acidic component in Dettol®.
- Chloroxylenol is a weak monobasic acid.
- The density of Dettol® is 1.00 $g\,cm^{-3}$.

Write the equation, using molecular formulae, for the acid dissociation of chloroxylenol.

Calculate the acid dissociation constant, K_a, for chloroxylenol.

K_a = ... $mol\,dm^{-3}$ **[5]**

Candidates produced some very good calculations. It was common for candidates to determine the correct K_a value of 1.71×10^{-10} mol dm^{-3}, after first calculating the hydrogen ion and weak acid concentrations. The initial calculation of the hydrogen ion concentration from 10^{-pH} proved to be the easiest mark. The weak acid concentration proved to be more difficult with a significant number unable to determine the correct molar mass of chloroxylenol as 156.5. Most candidates recognised that the molar concentration in mol dm^{-3} was required from the mass of chloroxylenol in 100 cm^3. Almost all candidates divided the mass of 4.80 by their molar mass but the scaling by ×10 was not always successful. Some candidates used the mole equations that they had learnt to obtain the ×10 scaling in a very roundabout way.

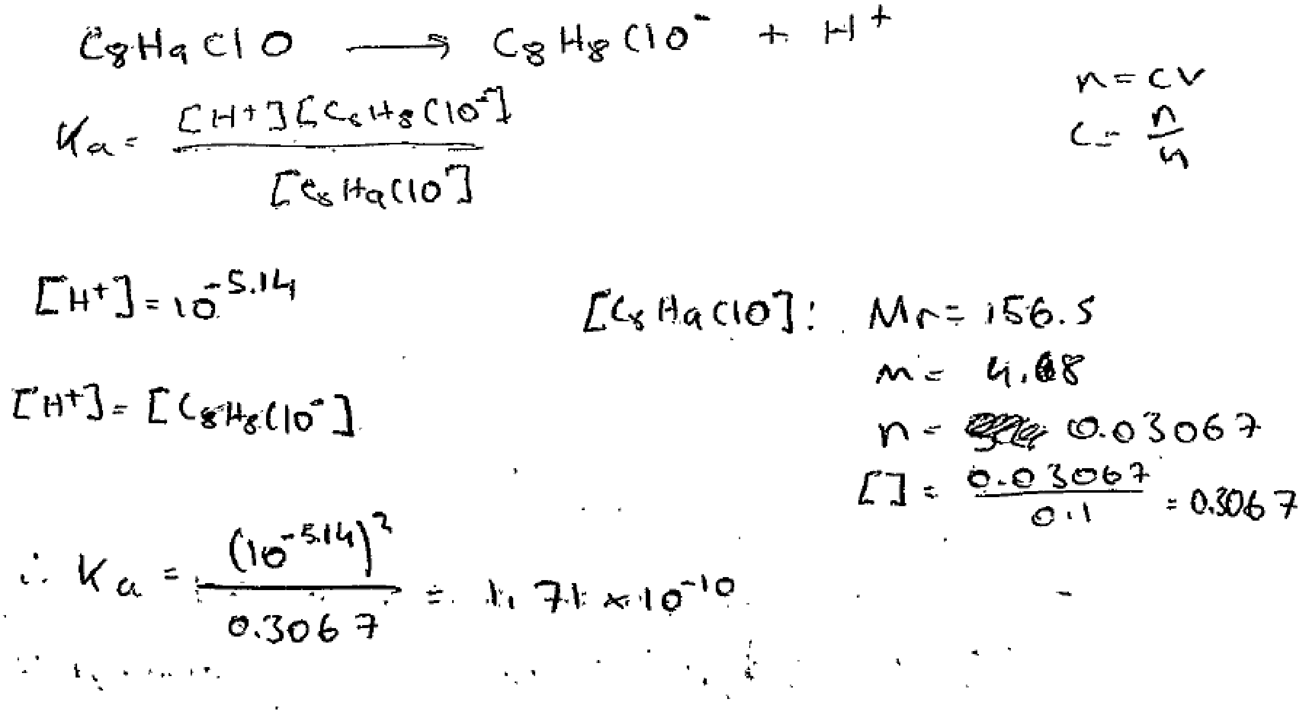
The final mark was often given by ECF (error carried forward) from an incorrect concentration.

The question did also ask for an equation, using molecular formulae, for the acid dissociation. This was sometimes omitted or written using C_8H_8ClOH as the molecular formula of chloroxylenol, instead of C_8H_9ClO. Even if the equation had been omitted, the mark could still given from a correct K_a expression using molecular formulae.

The usual advice of ‘read and answer the question’ still holds.

Exemplar 3 shows a clear and concise response to the question and was given all 5 marks. The equation has been written using molecular formulae and all stages of the calculation are clear to see. Most candidates worked out the hydrogen ion concentration as 7.244×10^{-6} mol dm^{-3} before carrying out the final K_a calculation. This candidate had combined these stages.

Exemplar 3



$C_8H_9ClO \longrightarrow C_8H_8ClO^- + H^+$

$K_a = \frac{[H^+][C_8H_8ClO^-]}{[C_8H_9ClO]}$

$n = cV$

$c = \frac{n}{V}$

$[H^+] = 10^{-5.14}$

$[H^+] = [C_8H_8ClO^-]$

$[C_8H_9ClO]$: $M_r = 156.5$

$m = 4.8$

$n = 0.03067$

$[\,] = \frac{0.03067}{0.1} = 0.3067$

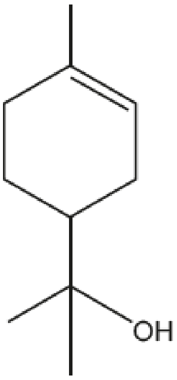
$\therefore K_a = \frac{(10^{-5.14})^2}{0.3067} = 1.71 \times 10^{-10}$

Question 4 (b) (i)

(b) Dettol® contains other chemicals including α-terpineol, shown below.

(i) α-Terpineol is a chiral compound.

Show with an asterisk, (*), the chiral centre(s) in the structure of α-terpineol.

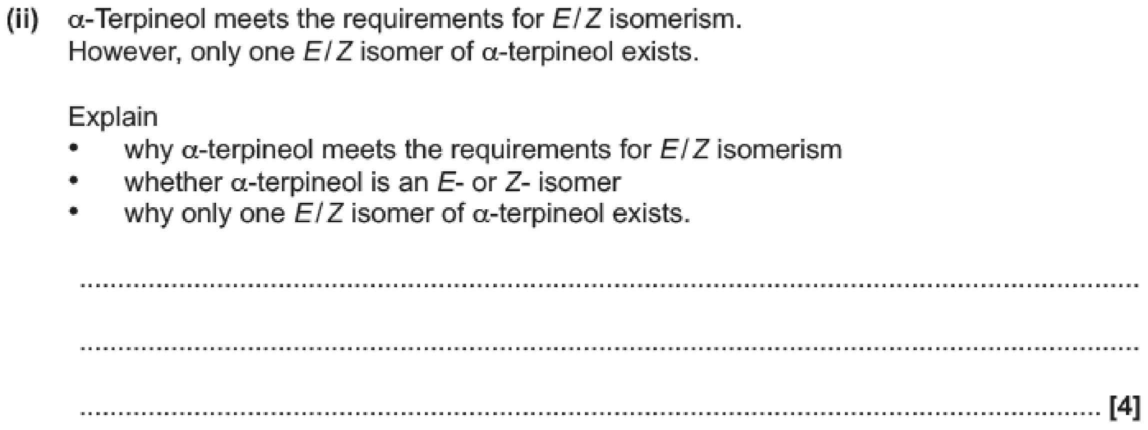


α-terpineol

[1]

Most candidates showed one asterisk at the base of the cyclic part of the structure. The most common error was to show two asterisks, the second being on $*C(CH_3)_2OH$, despite this carbon not being connected to four different groups.

Question 4 (b) (ii)



(ii) α-Terpineol meets the requirements for *E* / *Z* isomerism.
However, only one *E* / *Z* isomer of α-terpineol exists.

Explain

- why α-terpineol meets the requirements for *E* / *Z* isomerism
- whether α-terpineol is an *E*- or *Z*- isomer
- why only one *E* / *Z* isomer of α-terpineol exists.

....

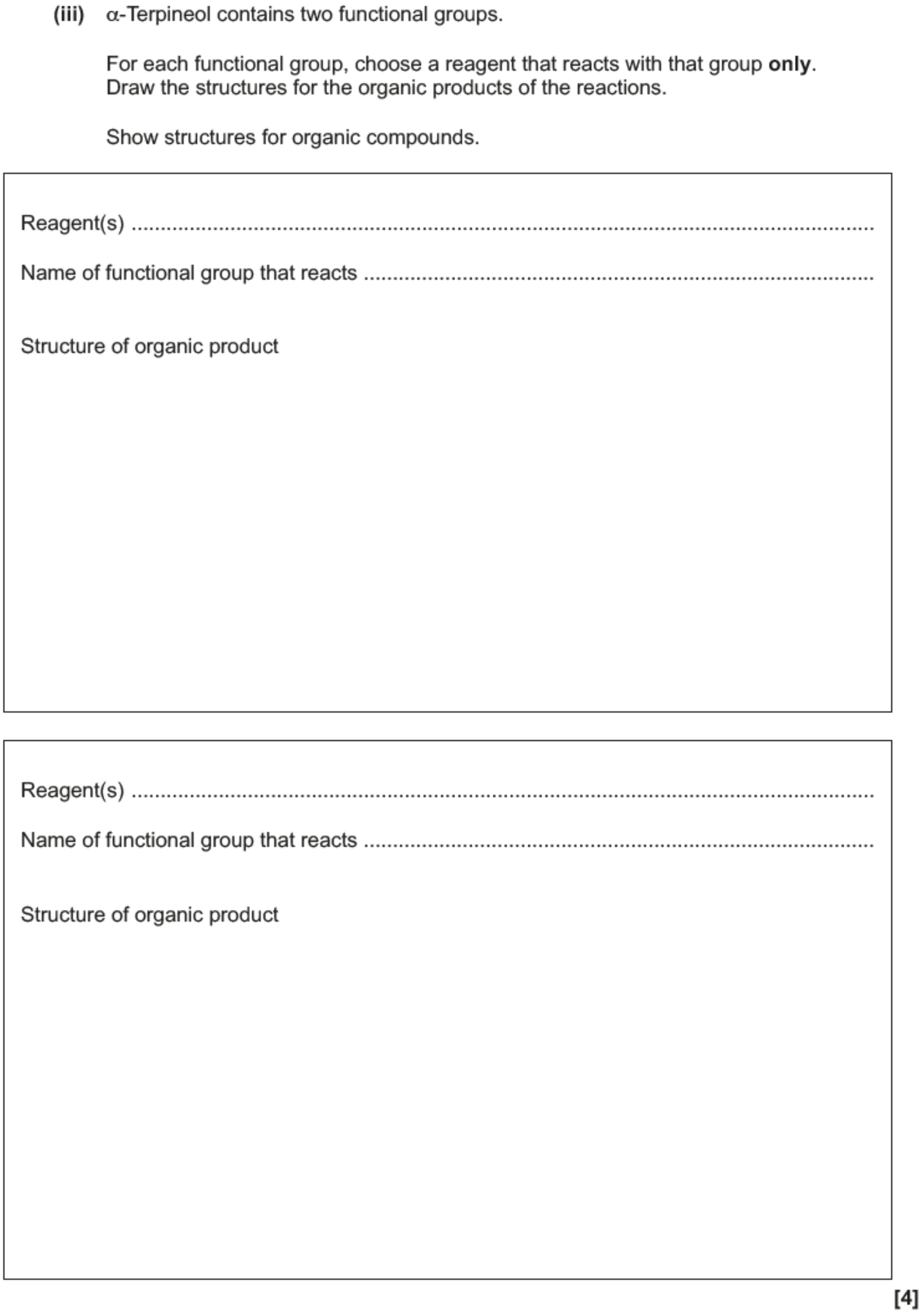
....

.... **[4]**

Candidates displayed a good knowledge of the requirements for *E*/*Z* isomerism in terms of a C=C double bond and different groups on the carbon atoms of the C=C bond. Many assigned terpineol as the Z isomer explained in terms of the priority groups being on the same side of the C=C bond.

Candidates found it difficult to explain why terpineol has only one *E*/*Z* isomer. Many candidates thought that the C=C bond could not rotate because it was part of the ring. however, a C=C bond cannot rotate whether it is in a ring or not. Few candidates considered the strain put on the ring if the priority groups (being part of the ring) were to be placed in an *E* conformation.

Question 4 (b) (iii)



(iii) α-Terpineol contains two functional groups.

For each functional group, choose a reagent that reacts with that group **only**.
Draw the structures for the organic products of the reactions.

Show structures for organic compounds.

Reagent(s) ....

Name of functional group that reacts ....

Structure of organic product

Reagent(s) ....

Name of functional group that reacts ....

Structure of organic product

[4]

In this question, candidates were given the opportunity to demonstrate some knowledge of organic reaction in a new context. The choice of reaction was up to the candidate.

Most candidates were able to identify the alkene group in terpineol and to suggest a reagent that would react with this functional group. A correct structure for the organic product then usually followed.

Although most candidates identified the alcohol group, many struggled with a reagent and resulting product. Although the alcohol –OH group has many reactions, (e.g. elimination, substitution, esterification) many candidates were fixated on oxidation with acidified dichromate despite a tertiary alcohol not being capable of oxidation with this reagent. Some candidates quoted acidified dichromate but then copied the structure of terpineol, stating that there was no reaction, despite the question directing them to select a reagent that would react with their chosen group.

Question 5 (a) (i)

5 This question is about copper(II) sulfate, $CuSO_4$, and sodium thiosulfate, $Na_2S_2O_3$.

(a) The enthalpy change of reaction, $\Delta_r H$, for converting anhydrous copper(II) sulfate to hydrated copper(II) sulfate is difficult to measure directly by experiment.

$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4{\bullet}5H_2O(s)$ $\Delta_r H$ **reaction 5.1**

The enthalpy changes of solution of anhydrous and hydrated copper(II) sulfate can be measured by experiment. The reactions are shown below.

In the equations, 'aq' represents an excess of water.

$CuSO_4(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4(s))$ **reaction 5.2**

$CuSO_4{\bullet}5H_2O(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4{\bullet}5H_2O(s))$ **reaction 5.3**

Experiment 1
A student carries out an experiment to find $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2**.

Student's method

- Weigh a bottle containing $CuSO_4(s)$ and weigh a polystyrene cup.
- Add about 50 cm^3 of water to the polystyrene cup and measure its temperature.
- Add the $CuSO_4(s)$, stir the mixture, and measure the final temperature.
- Weigh the empty bottle and weigh the polystyrene cup with final solution.

Mass readings

Mass of bottle + $CuSO_4(s)$ / g	28.04
Mass of empty bottle / g	20.06
Mass of polystyrene cup / g	23.43
Mass of polystyrene cup + final solution / g	74.13

Temperature readings

Initial temperature of water / °C	20.5
Temperature of final solution / °C	34.0

Experiment 2
The student carries out a second experiment with $CuSO_4{\bullet}5H_2O$ (**reaction 5.3**). The student uses the same method as in **Experiment 1**.

The student calculates $\Delta_{sol}H(CuSO_4{\bullet}5H_2O(s))$ as $+8.43\ kJ\ mol^{-1}$.

(i)* Calculate $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2** and determine the enthalpy change of **reaction 5.1**, $\Delta_r H$.

Assume that the specific heat capacity, c, of the solution is the same as for water.

Show your working, including an energy cycle linking the enthalpy changes. **[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 constructing and using an energy cycle. Levels were determined by the accuracy of the candidates' processing, calculations and use of the energy cycle. This question discriminated extremely well.

Level 3 candidates used the mass of solution as 50.7 g with $mc\Delta T$ to obtain an energy change of 2861 J. They then divided this value by the moles of $CuSO_4$ that reacted (0.05 mol) to obtain the enthalpy change of –57.22 kJ mol^{-1}. Finally, they constructed an energy cycle which they then used to obtain the second enthalpy change of –65.65 kJ mol^{-1}.

Level 2 candidates determined the first enthalpy change but may have used the approximate mass of 50 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.

A significant number of lower ability candidates used the solid mass of copper sulfate in their 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. An example was the mass of the solution (74.13 – 23.43) being seen as 49.7 rather than 50.7.

A significant number of candidates added or subtracted the mass of copper sulfate from 50.7 or 50 for their value of m in $mc\Delta T$, using for example 57.98 and 42.72. This limited the level that they could reach.

Exemplar 4 is an excellent response from a Level 3 candidate. All stages can be clearly followed, the initial energy change using $mc\Delta T$, the first enthalpy change using the energy change with the moles of copper sulfate, and the second enthalpy change including a clear energy cycle. Numbers are clearly shown and unrounded until the final values. This is an excellent response.

Exemplar 4

$q = mC\Delta T$

$q = 50.7 \times 4.18 \times 13.5 = 2861.001\ J$

$= 2.861001\ kJ$

$n(CuSO_4) = \frac{7.98}{159.6} = 0.05$

$\Delta_{sol}H(CuSO_4) = -\frac{2.861001}{0.05} = -57.22002$

$= -57.22\ kJmol^{-1}$

$$\begin{tikzcd}
CuSO_4 + 5H_2O \arrow[rr] \arrow[dr, "-57.22002"'] & & CuSO_4 \cdot 5H_2O \arrow[dl, "8.43\ kJmol^{-1}"] \\
& Cu^{2+} + SO_4^{2-} &
\end{tikzcd}$$

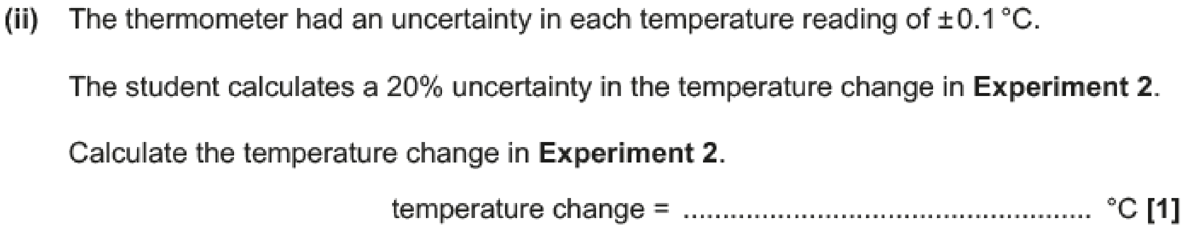
Additional answer space if required

Δ_rH (reaction 5.1) $= -57.22002 - 8.43$

$= -65.65002\ kJmol^{-1}$

$= -65.7\ kJmol^{-1}$

Question 5 (a) (ii)



(ii) The thermometer had an uncertainty in each temperature reading of ±0.1 °C.

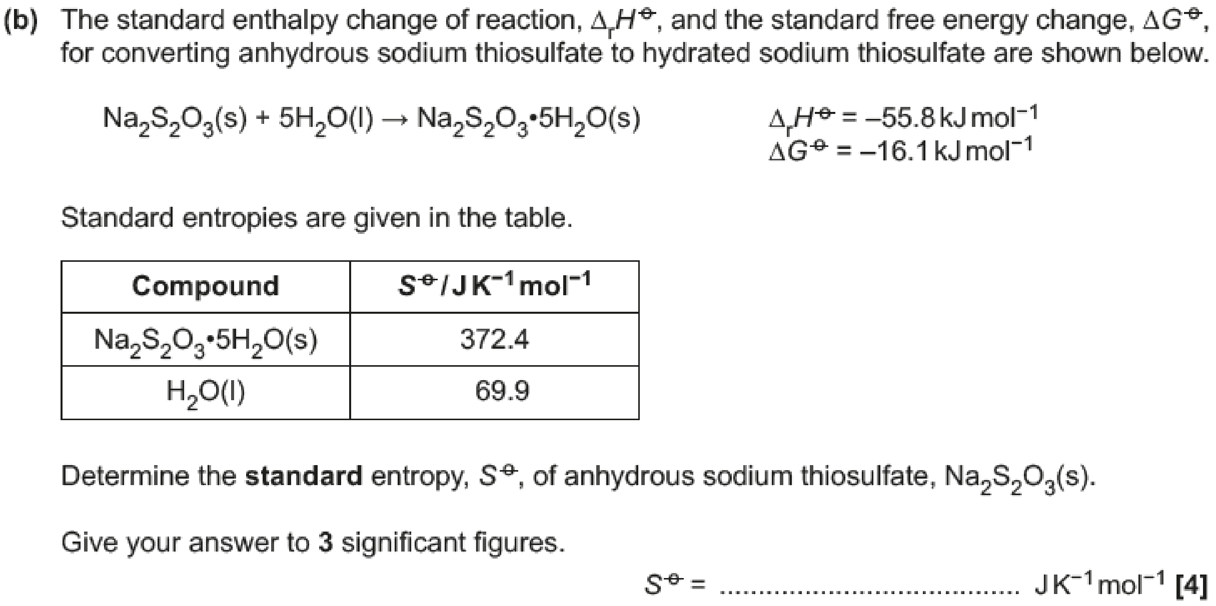
The student calculates a 20% uncertainty in the temperature change in **Experiment 2**.

Calculate the temperature change in **Experiment 2**.

temperature change = ... °C **[1]**

Just over half the candidates obtained the correct temperature change of 1°C. A common error was a temperature change of 0.5°C, the result of not considering that two temperature readings are made when calculating a temperature change.

Question 5 (b)



(b) The standard enthalpy change of reaction, $\Delta_r H^{\ominus}$, and the standard free energy change, $\Delta G^{\ominus}$, for converting anhydrous sodium thiosulfate to hydrated sodium thiosulfate are shown below.

$Na_2S_2O_3(s) + 5H_2O(l) \rightarrow Na_2S_2O_3{\bullet}5H_2O(s)$ $\Delta_r H^{\ominus} = -55.8\,kJ\,mol^{-1}$

$\Delta G^{\ominus} = -16.1\,kJ\,mol^{-1}$

Standard entropies are given in the table.

Compound	**$S^{\ominus}$ / J K^{-1} mol^{-1}**
$Na_2S_2O_3{\bullet}5H_2O(s)$	372.4
$H_2O(l)$	69.9

Determine the **standard** entropy, $S^{\ominus}$, of anhydrous sodium thiosulfate, $Na_2S_2O_3(s)$.

Give your answer to **3** significant figures.

$S^{\ominus}$ = ... J K^{-1} mol^{-1} **[4]**

This was a testing question. This question discriminated very well but lower ability candidates struggled to score marks.

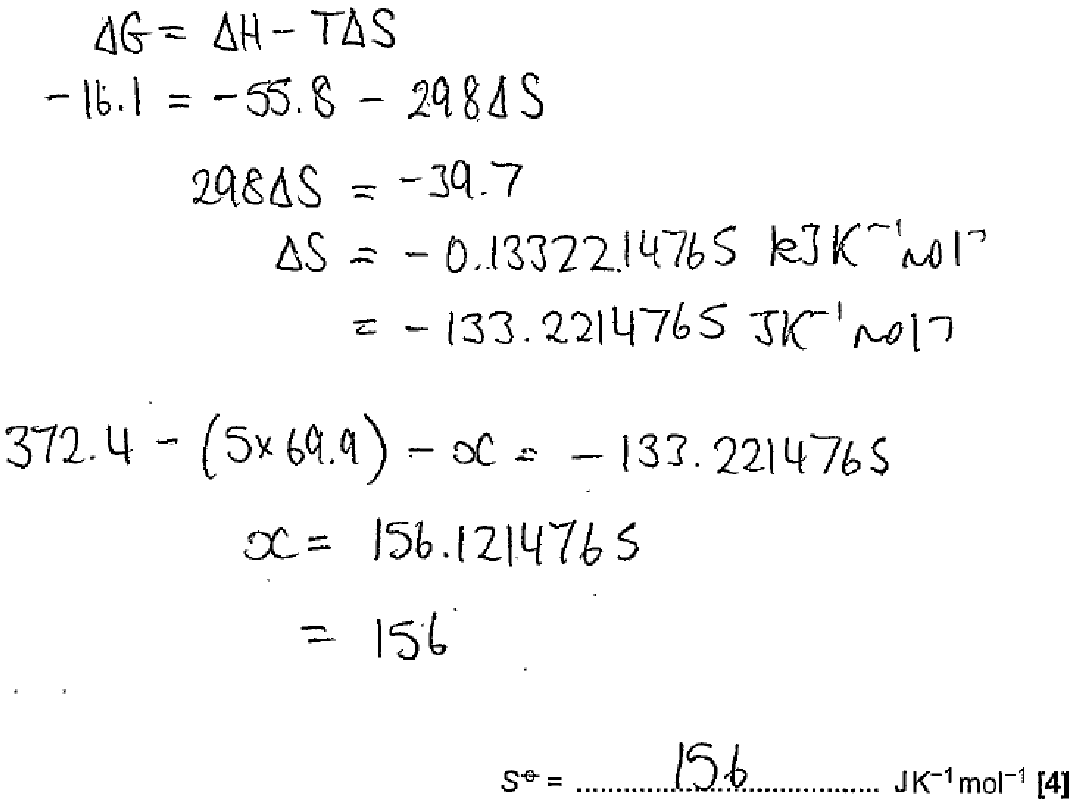
This unfamiliar scenario required candidates to first decide on a strategy for solving the problem. Candidates needed to use the Gibbs' equation and supplied data to determine the entropy change. They then needed to combine this value with other supplied data to determine the unknown standard entropy. The data provided were all standard, signified by the standard sign.

Candidates were expected to use 298 K as the standard temperature to first determine the entropy change. Although many candidates chose 298 K, many different temperatures were seen, with 273 K and 286.5 K (the temperature change in 5a(i)) being common. Some candidates were obviously thrown by the absence of a stated temperature and many omitted *T* from their Gibbs' equation, using $\Delta G = \Delta H - \Delta S$ instead.

This calculated value for ΔS (correct: –0.133 kJ) then needed to be combined with the supplied entropy data to determine the unknown standard entropy (correct: 156 J) to three significant figures. ECF could be applied during marking but this second calculation first required a unit conversion from kJ to J. Many candidates did not make this conversion. Some candidates made errors combining this information, e.g. incorrect signs, adding rather than subtracting and no unit conversions. Finally, some candidates, successful in their calculation, did not follow the instruction to quote their answer to three significant figures.

Exemplar 5 shows a very clear response. The candidate has used the Gibbs' equation to determine ∆S first in kJ and then, in preparation for the second part of the determination, in J. The ∆S value is combined with the supplied entropy data to obtain the unknown entropy change, shown by 'x' in the response. This calculated value is then rounded to the required three significant figures.

Exemplar 5



$\Delta G = \Delta H - T\Delta S$

$-16.1 = -55.8 - 298\Delta S$

$298\Delta S = -39.7$

$\Delta S = -0.1332214765\ \text{kJK}^{-1}\text{mol}^{-1}$

$= -133.2214765\ \text{JK}^{-1}\text{mol}^{-1}$

$372.4 - (5 \times 69.9) - x = -133.2214765$

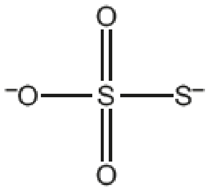
$x = 156.1214765$

$= 156$

$S^{\ominus}$ = ...156.......... $\text{JK}^{-1}\text{mol}^{-1}$ **[4]**

Question 5 (c) (i)

(c) Sodium thiosulfate contains the thiosulfate ion, $S_2O_3^{2-}$.
The displayed formula of $S_2O_3^{2-}$ can be shown as below.



thiosulfate ion

(i) Predict the O–S–S bond angle and name of the shape of the thiosulfate ion.

Bond angle ....

Name of shape ....
[1]

In this part, candidates were expected to use their knowledge and understanding of bond angles and shapes to predict a bond angle of 109.5º and a tetrahedral shape for the thiosulfate ion.

About half the candidates answered correctly but an array of other answers were obtained with bond angles ranging from 90º to 180º, and shapes from linear to octahedral.

Question 5 (c) (ii)

(ii) In some of its reactions, the thiosulfate ion forms the tetrathionate ion, $S_4O_6^{2-}$.

The $S_4O_6^{2-}$ ion is a 'dimer' of $S_2O_3^{2-}$.

Draw a displayed formula for the $S_4O_6^{2-}$ ion.

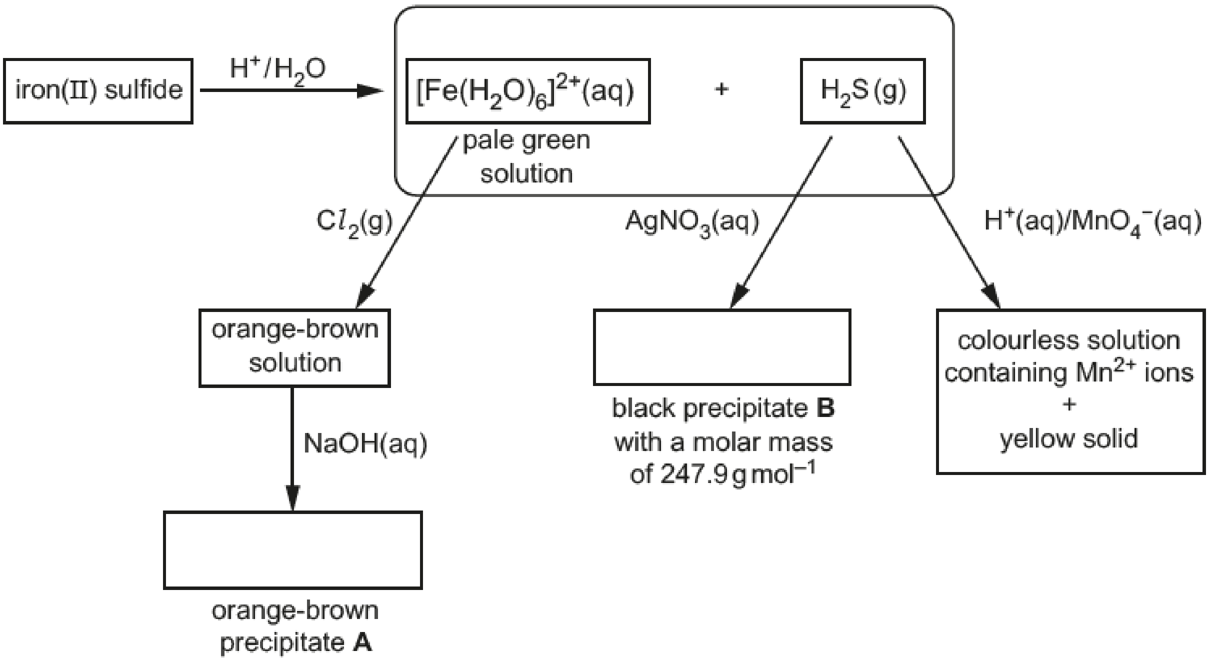
[1]

Candidates were required to combine two thiosulfate ions into a feasible dimer. Many acceptable shapes were allowed with different combinations of O and S atoms and several rings. A significant number of candidates did not seem to know where to start and less than half the candidates were able to draw an acceptable structure.

Question 6 (a) (i)

6 This question is about reactions of iron compounds.

(a) A student carries out the reactions in the flowchart, starting with iron(II) sulfide.



(i) In the boxes, write the formulae of **A** and **B**. **[2]**

Most candidates were given 1 or 2 marks for this part. The black precipitate **B** (Ag_2S) was identified correctly more often the orange precipitate **A**, which was often shown as $Fe(OH)_2$ instead of $Fe(OH)_3$ or $Fe(OH)_3(H_2O)_3$. Significantly, identification of **B** required interpretation of new information whereas **A** required knowledge of transition element chemistry.

Question 6 (a) (ii)

(ii) The student thinks that the reaction of iron(II) sulfide with H^+/H_2O is a redox reaction.

Explain, with reasons, whether the student is correct.

....

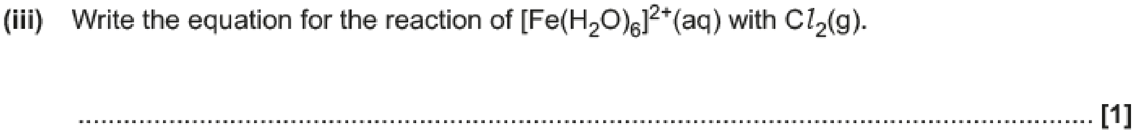
....

....

.... **[1]**

Just over half the candidates identified that the student was incorrect, and that the reaction is not redox. Candidates were expected to provide some evidence to support their statement, in terms of no oxidation number changes. Some candidates claimed that the reaction was not redox because only sulfur changed oxidation number, suggesting a misunderstanding of redox.

Question 6 (a) (iii)



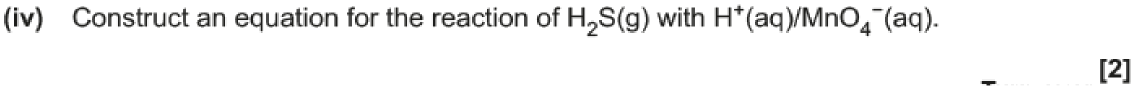
(iii) Write the equation for the reaction of $[Fe(H_2O)_6]^{2+}(aq)$ with $Cl_2(g)$.

.... **[1]**

Candidates found this equation extremely difficult with only a small number of candidates writing a correct equation. The problem lies with balancing the oxidation numbers and charges. Many wrote an equation with a 1:1 ratio or 1:2 ratio for $[Fe(H_2O)_6]^{2+}$: Cl_2. An equation balanced in oxidation number and charge required a 2:1 ratio.

When writing equations for redox reactions, candidates are recommended to check that oxidation changes and charges are balanced as well as atoms.

Question 6 (a) (iv)



(iv) Construct an equation for the reaction of $H_2S(g)$ with $H^+(aq)/MnO_4^-(aq)$.

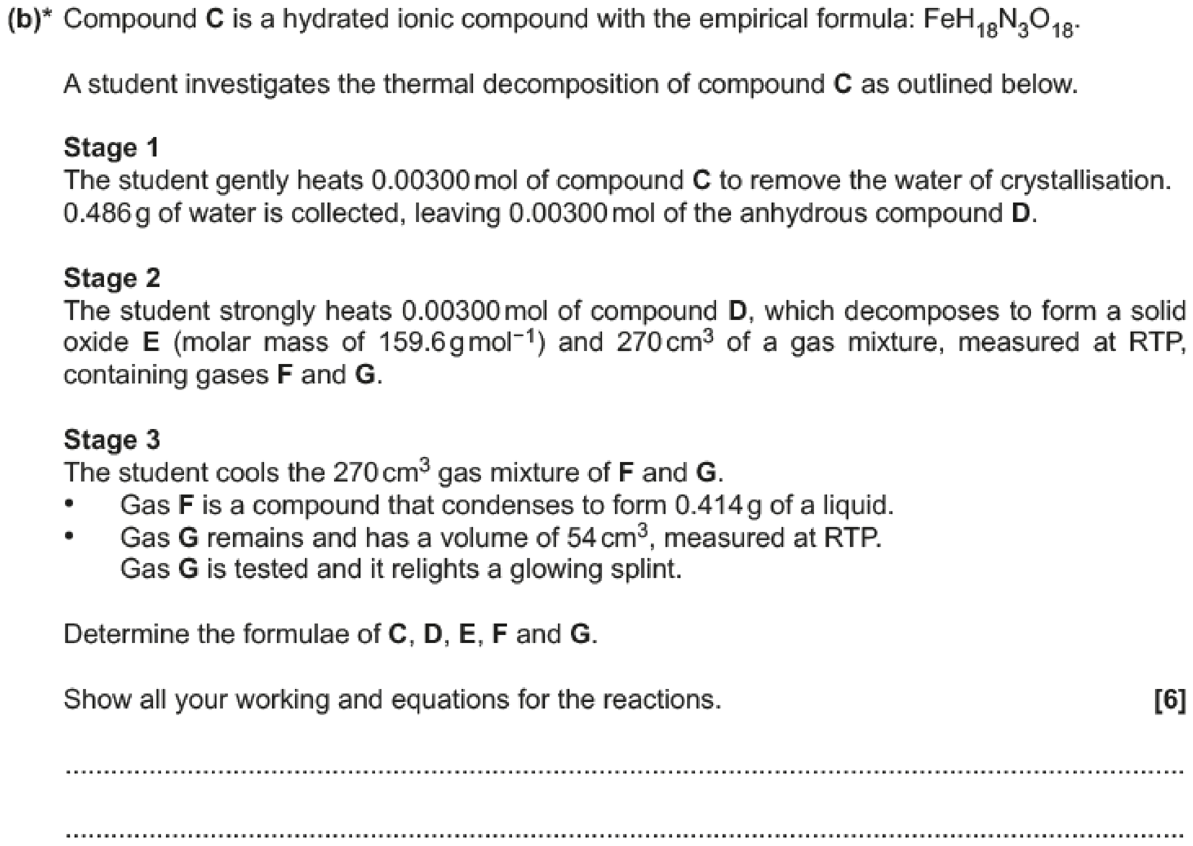
[2]

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

The clue that a yellow solid is a product proved to be very difficult to interpret as being sulfur. The equation then required H_2O to be added as the other product. Candidates found this equation difficult and relatively few correct equations were seen.

As with 6a(iii), many equations were not balanced by oxidation number or charge. Some candidates omitted this part entirely.

Question 6 (b)



(b)* Compound **C** is a hydrated ionic compound with the empirical formula: $FeH_{18}N_3O_{18}$.

A student investigates the thermal decomposition of compound **C** as outlined below.

Stage 1
The student gently heats 0.00300 mol of compound **C** to remove the water of crystallisation. 0.486 g of water is collected, leaving 0.00300 mol of the anhydrous compound **D**.

Stage 2
The student strongly heats 0.00300 mol of compound **D**, which decomposes to form a solid oxide **E** (molar mass of 159.6 g mol^{-1}) and 270 cm^3 of a gas mixture, measured at RTP, containing gases **F** and **G**.

Stage 3
The student cools the 270 cm^3 gas mixture of **F** and **G**.

- Gas **F** is a compound that condenses to form 0.414 g of a liquid.
- Gas **G** remains and has a volume of 54 cm^3, measured at RTP.
  Gas **G** is tested and it relights a glowing splint.

Determine the formulae of **C**, **D**, **E**, **F** and **G**.

Show all your working and equations for the reactions. **[6]**

....

....

This question presented a practical scenario in which candidates were asked to identify 5 unknown chemicals. There are many routes that lead to correct identifications of the unknowns.

Most candidates identified **G** as oxygen and made some headway towards identifying **C** and **D** by determining that 9 waters of crystallisation were present in **C**. The formulae of **C** and **D** sometimes followed but many candidates found it difficult to link $9H_2O$ to their formulae. The best responses showed the nitrate ion separately in the formula, e.g. $Fe(NO_3)_3$, but many showed the empirical formula instead, e.g. FeN_3O_9.

Gas **G** (NO_2) proved to be the most difficult unknown to identify as it required two pieces of data for its determination.

There were some very competent attempts at writing equations, with the decomposition of compound **D** in Stage 2 to form **E**, **F** and **G** being the most difficult.

Exemplar 6 is a Level 3 response. The candidate has first identified **C** and **D**, having first determined the 1:9 molar ratio of **C**: H_2O. The candidate then writes the correct equation for Stage 1, using NO_3 for the nitrate ion. The candidate then identifies **E**, **F** and **G** using a methodical approach with clear working throughout. Finally, the candidate writes the correct equation for the reaction in Stage 2.
This is an excellent Level 3 response, given 6/6 marks.

Exemplar 6

stage 1 $n = \frac{0.486}{18} = 0.027$ mols

$0.00300 : 0.027$

$1 : 9$

empirical formula of anhydrous compound: FeN_3O_9

D ⇒ $Fe(NO_3)_3$

C ⇒ $Fe(NO_3)_3 \cdot 9H_2O$

$Fe(NO_3)_3 \cdot 9H_2O \longrightarrow Fe(NO_3)_3 + 9H_2O$

stage 2

$Fe(NO_3)_3 \longrightarrow Fe_2O_{3(s)} + F +$ ~~$O_{2(g)}$~~ G

0.003

Fe_2O_3 E = Fe_2O_3

$\left.\begin{array}{l}\to 48\\ \to 111.6\end{array}\right\} 159.6$

Additional answer space if required.

stage 3 G $n = \frac{54}{24000} = 2.25 \times 10^{-3}$

G = $O_{2\,(g)}$

⇒ because it relights a glowing splint

$270 - 54 = 216$

$n = \frac{216}{24000} = 9 \times 10^{-3}$

$M_r = \frac{m}{n} = \frac{0.414}{9 \times 10^{-3}} = 46$ NO_2 $\left.\begin{array}{l}\to 32\\ \to 14\end{array}\right\} 46$

F = NO_2

stage 2 equation

$2Fe(NO_3)_3 \longrightarrow Fe_2O_3 + 6NO_2 + 1\frac{1}{2}O_2$

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