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Examiners' report

CHEMISTRY A

H432
For first teaching in 2015

H432/01 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 exams 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 exam 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 students 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 H432/01 series overview

H432/01 is the first of the three examination components for GCE Chemistry A. This component is focused on physical and inorganic chemistry and brings together topics from modules 3 and 5 of the specification, including relevant practical techniques. In this paper and H432/02 there is more of an emphasis on knowledge and understanding of the assessment outcomes from the specification, as compared to H432/03 which involves more application of knowledge.

The paper consists of two sections, comprised of multiple choice questions and a mixture of short and long response questions respectively.

Candidate performance overview

Candidates who did well on this paper generally:

- Produced clearly structured working for calculations – 16(b)(ii), 18(b), 19(b), 19(c), 20(d)(iv).
- Produced clear and concise responses for the two Level of Response questions – 17(a) and 21(d).
- Were able to make and justify predictions based on their knowledge – 16(a)(iv).
- Explained equilibrium changes in terms of Kp – 18(c)(ii).
- Gave answers to the correct number of significant figures – 17(b)(i), 19(a)(iii), 19(b).
- Ably converted between units when required – 20(c).
- Correctly recorded titre values to two decimal places (to ±0.05 cm^3) and could also successfully calculate the percentage uncertainty in these values – 20(d)(i) and 20(d)(ii).

Candidates who did less well on this paper generally:

- Found it difficult to apply what they had learned to unfamiliar situations.
- Produced unstructured responses to Level of Response questions which were lacking in depth or explanation, or contained contradictory information – 17(a) and 21(d).
- Did not clearly set out calculations, making it difficult for marks to be awarded for working – 16(b)(ii), 18(b), 19(c), 20(d)(iv).
- Did not give answers to calculations to the specified number of significant figures – 17(b)(i), 19(a)(iii), 19(b).
- Either did not realise the need to convert between units for some calculations, or found this difficult – 20(c).
- Did not record titre values to two decimal places and found calculating the percentage uncertainty in these values challenging – 20(d)(i) and 20(d)(ii).

There was no evidence that any time constraints had led to a candidate underperforming and scripts where there was no response to the final question also had large sections of the paper which had not been tackled.

Section A overview

A significant number of candidates did not provide an answer to every multiple choice question. Whether this was deliberate or caused by forgetting to return to the question at a later point in the examination is not certain, but centres should advise candidates to provide an answer to every multiple choice question. There is no penalty for giving a wrong answer.

Question 1

1 A sample of boron contains the isotopes ^{10}B and ^{11}B.
The relative atomic mass of the boron sample is 10.8.

What is the percentage of ^{11}B atoms in the sample of boron?

A 8.0%

B 20%

C 80%

D 92%

Your answer ☐ **[1]**

The majority of candidates were able to calculate the correct answer.

Question 2

2 In the compound $[ICl_2]^+ [SbCl_6]^-$, the oxidation number of chlorine is –1.

What are the oxidation numbers of I and Sb in the compound?

	I	Sb
A	+1	+5
B	+1	+7
C	+3	+5
D	+3	+7

Your answer ☐ **[1]**

The majority of candidates showed a good understanding of oxidation number and gave the correct answer.

Question 3

3 What is the number of hydrogen atoms in 0.125 mol of C_2H_5OH?

A 7.525×10^{22}

B 4.515×10^{23}

C 3.7625×10^{23}

D 3.612×10^{24}

Your answer ☐ **[1]**

This proved problematical for many candidates with A being a common distractor.

Question 4

4 A student titrates a standard solution of barium hydroxide, $Ba(OH)_2$, with nitric acid, HNO_3.

25.00 cm^3 of 0.0450 mol dm^{-3} $Ba(OH)_2$ are needed to neutralise 23.35 cm^3 of HNO_3(aq).

What is the concentration, in mol dm^{-3}, of the nitric acid?

A 0.0241

B 0.0482

C 0.0900

D 0.0964

Your answer ☐ **[1]**

The majority of candidates were able to calculate the correct answer.

Question 5

5 Which statement best explains why nitrogen has a larger first ionisation energy than oxygen?

A N atoms have less repulsion between p-orbital electrons than O atoms.

B N atoms have a smaller nuclear charge than O atoms.

C N atoms lose an electron from the 2s subshell, while O atoms lose an electron from the 2p subshell.

D N atoms have an odd number of electrons, while O atoms have an even number.

Your answer ☐ **[1]**

The majority of candidates knew the key factor affecting the relative ionisation energies of nitrogen and oxygen.

Question 6

6 In the Periodic Table, element **X** is in Group 2 and element **Y** is in Group 15 (5).

What is the likely formula of an ionic compound of **X** and **Y**?

A X_2Y_5

B X_2Y_3

C X_3Y_2

D X_5Y_2

Your answer ☐ **[1]**

Nearly all candidates were able to determine the most likely formula.

Question 7

7 Which statement about ammonium carbonate is **not** correct?

A It reacts with $Ba(NO_3)_2(aq)$ to form a white precipitate.

B It effervesces with dilute nitric acid.

C It release an alkaline gas with warm NaOH(aq).

D It has the formula NH_4CO_3.

Your answer ☐ **[1]**

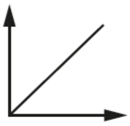
Most candidates knew that the formula given in D was incorrect.

Question 8

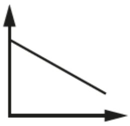
8 A reaction is first order with respect to a reactant **X**.

Which rate–concentration graph for reactant **X** is the correct shape?

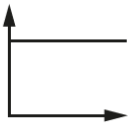
A



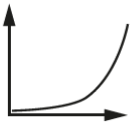
B



C



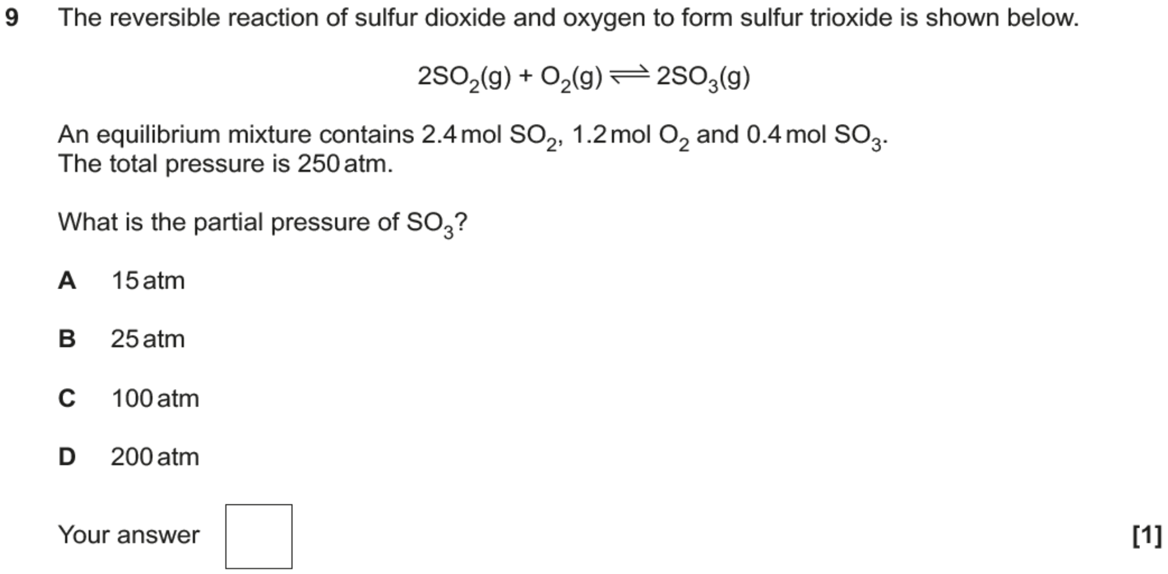
D



Your answer ☐ **[1]**

The vast majority of candidates knew graph A was correct.

Question 9



9 The reversible reaction of sulfur dioxide and oxygen to form sulfur trioxide is shown below.

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

An equilibrium mixture contains 2.4 mol SO_2, 1.2 mol O_2 and 0.4 mol SO_3.
The total pressure is 250 atm.

What is the partial pressure of SO_3?

A 15 atm

B 25 atm

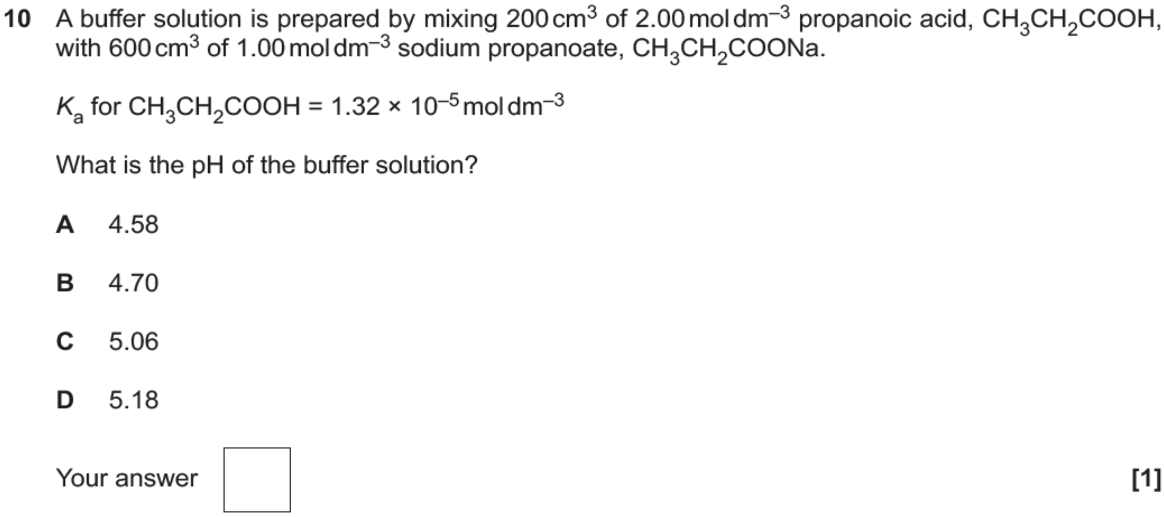
C 100 atm

D 200 atm

Your answer ☐ **[1]**

This was a very successful multiple choice question for nearly all candidates.

Question 10



10 A buffer solution is prepared by mixing 200 cm^3 of 2.00 mol dm^{-3} propanoic acid, CH_3CH_2COOH, with 600 cm^3 of 1.00 mol dm^{-3} sodium propanoate, CH_3CH_2COONa.

K_a for $CH_3CH_2COOH = 1.32 \times 10^{-5}$ mol dm^{-3}

What is the pH of the buffer solution?

A 4.58

B 4.70

C 5.06

D 5.18

Your answer ☐ **[1]**

This relatively difficult pH calculation was readily done successfully by higher ability candidates, but lower ability candidates found it difficult, with answer B proving a popular choice.

Question 11

11 The table below shows standard entropies, $S^\ominus$.

Substance	$CO(g)$	$H_2(g)$	$CH_3OH(l)$
$S^\ominus / J\,mol^{-1}\,K^{-1}$	197.6	130.6	239.7

What is the entropy change, $\Delta S^\ominus$, in $J\,mol^{-1}\,K^{-1}$, for the following reaction?

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

A –219.1

B –88.5

C +88.5

D +219.1

Your answer ☐ **[1]**

The correct answer to this was known by the more able candidates. Lower ability candidates struggled.

Question 12

12 The redox equilibria for a hydrogen–oxygen fuel cell in alkaline solution are shown below.

$$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq) \qquad E^\ominus = -0.83\,V$$

$$^1/_2O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH^-(aq) \qquad E^\ominus = +0.40\,V$$

What is the equation for the overall cell reaction?

A $H_2(g) + 4OH^-(aq) \rightarrow 3H_2O(l) + {}^1/_2O_2(g)$

B $3H_2O(l) + {}^1/_2O_2 \rightarrow H_2(g) + 4OH^-(aq)$

C $H_2O(l) \rightarrow H_2(g) + {}^1/_2O_2(g)$

D $H_2(g) + {}^1/_2O_2(g) \rightarrow H_2O(l)$

Your answer ☐ **[1]**

Most candidates knew the correct equation.

Question 13

13 Which enthalpy change(s) is/are endothermic?

1 The bond enthalpy of the C–H bond

2 The second electron affinity of oxygen

3 The standard enthalpy change of formation of magnesium

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

D was the common distractor given as the answer by many candidates, suggesting confusion with the first electron affinity and second electron affinity of oxygen.

Question 14

14 Which statement(s) explain(s) why reaction rates increase as temperature increases?

1 The activation energy is less.

2 Collisions between molecules are more frequent.

3 A greater proportion of molecules have energy greater than the activation energy.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

This was almost universally correct.

Question 15

15 Which statement(s) is/are correct for the complex $Pt(NH_3)_2Cl_2$?

1 One of its stereoisomers is used as an anti-cancer drug.

2 It has bond angles of 109.5°.

3 It has optical isomers.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

The drawing of many (incorrect) shapes based upon a tetrahedral arrangement around the central Pt ion suggested many were unaware of the square planar shape of the complex.

Section B overview

Question 16(a)(i)

16 This question is about enthalpy changes.

(a) **Table 16.1** shows enthalpy changes that can be used to determine the enthalpy change of hydration of fluoride ions, F^-.

Enthalpy change	**Energy / kJ mol^{-1}**
Hydration of Ca^{2+}	–1609
Solution of CaF_2	+13
Lattice enthalpy of CaF_2	–2630

Table 16.1

(i) Explain what is meant by the term *enthalpy change of hydration*.

....

....

....

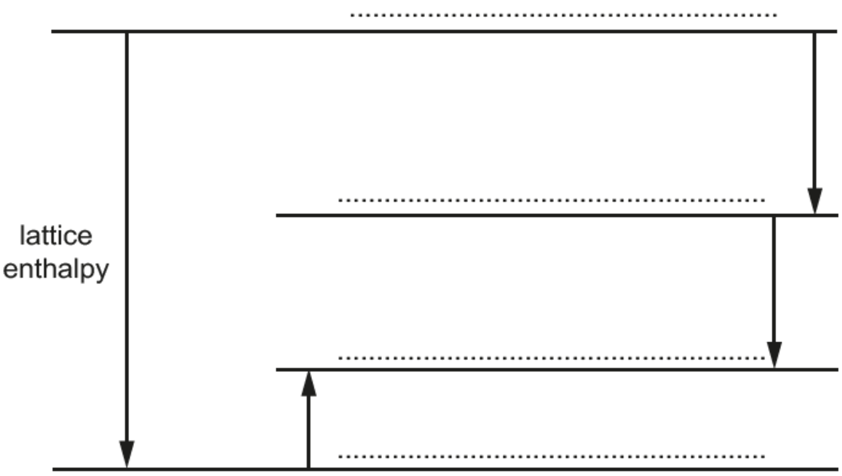
.... **[2]**

Most candidates were able to state that one mole of gaseous ions was dissolved into water. Common errors seen included candidates referring to the dissolving of one mole of substance (i.e. the enthalpy change of solution); the use of the generic term 'solvent' rather than water; and dissolving of gaseous ions into one mole of water.

Question 16(a)(ii)

(ii) The enthalpy change of hydration of F^- can be determined using the enthalpy changes in **Table 16.1** and the incomplete energy cycle below.

On the dotted lines, add the species present, including state symbols.



[4]

Most candidates were able to score some marks on this question with more able candidates scoring all 4 marks. Common errors included the omission of state symbols and the use of only one $F^-(g)$ ion (often despite a correct formula of CaF_2 being seen on the bottom line).

For some reason, many candidates write their lower case 's' in an identical way to their lower case 'g'. This means the examiner cannot distinguish between these state symbols on such scripts. Centres may wish to stress this point to prevent candidates losing marks unnecessarily.

Question 16(a)(iii)

(iii) Calculate the enthalpy change of hydration of fluoride ions, F^-.

enthalpy change of hydration = ... $kJ\,mol^{-1}$ **[2]**

Most candidates were able to do this relatively straightforward calculation by rearranging the values of the enthalpy changes associated with the energy cycle diagram. However, a significant number forgot to divide –1008 by 2 to score full marks.

Question 16(a)(iv)

(iv) Predict how the enthalpy changes of hydration of F^- and Cl^- would differ.

Explain your answer.

....

....

....

.... **[2]**

When comparing enthalpy changes candidates need to be aware that descriptions such as 'bigger' or 'smaller' are meaningless as there are often negative signs involved. The correct description required here was that the enthalpy change of hydration of F^- ions would be more negative than that of Cl^- ions. Although some candidates wrote in terms of charge density, it was those candidates who related the smaller size of the F^- ion to the difference in enthalpy change of hydration who received credit and went on to say that this was as a consequence of greater attraction to water molecules.

Question 16(b)(i)

(b) Fluorine reacts with steam as shown in the equation below.

$$2F_2(g) + 2H_2O(g) \rightarrow O_2(g) + 4HF(g) \qquad \Delta H = -598\,kJ\,mol^{-1}$$

Average bond enthalpies are shown in the table.

Bond	**Average bond enthalpy / kJ mol^{-1}**
O–H	+464
O=O	+498
H–F	+568

(i) Explain what is meant by the term *average bond enthalpy*.

....

....

....

.... **[2]**

Only the higher ability candidates could explain the term average bond enthalpy. The specification clarifies that candidates are not expected to memorise a formal definition, and makes clear the limits expected for candidate explanations. One mark was credited for mention of breaking one mole of bonds; to score the second mark candidates had to clarify that this is in gaseous molecules. A common error was to describe the enthalpy change as being applied to bonds in one mole of molecules.

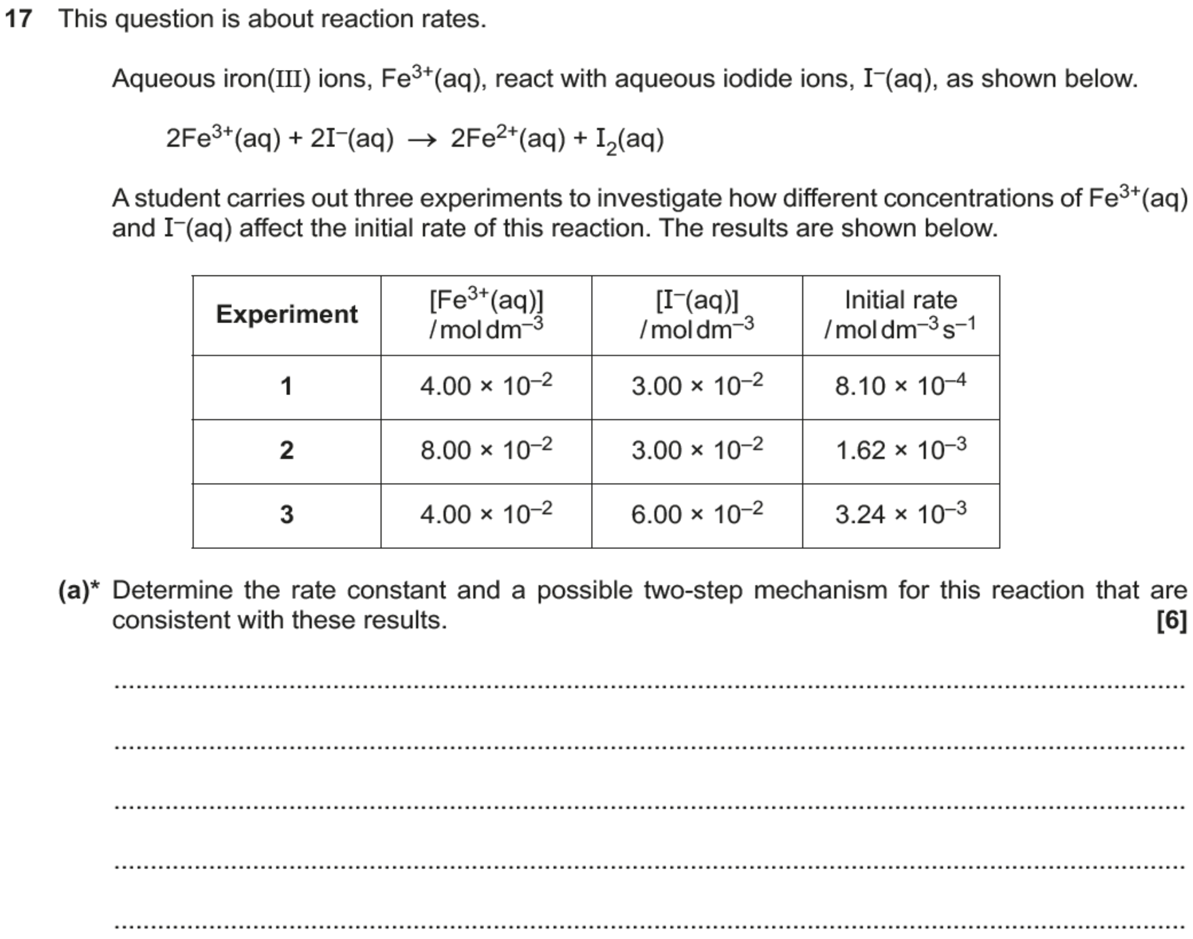
Question 16(b)(ii)

(ii) Calculate the bond enthalpy of the F–F bond.

bond enthalpy = ... kJ mol^{-1} **[3]**

This relatively straightforward calculation depended upon a candidates' knowledge that the sum of average bond enthalpies of bonds formed subtracted from the sum of average bond enthalpies of bonds broken was equal to ΔH (– 598 kJ mol^{-1}), and that a rearrangement of this sum gave the value of the bond enthalpy associated with 2 mol of F–F bonds (+316 kJ mol^{-1}). Thus, the bond enthalpy of the F–F bond required division by two.

Question 17(a)*



17 This question is about reaction rates.

Aqueous iron(III) ions, $Fe^{3+}(aq)$, react with aqueous iodide ions, $I^-(aq)$, as shown below.

$$2Fe^{3+}(aq) + 2I^-(aq) \rightarrow 2Fe^{2+}(aq) + I_2(aq)$$

A student carries out three experiments to investigate how different concentrations of $Fe^{3+}(aq)$ and $I^-(aq)$ affect the initial rate of this reaction. The results are shown below.

Experiment	$[Fe^{3+}(aq)]$ / mol dm^{-3}	$[I^-(aq)]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	4.00×10^{-2}	3.00×10^{-2}	8.10×10^{-4}
2	8.00×10^{-2}	3.00×10^{-2}	1.62×10^{-3}
3	4.00×10^{-2}	6.00×10^{-2}	3.24×10^{-3}

(a)* Determine the rate constant and a possible two-step mechanism for this reaction that are consistent with these results. **[6]**

Most candidates were able to use the information in the table to determine the order of reaction with respect to Fe^{3+} ions and I^- ions, which were 1 and 2 respectively.

Most candidates were then able to use this knowledge and further information from the table to determine the rate constant, including units (22.5 dm^6 mol^{-1} s^{-1}).

Many candidates appreciated that the mechanism involved a stoichiometric ratio of 1 : 2 with respect to Fe^{3+} ions and I^- ions, but only the more able were able to suggest a suitable possible two step mechanism.

Common errors in proposing a mechanism included equations such as

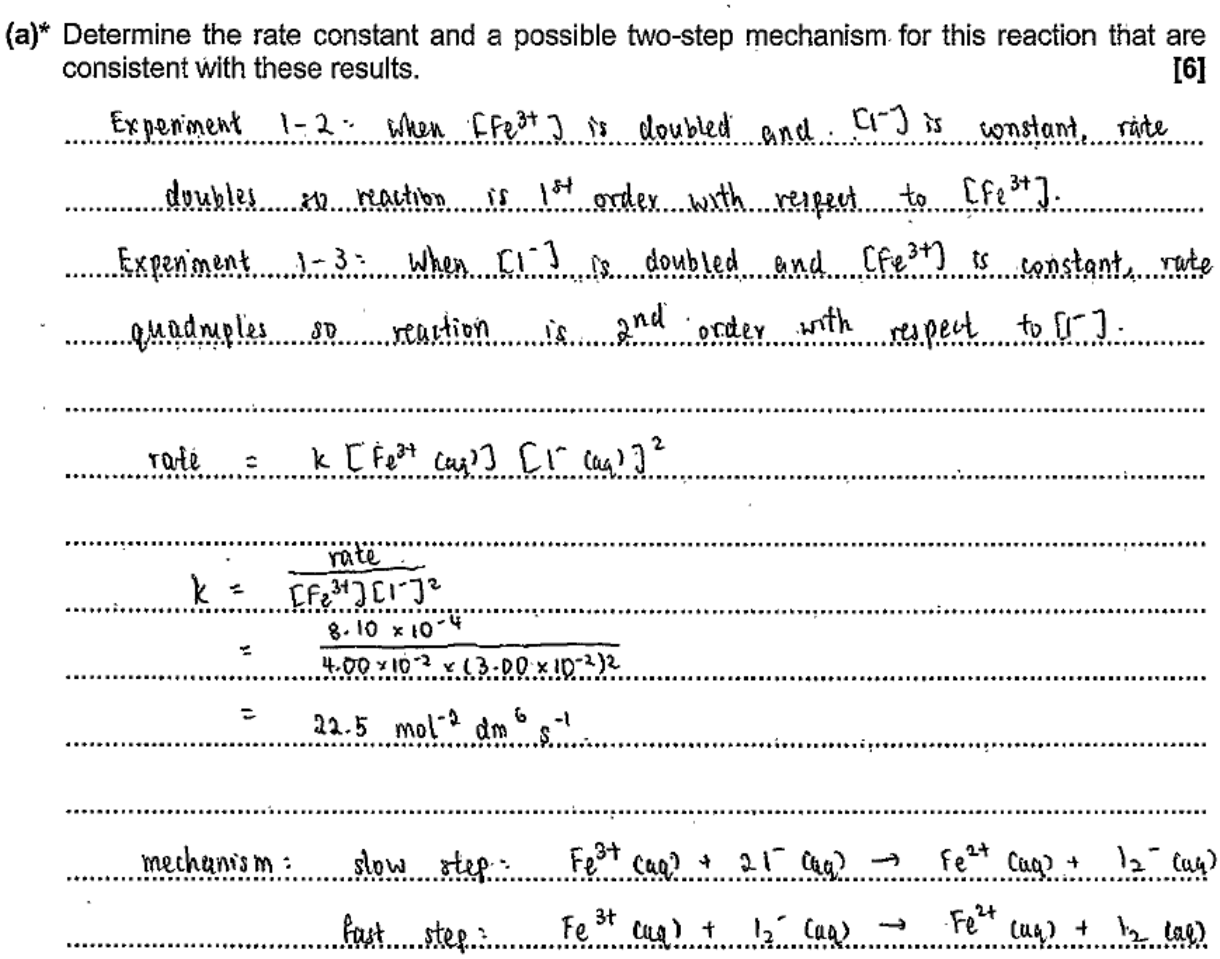
$Fe^{3+}(aq) + 2I^-(aq) \rightarrow Fe^{2+}(aq) + \frac{1}{2}I_2(aq) + I^-(aq)$ which gives a net ratio of 1 : 1 for the reactants.

or

$Fe^{3+}(aq) + 2I^-(aq) \rightarrow Fe^{2+}(aq) + I_2(aq) + e^-$ which although introducing a correct ratio of reactants also introduces a 'floating' electron which in all reality would have attached itself to one of the product species.

In questions such as 17a where the quality of extended responses is assessed candidates need to be aware of the need for explanation of their answers. For instance, just giving a correct order of a species in the rate equation is not as strong an answer as one which explains how altering, say doubling, the concentration of a reactant effects the overall rate of reaction, leading to determination of the order.

Exemplar 1



(a)* Determine the rate constant and a possible two-step mechanism for this reaction that are consistent with these results. **[6]**

Experiment 1-2: When $[Fe^{3+}]$ is doubled and $[I^-]$ is constant, rate doubles so reaction is 1st order with respect to $[Fe^{3+}]$.

Experiment 1-3: When $[I^-]$ is doubled and $[Fe^{3+}]$ is constant, rate quadruples so reaction is 2nd order with respect to $[I^-]$.

rate $= k[Fe^{3+}(aq)][I^-(aq)]^2$

$k = \frac{\text{rate}}{[Fe^{3+}][I^-]^2}$

$= \frac{8.10 \times 10^{-4}}{4.00 \times 10^{-2} \times (3.00 \times 10^{-2})^2}$

$= 22.5\ mol^{-2}\ dm^{6}\ s^{-1}$

mechanism: slow step: $Fe^{3+}(aq) + 2I^-(aq) \rightarrow Fe^{2+}(aq) + I_2^-(aq)$

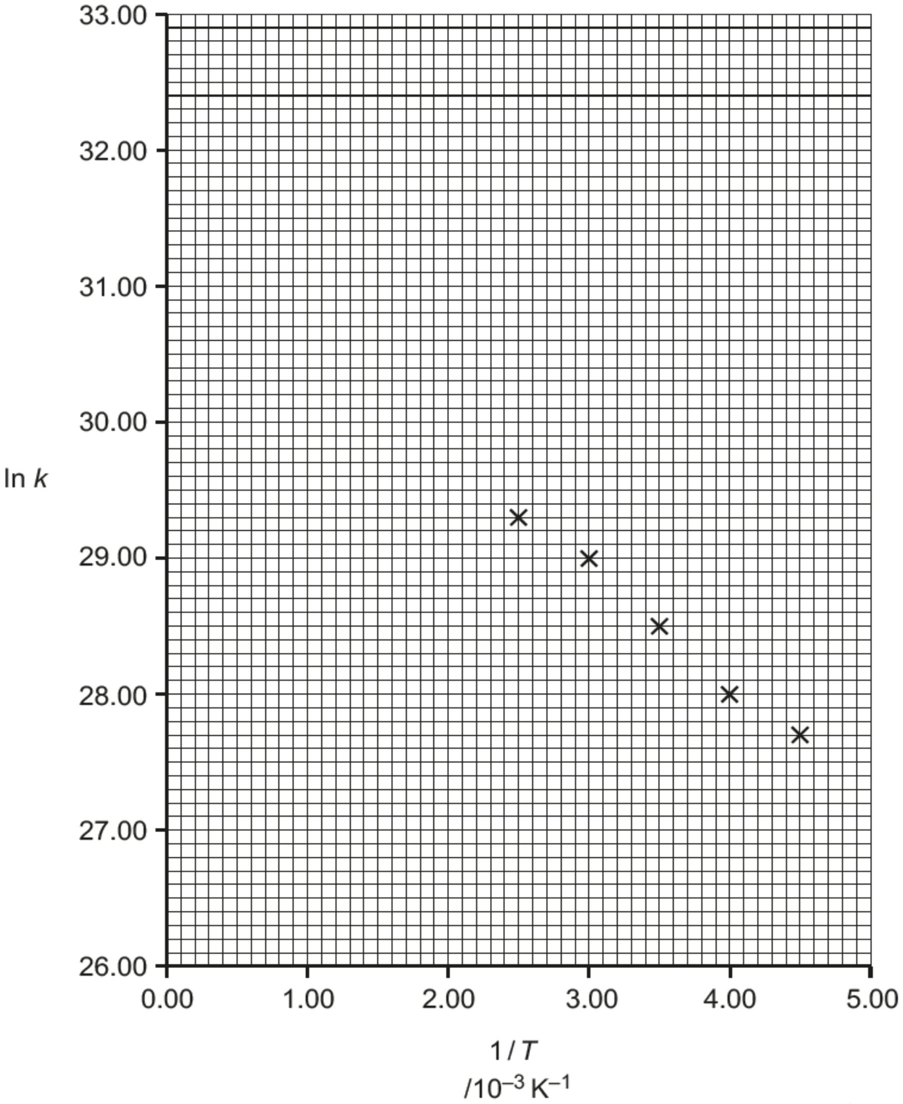
fast step: $Fe^{3+}(aq) + I_2^-(aq) \rightarrow Fe^{2+}(aq) + I_2(aq)$

This exemplifies how a concise response can gain full marks on a Level of Response question. The candidate has clearly identified which data they have referred to in the table, and explained the conclusions that can be drawn. The rate equation is then clearly shown, along with subsequent working to determine the value of the rate constant. Finally, the suggested mechanism is given, along with an indication of which is the slow step. The line breaks clearly identify each stage in the response, and it fully satisfies the level 3 criteria in the mark scheme.

Question 17(b)(i)

(b) A student carries out an investigation to find the activation energy, E_a, and the pre-exponential factor, *A*, of a reaction.

The student determines the rate constant, *k*, at different temperatures, *T*. The student then plots a graph of ln *k* against 1 / *T* as shown below.



(i) Draw a best-fit straight line and calculate the activation energy, in J mol^{-1}. Give your answer to **three** significant figures.

Show your working.

activation energy, E_a = + ... J mol^{-1} **[3]**

Higher ability candidates realised that the gradient was equivalent to $-E_a/R$ and determined a gradient within the range ± 800 to ± 1040, depending upon the line drawn. Credit was given to gradients of ± 0.800 to ± 1.040 resulting from calculations which omitted 10^{-3} on the x-axis.

The negative gradient was multiplied by R to determine E_a with a value rounded to 3 significant figures.

Common errors were omission of 10^{-3} in the calculation which led to E_a values between 6.65 and 8.65 J mol^{-1}, or not rounding to 3 significant figures.

Question 17(b)(ii)

(ii) Use the graph to calculate the value of the pre-exponential factor, *A*.

Show your working.

pre-exponential factor, *A* = ... **[2]**

Higher ability candidates realised that the y-intercept of ln k was equivalent to ln A and A was equivalent to $e^{(\ln A)}$ and were able to process this readily in their calculators.

Common errors were to mis-read the intercept. For example, 31.5 was frequently seen as 31.05. Other candidates assumed the y-intercept was log A and tried to determine A by $10^{(\log A)}$.

Question 18(a)

18 Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **equilibrium 18.1**.

$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ **Equilibrium 18.1**

(a) Write an expression for K_c for this equilibrium and state the units.

K_c =

Units = ... **[2]**

The expression and the units were almost universally known by the candidates.

Question 18(b)

(b) A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm^3.

- The mixture is allowed to reach equilibrium at constant temperature and volume.
- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O_2.
- Under these conditions, the numerical value of K_c is 45.

Calculate the amount, in mol, of NO_2 in the equilibrium mixture.

amount of NO_2 = ... mol **[4]**

There were three steps to this calculation:

Conversion of molar quantities of NO and O_2 to molar concentrations.

Insertion into the K_c expression and determination (via a square root calculation) of the molar concentration of NO_2.

Conversion of the molar concentration of NO_2 to a molar quantity.

Steps 1 and/or 3 of the calculation were occasionally omitted but if the calculation was presented in a coherent manner, even here, partial credit was awarded.

Question 18(c)(i)

(c) The values of K_p for **equilibrium 18.1** at 298 K and 1000 K are shown below.

$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ **Equilibrium 18.1**

Temperature / K	**K_p / atm^{-1}**
298	$K_p = 2.19 \times 10^{12}$
1000	$K_p = 2.03 \times 10^{-1}$

(i) Predict, with a reason, whether the forward reaction is exothermic or endothermic.

....

.... **[1]**

Most candidates knew the forward reaction was exothermic due to K_p decreasing as temperature increased.

A common error was to write vague responses such as 'K_p decreases with temperature'.

Question 18(c)(ii)

(ii) The chemist increases the pressure of the equilibrium mixture at the same temperature.

State, and explain in terms of K_p, how you would expect the equilibrium position to change.

....

....

....

....

....

....

.... **[3]**

Candidates almost universally secured the first mark for equilibrium shifting to the right. Many scored this by simple application of Le Chatelier's principle, and then went on to incorrectly explain K_p increased because of this shift.

Very few realised that (a constant) K_p drives Le Chatelier's principle (and not the other way around). An increase of pressure will increase the value of the partial pressures in the bottom half of the K_p expression more than the top half, thus (initially) decreasing the K_p ratio. Therefore, to **restore** K_p, the amount of NO_2 present must increase; consequently, the equilibrium shifts to the right.

Question 19(a)(i)

19 This question is about acids and bases found in the home.

(a) Ethanoic acid, CH_3COOH, is the acid present in vinegar.

A student carries out an experiment to determine the pK_a value of CH_3COOH.

- The concentration of CH_3COOH in the vinegar is 0.870 mol dm^{-3}.
- The pH of the vinegar is 2.41.

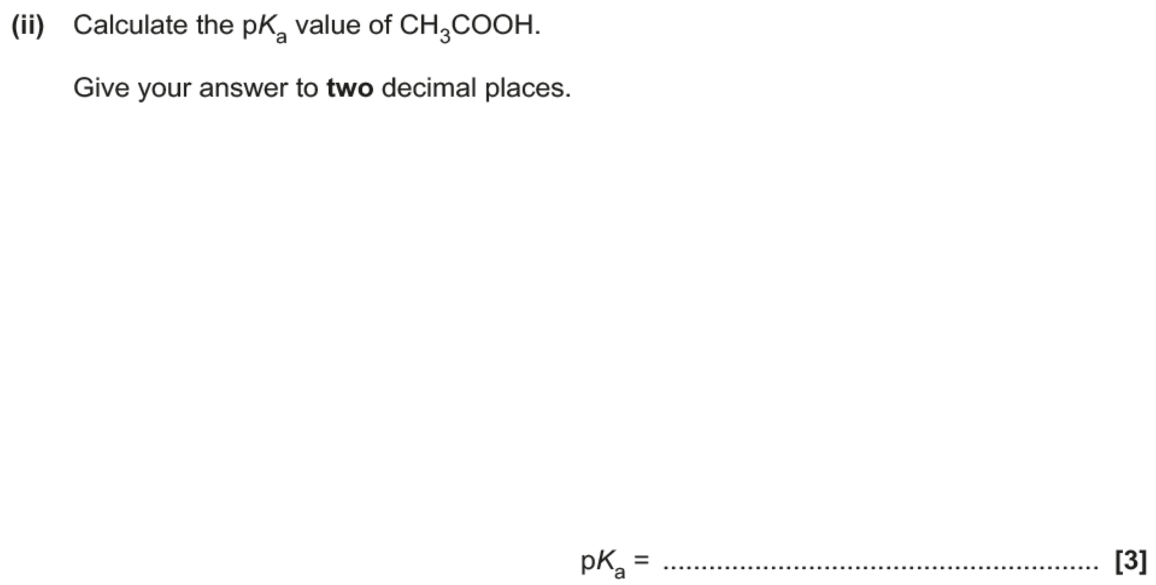
(i) Write the expression for the acid dissociation constant, K_a, of CH_3COOH.

[1]

Almost universally known.

Common errors were the use of [HA], [A$^-$] or [H$^+$]^2.

Question 19(a)(ii)



(ii) Calculate the pK_a value of CH_3COOH.

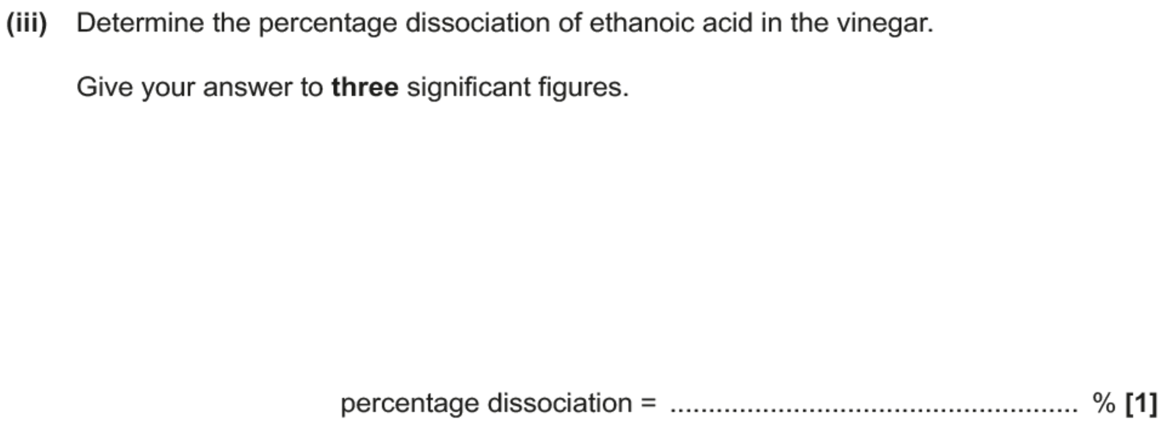
Give your answer to **two** decimal places.

pK_a = ... **[3]**

This three-step calculation was successfully completed by almost all candidates.

The common errors were to omit giving the final answer to 2 decimal places or to use $[H^+]$ rather than $[H^+]^2$ in the calculation, leading to a pK_a of 2.35.

Question 19(a)(iii)



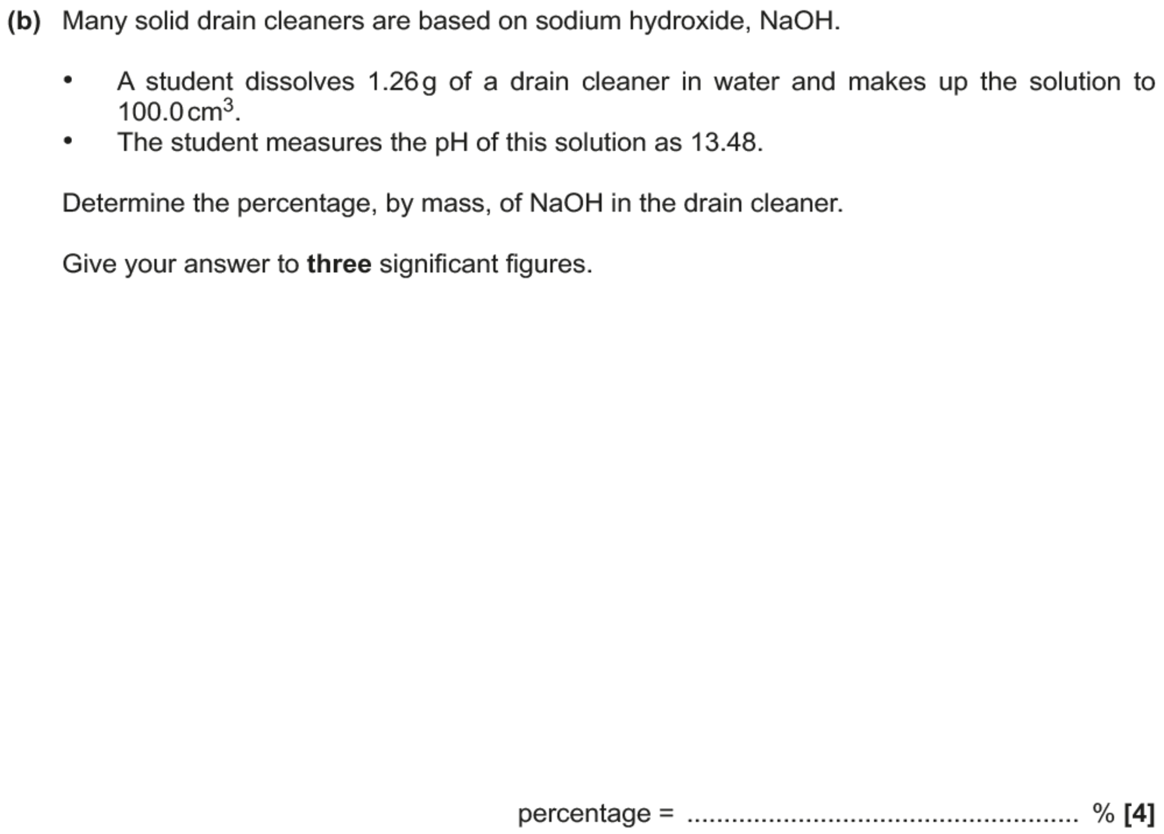
(iii) Determine the percentage dissociation of ethanoic acid in the vinegar.

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

percentage dissociation = ... % **[1]**

This proved a more difficult calculation than expected, but higher ability candidates realised that $[H^+]$ (determined from the pH) divided by the given concentration of CH_3COOH was required. Answers had to be expressed to three significant figures in order to receive credit.

Question 19(b)



(b) Many solid drain cleaners are based on sodium hydroxide, NaOH.

- A student dissolves 1.26 g of a drain cleaner in water and makes up the solution to 100.0 cm^3.
- The student measures the pH of this solution as 13.48.

Determine the percentage, by mass, of NaOH in the drain cleaner.

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

percentage = ... % **[4]**

To help candidates, on this occasion early rounding was ignored and consequently most candidates scored full marks in this multi-step calculation. However, candidates should be advised not to round in the early stages of calculations such as this, as this introduces rounding errors into the final answer.

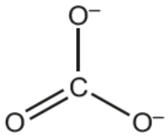
Candidates should be encouraged to indicate what they are attempting to calculate in unstructured calculations such as this.

The first step was frequently seen as $10^{-13.48}$ = 3.31… x 10^{-14} which most examiners could take to be $[H^+]$. However, it is clearer to write $[H^+] = 10^{-13.48}$ = 3.31… x 10^{-14} mol dm^{-3}. Even inclusion of units would help some candidates achieve partial credit as this might allow examiners to determine what a candidate is attempting to do.

Question 19(c)

(c) Sodium carbonate, Na_2CO_3, is a base used in washing soda.

Na_2CO_3 contains the carbonate ion, CO_3^{2-}, shown below.



Draw the '*dot-and-cross*' diagram for the carbonate ion.

Show outer electrons only and use different symbols for electrons from C and O, and any 'extra' electrons.

[2]

Most candidates could draw the three lots of C–O bonds including the double C=O bond as dot and cross arrangements but relatively few were able to score the second mark.

Common errors included 6 non-bonding electrons on the double bonded O atom; 5 non-bonding electrons on each single bonded O atom; not showing a clear enough difference for the 'extra' electrons for this difference to be recognised. A small triangle or square would have been better symbols to have chosen.

Question 20(a)

20 This question is about the halogen group of elements and some of their compounds.

(a) The halogens show trends in their properties down the group.

The boiling points of three halogens are shown below.

Halogen	**Boiling point / °C**
Chlorine	–35
Bromine	59
Iodine	184

Explain why the halogens show this trend in boiling points.

....

....

....

....

....

.... **[3]**

Most candidates realised that as the group is descended, each molecule has more electrons, resulting in stronger London forces (or greater induced dipole-dipole interactions), which require greater energy to overcome.

Common errors included describing the intermolecular forces as van der Waals' forces or permanent dipoles; stating that more energy is needed to overcome bonds (there are covalent bonds in these molecules) having previously used the term forces or interactions; and relating boiling point to reactivity based upon ease of electron loss due to differences in nuclear attraction.

Question 20(b)

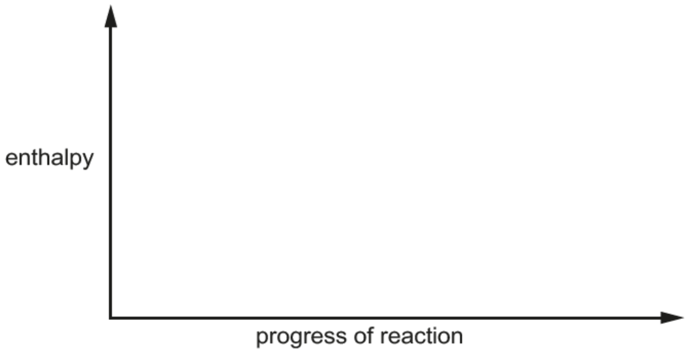
(b) Hydrogen iodide, HI, is decomposed by heat into its elements:

$$2HI(g) \rightarrow H_2(g) + I_2(g) \qquad \Delta H = +9.5\,kJ\,mol^{-1}$$

The decomposition is much faster in the presence of a platinum catalyst.

Complete the enthalpy profile diagram for this reaction using formulae for the reactants and products.

- Use E_a to label the activation energy **without** a catalyst.
- Use E_c to label the activation energy **with** a catalyst.
- Use ΔH to label the enthalpy change of reaction.



[3]

Apart from lower ability candidates, who opted to draw Boltzmann distributions, most candidates scored well here.

Common errors included: omission of formulae of reactants and/or products; using a double-headed arrow for ΔH; and masking the lower part of the E_a line with the E_c line so it appeared that E_a was an additional energy increase above the E_c value.

Question 20(c)

(c) Compound **A** is an oxide of chlorine that is a liquid at room temperature and pressure and has a boiling point of 83 °C.

When 0.4485 g of **A** is heated to 100 °C at 1.00×10^5 Pa, 76.0 cm^3 of gas is produced.

Determine the molecular formula of compound **A**.

Show all your working.

molecular formula of **A** = ... **[4]**

Candidates found the unit conversion into the $pV = nRT$ equation difficult but were able to rearrange the equation to arrive at a value of n. They were then able to determine a molar mass by dividing n into 0.4485 g. Having arrived at 183.0 g mol^{-1}, it was expected that candidates would realise that there must be an even number of Cl atoms. The next step would be to subtract 71.0 from 183.0. This gives 112.0, which divides by 16.0 to give 7, thus leading to Cl_2O_7.

The most common errors were seen in the unit conversions. Pressure is measured in Pa (not kPa), volume is measured in m^3 (not dm^3) and temperature is measured in K (in this case 373 K).

Another source of error was to attempt to determine n by dividing the volume by 24,000 cm^3.

Question 20(d)(i)

(d) Compound **B** is an iodate(V) salt of a Group 1 metal.
The iodate(V) ion has the formula IO_3^-.

A student carries out a titration to find the formula of compound **B**.

Step 1: The student dissolves 1.55 g of **B** in water and makes up the solution to 250.0 cm^3 in a volumetric flask.

Step 2: The student pipettes 25.00 cm^3 of the solution of **B** into a conical flask, followed by 10 cm^3 of dilute sulfuric acid and an excess of KI(aq).

The iodate(V) ions are reduced to iodine, as shown below.

$$IO_3^-(aq) + 6H^+(aq) + 5I^-(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$$

Step 3: The resulting mixture is titrated with 0.150 mol dm^{-3} $Na_2S_2O_3$(aq).

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

The student repeats **step 2** and **step 3** until concordant titres are obtained.

Titration readings

Titration	**Trial**	**1**	**2**	**3**
Final burette reading / cm^3	24.00	47.40	23.75	47.05
Initial burette reading / cm^3	0.00	24.00	0.00	23.20
Titre / cm^3				

Table 20.1

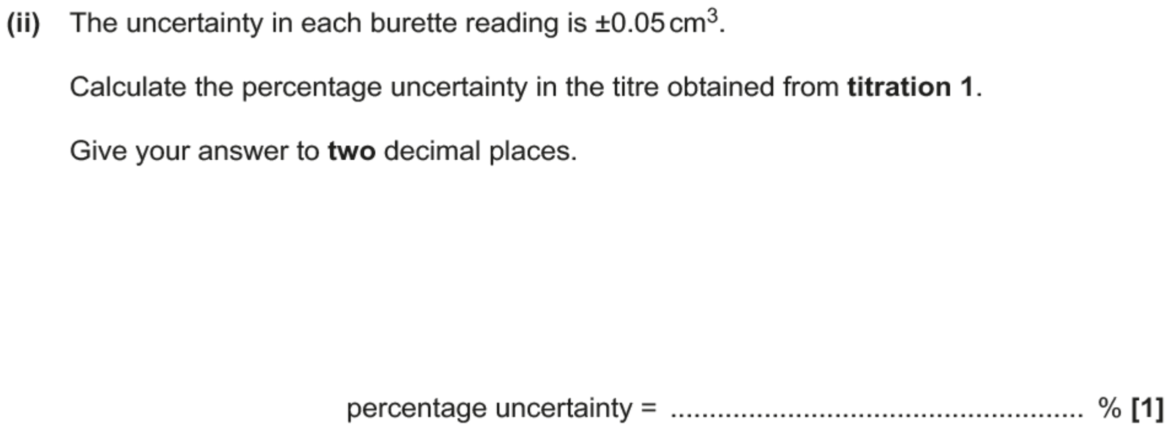
(i) Complete **Table 20.1** and calculate the mean titre that the student should use for analysing the results.

mean titre = ... cm^3 **[2]**

It is clear candidates are not as experienced at filling in titration tables as might be expected. Every value in a titration table should be recorded to a second decimal place to an accuracy of ± 0.05 cm^3.

The average titre should be calculated by averaging concordant titres, i.e. those within 0.10 cm^3 of each other.

Question 20(d)(ii)



(ii) The uncertainty in each burette reading is ±0.05 cm^3.

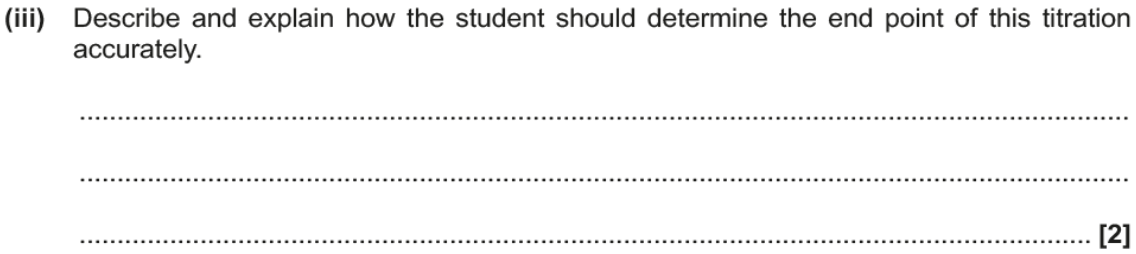
Calculate the percentage uncertainty in the titre obtained from **titration 1**.

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

percentage uncertainty = ... % **[1]**

Candidates are unfamiliar with determination of percentage uncertainty. Marks were credited for any percentage uncertainty calculation correctly determined from any titre value, as many opted to choose the trial value as titre 1 or used an average titre.

Question 20(d)(iii)



(iii) Describe and explain how the student should determine the end point of this titration accurately.

....

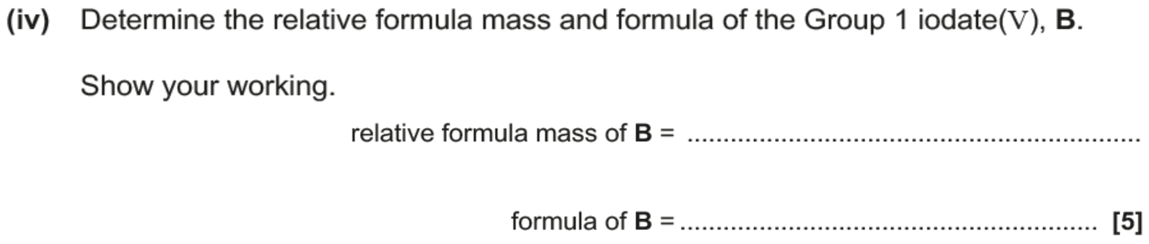
....

.... **[2]**

Only the higher ability candidates realised starch needed to be added close to the end-point and this made the resulting colour change (blue-black to colourless) easier to see.

The common error was to assume this was an acid-base titration and indicators such as methyl orange or phenolphthalein should be added.

Question 20(d)(iv)



(iv) Determine the relative formula mass and formula of the Group 1 iodate(V), **B**.

Show your working.

relative formula mass of **B** = ...

formula of **B** = ... **[5]**

This unstructured calculation was done well by the higher ability candidates. Lower ability candidates struggled to show what they were attempting to calculate and in particular did not appreciate the 1 : 6 ratio of $S_2O_3^{2-}$(aq) to IO_3^-(aq).

Candidates might be advised to start *n*(formula) = … at the start of each line of calculation

eg $n(S_2O_3^{2-})$ = … mol

No credit was given to candidates who grasped the identity of the Group 1 iodate from nowhere and calculated the theoretical relative formula mass.

Question 21(a)

21 This question is about some reactions of d block elements and their ions.

Table 21.1 shows standard electrode potentials which will be needed within this question.

$Zn^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Zn(s)$	$E^{\ominus} = -0.76\,V$
$Cr^{3+}(aq) + e^-$	$\rightleftharpoons$	$Cr^{2+}(aq)$	$E^{\ominus} = -0.42\,V$
$Ni^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Ni(s)$	$E^{\ominus} = -0.25\,V$
$I_2(aq) + 2e^-$	$\rightleftharpoons$	$2I^-(aq)$	$E^{\ominus} = +0.54\,V$
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	$E^{\ominus} = +0.77\,V$
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	$\rightleftharpoons$	$2Cr^{3+}(aq) + 7H_2O(l)$	$E^{\ominus} = +1.33\,V$
$H_2O_2(aq) + 2H^+(aq) + 2e^-$	$\rightleftharpoons$	$2H_2O(l)$	$E^{\ominus} = +1.78\,V$

Table 21.1

(a) Complete the electron configuration of

a Ni atom: $1s^2$ ....

a Ni^{2+} ion: $1s^2$ .... **[2]**

Most candidates knew the electron configuration of an Ni atom but the number knowing the electron configuration of the Ni^{2+} ion was considerably fewer. The common error was the failure to remove the two 4s electrons.

Question 21(b)(i)

(b) A standard cell is set up in the laboratory with the cell reaction shown below.

$$Ni(s) + I_2(aq) \rightarrow Ni^{2+}(aq) + 2I^-(aq)$$

(i) Draw a labelled diagram to show how this cell could be set up to measure its standard cell potential.

Include details of apparatus, solutions and the standard conditions required.

Standard conditions ....

....

.... **[4]**

A significant number of candidates did not draw a simple circuit. Most candidates scored the mark for the Ni electrode but fewer scored the mark for the Pt electrode in the $I^-(aq)/I_2(aq)$ mixture. The last mark, for the conditions (including concentrations of 1.00 mol dm^{-3}), was almost universally scored even by those who omitted the solutions in their diagram.

Common errors were: diagrams with electrodes not entering solutions; salt bridges not labelled or not entering solutions; making solid iodine an electrode; and assuming iodine to be a gas and adapting a standard hydrogen electrode to accommodate this.

Question 21(b)(ii)

(ii) Predict the standard cell potential of this cell.

standard cell potential = ... V **[1]**

This was the most successfully answered single mark question on the paper.

Question 21(c)(i)

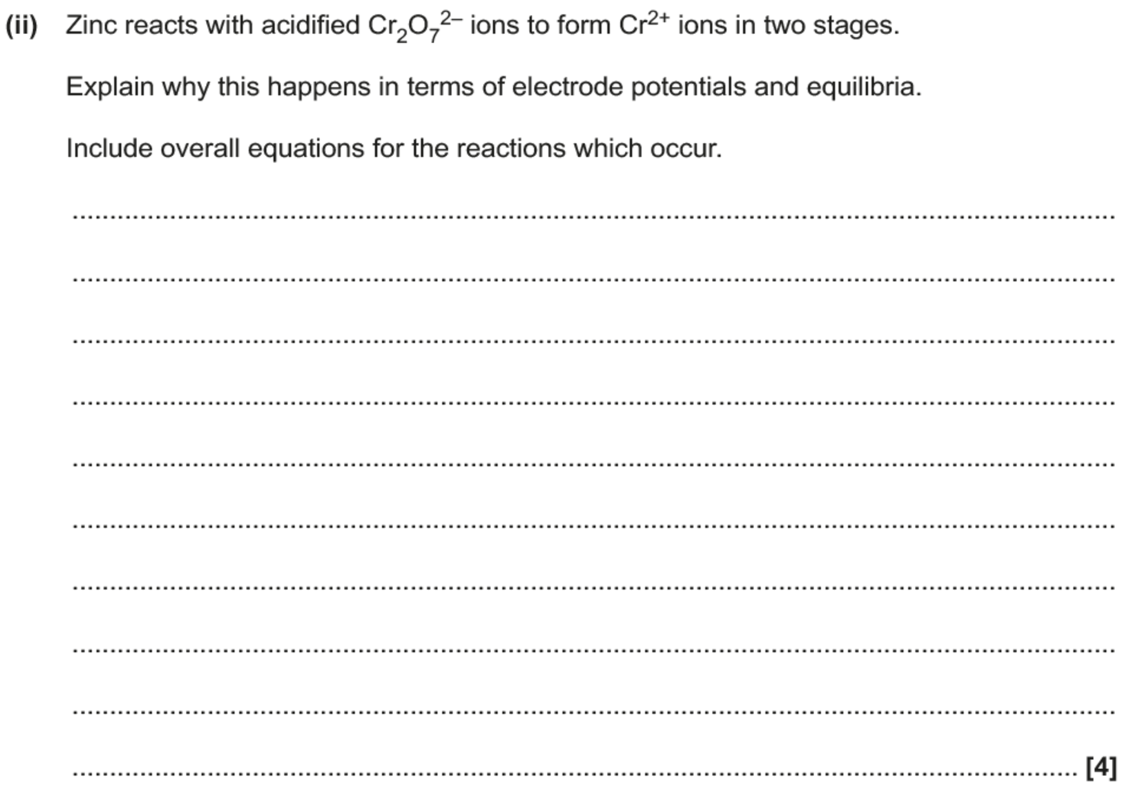
(c) Use the information in **Table 21.1** to help you answer both parts of this question.

(i) Write the overall equation for the oxidation of Fe^{2+} by acidified H_2O_2.

.... **[1]**

Most candidates got the equation correct. Occasionally a number was omitted causing incorrect stoichiometry and occasionally the equation was reversed.

Question 21(c)(ii)



(ii) Zinc reacts with acidified $Cr_2O_7^{2-}$ ions to form Cr^{2+} ions in two stages.

Explain why this happens in terms of electrode potentials and equilibria.

Include overall equations for the reactions which occur.

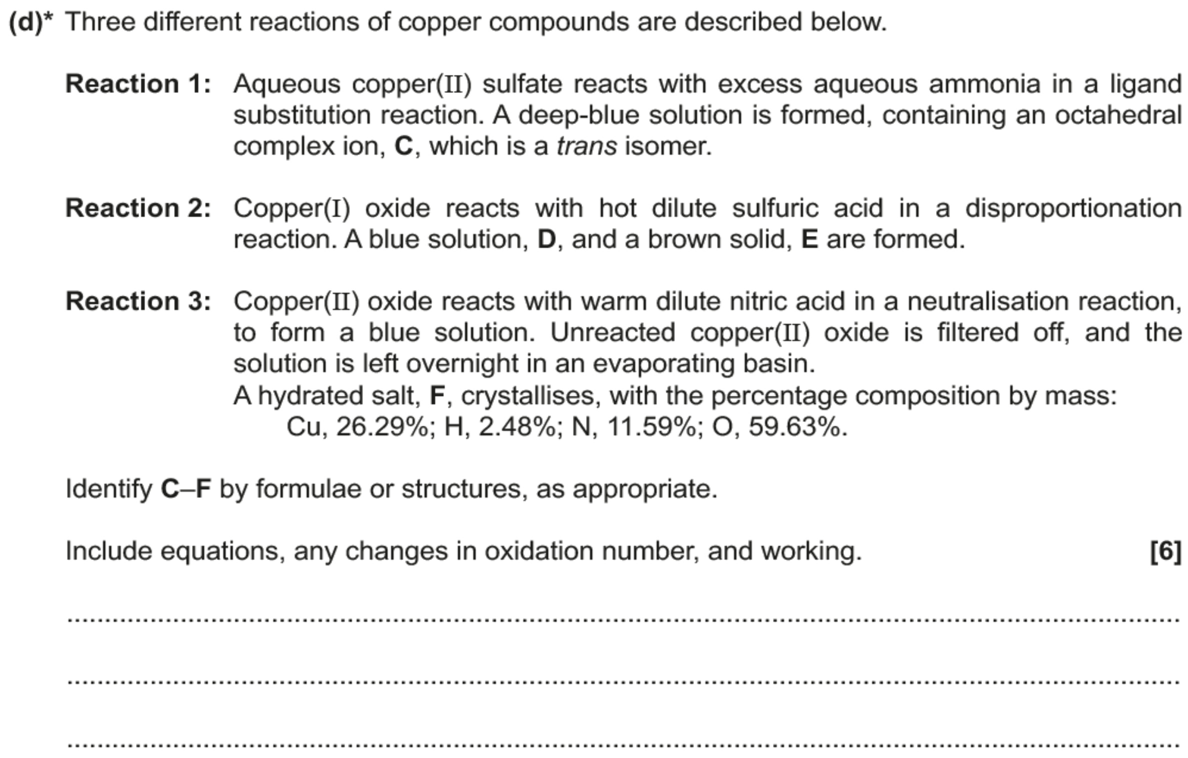
[4]

Only the higher ability candidates achieved full marks.

Most candidates were able to come up with both redox equations and some could state that zinc was oxidised or chromium was reduced as a result of zinc having a more negative electrode potential than either chromium species.

Common errors were: stating that zinc had a lower (not more negative) electrode potential; stating that zinc was an oxidising agent (as well as being oxidised); confusing the direction of change of equilibria shown; and not balancing the overall redox equations.

Question 21(d)*



(d)* Three different reactions of copper compounds are described below.

Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, **C**, which is a *trans* isomer.

Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, **D**, and a brown solid, **E** are formed.

Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.
A hydrated salt, **F**, crystallises, with the percentage composition by mass:
Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%.

Identify **C**–**F** by formulae or structures, as appropriate.

Include equations, any changes in oxidation number, and working. **[6]**

....

....

....

Many candidates had a stab at identifying **C**–**F** but neglected to include equations for the three reactions described or to show relevant working.

Most candidates recognised **C** as the ammoniacal copper(II) ion but the formula was frequently incorrect and correct attempts at a ligand substitution equation from $[Cu(H_2O)_6]^{2+}$ was rarely seen. Diagrams showing the *trans* isomer were attempted but often of poor quality due to incorrect linking.

Candidates recognised **D** as being $CuSO_4$ but often did not identify **E** as Cu due to a lack of familiarity with this common disproportionation reaction. $Cu(OH)_2(s)$ was a common incorrect identification of **E**. Only the best responses described the oxidation number changes which made this a disproportionation reaction.

F was identified by a percentage by mass calculation to determine an empirical formula and then by deduction to produce $Cu(NO_3)_2.3H_2O$. Having done this, many candidates did not give the relatively simple equation for reaction **3** between copper(II) oxide and dilute nitric acid.

Exemplar 2

(d)* Three different reactions of copper compounds are described below.

Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, **C**, which is a *trans* isomer. ⟹ 180

4 + 2

Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, **D**, and a brown solid, **E** are formed.

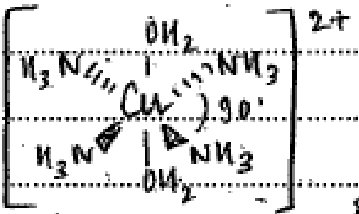
$CuSO_4$ Cu $+ H_2O$

Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.
A hydrated salt, **F**, crystallises, with the percentage composition by mass:
Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%.

Identify **C–F** by formulae or structures, as appropriate.

Include equations, any changes in oxidation number, and working. **[6]**

① $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$



octahedral

This is the trans isomer $\boxed{C}$ because the H_2O ligands are 180° apart.

② $Cu_2O_{(s)} + H_2SO_{4(aq)} \longrightarrow \underbrace{Cu_{(s)}}_{\text{brown solid}} + \underbrace{CuSO_{4(aq)}}_{\text{blue solution}} + H_2O_{(l)}$

$\boxed{E}$ $\boxed{D}$ ④ NOTE AT END

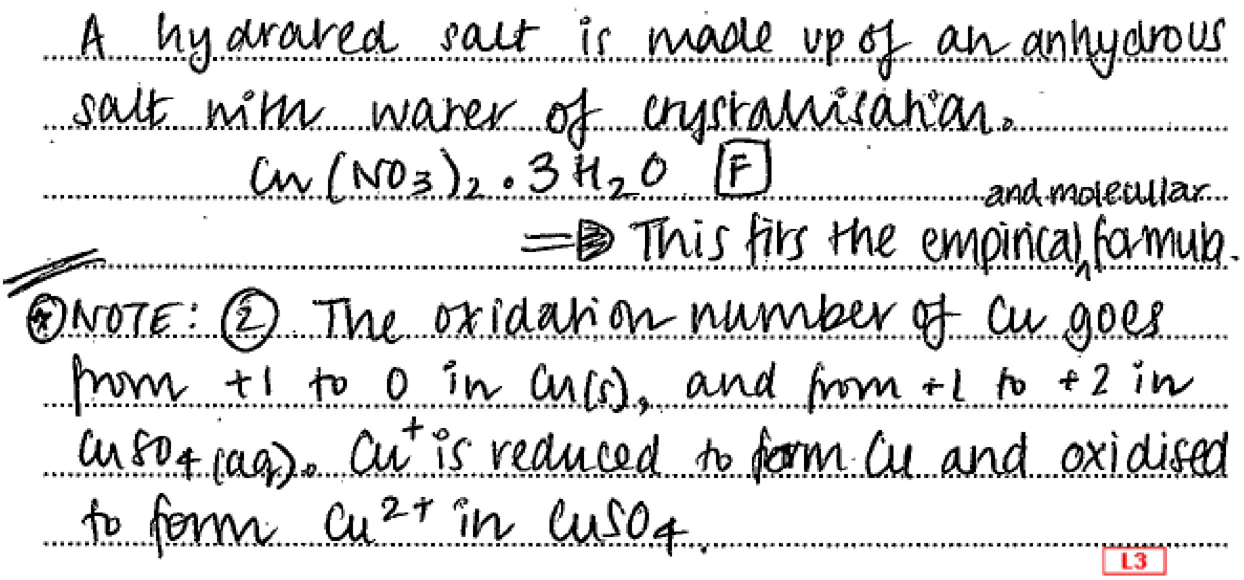
③ $CuO_{(s)} + 2HNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + H_2O_{(l)}$

	Cu	H	N	O
mass	26.29	2.48	11.59	59.63
Mr	63.5	1	14	16
mol	0.414	2.48	0.828	3.73

Additional answer space if required.

1 : 6 : 2 : 9

⟹ $CuH_6N_2O_9$



A hydrated salt is made up of an anhydrous salt with water of crystallisation.

$Cu(NO_3)_2 \cdot 3H_2O$ $\boxed{F}$

⇒ This fits the empirical and molecular formula.

⊛ NOTE: ② The oxidation number of Cu goes from +1 to 0 in Cu(s), and from +1 to +2 in $CuSO_4$(aq). Cu^+ is reduced to form Cu and oxidised to form Cu^{2+} in $CuSO_4$.

L3

This exemplifies how considered structuring of candidate responses can enhance their clarity. The clear labelling of C-F in the response, along with numbering which corresponds to the reactions in the question stem, make the candidate's line of reasoning easy to follow. The underlining and annotations in the question stem show good practice in picking out and interpreting key information.

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