

Principal examiner reports for teachers

Principal examiner reports for teachers summarise what candidates did well and what candidates needed to improve for this examination series only.

This report is to be used in conjunction with the question paper and mark scheme.

For guidance on teaching and learning we provide resources for many of our syllabuses.

Resource	Where to find it
Grade descriptions – Grade descriptions describe the level of performance typically demonstrated by candidates achieving the different grades awarded for a qualification.	School support hub Select: Subject > Resource finder > Syllabus and specimen materials
Schemes of work – Schemes of work are designed to support you in your teaching and lesson planning.	School support hub Select: Subject > Resource finder > Teaching and learning
Lesson planning – Guidance on how to plan a lesson.	Lesson planning
Resource plus – There may be additional resources such as teaching packs containing lesson plans, resources and worksheets and videos for aspects of your syllabus.	School support hub Select: Subject > Resource finder > Teaching and learning
Teaching tools	Teaching Tools
Exemplar candidate responses	School support hub Select: Subject > Resource finder > Teaching and learning
Learner guide – A guide for students to help them understand what the course involves.	School support hub Select: Subject > Resource finder > Teaching and learning
Community forums – Do you have a question or something to share? Our online forums are great way to keep up to date with your subject and the global Cambridge community.	Community forum on the school support hub
Access to scripts for this series.	Access to scripts service
Results analysis is available for some syllabuses.	Results analysis
Test maker is available for some subjects.	Test maker

Other services from Cambridge International Education

- [Digital mocks service](#)
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- [Professional development](#)
 - [Focus on assessment](#)
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CHEMISTRY

Paper 9701/11 Multiple Choice
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Key messages

Candidates performed well on **Questions 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 13, 15, 16, 17, 18, 21, 24, 26, 28, 29, 30, 32, 33, 35, 36, 37 and 40.**

Candidates performed less well on **Questions 5, 12, 14, 19, 20, 22, 23, 25, 27, 31, 34, 38 and 39.**

Candidates should take care to read the full question before answering. Some options may give answers that are either correct statements which do not answer the question or are statements that are only partially correct.

Comments on specific questions

Question 5

- Option **D** was a common incorrect answer.
- Graphite has a planar structure in which the carbon atoms form planar hexagonal rings. In these rings all bond angles are 120° .

Question 12

- Option **C** was a common incorrect answer.
- 7.04 g of oxygen is 0.22 mol present at equilibrium. From this it can be deduced that 0.44 mol of NO and 0.31 mol of NO₂ are present at equilibrium. If these amounts are divided by the volume of the vessel, they are converted into concentrations. If these concentrations are used in the expression for K_c , the value of K_c can be calculated.

Question 14

- Option **C** was a common incorrect answer.
- Since the temperature of the mixture has decreased, the rate of the forward reaction and the rate of the backward reaction will both decrease. The reason for the shift in position of equilibrium is that the rate of the forward reaction decreases less than the rate of the backward reaction, until equilibrium is re-established.

Question 19

- Option **C** was a common incorrect answer.
- Option **A** – 0.148 mol of magnesium are added to 0.225 mol of sulfuric acid. Magnesium is therefore the limiting reagent. 0.148 mol of hydrogen are produced.
- Option **B** – 0.160 mol of calcium carbonate are added to 0.240 mol of hydrochloric acid. Hydrochloric acid is therefore the limiting reagent. 0.120 mols of carbon dioxide are produced.
- Option **C** – 0.050 mol of strontium nitrate are decomposed. A total of 0.125 mol of nitrogen dioxide and oxygen are produced.
- Option **D** – 0.140 mol of barium carbonate are decomposed. 0.140 mol of carbon dioxide are produced.
- The smallest total number of moles of gas produced is 0.120 mol.

Question 20

- Option **C** was a common incorrect answer.
- Solution V is barium hydroxide. Mixture W contains barium chloride solution and magnesium hydroxide, which is a white precipitate. Mixture X is a mixture of barium chloride and magnesium chloride solutions. Mixture Y contains magnesium hydroxide and barium sulfate, both as white precipitates. Mixture Z contains magnesium chloride solution and barium sulfate, which is a white precipitate. There are white precipitates present in W, Y and Z.

Question 22

- Options **B** and **D** were common incorrect answers.
- Chlorine reacts with water according to the equation: $\text{Cl}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HCl} + \text{HOCl}$

Question 23

- Option **C** was a common incorrect answer.
- Out of the three halide ions in the question only iodide ions react with concentrated sulfuric acid to form hydrogen sulfide, H_2S . The oxidation number of sulfur in hydrogen sulfide is -2 .

Question 25

- Option **C** was a common incorrect answer.
- The formula of the cyclohexene ring is C_6H_9 . The formula of the terminal aldehyde group is CHO . Since the formula of 11-*cis*-retinal is $\text{C}_{20}\text{H}_{28}\text{O}$, the formula of the long aliphatic chain must be $\text{C}_{13}\text{H}_{18}$. This side chain must contain four $\text{C}=\text{C}$ double bonds, giving a total of five including the $\text{C}=\text{C}$ double bond in the cyclohexene ring. The two R groups are shown as *cis* in options **A** and **C** and as *trans* in options **B** and **D**.

Question 27

- Option **D** was a common incorrect answer.
- Compound Y must contain an alcohol group, $-\text{OH}$, to be a functional group isomer of ether X. Pentan-1-ol and pentan-3-ol do not have optical isomers. Pentan-2-ol does have optical isomers.

Question 31

- Option **B** was a common incorrect answer.
- When 2-bromobutane is strongly heated in a concentrated ethanolic solution of sodium hydroxide three organic products are formed. Each of these has the molecular formula C_4H_8 . These products are but-1-ene, *cis*-but-2-ene and *trans*-but-2-ene.

Question 34

- Option **C** was a common incorrect answer.
- Four isomers are listed. The 2nd, 3rd and 4th of these isomers contain aldehyde or ketone groups. Therefore, three of these isomers give a precipitate with 2,4-DNPH. The 1st, 3rd and 4th of these isomers contain either a $-\text{CHOHCH}_3$ group or a $-\text{COCH}_3$ group. Therefore, three of these isomers give a precipitate with alkaline $\text{I}_2(\text{aq})$.

Question 38

- Option **C** was a common incorrect answer.
- The formula of 1,1-dichloroethene is $\text{CH}_2=\text{CCl}_2$. Therefore, in the polymer formed:
 - every CH_2 group must be shown adjacent to, or possibly adjacent to, at least one CCl_2 group
 - every CCl_2 group must be shown adjacent to, or possibly adjacent to, at least one CH_2 group.

Question 39

- Option **C** was a common incorrect answer.
- 2.76 g of ethanol contains 0.0600 mol. Under the conditions described, the required organic product is ethanoic acid. 0.0600 mol of ethanoic acid has a mass of 3.60 g. The yield of product is given as 75.0%, therefore 2.70 g of ethanoic acid was collected.

CHEMISTRY

Paper 9701/12
Multiple Choice

Key messages

Candidates performed well on **Questions 1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 29, 31, 35, 37, 38 and 40.**

Candidates performed less well on **Questions 4, 6, 14, 18, 26, 27, 28, 30, 32, 33, 34, 36 and 39.**

Candidates should take care to read the full question before answering. Some options may give answers that are either correct statements which do not answer the question or are statements that are only partially correct.

Comments on specific questions

Question 4

- Option **A** was a common incorrect answer.
- If X and Y are carbon and boron, both students are correct.
If X and Y are magnesium and aluminium, neither student is correct.
If X and Y are oxygen and nitrogen, neither student is correct.
If X and Y are oxygen and sulfur, only student 2 is correct.

Question 6

- Option **A** was a common incorrect answer.
- The σ bond between the H atom and the C atom in HCN is produced by the overlap of an s orbital on the H and an sp hybrid orbital on the C. The triple bond between the C atom and the N atom in HCN consists of one σ bond and two π bonds. The σ bond is produced by the overlap of two sp hybrid orbitals. Each π bond is produced by the overlap of one p orbital on the C with one p orbital on the N. Therefore, the bonds described in descriptions 1 and 2 are present in an HCN molecule.

Question 14

- Option **D** was a common incorrect answer.
- Since the forward reaction is exothermic, a decrease in temperature will cause the equilibrium position to move to the right. This produces more H_3O^+ ions, so the pH decreases.

Question 18

- Option **C** was a common incorrect answer.
- Since there is an excess of oxygen, some of the NO that is added in procedure 1 will react with oxygen to form NO_2 .

Question 26

- Option **A** was a common incorrect answer.
- The structural formula of pentane is $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$. The possible first propagation steps are:
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\cdot + \text{HCl}$
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}\cdot\text{CH}_3 + \text{HCl}$
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\text{CH}\cdot\text{CH}_2\text{CH}_3 + \text{HCl}$

Question 27

- Option **C** was a common incorrect answer.
- There are eight isomers: pentanal, pentan-2-one, pentan-3-one, methylbutanone, 3-methylbutanal, dimethylpropanal and the two optical isomers of 2-methylbutanal. Five of these isomers – the five aldehydes – produce a silver mirror with Tollens' reagent.

Question 28

- Option **D** was a common incorrect answer.
- The mechanism is electrophilic addition. The first atom to add to the C=C double bond will be the more positive of the two, so this will be the iodine atom. It bonds to carbon atom one, forming a secondary carbocation, so the chlorine atom bonds to carbon atom two.

Question 30

- Option **C** was a common incorrect answer.
- The sample of 1-bromopropane consists of 0.300 mol. Under the conditions described, the desired product is butanenitrile. The reaction is described as having a 78.0% yield; this is 0.234 mol of butanenitrile. This has a mass of 16.2 g. This answer, 16.2 g, is reached by allowing extra decimal places to carry over on the calculator, rather than by rounding the intermediate answers.

Question 32

- Option **C** was a common incorrect answer.
- The major product of the reaction of methylpropene with steam is methylpropan-2-ol. This is a tertiary alcohol, so it is not oxidised by acidified KMnO_4 .

Question 33

- Option **B** was a common incorrect answer.
- Ethanal gives a positive result with alkaline $\text{I}_2(\text{aq})$; propanal does not. Ethanol and propan-2-ol both give a positive result with alkaline $\text{I}_2(\text{aq})$. Neither methanol nor propan-1-ol gives a positive result with alkaline $\text{I}_2(\text{aq})$. Propanone and butanone both give a positive result with alkaline $\text{I}_2(\text{aq})$.

Question 34

- Option **C** was a common incorrect answer.
- Reaction 1 is esterification; esterification is not a redox reaction. Reaction 2 is an acid-base reaction; acid-base reactions are not redox reactions.

Question 36

- Option **C** was a common incorrect answer.
- The C-C-N bond angle in ethanenitrile is 180° , since the middle carbon atom is sp hybridised. Heating ethanenitrile with an excess of sodium hydroxide until the reaction is complete produces X. X is sodium ethanoate. The C-C-O bond angle in sodium ethanoate is 120° , since the middle carbon atom is sp^2 hybridised.

Question 39

- Option **B** was a common incorrect answer.
- The four isomers are but-1-ene, *cis*-but-2-ene, *trans*-but-2-ene and methylpropene.

CHEMISTRY

Paper 9701/13
Multiple Choice

Key messages

Candidates performed well on **Questions 1, 2, 3, 4, 5, 7, 10, 11, 13, 14, 15, 17, 18, 20, 21, 25, 26, 27, 28, 30, 31, 33, 34, 35, 36, 38 and 40.**

Candidates performed less well on **Questions 6, 8, 9, 12, 16, 19, 22, 23, 24, 29, 32, 37 and 39.**

Candidates should take care to read the full question before answering. Some options may give answers that are either correct statements which do not answer the question or are statements that are only partially correct.

Comments on specific questions

Question 6

- Option **C** was a common incorrect answer.
- The σ bond between an H atom and a C atom in $\text{H-C}\equiv\text{C-H}$ is produced by the overlap of an s orbital on the H and an sp hybrid orbital on the C. The triple bond between the two C atoms in $\text{H-C}\equiv\text{C-H}$ consists of one σ bond and two π bonds. The σ bond is produced by the overlap of two sp hybrid orbitals. Each π bond is produced by the overlap of two p orbitals. Therefore, the bonds described in descriptions 1, 3 and 4 are present in a $\text{H-C}\equiv\text{C-H}$ molecule.

Question 8

- Option **C** was a common incorrect answer.
- The bonds that are in the reactants but not in the products are $\text{C}=\text{C}$ and H-Br , totalling $+976 \text{ kJ mol}^{-1}$. The bonds that are in the products but not in the reactants are C-C , C-Br and an additional C-H , totalling $-1040 \text{ kJ mol}^{-1}$.

Question 9

- Option **C** was a common incorrect answer.
- The enthalpy of formation of two moles of SO_2 is -593 kJ mol^{-1} . The enthalpy of formation of two moles of SO_3 is $-791.4 \text{ kJ mol}^{-1}$.

Question 12

- Option **B** was a common incorrect answer.
- At equilibrium, there is 0.700 mol of ammonia. The concentration of ammonia is $0.700 \div 0.500 = 1.400 \text{ mol dm}^{-3}$. At equilibrium there is 0.700 mol of hydrogen chloride. The concentration of hydrogen chloride is $0.700 \div 0.50 = 1.400 \text{ mol dm}^{-3}$. At equilibrium, there is 0.300 mol of ammonium chloride, but as a pure solid, its concentration is 1.00 mol dm^{-3} . $(1.400 \times 1.400) \div 1 = 1.96$.

Question 16

- Option **C** was a common incorrect answer.
- Since X has the greatest electronegativity, it has the highest atomic number and the smallest atomic radius, so it is probably chlorine.
Since W reacts with X to produce a liquid, W must be silicon or phosphorus.
Z must be sodium, so Z has the largest radius.
Y has an amphoteric oxide, so Y must be aluminium.

Question 19

- Option **A** was a common incorrect answer.
- The gases given off are nitrogen dioxide, oxygen and water vapour.

Question 22

- Option **D** was a common incorrect answer.
- Chloride ions do not reduce concentrated sulfuric acid. Bromide ions reduce concentrated sulfuric acid, but only to SO_2 . Iodide ions reduce concentrated sulfuric acid to a mixture that includes sulfur. Gaseous iodine is purple.

Question 23

- Option **A** was a common incorrect answer.
- Neither NO nor NO_2 reduces SO_2 . Only NO_2 oxidises SO_2 in the atmosphere.

Question 24

- Option **D** was a common incorrect answer.
- The ammonium ion acts as an acid when it reacts with hydroxide ions.
The H-N-H bond angle is 109.5° in an ammonium ion; it is 107° in an ammonia molecule.

Question 29

- Option **B** was a common incorrect answer.
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHBrCH}_3$ will eliminate HBr under the conditions described to form *cis*-pent-2-ene, *trans*-pent-2-ene and pent-1-ene. $(\text{CH}_3\text{CH}_2)_2\text{CHBr}$ will eliminate HBr under the conditions described to form *cis*-pent-2-ene and *trans*-pent-2-ene only. This means the key must be options **A** or **B**.
- $\text{CH}_3\text{CH}_2\text{CBr}(\text{CH}_3)_2$ will eliminate HBr under the conditions described to form 2-methylbut-1-ene and 2-methylbut-2-ene. $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{Br}$ will eliminate HBr under the conditions described to form 2-methylbut-1-ene only.

Question 32

- Option **B** was a common incorrect answer.
- To make propene from propanoic acid the acid should first be reduced to propan-1-ol. NaBH_4 cannot do this. Then the propan-1-ol should be dehydrated. Ethanolic NaOH cannot do this.

Question 37

- Option **C** was a common incorrect answer.
- Primary amine Z is methylpropylamine. 4.50 g of methylpropylamine is 0.06164 mol. Since this is a 56.0% yield, the amount of 2-methyl-1-bromopropane present at the start is 0.110 mol. This has a mass of 15.07 g. The correct conditions for the reaction are NH_3 in ethanol, heated under pressure.

Question 39

- Option **D** was a common incorrect answer
- The infrared spectrum shows a strong absorption at 1740 cm^{-1} . This is characteristic of a C=O bond. This means the key must be options **B** or **D**. The infrared spectrum does not show a strong and broad absorption between 2500 cm^{-1} and 3000 cm^{-1} so there is no carboxyl O–H group present.

CHEMISTRY

Paper 9701/14 Multiple Choice
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Key messages

Candidates performed well on **Questions 1, 3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 17, 18, 19, 20, 22, 24, 26, 27, 28, 30, 33, 34, 35, 36, 37 and 39.**

Candidates performed less well on **Questions 2, 8, 9, 11, 16, 21, 23, 25, 29, 31, 32, 38 and 40.**

Candidates should take care to read the full question before answering. Some options may give answers that are either correct statements which do not answer the question or are statements that are only partially correct.

Comments on specific questions

Question 2

- Option **C** was a common incorrect answer.
- Carbon has a larger fifth ionisation energy than neon, as the electron is removed from the first shell. Nitrogen has a smaller fifth ionisation energy than boron, as the electron is removed from the second shell.

Question 8

- Option **C** was a common incorrect answer.
- The hydrogen halides become less polar down Group 17, so the factor cannot be strength of hydrogen bonding, permanent dipole-dipole attractions or polarity of the bond. The number of electrons increases down Group 17, and this increases instantaneous dipole-induced dipole forces.

Question 9

- Option **D** was a common incorrect answer.
- A correct Hess's law cycle gives the enthalpy of formation of two moles of NO_2 as +32 kJ. Therefore, the enthalpy of formation of NO_2 is +16 kJ mol⁻¹.

Question 11

- Option **B** was a common incorrect answer.
- One mole of $\text{Cr}_2\text{O}_7^{2-}$ is reduced to give two moles of Cr^{3+} ions. This is a total change in oxidation number of six. This means that one mole of $\text{Cr}_2\text{O}_7^{2-}$ can oxidise six moles of Fe^{2+} to Fe^{3+} .

Question 16

- Option **C** was a common incorrect answer.
- Ammonia does act as a Brønsted-Lowry base since it gains a proton. The H–N–H bond angle increases from 107° in the ammonia molecule to 109.5° in the ammonium ion. The ammonia molecule and the ammonium ion both contain ten electrons.

Question 21

- Option **B** was a common incorrect answer.
- Solution Y contains barium nitrate. It may also contain barium hydroxide or magnesium nitrate; this depends on whether barium oxide or magnesium nitrate was originally in excess. However, this does not matter, since with either original excess, barium nitrate is present in solution Y and gives a white precipitate with an excess of dilute sulfuric acid.
White solid Z is magnesium hydroxide, which gives a colourless solution with an excess of dilute sulfuric acid.

Question 23

- Option **B** was a common incorrect answer.
- The reaction of chlorine with hot aqueous sodium hydroxide also produces sodium chloride as one product, so statement 1 is correct.
The reaction of chlorine with hot aqueous sodium hydroxide produces both Cl^- ions and ClO_3^- ions, so statement 2 is correct.
The equation for the reaction of chlorine with hot aqueous sodium hydroxide is $6\text{NaOH} + 3\text{Cl}_2 \rightarrow \text{NaClO}_3 + 5\text{NaCl} + 3\text{H}_2\text{O}$, so statement 3 is correct.
Statements 1, 2 and 3 are all correct.

Question 25

- Option **C** was a common incorrect answer.
- The isomers are methylpropene, but-1-ene, *cis*-but-2-ene and *trans*-but-2-ene.

Question 29

- Option **C** was a common incorrect answer.
- PCl_3 will convert propan-2-ol to 2-chloropropane, so reagent 1 is correct.
 Cl_2 will not convert propan-2-ol to 2-chloropropane, so reagent 2 is incorrect.
 KCl with concentrated H_2SO_4 will convert propan-2-ol to 2-chloropropane, so reagent 3 is correct.
Reagents 1 and 3 will both bring about the stated conversion.

Question 31

- Option **A** was a common incorrect answer.
- Reaction 1 will give butanenitrile.
Reaction 2 gives propylamine.
Reaction 3 gives propan-1-ol.

Question 32

- Option **B** was a common incorrect answer.
- $(\text{CH}_3)_3\text{CBr}$ is a tertiary halogenoalkane. Tertiary halogenoalkanes tend to react via the $\text{S}_{\text{N}}1$ mechanism. The first step of the mechanism is the heterolytic fission of the $\text{C}-\text{Br}$ bond. Since this means that the bromine atom keeps both of the bonding electrons, the carbon atom is now surrounded by only six valence electrons. It is sp^2 hybridised. This means that the intermediate is planar.

Question 38

- Option **B** was a common incorrect answer.
- The esters with molecular formula $\text{C}_4\text{H}_8\text{O}_2$, along with the products of their acid hydrolysis, are listed:
 - Methyl propanoate, which hydrolyses to give methanol and propanoic acid.
 - Ethyl ethanoate, which hydrolyses to give ethanol and ethanoic acid.
 - Propyl methanoate, which hydrolyses to give propan-1-ol and methanoic acid.
 - Isopropyl methanoate, which hydrolyses to give propan-2-ol and methanoic acid.
 - This is a total of seven different organic compounds.

Question 40

- Option **D** was a common incorrect answer.
- All the peaks in any mass spectrum are due to positive ions.
The abundances of the M^+ ion and the $[M+1]^+$ ion can be used to calculate the number of carbon atoms in an organic molecule.
- In the absence of bromine or chlorine, there is no peak that would be described as an $[M+2]^+$ peak.

CHEMISTRY

Paper 9701/21
AS Level Structured Questions

Key messages

What candidates did well

- Candidates laid out their answers clearly, in both extended written response and calculations.
- Chemical terminology was used precisely, which reduced the volume of explanatory text that candidates needed to write.

What candidates needed to improve

- Candidates are reminded to address 'explain' questions fully — not merely to state facts or rules of thumb, but then to show how these combine to give reasons for chemical phenomena. This often requires a secure understanding of bonding and structure within molecules, in particular for organic species, linking structural features to mechanistic probabilities.
- Working in calculations should be shown, especially where a numerical answer might be obtained by different methods, correctly or incorrectly. Harsh or early rounding of numbers should be avoided, as it leads to sizable inaccuracies later.
- Candidates need to pay attention to detail in the positioning of curly arrows and use of lone pairs in mechanisms.
- Candidates need to refer to isotopic masses and fragment ions when analysing mass spectra data.

Comments on specific questions

Question 1

(a) (i) Comprehensive responses

- Most candidates drew clear, well organised electron arrangements demonstrating a secure understanding of covalent bonding and the expanded octet in sulfur.

Limited responses

- A few candidates omitted the lone pairs on the fluorine atoms.
- Some candidates did not attempt this question.

(ii) Comprehensive responses

- Most candidates were able to use the electron pair domains to assign the correct shape to the molecule.

Limited responses

- Some candidates selected shapes such as bipyramidal, indicating that they were drawing on familiar examples even if they did not apply VSEPR theory fully to SF₆.
- A few candidates gave trigonal bipyramidal.

(b) (i) Comprehensive responses

- Most candidates could name and draw the lowest energy level orbital.

Limited responses

- Some candidates omitted the '1' of '1s' or identified the s orbital as '2' or '3'.

(ii) Comprehensive responses

- Candidates wrote a correct equation, with state symbols, for the first ionisation energy of chlorine.

Limited responses

- Candidates did not include state symbols in their responses or ionised Cl_2 not Cl .

(iii) Comprehensive responses

- Many candidates linked the concepts of nuclear charge, shielding and nuclear attraction to the difference in ionisation energy.

Limited responses

- Many candidates referred to the spin-pairing in S or electronegativity of S and Cl .
- Some stated 'the ionisation energy is higher because ionisation energy increases across a period' without explanation.
- Some candidates omitted the idea of shielding from otherwise correct explanations.

(c) (i) Comprehensive responses

- Many candidates were able to apply VSEPR to the molecule to predict the bond angle of the given molecule.

Limited responses

- Many candidates were able to identify the two lone pairs of electrons on the central atom. Ideas about bonding pairs of electrons were not always included.
- Many candidates did not comment on the lone pairs having stronger repulsion than the bond pairs.
- Some candidates referred to each lone pair reducing the bond angle by 2.5° per lone pair. They sometimes did not develop or explain this idea.

(ii) Comprehensive responses

- Most candidates drew correct partial charges on the molecule, with some candidates using the alternative 'arrow' representation for the dipole.

Limited responses

- Some candidates drew the dipole upside down.
- Some candidates omitted to annotate the diagram or drew lone pairs of electrons on the atoms and not the required dipole.

(d) (i) Comprehensive responses

- Most candidates could identify the number of electrons in SCl_2 .

Limited responses

- Some candidates quoted 18, 22 or 30 electrons.

(ii) Comprehensive responses

- Many candidates could link the idea of electron number with the strength of instantaneous dipole-induced dipole attractions.

Limited responses

- Some candidates referred to permanent dipoles or hydrogen bonds.

(iii) Comprehensive responses

- Many candidates could describe the differences in electronegativity between O and H and S and Cl to explain why water has a greater dipole moment.

Limited responses

- Some candidates referred to permanent dipoles or hydrogen bonds or outlined the polarity of molecules/bonds.
- Some candidates used the word 'electronegativity' to mean difference in electronegativity for example, the electronegativity of water is greater than that of SCl_2 .
- Some candidates compared the difference in electronegativity between oxygen and sulfur or chlorine.

(e) Comprehensive responses

- Many candidates could use the data in the question to calculate the molecular formula of compound X.

Limited responses

- Some candidates carried out a correct calculation and then incorrectly quoted the molecular formula as 2SCl .
- Some candidates identified a 1 : 1 mole ratio for the empirical formula and then did not scale up using the M_r of the molecule.
- Some candidates attempted the calculation using A_r and some attempted the calculation using just the ratios from the percentages.

Question 2

(a) Comprehensive responses

- Most candidates provided a balanced equation using the correct species for stage 3.

Limited responses

- A few candidates provided an equation producing oxygen and sometimes hydrogen.

(b)(i) Comprehensive responses

- Many candidates included a comment of yield and position of equilibrium.

Limited responses

- Many explanations did not refer to Le Chatelier's principle.
- Many responses did not refer to equilibrium moving to the right.
- Some candidates stated Le Chatelier's principle. They did not relate it to the change in the conditions for stage 2.
- Some candidates included information regarding exothermic and endothermic reactions.

(ii) Comprehensive responses

- Most candidates could explain the idea of a catalyst and its effect on a reaction, with many candidates defining a catalyst.

Limited responses

- A few candidates just put a statement about V_2O_5 being a catalyst, thinking this was enough to imply a faster rate.
- Some candidates did not add the 'time element' into their more successful collisions.
- A few candidates used the terms 'activation energy' or 'activantial energy' instead of activation energy.

(c) (i) Comprehensive responses

- Most candidates could state the environmental consequence.

Limited responses

- A few candidates were too vague in their responses, quoting 'it's a pollutant'.
- A few candidates suggested ozone depletion or global warming.

(ii) Comprehensive responses

- Most candidates could recall the ideal gas equation and use the data correctly to calculate the volume of gas with a clear layout in their calculation and attention to detail regarding units.

Limited responses

- Some candidates used the incorrect number of moles or an incorrect temperature conversion to Kelvin.
- Some candidates did not attempt the unit conversion for temperature or pressure.
- Some candidates did not give the appropriate units to the value they presented.
- Some candidates attempted to derive a unit for volume using the other units to involve Pa / J or mol.

Question 3

(a) (i) Comprehensive responses

- Most candidates were able to write a fully balanced equation using the correct species for reaction 1.

Limited responses

- Some candidates gave an incorrect formula for sodium sulfate; the most common being NaSO_4 .
- Some candidates used the correct species. They did not then balance the equation when making sodium sulfate and HCl .

(ii) Comprehensive responses

- Most candidates could identify the Brønsted-Lowry acid.

Limited responses

- A few candidates quoted sulfuric acid and more rarely just Na.

(b) Comprehensive responses

- Most candidates were able to state the identity of the vapours using the formula of the halogens.

Limited responses

- Some candidates did not use formulae.
- Some candidates referred to halide ions.
- A few candidates thought that the brown gas was nitrogen dioxide.

(c) Comprehensive responses

- Some candidates identified the oxidation of iodide ions as the reaction responsible for the production of iodine.

Limited responses

- Many candidates discussed the idea of iodine turning into a gas, omitting how the iodine was formed.
- Many candidates discussed a generic reaction rather than oxidation.
- Many candidates used the terms iodide and iodine interchangeably.
- A few candidates talked about reduction of iodide ions.
- A few candidates thought that the purple vapour was HI .

(d) Comprehensive responses

- Most candidates could deduce oxidation numbers correctly.

Limited responses

- A few candidates omitted the negative sign for the oxidation number of H_2S .

(e) Comprehensive responses

- Some candidates gave a comparison of halide ions and their reducing power.

Limited responses

- Some candidates discussed halogens rather than halide ions; the terms halogen and halide were used interchangeably.
- Some candidates discussed bromine being more reactive than iodine.
- Some candidates confused the oxidising or reducing power of halogens or halides.

(f) (i) Comprehensive responses

- Most candidates recalled the correct colour of the precipitate and the fact that it is insoluble.

Limited responses

- Some candidates gave incorrect precipitate colours, discussed the precipitate dissolving or stated that effervescence would be seen.

(ii) Comprehensive responses

- Most candidates wrote an ionic equation including the correct charges and state symbols, although the latter were not required.

Limited responses

- Many candidates included NaI in the equation, for example, $\text{Ag}^+ + \text{NaI} \rightarrow \text{AgI} + \text{Na}^+$.
- Some candidates had the wrong formula: AgI_2 .
- Some candidates omitted charges.
- Many candidates included sodium ions in their ionic equation.

Question 4

(a) (i) Comprehensive responses

- Most candidates described the correct colour change for the reaction.

Limited responses

- A few candidates quoted the colour change the wrong way around or referenced a colour change from purple to colourless.

(ii) Comprehensive responses

- Some candidates balanced the equation for the oxidation of **Z**.

Limited responses

- Some candidates noticed the correct ratio of $\text{Cr}_2\text{O}_7^{2-}$ to Cr^{3+} . They did not then develop this further and balance the H^+ and H_2O .

(b) (i) Comprehensive responses

- Most candidates described the correct observations.

Limited responses

- A few candidates commented on 'seeing a gas' or commented on how the identity of the gases could be tested.
- A few candidates stated observing a white precipitate or white fumes for Na with the alcohol.

(ii) Comprehensive responses

- A few candidates were able to suggest that Fehling's reagent only reacts with aldehydes as Fehling's reagent can oxidise aldehydes but not alcohols or compound **A**.

Limited responses

- Many candidates discussed ketones or did not include sufficient key terms.
- Some candidates identified that aldehydes 'react'. They did not expand on this in terms of oxidation and restated the question.
- Some candidates realised they needed to talk about oxidation. They did not always develop this idea and link it to compound **A** or aldehydes and Fehling's reagent.

(iii) Comprehensive responses

- Most candidates were able to draw the oxidation product of compound **A** with the correct number of carbon atoms.

Limited responses

- Some candidates drew the carboxylic acids such that two more carbon atoms were added to the structure.
- For those candidates using displayed formulae, hydrogen atoms were often omitted.

(c) Comprehensive responses

- A few candidates were able to identify the reduction product of compound **B** and balance the equation with the correct number of (H) and H₂O.

Limited responses

- Some candidates included oxygen, lithium or hydrogen as the additional product rather than water.
- Many candidates lost a C to give a product with –CH(OH)₂ at the end.
- Most candidates did not reduce all the functional groups.

Question 5

(a) Comprehensive responses

- Most candidates identified the hybridisation of the atoms.

Limited responses

- A few candidates got the hybridisation the wrong way around.

(b) Comprehensive responses

- Most candidates identified the mechanism for the reaction.

Limited responses

- Some candidates contradicted their answers with additional details such as S_N1 or S_N2.
- Some candidates used the key term nucleophile rather than electrophile.
- Some candidates quoted radical substitution.

(c) Comprehensive responses

- A few candidates were able to give a correct definition.

Limited responses

- Most candidates identified the breaking/splitting of a covalent bond.
- Many responses discussed 'uneven breaking' of the bond or ideas about ions forming.
- Many candidates discussed all the electrons moving rather than both electrons.
- Many candidates used electronegativity arguments to explain where the electrons went, as well as talking about electrophiles and nucleophiles being formed.
- Some gave definitions of homolytic fission instead of heterolytic fission.

(d) Comprehensive responses

- Most candidates could clearly show two curly arrows originating from the double bond of the alkene and flowing to the δ^+ Cl of $\text{Cl}-\text{Cl}$.
- Most candidates could clearly draw a curly arrow originating from the lone pair of Cl^- to the carbocation intermediate.

Limited responses

- Some candidates added partial charges to ethene.
- Some responses had the dipole on chlorine the wrong way around and had curly arrows starting from a carbon atom and not the double bond in the alkene.
- Some candidates included radicals in the mechanism or had two positive charges on the intermediate.
- Some responses missed the Cl and/or the + charge from the intermediate, had a chloride ion that lacked a charge and/or a lone pair, or the curly arrow did not come from the lone pair on Cl.

(e) Comprehensive responses

- Some candidates used the key term correctly.

Limited responses

- Many candidates could not identify the type of reaction with the most common suggestions being dehydration, dehalogenation, propagation, condensation, combustion, decomposition, cracking and hydrolysis.

(f) Comprehensive responses

- Most candidates could draw the repeat unit with end bonds shown.

Limited responses

- Some candidates added two chlorine atoms to the structure, had the double bond still present in the structure, or omitted the end bonds.

(g)(i) Comprehensive responses

- Some candidates identified the species for each peak and identified the chlorine isotope responsible for the peak at 64.

Limited responses

- Many species lacked positive charges.
- Many candidates did not identify the chlorine isotope responsible for the peak at 64.
- Some candidates did not engage with the data in the question and stated elements from the periodic table, e.g. carbon, hydrogen, aluminium or gadolinium.

(ii) Comprehensive responses

- A few candidates linked the idea of the two isotopes of chlorine and their percentage abundances using the peaks given in the mass spectra.

Limited responses

- Most candidates discussed the relative abundance of the two peaks with no reference to what they might be formed from.
- Many candidates could not correctly read off the relative abundances from the scale.
- Some candidates did not explicitly link the natural abundance of the isotopes to what was observed in the mass spectra.

CHEMISTRY

Paper 9701/22 AS Level Structured Questions
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Key messages

What candidates did well

- Candidates laid out their answers clearly, in all types of responses.
- Many candidates knew syllabus definitions and reaction conditions.
- Most diagrams and structures were accurate and clearly given.

What candidates needed to improve

- Candidates must ensure that the correct terminology is used. Common incorrect terminology included:
 - successive collisions instead of successful collisions
 - homologous when homolytic was meant
 - dehydrogenating instead of dehydrating.
- Some candidates referred to an increase in the number of outer shells when they meant an increase in the number of shells.
- Some candidates referred to an increase in nuclear charge when they meant nuclear attraction.
- Precise chemical vocabulary, especially for rate, redox, bonding and stereoisomerism, is needed.
- Some responses were not complete. For example, some responses referred to bromide ions as good reducing agents but did not include the species that was being reduced. Similarly, some candidates defined an acid as a proton donor but did not identify the acid that the question was describing.
- Common errors included not drawing fully displayed formulae when drawing organic structures. This could make it more difficult to ensure there were four bonds to each carbon atom.
- Some candidates need to improve writing formulae and balancing equations.

Comments on specific questions

Question 1

(a) (i) Comprehensive responses

- Candidates stated the number 4. Some gave the full, correct electronic configuration; this was unnecessary.

Limited responses

- Candidates did not apply the question to oxygen atoms and gave the maximum possible number of electrons occupying a 2p sub-shell.

(ii) Comprehensive responses

- Candidates carefully drew the correct shape of a p-orbital and named the precise orbital containing the highest energy electron as 2p.

Limited responses

- Many candidates omitted the reference to the second quantum level and stated 'p' alone. Other candidates drew and named spherical orbitals.

(b) Comprehensive responses

- Candidates deduced that a diagram for ionic bonding was required and were able to draw a completely correct dot-and-cross diagram of two lithium ions with a single positive charge and one oxygen ion with a 2– charge. Sometimes candidates did not include the inner-shell electrons which were required by the question.

Limited responses

- The data given in the question enabled candidates to realise that lithium oxide must be ionic. Some candidates attempted to construct a covalent molecule.
- Candidates who did realise it was ionic sometimes gave incorrect numbers of electrons, incorrect charges, or the incorrect ratio of ions, or a combination of these errors.

(c) (i) Comprehensive responses

- Candidates were able to state sodium oxide.

Limited responses

- Some candidates gave the formula, not noting that the question demanded the name.

(ii) Comprehensive responses

- Candidates wrote a correctly balanced equation for the formation of the hydroxide.

Limited responses

- Some candidates tried to construct equations with hydrogen gas as a product. This suggested that candidates confused the reactions of lithium and lithium oxide with cold water.

(iii) Comprehensive responses

- Candidates used the information given in the question and identified phosphorus(V) chloride and aluminium chloride only. Candidates identifying phosphorus chloride by name were required to give the oxidation state to distinguish it from phosphorus(III) chloride.

Limited responses

- Some candidates listed a wide range of compounds, including many Period 3 chlorides as well as compounds involving other elements. Silicon tetrachloride was a common proposal.

(d) Comprehensive responses

- Candidates needed only to identify the gas.

Limited responses

- Limited responses considered only part of the question.
- Common incorrect answers involved giving a brown gas such as bromine, which could not be formed from lithium nitrate, or giving a gas that was linked to lithium nitrate that is not brown, such as nitrogen.

(e) (i) Comprehensive responses

- Candidates used detailed syllabus knowledge of the Haber process and were able to state the exact pressure required with units and to identify a correct catalyst.

Limited responses

- Some candidates proposed pressures which were less than that stated in the syllabus or gave incorrect units such as 'atp'.
- Other candidates re-stated a temperature or gave a wrong catalyst such as vanadium oxide, suggesting confusion with other industrial processes.

(ii) Comprehensive responses

- Candidates engaged with the question details and used collision theory to explain why the initial rate was increased. They paid attention to giving full explanations, referring to collision frequency and activation energy.

Limited responses

- Some candidates misunderstood the question and responded in terms of equilibria. This would only be appropriate if the question had dealt with yield rather than rate.
- Some candidates who did refer to collision theory discussed activation energy of collisions, rather than particles, and commented on the number, rather than frequency, of collisions.

Question 2

(a) (i) Comprehensive responses

- Candidates identified the types of particles correctly as electrons and protons.

Limited responses

- Limited responses had the particles the wrong way around, perhaps misidentifying the charges on the particles, or not engaging with the detail in the diagram.

(ii) Comprehensive responses

- Most candidates correctly associated the degree of deflection with the mass of the particle.

Limited responses

- Candidates thought the deflection was charge related, either the charge of the particles themselves or that of the plates.

(b) (i) Comprehensive responses

- In comprehensive responses, candidates identified a correct pair of atoms to support the hypothesis given.

Limited responses

- Limited responses did not engage with the question and gave the symbol or letter of one element. A pair was required to prove the hypothesis.

(ii) Comprehensive responses

- Candidates identified a correct pair of atoms to show the hypothesis given was false.

Limited responses

- Some candidates did not engage with the question and gave the symbol or letter of one element. A pair was required to disprove the hypothesis.

(iii) Comprehensive responses

- These responses concisely linked the idea of the number of electron shells with the attraction between the nucleus and the valence electrons. Candidates writing such responses often included a comment on shielding.

Limited responses

- Many candidates did not make the required link to the attraction between the nucleus and the valence electrons. Others referred to an increase in nuclear charge in atom **A** instead of an increase in nuclear attraction.

Question 3

(a) (i) Comprehensive responses

- Candidates provided an equation showing the production of either Na_2SO_4 or NaHSO_4 .

Limited responses

- Candidates wrote equations including the production of hydrogen gas or NaSO_4 .

(ii) Comprehensive responses

- Some candidates correctly identified the acid and base, noting that it is the chloride ion within sodium chloride that is the base, rather than the entire compound.
- Many candidates understood the concept of Brønsted-Lowry acids and bases.

Limited responses

- Some candidates did not relate proton donor/acceptor to the relevant species in the reaction, or they neglected to mention which was the acid and which was the base.
- A common error was using NaCl instead of Cl^- as a base.

(b) Comprehensive responses

- Some candidates identified HBr, Br_2 and SO_2 by formula.

Limited responses

- In limited responses, candidates identified substances by name or gave incorrect formulae.
- Some candidates appeared to think only about the description in the question stem, rather than the wider context, and identified 'steamy fumes' as HCl or as steam, and the brown gas as NO_2 .

(c) Comprehensive responses

- Comprehensive responses described bromide ions as being oxidised to bromine by sulfuric acid.

Limited responses

- Some candidates correctly attributed the brown colour to bromine, without explaining why bromine should be produced in this reaction.

(d) Comprehensive responses

- Some candidates understood the nature of the redox chemistry involved in this reaction and were able to give a meaningful comment in terms of oxidising and reducing abilities.

Limited responses

- Many candidates could not explain why sulfur dioxide was formed in reaction 2 and not in reaction 1. Application of redox ideas in this context was not fully understood. Candidates misidentified reducing agents as bromine or chlorine.

Question 4

(a) (i) Comprehensive responses

- Some candidates were able to apply syllabus knowledge to identify a suitable reagent for this reaction.

Limited responses

- Some candidates did not have the syllabus knowledge required and a wide range of compounds were presented.

(ii) Comprehensive responses

- Some candidates identified the role as that of a dehydrating agent or as a catalyst.

Limited responses

- Oxidising or reducing agents were common incorrect responses.

(iii) Comprehensive responses

- In comprehensive responses, candidates drew an unambiguous structure representing methylpropene.
- Most candidates followed the example set by **Figure 4.1** and used skeletal formulae, although this was not a requirement.

Limited responses

- Candidates attempted to draw the skeletal formula with a pentavalent carbon atom.
- Those attempting a condensed structural formula also gave the wrong number of hydrogens.

(b)(i) Comprehensive responses

- Candidates stated the correct colour change as orange to green.

Limited responses

- Purple to colourless was commonly seen.

(ii) Comprehensive responses

- Most candidates performed this straightforward calculation with ease.

Limited responses

- Very few incorrect answers were seen.

(iii) Comprehensive responses

- Most candidates performed well on this calculation.

Limited responses

- Some candidates' calculations contained rounding errors.

(c)(i) Comprehensive responses

- Candidates used the data in the question to deduce the mole ratio between **W** and dichromate ions, before going on to balance the rest of the equation.

Limited responses

- Some candidates appeared to ignore the data relating to **W** and dichromate and attempted to balance the entire equation based purely on the number of atoms.

(ii) Comprehensive responses

- Some candidates produced a clearly displayed, fully correct structure.
- Candidates who were fully successful had often made margin notes to help them pull together all the strands of information provided in the question before going on to draw their structure.

Limited responses

- Many candidates did not take account of the need for a secondary and a tertiary hydroxyl group.
- A notable number drew the oxidation products of **W**, suggesting they had misinterpreted the requirements of the question.

Question 5

(a) Comprehensive responses

- Some candidates gave the correct answers of 1-chlorohexane and 2-chlorohexane.

Limited responses

- In limited responses, systematic names were not used.
- Some candidates had the wrong carbon chain length; heptane and pentane were the most frequently seen errors.

(b)(i) Comprehensive responses

- Comprehensive responses gave a syllabus definition of a free radical as a species with one or more unpaired electrons.

Limited responses

- Some candidates implied that a free radical is an unpaired electron, rather than a species that has an unpaired electron.
- Some confused responses described a free radical as 'a species with a pair of unpaired electrons' or referred to 'lone' or 'free' electrons.

(ii) Comprehensive responses

- In comprehensive responses, candidates stated that the type of bond breaking was homolytic.

Limited responses

- Some candidates stated only the type of bond (covalent) and did not refer to the nature of its breaking.

(iii) Comprehensive responses

- In comprehensive responses, candidates showed an understanding of the radicals involved in the chain reaction and of these propagation steps. Such responses used the structure of the given product to identify which carbon atom lost the H atom.
- The very best responses showed deep understanding by positioning their radical dot on the correct carbon atom.

Limited responses

- Although some candidates showed that they understood the role of chlorine radicals and chlorine molecules in propagation steps, they were unable to deduce the precise structure of the radical needed to make the product given on the paper.

(iv) Comprehensive responses

- Candidates noted that for the isomeric product, an alternative alkyl radical was required and were able to draw the primary radical.

Limited responses

- Some candidates used the same radicals they had drawn in **Question 5(b)(iii)**, even though this part of the question involved an isomeric product.

(c) Comprehensive responses

- Comprehensive responses made the link between the stability of radicals and their prior study of carbocation stability. They thus identified the number of alkyl groups as the key factor, often supporting it with a relevant comment on the positive inductive effect, although this was not essential to answering the question.

Limited responses

- Many candidates cited the number of hydrogen atoms rather than the number of alkyl groups as the factor.
- Others discussed carbocation stability directly, without reference to the radicals.

Question 6

(a) (i) Comprehensive responses

- These responses came from candidates who appreciated that the C=C is responsible for stereoisomerism in **P** and therefore drew the appropriate *cis* isomer.

Limited responses

- Some candidates attempted to draw a *cis* isomer based on the relative orientation of the carbonyl groups, often without changing the stereochemistry around the C=C.

(ii) Comprehensive responses

- Some candidates used syllabus knowledge to explain that stereoisomers arise when there is limited rotation around the C=C and that the molecule has two different groups on each carbon of that C=C.
- Some candidates noted that there were three double bonds in **P**, only one of which was a C=C, and they were careful to be very precise in their language.

Limited responses

- Limited responses referred to 'double bonds' which could have been the C=O bonds in **P** or the C=C.
- Other responses were too vague in their description, referring to different groups on 'each side' of the double bond.

(b)(i) Comprehensive responses

- Some candidates used syllabus knowledge to give steam as a reagent and phosphoric(V) acid as a catalyst.

Limited responses

- Many candidates omitted the state symbol for H₂O.
- Cold dilute KMnO₄ was a common error. These candidates confused the conditions for the oxidation of alkenes to form diols with those for the hydration of alkenes to form alcohols.

(ii) Comprehensive responses

- Some candidates interpreted the skeletal formula given in the question and correctly identified four distinct groups attached to the chiral centre. They were then able to draw the reflection of the molecule to produce the enantiomer.

Limited responses

- Many candidates did not note the context of the question in terms of molecule **Q** and drew a reflection of the empty bond framework provided on the paper without identifying and drawing the groups attached to the chiral centre in **Q**.

(c)(i) Comprehensive responses

- Comprehensive responses made a clear link between the molecular ion peak and the relative molecular mass of **P**.

Limited responses

- Some candidates attempted to answer in terms of fragmentation patterns, or identified the molecular ion peak without making a sufficiently clear link between this peak and the *M_r* of **P**.

(ii) Comprehensive responses

- Candidates considered the structure of **P** and identified the correct structure for these fragments, in addition to knowing that a + charge was required for a fragment produced by mass spectrometry.

Limited responses

- Candidates omitted the + charge or produced fragments which added up to the correct mass without linking them to the given structure **P**.
- The requirement for one peak was often overlooked, and some were unwilling to commit to 116, citing its position as 'near to 115' or similar.

(iii) Comprehensive responses

- Candidates identified a suitable reagent and then made clear links between their observations and molecules **R** and **S**.

Limited responses

- General observations were made with reagents, suitable or otherwise, rather than applying their knowledge to the exact context of the question.
- A notable minority thought that 2,4-DNP would produce a precipitate with a carboxylic acid.
- Others did not note to which of the compounds the positive test applied.

CHEMISTRY

Paper 9701/23
AS Level Structured Questions

Key messages

What candidates did well

- Many candidates demonstrated good knowledge of the:
 - formula and type of bonding in the Period 3 chlorides
 - relative reactivity of the Group 17 elements as oxidising agents
 - name of the mechanism for the reaction of propane with chlorine gas.
- The majority of candidates applied relevant knowledge and understanding to:
 - deduce the number of primary, secondary and tertiary hydroxy groups present in the structure of an unfamiliar molecule
 - deduce that reaction 1 in **Question 3(a)** was exothermic and represent an exothermic reaction profile in a reaction pathway diagram.
- Most candidates used the appropriate equation, $PV = nRT$, to calculate the molecular mass of gas **X** in **Question 2(c)**.

What candidates needed to improve

- Many candidates ignored directive words and therefore did not address the question asked, such as:
 - 'identify which isomer' in **Question 5(d)(i)** and incorrectly identified more than one isomer
 - 'use **Table 2.1**' in **Question 2(b)** and identified a gas that was not present in the table.
- Most candidates did not consider the overall charge of species on both sides of an equation to balance redox equations.
- Most candidates did not apply knowledge of propagation and termination steps to propose an appropriate reaction sequence in **Question 5(b)(iii)**.

Comments on specific questions

Question 1

(a) (i) Comprehensive responses

- Knowledge of the formula of each of the chlorides and the type of bonding was well known.

Limited responses

- Incorrect identification of the type of reaction with sodium chloride was often given as 'hydrolysis' or 'acid-base'.
- Identification of the type of reaction with silicon(IV) chloride was sometimes too vague, such as 'vigorous', or incorrect, such as 'redox'.

(ii) Comprehensive responses

- Many candidates gave equations that identified all species and were balanced correctly.

Limited responses

- Some equations were not balanced.
- Some equations identified POCl_3 as the product of the reaction on addition of an excess of cold water.

(b)(i) Comprehensive responses

- Correct equations with both HCl and HOCl were seen frequently.

Limited responses

- Some candidates produced equations that described the production of O_2 with HCl .

(ii) Comprehensive responses

- Very few answers explained the role of chlorine in water purification in terms of ' HOCl or OCl^- killing bacteria'.

Limited responses

- Many answers stated the role of chlorine in water purification only in terms of 'kills bacteria', with no identification or incorrect identification of the active species involved.

(c)(i) Comprehensive responses

- The trend in relative strength as oxidising agents down Group 17 was well known by the majority of candidates.

Limited responses

- Occasionally, the trend stated was incorrect.

(ii) Comprehensive responses

- A small proportion of answers demonstrated good knowledge of the displacement reactions of the halogens.

Limited responses

- Some descriptions of the appearance of the sample did not distinguish between the presence of Br_2 or I_2 .
- Many answers incorrectly described a reaction occurring when I_2 was added to NaBr .

(d) Comprehensive responses

- Many candidates knew the appropriate observations for the reaction of Ag^+ followed by $\text{NH}_3(\text{aq})$ with aqueous sodium bromide.

Limited responses

- The presence of the wrong colour precipitate on addition of $\text{Ag}^+(\text{aq})$ was given in some answers.
- Incorrect reference to the disappearance of the precipitate on addition of $\text{NH}_3(\text{aq})$ was less common.

Question 2

(a) Comprehensive responses

- Clear responses identified the increase in atomic radius down the group and gave an explanation using appropriate terminology, such as 'more shells' or 'more energy levels'.

Limited responses

- Some explanations were ambiguous or vague, such as: 'more sub-shells' or 'more orbitals' or 'more valence shells'.

(b) Comprehensive responses

- Excellent application of knowledge of ideal gas behaviour was demonstrated in answers that identified neon.

Limited responses

- Some answers identified a gas that was not present in **Table 2.1**, such as helium.
- Some answers only stated the properties of an ideal gas.

(c) Comprehensive responses

- Logical calculations worked through all relevant steps, using $PV = nRT$ to produce the correct answer.

Limited responses

- Occasionally, answers were given with incorrect or no conversion of volume and pressure units.
- Some answers used the incorrect formula:
molecular mass = number of moles $\div$ mass of sample
- Sometimes calculations ignored the details that the volume of gas was measured at 300 K and 101 kPa. These calculations were based on the assumption that 1 mole of gas occupies 24 dm³ at room temperature and pressure.

Question 3

(a) Comprehensive responses

- A significant proportion of answers showed exothermic profiles with clearly labelled arrows that pointed in the appropriate direction for both the enthalpy change and the activation energy.

Limited responses

- Sometimes enthalpy change was indicated by a line or a double-headed arrow rather than an arrow pointing from the energy of the reactants to the energy of the products.

(b) Comprehensive responses

- Thorough and complete definitions described the movement of the position of equilibrium to minimise the effect of the change in conditions.

Limited responses

- Some responses were too vague, such as referring only to 'movement of the system'.

(c) Comprehensive responses

- The majority of candidates stated the correct effect on yield, K_p and rate of reaction when the reaction temperature is increased and in the absence of the catalyst.

Limited responses

- Some answers stated that there was no effect on the value of K_p when the temperature was increased.
- Some answers stated that catalysts affect the value of K_p .

(d)(i) Comprehensive responses

- Some candidates successfully:
 - used the stoichiometry of the reaction to find the amounts at equilibrium.
 - used the mole fraction data present in **Table 3.2** to calculate the mole fraction of SO₃.

Limited responses

- Some answers described the amounts of SO₂ and O₂ used up to reach equilibrium rather than the amount present at equilibrium.
- Some candidates incorrectly described the mole fraction of SO₃ as equal to the amount present at equilibrium.

(ii) Comprehensive responses

- Logical calculations used the correct expression to work out the value of K_p and either included the units stated in the question, kPa, or converted their answers appropriately to Pa.

Limited responses

- Confusion between the terms K_p and K_c was seen in some answers that did not use any pressure data in calculations.
- Some calculations that expressed the unit as Pa did not use appropriate conversion of kPa to Pa.

Question 4

(a) (i) Comprehensive responses

- Appropriate recognition of different types of hydroxy groups present in **V** was common.

Limited responses

- Some answers showed misunderstanding of the differences in structure between primary, secondary and tertiary hydroxy groups.
- On some occasions, the total number of hydroxy groups included in **Table 4.1** was different from the total number of hydroxy groups present in **V**.

(ii) Comprehensive responses

- Those with a sound knowledge of the reactions of alcohols with Na(s) and 2,4-dinitrophenylhydrazine produced appropriate observations.

Limited responses

- Some answers indicated that no reaction occurs when an alcohol is added to Na(s).
- Some answers indicated that alcohol groups react with 2,4-dinitrophenylhydrazine.

(iii) Comprehensive responses

- Comprehensive explanations were given that compared the relative strength of alcohols and aldehydes as oxidising agents.

Limited responses

- Sometimes answers compared the relative ability of alcohols and aldehydes to react with Fehling's reagent without referring to oxidation or oxidising agents.
- Confusion was seen in some answers that stated the aldehyde was the oxidising reagent when it reacts with Fehling's reagent.

(b) (i) Comprehensive responses

- Some candidates knew the appropriate change in colour during an oxidation reaction using acidified potassium dichromate.

Limited responses

- Some answers described the colour change in reverse, from green to orange.
- Some answers described the colour change that occurs with acidified potassium manganate(VII).

(ii) Comprehensive responses

- Thorough knowledge and understanding of the oxidation of primary, secondary and tertiary alcohols was seen.

Limited responses

- Some answers showed the incomplete oxidation of primary alcohol groups to aldehydes.

(c) (i) Comprehensive responses

- Some excellent responses described the term structural isomerism unambiguously in terms of both the number of atoms of each element in a molecule and the arrangement of these atoms.

Limited responses

- Sometimes answers were vague or incomplete and, as a consequence, did not distinguish between structural isomerism and stereoisomerism.

(ii) Comprehensive responses

- Those candidates who identified both **W** and **V** as stereoisomers often gave appropriate explanations, in terms of the presence of at least one chiral centre on each molecule.

Limited responses

- Some answers identified only one of the two stereoisomers.
- Some answers identified structures that did not show stereoisomerism.

(iii) Comprehensive responses

- Recognition of **E** with ester functional groups was seen by those who identified methanoic acid as the reagent.
- Some answers included the presence of the catalyst concentrated sulfuric acid.

Limited responses

- Some candidates misinterpreted the functional group present in **E** and described reagent **R** as an oxidising agent.
- Some candidates identified the catalyst for this reaction and did not include the name of the reagent.

(d)(i) Comprehensive responses

- Those candidates who appreciated that the organic compound produced contains four carboxylic acid groups and has the molecular formula $C_5H_4O_8$ correctly identified structure **Y**.

Limited responses

- Some candidates identified more than one isomer.
- Some candidates did not use the molecular formula of the organic compound produced to work out the answer.

(ii) Comprehensive responses

- Fully balanced equations were seen by those candidates that used the ratio of the amounts of isomer used and organic product made, and considered the overall charges on the species on both sides of the equation.

Limited responses

- Some candidates used the ratio of the amounts of isomer used and organic product made and balanced only in terms of the number of atoms of each element.

Question 5

(a)(i) Comprehensive responses

- Many candidates represented correct structures based on the names of the products.

Limited responses

- Common incorrect answers described structures with:
 - too few or too many carbon atoms
 - too few or too many hydrogen atoms
 - $(CH_2)_6$ for hexane.

(ii) Comprehensive responses

- Many answers recognised the correct term for this mechanism.

Limited responses

- Some answers only identified the type of reaction, e.g. substitution.
- Some answers described one of the stages in the free-radical substitution reaction, e.g. initiation.

(b)(i) Comprehensive responses

- A relatively small proportion of candidates recognised that the chlorine radical produced after homolytic fission is a chlorine atom.

Limited responses

- The most common incorrect answers showed the electronic arrangement of a chloride ion.

(ii) Comprehensive responses

- Some candidates applied knowledge of the process involved during a propagation reaction to correctly deduce that:
 - a chlorine radical reacts with $\text{CH}_3\text{CH}_2\text{CH}_3$ to produce an alkyl radical and HCl
 - the alkyl radical reacts with Cl_2 to produce $\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$ and a chlorine radical.

Limited responses

- Incorrect equations often showed misconceptions about propagation steps when an alkane reacts with chlorine, such as:
 - production of hydrogen radicals in the first equation.
 - the reaction of two chlorine radicals rather than Cl_2 in the second equation.

(iii) Comprehensive responses

- A small proportion of candidates showed understanding of propagation and termination steps to deduce a pair of appropriate equations for this unfamiliar free radical substitution reaction.

Limited responses

- Many candidates were unable to deduce the correct radical used in the termination step to produce $(\text{CH}_3)_2\text{CHCH}(\text{CH}_3)_2$.
- Termination steps using the incorrect radical $\text{CH}_3\text{CH}_2\text{CH}_2$ were quite common.

(c) (i) Comprehensive responses

- Comprehensive answers referred to the presence of the two chlorine isotopes, 35 and 37.

Limited responses

- Some candidates did not recognise that the two peaks arose because there are two different chlorine isotopes.
- Some candidates did not link the difference in abundance of these two isotopes to the relative abundance shown on the mass spectrum at these peaks.
- Some candidates confused the term 'molecular mass' with 'atomic mass'.

(ii) Comprehensive responses

- A relatively small number of candidates used the molecular formula of **A** and the m/e values provided to deduce the formula of cations that could be responsible for the peak.

Limited responses

- Some candidates did not appreciate that the peaks shown in the mass spectrum are produced by positively charged ions.
- Some candidates described structures with an incorrect m/e value
- Some candidates did not identify the chlorine isotopes that were present in each species.

CHEMISTRY

Paper 9701/24 AS Level Structured Questions
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Key messages

What candidates did well

- Many candidates were able to work through calculations to achieve the required answer.
- Candidates laid out their answers to calculations clearly, with each step in their evaluation shown.
- Mechanisms were drawn neatly and accurately and of a sufficient size to be scrutinised.
- Candidates demonstrated a good range of knowledge across the Chemistry syllabus.

What candidates needed to improve

- Some three-dimensional structures were not drawn correctly.
- Candidates need to understand what is required from the different command words in a question, e.g. explain, describe, deduce, suggest.

Comments on specific questions

Question 1

(a) (i) **Comprehensive responses**

- Candidates were familiar with numbers of protons and neutrons in each species.

Limited responses

- Some responses showed an incorrect number of protons and neutrons in Al^{3+} .

(ii) **Comprehensive responses**

- Many candidates gave the full electronic configuration, properly formatted.

Limited responses

- Some candidates suggested one 3s electron and two 3p electrons.

(b) **Comprehensive responses**

- Some candidates gave the correct formula of aluminium nitrate(V).

Limited responses

- In limited responses, (V) was suggested as the number of nitrate ions $Al(NO_3)_5$.

(c) **Comprehensive responses**

- Some candidates described a lone pair (of electrons) on a Cl being donated to Al.
- Those candidates who drew the dative bond on their diagram demonstrated the pair of electrons being donated to Al.

Limited responses

- In limited responses, the Cl had a lone pair (of electrons).
- Occasionally, candidates described the lone pair as being donated by Al, or Cl donating only one electron to Al.

(d)(i) Comprehensive responses

- Some candidates named the shape as tetrahedral and the bond angle as 109.5° .

Limited responses

- Some candidates named the shape as trigonal pyramidal with a bond angle of 109.5° .
- Occasionally, bond angles of 90° or 107° were given.

(ii) Comprehensive responses

- Some candidates drew the correct three-dimensional shape of the AlCl_4^- ion.

Limited responses

- Some candidates drew the AlCl_4^- ion with an incorrect representation of the position of the different bond types relative to each other.

Question 2

(a)(i) Comprehensive responses

- Comprehensive responses described sideways overlap of (adjacent) p orbitals above and below the covalent (sigma) bond.

Limited responses

- Some candidates described overlap of p orbitals with no reference to sideways or the location of the pi bond.

(ii) Comprehensive responses

- Some candidates explained the triple bond in nitrogen as being strong and non-polar.

Limited responses

- Limited responses explained the strength of the triple bond with no reference to it being non-polar.

(b)(i) Comprehensive responses

- Comprehensive responses had a completed reaction pathway diagram for the catalyst with an appropriate line.

Limited responses

- Some candidates identified E_a and ΔH on the diagram without including the line for the catalyst pathway.

(ii) Comprehensive responses

- Some candidates stated temperatures in the range of $400\text{--}500^\circ\text{C}$ and pressure in the range of $150\text{--}250$ atmospheres in the Haber process.

Limited responses

- Limited responses had temperatures and pressures outside the range used in the Haber process.
- Units were often stated as Pa or kPa instead of atmospheres, which would otherwise have been correct.

(c)(i) Comprehensive responses

- Some candidates completed **Table 2.1** with the correct number of moles for each species.

Limited responses

- Some candidates completed **Table 2.1** with the amount at equilibrium and change in amount transposed.

(ii) Comprehensive responses

- Candidates calculated correctly the mole fraction of NH_3 in the equilibrium mixture.

Limited responses

- Candidates attempted to introduce the stoichiometry from the Haber process equation into their mole fraction expression.
- Some candidates recorded the final answer as a percentage.

(iii) Comprehensive responses

- Some candidates referred to the expression:
 $\text{partial pressure} = \text{mole fraction (of a gas)} \times \text{total pressure}$

Limited responses

- Some candidates could not describe what is meant by partial pressure. There was a tendency to describe partial pressure as the pressure of an individual gas.

(iv) Comprehensive responses

- Comprehensive responses had calculated correctly the partial pressure of NH_3 at equilibrium, with working shown.

Limited responses

- Some candidates made incorrect attempts to convert kPa to Pa in their working and then converted back to kPa in their final answer.

(d) Comprehensive responses

- Comprehensive responses fully explained the effects of increasing temperature on the rate of reaction.

Limited responses

- Limited responses explained that this would increase the rate of the reaction.
- Some candidates referred to an increase in the number of collisions and that molecules have more energy. Explanations needed to refer to an increase in the frequency of successful collisions and more molecules have energy higher than the E_a .
- Some candidates discussed the reaction being an equilibrium which led to incorrect outcomes.

(e) Comprehensive responses

- Some candidates sketched the correct Boltzmann distribution curve at a temperature higher than T.

Limited responses

- Some candidates drew their curve at the same peak height as the original curve, or their curve crossed the original at two points.

Question 3

(a) (i) Comprehensive responses

- Many candidates correctly identified a decreasing trend in atomic radius across Period 3.

Limited responses

- Candidates occasionally suggested there was an increasing trend.

(ii) Comprehensive responses

- Many candidates correctly identified Na_2O as the formula of the oxide.

Limited responses

- Some candidates gave an unacceptable oxide formula.

(iii) Comprehensive responses

- Some candidates gave correct equations for the reaction of MgO with H_2O .

Limited responses

- Some candidates suggested that hydrogen was also a product, resulting in an incorrect equation.

(b)(i) Comprehensive responses

- Many candidates completed **Table 3.1** using the correct abbreviations given in the question.

Limited responses

- Some candidates identified the correct bonding in the two chlorides.
- Occasionally, NaCl was identified as simple and SiCl_4 as giant.

(ii) Comprehensive responses

- Some candidates stated the correct formula as H_3PO_4 and pH in the range of 0–4.

Limited responses

- Some candidates suggested that the phosphorus-containing product was POCl_3 or they wrote an equation with two phosphorus-containing products.

(c)(i) Comprehensive responses

- Many candidates correctly stated that a brown gas would be observed when solid strontium nitrate decomposes on heating.

Limited responses

- Some candidates suggested white fumes, bubbling, a white solid is formed, or that the solid disappears.

(ii) Comprehensive responses

- Some candidates stated that the solubility of Group 2 hydroxides increase down the group.

Limited responses

- In limited responses, the trend down the group was given as decreasing.

Question 4

(a) Comprehensive responses

- Some candidates classified alcohol **S** as a tertiary alcohol.

Limited responses

- Some candidates named alcohol **S** or gave the molecular formula instead of classifying it as tertiary.

(b) Comprehensive responses

- Some candidates completed **Table 4.1** with the correct observations of each test on **T**.

Limited responses

- Many candidates identified Na fizzing with **T**.
- There were occasional references to an incorrect initial colour of acidified $\text{K}_2\text{Cr}_2\text{O}_7$ or to purple with alkaline $\text{I}_2(\text{aq})$.

(c) Comprehensive responses

- Some candidates identified the two absorbances from the infrared spectrum that confirm **W** is a primary alcohol.
- Comprehensive responses also stated the correct bonds and correct functional groups for each absorbance.

Limited responses

- Some candidates incorrectly stated the infrared absorbances relative to the C=O or O–H bond.
- Occasionally, reference to the functional group as carboxyl/carboxylic acid was omitted.
- Some candidates identified C–H and C–O from their infrared spectrum, and suggested that the absorbance at 3000 cm^{-1} was due to C–H.
- The C=O bond was sometimes identified as an ester with an absorbance in the range $1710\text{--}1750\text{ cm}^{-1}$.

(d)(i) Comprehensive responses

- Some candidates suggested the correct reagents and conditions for step 1 and step 2 in **Figure 4.3**.

Limited responses

- Some candidates suggested HCl or only UV light in step 1.
- Occasionally, candidates included HCN in step 2.

(ii) Comprehensive responses

- Some candidates drew the displayed formula of the organic product made in the reaction between pentanenitrile and dilute acid.

Limited responses

- Some candidates drew the correct alcohol product with the –OH not displayed.
- Occasionally, candidates suggested an incorrect product from the reaction.

Question 5

(a) Comprehensive responses

- Comprehensive responses stated the correct conditions for the cracking of alkanes as Al_2O_3 and heat/high temperature.
- High pressure was also often suggested as an additional condition.

Limited responses

- Some candidates stated a high temperature was required without reference to Al_2O_3 as the catalyst.

(b)(i) Comprehensive responses

- Some candidates drew the correct repeat unit of the polymer with all bonds correctly displayed.

Limited responses

- Candidates occasionally omitted the continuation bonds, or their structure contained the original C=C.
- Occasional structures with three carbon atoms in a straight chain with continuation bonds were also given.

(ii) Comprehensive responses

- Some candidates correctly identified non-biodegradability as a disadvantage.

Limited responses

- Some candidates suggested environmental problems, e.g. smog, acid rain, harm to environment, global warming.

(iii) Comprehensive responses

- Candidates stated the correct observation as brown/orange turning to colourless when aqueous bromine is added to propene.

Limited responses

- Candidates confused the colour change as being colourless to brown/orange.

(c) Comprehensive responses

- Candidates stated the type of structural isomerism shown by but-1-ene and but-2-ene as positional.

Limited responses

- Candidates occasionally suggested chain isomerism.

(d)(i) Comprehensive responses

- Comprehensive responses stated that HBr was acting as an electron pair acceptor when but-2-ene reacts with HBr(g).

Limited responses

- Some candidates identified HBr as an electron acceptor without referring to an electron pair acceptor.
- Occasionally, HBr was identified as an electron donor.

(ii) Comprehensive responses

- Many candidates were familiar with the mechanism of electrophilic addition of HBr to an alkene and included all the relevant detail.

Limited responses

- In limited responses, mechanisms were missing some of the relevant detail. This included omission of:
 - the initial arrow required to be from the C=C bond to the H of H-Br
 - the correct dipole on $\text{H}^{\delta+}-\text{Br}^{\delta-}$ with a curly arrow from the H-Br bond to Br
 - the correct intermediate with a + charge on C
 - the curly arrow from the lone pair on $:\text{Br}^-$ to C^+ on the intermediate.

(e) Comprehensive responses

- Some candidates gave the correct systematic name for product **P**.

Limited responses

- A common error was 1, 2-bromobutane.

(f) Comprehensive responses

- Comprehensive responses explained fully why **R** is the major product, due to being formed from a more stable carbocation with a greater positive inductive effect.

Limited responses

- Limited responses did not refer to **R** being produced from a more stable tertiary carbocation and instead described **R** as being more stable.
- There were some references to **Q** being formed from a secondary carbocation.
- Some candidates related stability of product **R** to inductive effect and number of alkyl groups without comparing the inductive effect for **Q** with that of **R**.

CHEMISTRY

Paper 9701/31 Advanced Practical Skills
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Key messages

What candidates did well

- In comprehensive responses candidates were able to:
 - manipulate apparatus and take accurate measurements and make detailed observations
 - present their results in a clear way
 - analyse their results to draw conclusions and evaluate their procedures or their results.
- Some candidates were able to use the Qualitative analysis notes to help distinguish changes in appearance when testing an unknown ionic compound.
- Some candidates used the prompts given in the question paper to devise their own tests on a different unknown element or compound.
- Many candidates drew a suitable table for their results prior to starting a practical procedure.
- Many candidates used the titration apparatus successfully.

What candidates needed to improve

- Some candidates did not read the rubric given at the start of the Qualitative analysis notes and the quantitative analysis sections of the question paper.
- Some candidates did not read the introduction to the question and then act on information given.
- Some candidates did not follow the methods given carefully and fully.
- Some candidates did not understand the limitations of the apparatus used in calculating maximum percentage errors in readings.
- In limited responses, candidates did not have a clear understanding of the procedures carried out both in terms of chemical reactions and in any inherent limitations.
- A few candidates did not write answers in black or dark blue ink. The use of a pencil is only appropriate when plotting a graph or when drawing apparatus.

Comments on specific questions

Question 1

(a) (i) Comprehensive responses

- Comprehensive responses showed a distinction between colours of solutions and precipitates, making use of the Qualitative analysis notes, e.g. potassium manganate(VII) was decolourised when added dropwise and the precipitate turned dark brown rather than simply brown.
- Some candidates considered the possible outcomes before starting the test, e.g. being ready to test for oxygen when hydrogen peroxide was added, or carbon dioxide when nitric acid was added to the resulting mixture formed after adding aqueous sodium carbonate.

Limited responses

- Limited responses described the precipitates formed on adding the alkalis as yellow or cream.
- Some candidates described a precipitate as a 'cloudy solution', which cannot exist.
- A common error was describing a solution as 'clear', which is true of all solutions, instead of 'colourless'.
- Some candidates assumed the outcome of adding aqueous ammonia to the precipitate formed on adding aqueous silver nitrate rather than adding the alkali to excess.

(ii) Comprehensive responses

- Some candidates were able to give correct and clearly written formulae.

Limited responses

- In limited responses, names were written in place of formulae.
- Some candidates selected incorrect ions as a result of imprecise observations.

(iii) Comprehensive responses

- Some candidates gave one of the two relevant equations.

Limited responses

- In limited responses, full equations were given rather than ionic, or the equation for Test 3 with aqueous silver nitrate was given instead of the one for Test 4.

(iv) Comprehensive responses

- A few candidates were able to analyse and describe the reason for the silver chloride precipitate appearing to remain and to darken.

Limited responses

- Limited responses did not give sufficient detail, e.g. ammonia is used to test for cations.

(b)(i) Comprehensive responses

- The syllabus specifies drawing a single table for results and comprehensive responses included a table with suitable headings.
- Some candidates added the alkalis dropwise and then to excess, each giving rise to two observations.
- Some candidates selected either aqueous barium chloride or aqueous barium nitrate and either the resulting precipitate was tested with a suitable acid or **FA 2** was tested with aqueous potassium manganate(VII).

Limited responses

- Some candidates did not follow the format given in **Question 1(a)(i)**.
- Some candidates added insufficient alkali or, possibly, the test-tube was not shaken to ensure mixing.
- Some candidates tested with aqueous silver nitrate, which was inappropriate given the anion consisted of elements from Group 16 only.
- Some candidates tested the barium sulfate precipitate with sulfuric acid, which was inappropriate, and some reported the precipitate being soluble in one of the suitable (hydrochloric or nitric) acids.

(ii) Comprehensive responses

- Many candidates gave the correct formula.

Limited responses

- Some candidates gave incorrect formulae for the correct compound, e.g. $AlSO_4$.
- Some candidates did not carry out sufficient tests to form a conclusion.

Question 2

(a) Comprehensive responses

- Comprehensive responses included a single table including all seven headings with correct descriptions and correct units.
- Most candidates recorded masses to two decimal places.
- Those candidates who followed the method using Bunsen or gas burners were generally successful in obtaining a second balance reading after heating close to their previous balance reading.
- Many candidates' mass ratio was accurate when compared to the identity of **FA 3** given in the supervisor's report.

Limited responses

- Some candidates described the heated contents of the crucible as '**FA 3** after heating', which is incorrect as **FA 3** was the hydrated salt.
- Some omitted one of the calculated masses or confused the mass lost with the mass of residue.
- A few weighed out a mass of **FA 3** that was either smaller or larger than the range given in the method.
- Some appeared to have heated **FA 3** too strongly too soon, which would cause frothing and the loss of some of the solid.

(b)(i) Comprehensive responses

- The correct calculation was carried out by many candidates and the answer given to two to four significant figures, which is the expected range in this type of experiment.

Limited responses

- A few recorded their answer to one significant figure or more than 4 significant figures.
- A few rounded their answers incorrectly: $\#.\#5$ is always rounded up.

(ii) Comprehensive responses

- Most calculated the relative formula mass, M_r , of $\text{Al}_2(\text{SO}_4)_3$ correctly, which showed the use of 32.1 as the relative atomic mass, A_r , of sulfur.

Limited responses

- A few used 32 as the A_r of sulfur.
- Some of those using barium nitrate for the calculation gave the formula as BaNO_3 .

(iii) Comprehensive responses

- Most candidates used their mass of residue and the answer to **Question 2(b)(ii)** correctly and gave the answer to the expected number of significant figures.

Limited responses

- A few candidates used their mass of hydrated salt.

(iv) Comprehensive responses

- Many candidates worked out the correct mole ratio and rounded their answer to the nearest integer value.

Limited responses

- A few candidates did not write the complete formula for their hydrated salt.

(c) (i) Comprehensive responses

- Some candidates stated the appropriate uncertainty of a reading for the balance they used and calculated the maximum percentage error correctly.

Limited responses

- Many candidates who used a two-decimal place balance stated incorrectly that the uncertainty was 0.01 g.
- Some candidates did not consider that the calculated mass of **FA 3** required two balance readings, so the uncertainty is doubled.

(ii) Comprehensive responses

- Many candidates realised the loss of water was the problem.
- A few candidates explained why the results would be less accurate if the mass of **FA 3** used was doubled.

Limited responses

- Some candidates did not identify how the method would have to change to drive out all the water.

Question 3

(a) Comprehensive responses

- Many candidates provided the initial and final readings for a rough titre, either in the space provided or clearly labelled in a main table.
- Most candidates drew a single table for their accurate titrations and gave appropriate headings and correctly displayed units.
- Most candidates' burette readings were provided to an accuracy of 0.05 cm^3 and concordant results, where the final titre was within 0.10 cm^3 of another titre, were recorded by many.
- Many candidates were able to obtain results that demonstrated a high level of accuracy when compared to supervisor results.

Limited responses

- Some candidates omitted their burette readings for the rough titre. These may be given to one decimal place or to integer values.
- Some candidates used a label of 'burette readings' for a column of readings and titre.
- Some candidates gave a heading 'volume of **FA 7**' in place of 'titre' without stating that this was the volume of **FA 7** used or added.
- Some candidates continued carrying out titrations even when concordance had been achieved and some of the final titres were not within 0.10 cm^3 of any of the previous values.
- A few candidates omitted a table of burette readings and wrote apparent titre values in the examiner marking boxes.

(b) Comprehensive responses

- Most candidates selected appropriate titre values from their tables and gave the answer correct to two decimal places.

Limited responses

- Some candidates used a spread of titre values greater than 0.20 cm^3 .
- A few candidates gave their answers to an inappropriate number of decimal places.

(c) (i) Comprehensive responses

- Many of those completing the calculations gave their answers to the expected three or four significant figures in accordance with the uncertainties of the apparatus used and the accuracy with which the solutions provided had been prepared.

Limited responses

- Some candidates omitted parts of the calculations.
- Some candidates gave answers to two significant figures.

(ii) Comprehensive responses

- Many candidates used 56.1 as the M_r of KOH.
- Fewer candidates used the pipetted volume of **FA 5** (shown in **Question 3(b)**) in their calculation.

Limited responses

- Some candidates used their titre volume instead of the pipetted volume in the calculation.

(iii) Comprehensive responses

- A minority completed the balanced equation with appropriate state symbols successfully.

Limited responses

- Some candidates gave KSO_4 as the salt product of the neutralisation reaction taking place in the titration.
- A few equations had incorrect formulae and were unbalanced.
- Many candidates either omitted or gave incorrect state symbols.

(iv) Comprehensive responses

- Many candidates used the stoichiometry of their equation in this part.
- Fewer candidates used their titre value in the calculation.

Limited responses

- Many candidates used a factor of $1000 \div 25$ in their calculation instead of $1000 \div \text{mean titre}$.

(v) Comprehensive responses

- Most candidates correctly used 98.1 as the M_r of H_2SO_4 .
- Some candidates used the 'scale-up' factor to convert diluted **FA 7** to **FA 4**.

Limited responses

- Many calculations omitted the 'scale-up' factor.

(d) Comprehensive responses

- A few candidates gave full answers linking the lower M_r of NaOH (compared to KOH) with the increase in concentration (of OH^- ions) followed by linking this to an increase in titre, hence a decrease in the calculated concentration of H_2SO_4 .

Limited responses

- Many candidates gave answers that were ambiguous by referring to 'it' rather than to a specific chemical.
- Many candidates did not link the lower M_r of NaOH with the increase in concentration of OH^- ions.
- Some candidates did not mention the difference in M_r of the two alkalis.
- Some of those concluding the titre would increase linked this with an increase in concentration of H_2SO_4 .

CHEMISTRY

Paper 9701/32 Advanced Practical Skills
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Key messages

What candidates did well

- Many candidates recalled equations correctly, including $q = mc\Delta T$.
- The use of appropriate significant figures in working and answers was generally good.
- Many candidates correctly labelled axes on graphs and chose suitable scales and went on to plot points correctly.
- Some candidates included units when recording data.
- Comprehensive responses included the correct selection and use of analysis tests from the provided information.
- Some candidates were able to identify ions from observations.

What candidates needed to improve

- When handling data taken to a given number of significant figures (e.g. temperature ending .0 or .5) candidates need to present their answer to the same level of accuracy as the recorded data.
- Some candidates needed to ensure they set out working in a clear, logical order and clearly label the meaning of each value they calculate as part of that working.
- Some candidates needed to include all data in one table, with headings for all items requested in the question stem.
- Limited responses lacked proper terms and needed more precise observations (e.g. colourless, not clear; precipitate, not cloudy; fizzing, not gas produced, etc.).
- Candidates needed to check that their answer was chemically correct and logical.
- Some candidates needed to carefully read the question to give answers in the required format (i.e. formula of an ion, not name).

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates recorded temperature values to .0 or .5.
- Most candidates obtained accurate results.

Limited responses

- Limited responses had temperatures recorded as integer values, or to .00, or to other decimal place values (e.g. .1).

(b)(i) Comprehensive responses

- Some candidates correctly labelled their graph axes with suitable units.
- Where a suitable scale was selected by the candidate, many were able to plot points correctly.

Limited responses

- Some axis labels had incorrect or mis-matched units, e.g. C° for temperature or use of seconds in place of minutes without conversion of values.
- Some candidates omitted the additional 10 °C on y-axis scale.
- Some y-axis scales did not cover more than 50% of the plot area.
- Some scales were not based on increments of 1, 2 or 5.
- Very few candidates correctly drew lines of best fit. The cooling results should fit a curve pattern, and this was often shown in results; instead a straight line of best fit was drawn.

(ii) Comprehensive responses

- Some candidates correctly used the graph to extend the line of best fit and matched the accuracy of the answer to that of the temperature recording.

Limited responses

- In limited responses, the working was not clearly shown on the graph, or lines did not extend to 2 minutes.
- Some candidates took readings from the table, not from the graph.
- Many candidates read the maximum temperature, omitting to subtract the initial temperature.

(c)(i) Comprehensive responses

- Some candidates gave concise answers that stated the correct colours.
- Some used the term 'colourless' for the filtrate.

Limited responses

- In limited responses, the terms 'clear' or 'transparent' were used in place of colours.
- Incorrect observations suggesting incorrect filtering of the mixture were seen.

(ii) Comprehensive responses

- Comprehensive responses used NaOH and NH₃ as reagents.
- Correct observations for both initial addition and use of excess were seen.
- Some candidates gave the correct identification of the ion from the observations.

Limited responses

- In limited responses, incorrect reagents were selected, or only one reagent was selected.
- Some responses had incorrect observations. A common error was to state that the white precipitate formed was insoluble in excess.
- In some responses, the metal ion selected did not match the observations (e.g. white precipitate seen, with Cr³⁺ given as **M**).

(d)(i) Comprehensive responses

- A few candidates correctly wrote an ionic equation for the reaction.

Limited responses

- Limited responses included sulfate ions in the equation.
- Some candidates did not separate the ions (i.e. CuSO₄ rather than Cu²⁺).

(ii) Comprehensive responses

- Comprehensive responses had working shown clearly, with the use of 25 (mass) and 4.18 (specific heat capacity of water).
- Some candidates restarted and determined a suitable temperature change for their reaction.

Limited responses

- Limited responses used 4.2 in place of 4.18.
- Some candidates used the mass of powder used in place of, or in addition to, 25 g of solution.
- Limited responses converted the units from °C to K by addition of 273, despite this being a temperature change and therefore the same in both units.
- Many candidates gave their answer to an inappropriate number of significant figures, usually giving it to more than four significant figures.

(iii) Comprehensive responses

- Comprehensive responses included a correct calculation of the number of moles using concentration and volume.
- Many candidates correctly identified the negative sign for an exothermic reaction and divided their answer to **Question 1(d)(ii)** by 1000 and their moles value.

Limited responses

- Limited responses used 0.95 (concentration) in place of a calculated value of moles.
- Some candidates omitted to divide by 1000 to convert J mol⁻¹ into kJ mol⁻¹.

Question 2

(a) Comprehensive responses

- Comprehensive responses included tables arranged in a clear and logical manner, suggesting that this was done before readings were taken.
- The majority of balance readings were given to two decimal places.
- Where attempted, subtractions to determine the mass of **FB 3**, the residue and water lost were correct.

Limited responses

- Some results were not arranged in a single, clear table.
- Many candidates referred to '**FB 3**' instead of residue after heating.
- In some responses, the second balance reading showed a significant decrease, indicating that a further reading should be taken.
- Several candidates swapped the mass of residue with the mass of water lost.
- Some candidates had inconsistencies in their headings, such as inclusion of the lid in only some readings.

(b)(i) Comprehensive responses

- Many candidates answered this well with clear working and answers given to an appropriate number of significant figures.

Limited responses

- Some candidates used the mass of **FB 3** in place of the mass of residue.

(ii) Comprehensive responses

- In comprehensive responses, candidates worked from their own data to obtain a result in line with their own observations and results.
- This was well answered with clear working and answers given to an appropriate number of significant figures.
- The value of x was often correctly rounded to give an integer value.

Limited responses

- Some candidates used the difference between first and second heating readings in place of the mass of water lost.
- Several candidates had an answer of '5' for x , without working or with working which did not give this value.

(c) Comprehensive responses

- Many candidates recorded the state (solid) and colour change (white to blue).

Limited responses

- Many candidates did not identify the solution formed or did not clearly distinguish this from the initial colour change of the solid to blue.
- Many candidates did not identify that the crucible heated up.

(d)(i) Comprehensive responses

- Comprehensive responses identified decomposition, or the formation of copper oxide.

Limited responses

- Many candidates incorrectly referred to a reaction with oxygen (combustion, burning, charring etc.).

(ii) Comprehensive responses

- Most candidates did identify the change in the value of x (increase).

Limited responses

- Some candidates referred to increased loss of water from the anhydrous salt, rather than an increase in the overall mass lost.

Question 3

(a) Comprehensive responses

- Many candidates identified the starting colour as green and the change to a black colour.
- Some candidates identified condensation on the walls of the test-tube.

Limited responses

- Limited responses had vague or incorrect references to 'fumes' or 'vapour' in place of condensation.
- Very few candidates correctly described the appearance of the solid before and after heating.

(b) Comprehensive responses

- Many candidates identified fizzing with the acid and the colour of the resulting solution.

Limited responses

- Several candidates suggested that the filtrate was cloudy or contained a precipitate.
- Some candidates described the result with limewater as 'cloudy' or 'milky' rather than a white precipitate.

(c) Comprehensive responses

- Comprehensive responses had clear and concise observations, which were laid out in a logical manner.
- Some candidates gave observations using appropriate terminology (e.g. precipitate, fizzing, insoluble).

Limited responses

- Some observations suggested that candidates did not distinguish the solid precipitate from the solution, giving one overall observation rather than identifying each part of the mixture.
- Some responses had incorrect colours recorded.
- Some candidates did an incorrect gas test on addition of aluminium foil with heating.
- Few candidates suggested suitable tests to confirm the identity of the anion.
- Many candidates added KMnO_4 in Test 4. This would react with the Fe^{2+} ions identified in the earlier tests and is therefore not a suitable test to confirm the identity of the anion.

(d) Comprehensive responses

- Comprehensive responses correctly identified the ions and gave clear and correct formulas.

Limited responses

- Some candidates identified SO_3^{2-} (sulfite ion) in place of SO_4^{2-} (sulfate ion).
- In some responses, the names of ions or metals were given in place of formulas.

CHEMISTRY

Paper 9701/33 Advanced Practical Skills
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Key messages

What candidates did well

- Many candidates successfully set up and used apparatus to collect gas over water.
- Most candidates were able to carry out a titration and obtain concordant results.
- Many candidates obtained gas volumes (**Question 1**) and concordant titres (**Question 2**) that were in close agreement with those of their Supervisor.
- Most candidates presented numerical data clearly in a single table with clear headings and correctly displayed units.
- Most candidates presented balance and burette readings to the correct precision for the measuring instrument used.
- Most candidates displayed their numerical working clearly during calculations.
- Many candidates gave their answers to an appropriate number of significant figures.
- Some candidates were able to use their measured mass of magnesium to calculate an expected volume of gas produced in a chemical reaction.
- Many candidates were able to use titration results to determine information about the relative molecular mass of a reagent.
- Many candidates were able to identify at least one unknown ion by using their results from qualitative chemical tests.

What candidates needed to improve

- When carrying out qualitative tests, candidates should be aware of the range of observations which may be possible, e.g. the appearance of a precipitate and its solubility or insolubility in excess reagent; or the effervescence of a gas, which may then be tested to identify it.
- Candidates should be aware of the appropriate level of precision for volume readings taken using a measuring cylinder.
- Candidates should record qualitative observations to an appropriate level of detail, recording colour in simple language and using terms such as 'pale' or 'dark' to provide fine discrimination.
- Candidates should practise using the Qualitative analysis notes together with their own observations to identify ions following a series of chemical tests using a compound or its solution.
- Candidates should be aware of how to identify the maximum uncertainty associated with a single reading, based on consideration of half the difference between closest calibrations.
- Candidates should practise writing ionic equations.

Comments on specific questions

Question 1

(a) **Comprehensive responses**

- Most candidates appropriately recorded a full set of results, using suitable headings and correctly displayed units.
- Most candidates recorded mass values to the appropriate precision. Some candidates also recorded their measured gas volume to the appropriate precision.
- Most candidates correctly calculated the mass of **FA 1** used. Volumes of gas collected by candidates and their Supervisors were usually in good agreement.

Limited responses

- Many candidates recorded their volume of gas to one or more decimal places, which is not appropriate for the measuring equipment used.

(b)(i) Comprehensive responses

- Most candidates used the correct formula and correctly calculated the moles of magnesium used.

Limited responses

- Some candidates used 24 as the A_r of Mg rather than 24.3.
- A few candidates did not round their answer correctly.

(ii) Comprehensive responses

- A few candidates were able to write the correct ionic equation for the reaction between magnesium and the H^+ ions from the organic acid, with the correct state symbols.

Limited responses

- Most candidates wrote an equation which included the full formula of the organic acid, or the anion for the organic acid rather than H^+ .
- A small number of candidates who wrote an otherwise correct ionic equation had missing or incorrect state symbols.

(iii) Comprehensive responses

- Many candidates correctly used the molar volume of a gas, applying a factor of 24 000 to calculate the theoretical volume of hydrogen in cm^3 .

Limited responses

- Some candidates used 24 as the molar volume, thus obtaining a volume in dm^3 .
- Some candidates gave answers to five significant figures, even though their experimental data did not justify such a high level of precision.

(c) Comprehensive responses

- Many candidates identified gas escaping before the bung was replaced as a source of error.
- Some candidates identified impurities in the magnesium as a source of error.
- A very small number of candidates commented on the laboratory temperature being lower than the standard laboratory conditions.

Limited responses

- Many candidates commented on hydrogen dissolving in water. The solubility of hydrogen is too low for this to have had a significant effect.
- Some candidates referred to leaks from the apparatus without linking this to the delay in replacing the bung.

(d) Comprehensive responses

- Some candidates were aware that the maximum uncertainty associated with a quantitative measurement is half the difference between the closest calibrations on the measuring apparatus, e.g. 0.005 g for a two decimal place balance.
- Many candidates who stated the correct uncertainty went on to correctly calculate the maximum percentage error in the mass of magnesium used.

Limited responses

- Many candidates incorrectly gave the maximum balance uncertainty as being the same as the difference between the closest calibrations, e.g. 0.01 g for a two decimal place balance.
- A few candidates who stated the correct uncertainty did not appreciate that they needed to double this uncertainty to calculate the maximum percentage error, because their determination of the mass of magnesium used involved taking two balance readings.

Question 2

(a) Comprehensive responses

- Most candidates answered this question well. They presented their accurate titration data in a single table with correct headings and units. All burette readings were recorded to the correct precision ($.#0$ or $.#5\text{ cm}^3$) and titrations were repeated until concordant results were achieved.
- Some candidates carried out their titrations accurately, obtaining titres which were very close to the Supervisor's mean titre.

Limited responses

- A few candidates did not record burette readings for their rough titre, labelled their burette readings incorrectly, e.g. 'initial titre' or recorded burette readings to one decimal place only.
- A minority of candidates did not carry out titrations until they had two titres within 0.1 cm^3 .

(b) Comprehensive responses

- Most candidates clearly selected two or more titres within a range of 0.2 cm^3 and correctly averaged them to two decimal places.

Limited responses

- A few candidates did not show, either by ticks next to the titres in their results table or in (b), which titres they chose to average.
- A few candidates either did not correctly round their mean titre or did not display their answer to two decimal places.

(c) (i) Comprehensive responses

- Many candidates answered all parts of (c) and displayed each answer to three or four significant figures.

Limited responses

- Some candidates did not attempt (c)(ii), (iii) and (iv).
- Some candidates displayed one or more answers to fewer than three or more than four significant figures.

(ii) Comprehensive responses

- Most candidates correctly calculated the amount of sodium hydroxide.

Limited responses

- A few candidates did not apply the correct factor of 1000 or used an incorrect formula for the number of moles.

(iii) Comprehensive responses

- Many candidates noted the 1 : 1 ratio between moles of sodium hydroxide and moles of **FA 4** and then used the volume of **FA 4** from their experiment to obtain the concentration of **FA 4**.

Limited responses

- Some candidates attempted to derive the concentration of **FA 4** in mol dm^{-3} directly from the concentration in g dm^{-3} , without realising that this would require a knowledge of the M_r of **FA 4**.
- A few candidates did not apply the correct factor of 1000 to their volume.

(iv) Comprehensive responses

- Some candidates divided the concentration of **FA 4** in g dm^{-3} by their calculated concentration in mol dm^{-3} to obtain the M_r of **FA 4**.

Limited responses

- Some candidates attempted to use the formula of **FA 4** to calculate an M_r using A_r values, without appreciating that this would require knowledge of the identities of both **R'** and **Z** within the formula of **FA 4**.

(d)(i) Comprehensive responses

- Some candidates correctly identified that both silver nitrate and ammonia are required to identify the halogen present in **FA 4**. These candidates went on to describe the colour of the precipitate formed with silver nitrate and its solubility in dilute ammonia, and thus correctly identified **FA 4** as containing bromine.

Limited responses

- Some candidates used silver nitrate to test for the halogen present in **FA 4** and then did not go on to test the solubility of their precipitate using dilute ammonia.
- Some candidates incorrectly identified the colour of the precipitate formed with silver nitrate, and therefore did not correctly identify **Z**.

(ii) Comprehensive responses

- A few candidates recognised that the role of the nitric acid was to remove hydroxide ions and explained that this was necessary to prevent the hydroxide ions forming a precipitate with Ag^+ ions.

Limited responses

- Many candidates stated that the acid was added to neutralise the sodium hydroxide, without explaining that this was necessary because otherwise a precipitate would have been formed.

(e) Comprehensive responses

- Some candidates used their calculated value from **(c)(iv)** and the identity of **Z** from **(d)(i)** to calculate an M_r value for the R' group.
- Some candidates went on to work out the correct number of carbon atoms present in their R' group and gave the correct formula for alkyl group R' .

Limited responses

- Some candidates made an error in calculating an M_r value for R' . Some of these candidates gave a correct formula for R' to match their calculated M_r .
- Some candidates correctly calculated the M_r of R' , then suggested R' might be an element, or gave the general formula for an alkyl group rather than a specific formula.

(f) Comprehensive responses

- A few candidates understood that the calculated M_r values from the two experiments would be similar but not identical. They were then able to link this to the large difference in M_r for R groups containing different numbers of carbon atoms to justify why the same R group was obtained.

Limited responses

- Some candidates understood that M_r values would be similar, then did not go on to explain why this would result in obtaining the same identity for the R' group.
- Some candidates simply stated that the results from the two experiments were so similar that it would make no difference to the overall outcome of the experiment, without appreciating that the difference in titre values would have an impact on the calculated M_r .

Question 3

(a) Comprehensive responses

- Some candidates clearly identified the correct reagent to test for unsaturation, giving the correct formula, KMnO_4 , or the full name, potassium manganate(VII).
- Many of these candidates gave the correct observation for **FA 2** with KMnO_4 and deduced that **FA 2** is saturated.

Limited responses

- Some candidates described the use of bromine water to test for unsaturation even though bromine water was not supplied for this practical examination.
- Some candidates who correctly identified KMnO_4 then described its colour as 'turning' purple. Observations involving KMnO_4 should be described based on the colour change of the KMnO_4 , which 'remains' purple.
- A few candidates used incorrect capitalisation when giving the formula for KMnO_4 , for example giving the formula as KmNO_4 .

(b)(i) Comprehensive responses

- Some candidates made effective use of the Qualitative analysis notes to assist in their descriptions of their observations, particularly for the tests on **FA 7**.
- Many candidates were able to describe solids formed when two solutions were mixed as precipitates and stated each precipitate's colour. Some also identified whether the precipitate went on to dissolve when additional reagent or another solution was added.
- Some candidates gave a clear description of the gas test carried out on **FA 7** during Test 1.

Limited responses

- A few candidates did not use correct technical terms when describing observations, for example describing a precipitate simply as a 'solid'.
- A few candidates recorded 'no observation' in place of 'no change'. Candidates should note the information in the stem of the question, as it gives advice on how to record their observations.
- Some candidates did not give sufficient detail in their responses. Examples included candidates who did not record the solubility in excess reagent after having identified a precipitate, and candidates who did not carry out a gas test after having observed effervescence.

(ii) Comprehensive responses

- Some candidates correctly identified the cations present in **FA 7** and **FA 8**.

Limited responses

- Some candidates successfully identified Cr^{3+} in **FA 7** and then did not appreciate that the data in **Table 3.1** does not allow the identification of the cation in **FA 8**. The correct answer should have been 'unknown'.
- Common incorrect answers were Na^+ and Cu^{2+} .

(iii) Comprehensive responses

- Some candidates successfully identified both anions present in **FA 7** and explicitly linked each anion to the evidence they recorded in **Question 3(b)(i)**.

Limited responses

- Some candidates correctly identified both ions without making a sufficiently clear link to the data in **Table 3.1** to justify their observations.
- Some candidates did not have sufficient evidence recorded in **Table 3.1** to be able to justify their identification of the anions.

(iv) Comprehensive responses

- Some candidates correctly identified the hydroxide ion.

Limited responses

- Many candidates incorrectly identified a halide ion as the anion present in **FA 8**.

CHEMISTRY

Paper 9701/34 Advanced Practical Skills
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Key messages

What candidates did well

- Comprehensive responses showed that candidates were able to:
 - plan experiments and investigations
 - collect, record and present observations, measurements and estimates
 - analyse and interpret experimental data to reach conclusions
 - evaluate methods and quality of experimental data and suggest improvements to experiments.
- Many candidates were able to present and label work clearly.
- In quantitative work, some results were presented to an appropriate level of precision. Some calculations were carried out correctly with clear working shown.
- In qualitative work, some responses clearly recorded at which stage in a test an observation was made using the terms given in the qualitative analysis notes as a guide.
- Some candidates were able to use the results of qualitative tests to identify ions and also appreciate the limitations of the tests carried out.

What candidates needed to improve

- Some candidates did not complete the paper using black or dark blue pen as indicated in the instructions. Pencil should only be used for diagrams and graphs.
- Some candidates did not write numbers and formulae clearly and unambiguously.
- Some candidates did not appear to read and follow the instructions carefully. For example, **Question 2** required only one heating and in **Question 3**, page 7 stated that 'No additional tests should be attempted'.
- When reporting burette readings, some candidates did not record volumes to 0.05 cm³.
- Some candidates were not familiar with the use of starch solution as an indicator added towards the end of a titration.
- Some candidates needed to make more use of the qualitative analysis notes and to use the precise language given there – e.g. white precipitate, not cloudy/milky solution, and where no change is observed, candidates should write 'no change'.

Comments on specific questions

Question 1

(a) Comprehensive responses

- In comprehensive responses, candidates provided initial and final readings for a rough titre either in the space provided on page 2 or clearly labelled in a table on page 3.
- Some candidates provided a single accurate table with correct headings and correctly displayed units.
- Some burette readings were given to an accuracy of 0.05 cm³ and concordant results (the final titre within 0.10 cm³ of another titre) were recorded.
- Many candidates were able to obtain results that demonstrated a high level of accuracy when compared to the Supervisor's results.

Limited responses

- In limited responses, no initial and final burette readings for the rough titre were provided. A small number of candidates recorded their titres in the marking boxes for examiner use only and did not produce a table.
- In a small number of responses, incorrect units, such as mL, were seen and some units were displayed incorrectly.
- Headings such as 'initial' and 'final' were provided by some candidates without '(burette) reading/volume' or 'initial titre' and 'final titre' recorded as headings.
- Some limited responses gave correct headings and units and then transposed the readings, making the headings invalid.
- Limited responses provided a heading 'volume of **FB 1**' in place of 'titre' without stating that this was the volume of **FB 1** used or added.
- Some limited responses stated the amount of **FB 1** used, which refers to moles rather than volume.
- Some limited responses did not give readings to the level of precision required by a comprehensive response, giving readings to 0.1 cm³ or integer values. The initial reading must show the precision of the burette; 0 cm³ was seen in some responses. Initial readings were sometimes given as 50.00 cm³ rather than 0.00 cm³.
- In some responses, results tables showed that two concordant titres were recorded followed by a third titration that was not concordant. The final titre recorded should be within 0.10 cm³ of a previously recorded titre.
- In this titration, candidates were instructed to run **FB 1** into the conical flask until a yellow colour was observed, then to add **FB 5** (starch indicator) to make the solution turn blue-black. The end point is reached when further addition of **FB 1** causes the solution to turn colourless.
- Limited responses did not record the correct initial volume of **FB 1**; instead used the point of addition of **FB 5** as the initial burette reading. This resulted in very small titres with an initial burette reading that was invalid. The volume of **FB 1** that had already reacted with the iodine produced up to the point of addition of **FB 5** was not measured and/or recorded.
- Titre values were more likely to be spread out and not close to the Supervisor's value.

(b) Comprehensive responses

- Comprehensive responses clearly showed two or more titres from the table within 0.20 cm³ and a calculation used to produce a mean value. If a calculation was not shown, the selected values were clearly indicated by use of a tick or other clear symbol in the table in (a). The mean was correctly rounded to two decimal places.

Limited responses

- Limited responses had selected values that were greater than 0.20 cm³ apart. This was often seen by the selection of more than two titres such as 22.20 cm³, 22.40 cm³ and 22.60 cm³, which has a total spread of 0.40 cm³. In this case, two of the closer values should be selected or a further titration carried out to obtain more concordant results.
- Limited responses used titres that had been incorrectly calculated in the results table or included the rough titre.
- Some mean values were provided to one or three decimal places rather than two.

(c) (i) Comprehensive responses

- Comprehensive answers to **Question 1(c)(ii)**, **1(c)(iii)** and **1(c)(iv)** were provided to three to four significant figures.

Limited responses

- Limited responses provided answers to two significant figures, five significant figures, left a question part blank or provided a three- to four-significant figure answer with no relevant working.

(ii) Comprehensive responses

- Comprehensive responses clearly displayed the use of the M_r of KIO_3 either via a number string of the A_r values used ($39.1 + 126.9 + (3 \times 16)$) or by 214.
- Correct use of the mass of KIO_3 stated on page 2 (3.35g) to work out the number of moles of KIO_3 in 1 dm³ of **FB 2** and hence the number of moles of KIO_3 in the 25.0 cm³ of **FB 2** used in the titration was also seen.

Limited responses

- Limited responses calculated the M_r of IO_3^- (174.9) rather than KIO_3 or calculated the mass of **FB 2** in 25.0 cm³ rather than the amount in moles.
- Some candidates carried out the calculation in two steps, rounding their answer to less than three significant figures after the first stage. This resulted in an inaccurate calculation.
- Many candidates did not use an M_r , giving $3.35 \times 25 \times 10^{-3}$ (0.08375) as their answer.

(iii) Comprehensive responses

- Comprehensive responses used the stoichiometry of the two equations provided and multiplied the answer to **(c)(ii)** by 6.

Limited responses

- Limited responses used the stoichiometry of the two equations provided incorrectly and multiplied **(c)(ii)** by factors such as 3, 2, 3/2, 2/3, 0.5 or 1.

(iv) Comprehensive responses

- Some candidates divided the answer to **(c)(iii)** by the titre in **(b)**. This was often accessed via an error carried forward.

Limited responses

- Some candidates divided the answer to **(c)(iii)** by an incorrect value such as 0.025.
- Some responses did not convert the titre to dm³, missing a factor of 1000.

Question 2

(a) (i) Comprehensive responses

- In comprehensive responses, the instructions in the method had clearly been read and followed.
- In these responses, the three masses and three calculated values were clearly provided in the results space, with units in grams correctly displayed for all.
- If masses were included, the inclusion of the crucible lid was consistent.
- After heating, the final heading was given by some candidates as the 'mass of crucible, (lid) and contents or residue'.
- Some candidates gave the three masses to a consistent number of decimal places (two to three).
- The mass of **FB 6**, residue and mass lost were correctly calculated by many candidates.
- Many candidates were able to demonstrate a high level of accuracy compared to the Supervisor results.

Limited responses

- Some responses did not provide three masses and it was not possible to calculate the data required.
- In limited responses, headings were not clear and included **FB 6** after heating when the residue is no longer **FB 6**. Numbers were difficult to read and ambiguous. Some headings included the lid with an initial crucible mass, but after heating the heading did not include the lid.
- Some candidates referred to weight rather than mass.
- Some candidates provided more than three masses; the method states that only one heating and cooling cycle should be completed rather than multiple cycles.
- The mass of residue and the mass loss were sometimes the wrong way round and often one of the values was not calculated.
- Some results were not possible, such as the final mass after heating being lower than that of the initial mass of the empty crucible.

(ii) Comprehensive responses

- The residue was a solid. Comprehensive responses included the need to first dissolve the residue in water (or nitric acid) to produce a solution for testing.
- In comprehensive responses, silver nitrate was selected to test for the halide ion, producing a white precipitate. The precipitate was tested with ammonia and anion **X** identified as chloride.

Limited responses

- Many responses described the addition of a solid residue to silver nitrate, which is not an appropriate test to assess whether a precipitate is formed. A precipitate is formed when two solutions are mixed. It is possible that candidates did dissolve the residue in water but did not include this in their answer. Very few responses included this step.
- When giving the details of a reagent, the correct formula should be used. Some responses gave only Ag^+ rather than AgNO_3 .
- Some limited responses gave the wrong formula for silver nitrate ($\text{Ag}(\text{NO}_3)_2$) or confused the two test reagents as AgNH_3 .
- Some tests were presented for non-halide ions suggesting that some candidates had not read the question carefully.
- Some responses recorded the precipitate as off-white rather than white and concluded that the anion was bromide or presented correct tests and then identified the anion as chlorine (rather than chloride) or Cl_2 .

(b)(i) Comprehensive responses

- The amount of water lost in mol was correctly calculated to an appropriate precision (two to four significant figures) by dividing the mass lost from **(a)(i)** by 18.

Limited responses

- Some responses used 2×18 rather than 18.
- Rounding errors were noted in some responses.
- Some responses were given to only one significant figure, which was not precise.

(ii) Comprehensive responses

- Some candidates presented a correct calculation of the moles of residue by use of the fact that two moles of water are produced for each mole of residue. The number of moles of residue or **FB 6** could be calculated via **(b)(i)** $\div 2$ and hence the M_r calculated by use of the mass of residue recorded in **(a)(i)** or the mass of **FB 6** recorded in **(a)(i)** followed by subtraction of $36 \times (2 \times 18)$.
- Many answers were provided to an appropriate precision (two to four significant figures).
- Many answers were clearly set out and correctly calculated.

Limited responses

- Incorrect use of stoichiometry was seen, with **(b)(i)** used as the moles of residue rather than **(b)(i)** $\div 2$.
- In some responses, the mass of **FB 6** was used rather than the mass of residue without subtraction of 36.
- Some answers were given to five significant figures.
- Some candidates selected a Group 2 metal chloride in **(b)(iii)** and worked backwards rather than using their experimental results as the question required.

(iii) Comprehensive responses

- Most candidates were able to use their answer to **(b)(ii)** and $2 \times$ the A_r of the halide deduced in **(a)(ii)** to calculate the A_r of the metal **M**.
- Comprehensive answers gave this value to an appropriate number of significant figures (two to four) and stated either the name of the metal or the ion with a +2 charge.

Limited responses

- In some responses, the question had not been read carefully as the A_r calculated was assigned to the closest element or metal, rather than the closest Group 2 metal. The cation was given as Ba or Ca rather than Ba^{2+} or Ca^{2+} .

(c) (i) Comprehensive responses

- Using the cation **M** identified in **(b)(iii)** and the anion in **(a)(ii)**, the actual M_r of **MX₂** was correctly calculated in comprehensive responses.
- In comprehensive responses, the difference between this value and **(b)(ii)** was calculated, divided by the actual M_r of **MX₂** and expressed as a percentage.
- Some responses had working that was displayed clearly.

Limited responses

- The question had not been read carefully enough in some cases, as answers expressed the percentage error as the difference in the A_r of **M** rather than the difference in M_r of **MX₂**.
- Some responses used equipment errors from the balance or used the mean of the actual and experimental values as the denominator in the calculation.

(ii) Comprehensive responses

- Some candidates recognised that the method only included one heating cycle and that to reduce the percentage error the sample should be heated again until there was a constant mass. This would ensure that all the water had been removed.

Limited responses

- Some limited responses recognised that further heating or longer heating was required to ensure all the water was lost. They did not suggest that a constant mass was required to confirm this.
- Responses such as repeating the experiment and taking a mean, using different masses of **FB 6** and using a more precise balance formed all or part of limited answers. These suggestions would not guarantee that all the water was lost.

Question 3

(a) (i) Comprehensive responses

- There were some very well organised responses to this question. Candidates clearly stated the colour and state of **FB 7** at the start and end of the experiment.
- In comprehensive responses, the gas was tested with a glowing splint which re-lit and was identified as oxygen.
- Some candidates noted that the solid moved around during heating.

Limited responses

- The initial and final colours of **FB 7** were often missing in limited responses.
- Some responses noted 'popping' rather than the solid moving around or did not explain this in enough detail.
- Some observations were not appropriate, for example 'fizzing' when there was no liquid present or a black gas.
- The description of the splint test was not precise in some responses, with it being stated to be 'burning' rather than glowing and some incorrect gas tests were noted.
- Many candidates only tested for and identified the gas.
- Hydrogen was commonly wrongly identified as the gas.

(ii) Comprehensive responses

- Some candidates had studied this reaction and were aware that the KMnO_4 decomposes into K_2MnO_4 , MnO_2 and O_2 .
- Precise descriptions of the reduction of manganese from +7 to +6 and / or +4 were given by many candidates.
- Other candidates were able to state that the reaction was a redox reaction as the manganese was reduced and the oxygen was oxidised or that the oxidation state of the oxygen changes from -2 to 0.

Limited responses

- Candidates writing about the reduction of manganese often stated that the final oxidation state was +2, which is the state reached when carrying out a redox titration rather than the oxidation state reached after a thermal decomposition.
- It was common to see manganate 'reduced' rather than manganese reduced.
- Some responses discussed only the loss of oxygen as a reason for the redox reaction and others suggested that the oxidation state of potassium was changing when it remains the same.
- Several responses referred to hydrogen, possibly due to a claim of its presence in **(a)(i)**.
- Many candidates were able to recognise that KMnO_4 was an oxidising agent. They did not then explain why a redox reaction was occurring.

(b)(i) Comprehensive responses

- This question required the candidates to carry out four tests on both **FB 8** and **FB 9**. **FB 8** was a mixture of ammonium chloride and sodium sulfite. **FB 9** was sulfuric acid.
- In Test 1, comprehensive responses detailed the changes to the (acidified aqueous) potassium manganate(VII) solution, stating that it decolourised (or changed from purple to colourless) with **FB 8** and did not with **FB 9**.
- In Test 2, comprehensive responses stated that **FB 9** produced effervescence of hydrogen gas with the Mg that was added and described a 'pop' with a lighted splint as stated in the qualitative analysis notes. Detailed answers noted that the test-tube became warm. **FB 8** was described as producing little or no effervescence.
- In Test 3, both **FB 8** and **FB 9** produced white precipitates in comprehensive responses.
- Some responses observed that in Test 4, no change was reported with **FB 8** and **FB 9** produced an off-white/pale yellow precipitate slowly.

Limited responses

- In Test 1, limited responses described changes (or lack of change) to **FB 8** and **FB 9**, not the potassium manganate(VII) solution. **FB 9** was described as 'turning purple' rather than the potassium manganate(VII) solution remaining purple and **FB 8** was described as 'remaining colourless' or 'no change' when a reaction was occurring.
- Many candidates noted effervescence. Some responses did not describe a lit splint popping or claimed another gas via an incorrect test, e.g. carbon dioxide, oxygen or ammonia.
- On page 7, there is an instruction that no additional tests should be attempted. Both **FB 8** and **FB 9** produced a white precipitate in Test 3. Limited responses described this as a white solution or carried out a further test such as adding a strong acid or potassium manganate(VII) solution. Infrequently, use of sulfuric acid was seen which invalidated this test for sulfate or sulfite ions.
- In Test 4, candidates added sodium thiosulfate, generally recording that **FB 8** produced no change. Limited responses described this as 'no observation' suggesting that no observations had been made rather than 'no change'. Many candidates noted a precipitate with **FB 9**; they did not then qualify that it was formed slowly. Vague statements such as a milky or cloudy solution were seen.

(ii) Comprehensive responses

- In comprehensive responses, it was clearly recorded at which stage in a test a change occurred.
- In these responses, appropriate reagents were selected to test for cations and no additional tests for anions were carried out.
- The results were reported in clear stages; no change or no precipitate with NaOH, then a gas produced on warming that turned damp red litmus blue.

Limited responses

- In limited responses, it was unclear whether NaOH was present at all stages of the test.
- Some responses described the test results with NaOH and ammonia, then heated the mixture. It was not then clear which reagent (if any) was included during the heating.
- Some responses gave no result on addition of NaOH. The solution was not warmed and/or the litmus paper was described as turning blue but it was not clear that it was the gas/ammonia that was the cause. The litmus paper would turn blue if dipped in the solution, so this distinction is required.
- Most issues with limited responses were due to the tests not being set out and explained clearly.
- Some responses described an additional test, usually for an anion such as chloride. No additional tests should be attempted.

(iii) Comprehensive responses

- Comprehensive responses used results from **(b)(i)** and **(b)(ii)** to identify the cation as ammonium/ NH_4^+ and the anions as sulfite/ SO_3^{2-} and unknown.

Limited responses

- Some responses gave the formula for ammonium as NH_4^+ .
- Some candidates did not carry out any tests to identify any other ions in **FB 8**, including chloride.

(iv) Comprehensive responses

- Many candidates used results from **(b)(i)** to correctly identify that **FB 9** was acidic, contained sulfate ions and was therefore H_2SO_4 .

Limited responses

- Some responses suggested that the anion was thiosulfate, perhaps recognising that acid produces sulfur slowly with thiosulfate, but confusing which reagent was **FB 9** and which was **FB 1**.
- Another common response was BaSO_4 .

(v) Comprehensive responses

- Good responses provided the reaction of H^+ with Mg to produce hydrogen gas with correct stoichiometry and state symbols or the production of barium sulfate from Ba^{2+} and SO_4^{2-} , again with correct stoichiometry and state symbols.

Limited responses

- Many responses were not ionic equations, using H_2SO_4 in the equation.
- State symbols were often omitted or incorrect (often $\text{BaSO}_4(\text{aq})$ rather than $\text{BaSO}_4(\text{s})$).
- The production of H_2 from a single H^+ was seen several times.
- No correct ionic equations using thiosulfate and acid to produce sulfur were reported.
- Some equations were provided for tests that had not been carried out, such as neutralisation.

CHEMISTRY

Paper 9701/35 Advanced Practical Skills
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Key messages

What candidates did well

- In comprehensive responses, candidates:
 - used apparatus to collect an appropriate quantity of data
 - made accurate and consistent measurements
 - produced graphs with a sensible choice of scale and correctly labelled axes
 - presented their data in a single table of results
 - found an unknown value by using the intersection point on a graph.
 - identified ions from observations.
- Although observations were sometimes incomplete, candidates were generally able to link those observations to the correct ions.

What candidates needed to improve

- Some candidates recorded thermometer readings either as integers or to two decimal places rather than to the nearest .0 or .5.
- Some candidates did not plot all the data points correctly. Where a point falls on a line, it should be plotted on that line.
- Many candidates did not correctly calculate the percentage error in **Question 1**.
- Many candidates did not demonstrate an understanding of the dilution calculation in **Question 2**.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates recorded the required data in an appropriate table and used the correct units.
- Most candidates demonstrated good experimental technique by recording the expected volume of gas for the experiment.

Limited responses

- Some candidates did not use the appropriate level of precision when recording the volume of gas. The question instructs candidates to record the volume to the nearest cm^3 .
- Some candidates omitted the volume of gas from their results table and recorded it in **(b)(i)** instead.
- The use of 'weight' or 'amount' rather than 'mass' was occasionally seen in the results table.

(b)(i) Comprehensive responses

- Most candidates correctly divided their recorded volume by 24 000 to work out the amount of hydrogen produced.

Limited responses

- A few candidates only used one significant figure in their final answer.

(ii) Comprehensive responses

- Most candidates correctly doubled their answer to **(b)(i)** and divided by 0.03 to work out the concentration of the hydrochloric acid.

Limited responses

- Some candidates did not convert the volume of acid used from cm^3 to dm^3 and so divided by 30 rather than 0.03.
- A few candidates did not double their answer to **(b)(i)** as suggested by the equation at the start of the question.

(iii) Comprehensive responses

- Some candidates recorded the correct uncertainty for the balance that they had used (e.g. 0.005 g for a two-decimal-place balance). Some candidates were also able to use this value to calculate the correct maximum percentage error.

Limited responses

- Many candidates used a value that was double the correct value for the uncertainty in a single reading (e.g. 0.01 g was seen rather than 0.005 g for a two decimal place balance).
- Some candidates did not multiply by two to reflect the fact that two readings had been taken when calculating the maximum percentage error.
- A few candidates attempted to use both the recorded masses including the container rather than the difference between the two when calculating the maximum percentage error.

(iv) Comprehensive responses

- Most candidates recognised that the magnesium must have been in excess because some of it was still visible when no more bubbles of gas were being produced.

Limited responses

- A few candidates incorrectly stated that the reaction did not go to completion.

(c) (i) Comprehensive responses

- Most candidates correctly linked the higher surface area of the powder to a faster rate of reaction.
- Some candidates went on to state what effect this would have on the volume of gas collected.

Limited responses

- A few candidates incorrectly stated that less hydrogen would be produced by the reaction.

(ii) Comprehensive responses

- Only a few candidates noted that the small loss in mass when hydrogen was produced would lead to a large percentage error.

Limited responses

- Many candidates incorrectly attempted to answer the question in terms of the reaction being used in this part (acid plus carbonate) rather than in terms of the method (mass loss) as indicated by the question.

Question 2

(a) Comprehensive responses

- Most candidates recorded the correct total volumes of **FA 4** added and provided a complete set of temperature readings to an appropriate level of precision.
- Most candidates demonstrated good experimental technique by recording the expected temperature rise for the experiment.

Limited responses

- A few candidates gave thermometer readings either to two decimal places or to the nearest integer rather than to the nearest .0 or .5 °C.

(b)(i) Comprehensive responses

- Most candidates provided graphs with correctly labelled axes and a suitable choice of scale.

Limited responses

- A few candidates did not label their axes.
- Some candidates made errors when plotting data. Candidates should be reminded that if a point is supposed to be plotted on a line, then it should be accurately centred on that line.

(ii) Comprehensive responses

- Most candidates drew a correct line of best fit for the points after the maximum temperature had been reached.

Limited responses

- Very few candidates drew an appropriate line of best fit for the points when the temperature was increasing. Most candidates drew a straight line rather than the curve suggested by the data.

(iii) Comprehensive responses

- Most candidates correctly used the intersection of their two lines of best fit to answer the question.

Limited responses

- A small number of candidates misread the scale on their x-axis, e.g. by interpreting the scale as 1.0 cm³ per small square rather than 0.5 cm³ per small square.

(c)(i) Comprehensive responses

- Most candidates successfully completed the first part of the calculation, namely the moles of sodium hydroxide used. Some of these candidates then used their answer to **(b)(iii)** to correctly calculate the concentration of the hydrochloric acid.

Limited responses

- Some candidates did not use their answer to **(b)(iii)** to complete the calculation.

(ii) Comprehensive responses

- A small number of candidates were able to complete this calculation correctly by using their answers to previous question parts.

Limited responses

- Many candidates did not demonstrate the required understanding of a dilution calculation.

(d) Comprehensive responses

- Some candidates showed that they understood that a graphical method introduces some errors caused by drawing lines of best fit and then extrapolating the lines.
- A smaller number of candidates also gave good responses in terms of the titration being easier to repeat and the ability to check for concordant results.

Limited responses

- Some candidates gave responses that were too vague, referring simply to 'more accurate' or 'less human error'.
- A few candidates referenced heat loss, which is not relevant in this question.

Question 3

(a) (i) **Comprehensive responses**

- Most candidates correctly recorded at least half of the observations expected.
- The question states that all the ions are listed in the Qualitative analysis notes and many candidates clearly kept this information in mind when answering this question.

Limited responses

- In Test 1 with **FA 6**, some candidates incorrectly recorded the precipitate as being soluble in dilute nitric acid.
- In Test 2, some candidates did not record their observation from the point of view of the potassium manganate(VII). For example, 'no change' was the correct observation with **FA 7** rather than 'solution turns purple'.
- In Test 3, some candidates did not make it clear when testing for ammonia that it was the gas produced rather than the solution that turns the red litmus paper blue.
- A few candidates recorded colours and other observations that are not present in the Qualitative analysis notes.

(ii) **Comprehensive responses**

- Most candidates correctly identified at least three of the ions present.
- Only a few candidates identified either six or all seven of the ions.

Limited responses

- Some candidates concluded incorrectly that the precipitate produced by **FA 5** in Test 3 indicated the presence of Fe^{3+} .
- Some candidates did not do a successful ammonia test with **FA 6** and so omitted the ammonium ion as a correct conclusion.
- Some candidates were unsure of the exact colour of the precipitate produced by **FA 6** in Test 3 and so gave Cr^{3+} as an incorrect conclusion.
- The formula of a halide ion was a common incorrect answer for the **FA 5** anion.

(iii) **Comprehensive responses**

- Only a few candidates provided a fully correct equation with state symbols.

Limited responses

- Some candidates gave a correct equation but omitted the state symbols. A precipitate with a state symbol of '(aq)' was also seen in some responses.

(iv) **Comprehensive responses**

- Some candidates recognised that **FA 6** must be a reducing agent and correctly linked their answer to the relevant observation.

Limited responses

- Some candidates gave a partially correct answer that did not attempt to link their conclusion to their observations.

(b) **Comprehensive responses**

- Many candidates correctly reported seeing a green powder that turned black.
- A smaller number of candidates also reported the formation of condensation and attempted to test for a gas using limewater.

Limited responses

- Some candidates appeared to not make full use of the Qualitative analysis notes and reported the limewater going 'cloudy' or 'milky' rather than forming a white precipitate.

CHEMISTRY

Paper 9701/37 Advanced Practical Skills
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Key messages

What candidates did well

- Many candidates successfully set up and used apparatus to collect gas over water.
- Most candidates were able to carry out a titration and obtain concordant results.
- Many candidates obtained gas volumes (**Question 1**) and concordant titres (**Question 2**) that were in close agreement with those of their Supervisor.
- Most candidates presented numerical data clearly in a single table with clear headings and correctly displayed units.
- Most candidates presented balance and burette readings to the correct precision for the measuring instrument used.
- Most candidates displayed their numerical working clearly during calculations.
- Many candidates gave their answers to an appropriate number of significant figures.
- Some candidates were able to use their measured mass of magnesium to calculate an expected volume of gas produced in a chemical reaction.
- Many candidates were able to use titration results to determine information about the relative molecular mass of a reagent.
- Many candidates were able to identify at least one unknown ion by using their results from qualitative chemical tests.

What candidates needed to improve

- When carrying out qualitative tests, candidates should be aware of the range of observations which may be possible, e.g. the appearance of a precipitate and its solubility or insolubility in excess reagent; or the effervescence of a gas, which may then be tested to identify it.
- Candidates should be aware of the appropriate level of precision for volume readings taken using a measuring cylinder.
- Candidates should record qualitative observations to an appropriate level of detail, recording colour in simple language and using terms such as 'pale' or 'dark' to provide fine discrimination.
- Candidates should practise using the Qualitative analysis notes together with their own observations to identify ions following a series of chemical tests using a compound or its solution.
- Candidates should be aware of how to identify the maximum uncertainty associated with a single reading, based on consideration of half the difference between closest calibrations.
- Candidates should practise writing ionic equations.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates appropriately recorded a full set of results, using suitable headings and correctly displayed units.
- Most candidates recorded mass values to the appropriate precision. Some candidates also recorded their measured gas volume to the appropriate precision.
- Most candidates correctly calculated the mass of **FA 1** used. Volumes of gas collected by candidates and their Supervisors were usually in good agreement.

Limited responses

- Many candidates recorded their volume of gas to one or more decimal places, which is not appropriate for the measuring equipment used.

(b)(i) Comprehensive responses

- Most candidates used the correct formula and correctly calculated the moles of magnesium used.

Limited responses

- Some candidates used 24 as the A_r of Mg rather than 24.3.
- A few candidates did not round their answer correctly.

(ii) Comprehensive responses

- A few candidates were able to write the correct ionic equation for the reaction between magnesium and the H^+ ions from the organic acid, with the correct state symbols.

Limited responses

- Most candidates wrote an equation which included the full formula of the organic acid, or the anion for the organic acid rather than H^+ .
- A small number of candidates who wrote an otherwise correct ionic equation had missing or incorrect state symbols.

(iii) Comprehensive responses

- Many candidates correctly used the molar volume of a gas, applying a factor of 24 000 to calculate the theoretical volume of hydrogen in cm^3 .

Limited responses

- Some candidates used 24 as the molar volume, thus obtaining a volume in dm^3 .
- Some candidates gave answers to five significant figures, even though their experimental data did not justify such a high level of precision.

(c) Comprehensive responses

- Many candidates identified gas escaping before the bung was replaced as a source of error.
- Some candidates identified impurities in the magnesium as a source of error.
- A very small number of candidates commented on the laboratory temperature being lower than the standard laboratory conditions.

Limited responses

- Many candidates commented on hydrogen dissolving in water. The solubility of hydrogen is too low for this to have had a significant effect.
- Some candidates referred to leaks from the apparatus without linking this to the delay in replacing the bung.

(d) Comprehensive responses

- Some candidates were aware that the maximum uncertainty associated with a quantitative measurement is half the difference between the closest calibrations on the measuring apparatus, e.g. 0.005 g for a two decimal place balance.
- Many candidates who stated the correct uncertainty went on to correctly calculate the maximum percentage error in the mass of magnesium used.

Limited responses

- Many candidates incorrectly gave the maximum balance uncertainty as being the same as the difference between the closest calibrations, e.g. 0.01 g for a two decimal place balance.
- A few candidates who stated the correct uncertainty did not appreciate that they needed to double this uncertainty to calculate the maximum percentage error, because their determination of the mass of magnesium used involved taking two balance readings.

Question 2

(a) Comprehensive responses

- Most candidates answered this question well. They presented their accurate titration data in a single table with correct headings and units. All burette readings were recorded to the correct precision ($.#0$ or $.#5\text{ cm}^3$) and titrations were repeated until concordant results were achieved.
- Some candidates carried out their titrations accurately, obtaining titres which were very close to the Supervisor's mean titre.

Limited responses

- A few candidates did not record burette readings for their rough titre, labelled their burette readings incorrectly, e.g. 'initial titre' or recorded burette readings to one decimal place only.
- A minority of candidates did not carry out titrations until they had two titres within 0.1 cm^3 .

(b) Comprehensive responses

- Most candidates clearly selected two or more titres within a range of 0.2 cm^3 and correctly averaged them to two decimal places.

Limited responses

- A few candidates did not show, either by ticks next to the titres in their results table or in (b), which titres they chose to average.
- A few candidates either did not correctly round their mean titre or did not display their answer to two decimal places.

(c) (i) Comprehensive responses

- Many candidates answered all parts of (c) and displayed each answer to three or four significant figures.

Limited responses

- Some candidates did not attempt (c)(ii), (iii) and (iv).
- Some candidates displayed one or more answers to fewer than three or more than four significant figures.

(ii) Comprehensive responses

- Most candidates correctly calculated the amount of sodium hydroxide.

Limited responses

- A few candidates did not apply the correct factor of 1000 or used an incorrect formula for the number of moles.

(iii) Comprehensive responses

- Many candidates noted the 1 : 1 ratio between moles of sodium hydroxide and moles of **FA 4** and then used the volume of **FA 4** from their experiment to obtain the concentration of **FA 4**.

Limited responses

- Some candidates attempted to derive the concentration of **FA 4** in mol dm^{-3} directly from the concentration in g dm^{-3} , without realising that this would require a knowledge of the M_r of **FA 4**.
- A few candidates did not apply the correct factor of 1000 to their volume.

(iv) Comprehensive responses

- Some candidates divided the concentration of **FA 4** in g dm^{-3} by their calculated concentration in mol dm^{-3} to obtain the M_r of **FA 4**.

Limited responses

- Some candidates attempted to use the formula of **FA 4** to calculate an M_r using A_r values, without appreciating that this would require knowledge of the identities of both **R'** and **Z** within the formula of **FA 4**.

(d)(i) Comprehensive responses

- Some candidates correctly identified that both silver nitrate and ammonia are required to identify the halogen present in **FA 4**. These candidates went on to describe the colour of the precipitate formed with silver nitrate and its solubility in dilute ammonia, and thus correctly identified **FA 4** as containing bromine.

Limited responses

- Some candidates used silver nitrate to test for the halogen present in **FA 4** and then did not go on to test the solubility of their precipitate using dilute ammonia.
- Some candidates incorrectly identified the colour of the precipitate formed with silver nitrate, and therefore did not correctly identify **Z**.

(ii) Comprehensive responses

- A few candidates recognised that the role of the nitric acid was to remove hydroxide ions and explained that this was necessary to prevent the hydroxide ions forming a precipitate with Ag^+ ions.

Limited responses

- Many candidates stated that the acid was added to neutralise the sodium hydroxide, without explaining that this was necessary because otherwise a precipitate would have been formed.

(e) Comprehensive responses

- Some candidates used their calculated value from **(c)(iv)** and the identity of **Z** from **(d)(i)** to calculate an M_r value for the R' group.
- Some candidates went on to work out the correct number of carbon atoms present in their R' group and gave the correct formula for alkyl group R' .

Limited responses

- Some candidates made an error in calculating an M_r value for R' . Some of these candidates gave a correct formula for R' to match their calculated M_r .
- Some candidates correctly calculated the M_r of R' , then suggested R' might be an element, or gave the general formula for an alkyl group rather than a specific formula.

(f) Comprehensive responses

- A few candidates understood that the calculated M_r values from the two experiments would be similar but not identical. They were then able to link this to the large difference in M_r for R groups containing different numbers of carbon atoms to justify why the same R group was obtained.

Limited responses

- Some candidates understood that M_r values would be similar, then did not go on to explain why this would result in obtaining the same identity for the R' group.
- Some candidates simply stated that the results from the two experiments were so similar that it would make no difference to the overall outcome of the experiment, without appreciating that the difference in titre values would have an impact on the calculated M_r .

Question 3

(a) Comprehensive responses

- Some candidates clearly identified the correct reagent to test for unsaturation, giving the correct formula, KMnO_4 , or the full name, potassium manganate(VII).
- Many of these candidates gave the correct observation for **FA 2** with KMnO_4 and deduced that **FA 2** is saturated.

Limited responses

- Some candidates described the use of bromine water to test for unsaturation even though bromine water was not supplied for this practical examination.
- Some candidates who correctly identified KMnO_4 then described its colour as 'turning' purple. Observations involving KMnO_4 should be described based on the colour change of the KMnO_4 , which 'remains' purple.
- A few candidates used incorrect capitalisation when giving the formula for KMnO_4 , for example giving the formula as KmNO_4 .

(b)(i) Comprehensive responses

- Some candidates made effective use of the Qualitative analysis notes to assist in their descriptions of their observations, particularly for the tests on **FA 7**.
- Many candidates were able to describe solids formed when two solutions were mixed as precipitates and stated each precipitate's colour. Some also identified whether the precipitate went on to dissolve when additional reagent or another solution was added.
- Some candidates gave a clear description of the gas test carried out on **FA 7** during Test 1.

Limited responses

- A few candidates did not use correct technical terms when describing observations, for example describing a precipitate simply as a 'solid'.
- A few candidates recorded 'no observation' in place of 'no change'. Candidates should note the information in the stem of the question, as it gives advice on how to record their observations.
- Some candidates did not give sufficient detail in their responses. Examples included candidates who did not record the solubility in excess reagent after having identified a precipitate, and candidates who did not carry out a gas test after having observed effervescence.

(ii) Comprehensive responses

- Some candidates correctly identified the cations present in **FA 7** and **FA 8**.

Limited responses

- Some candidates successfully identified Cr^{3+} in **FA 7** and then did not appreciate that the data in **Table 3.1** does not allow the identification of the cation in **FA 8**. The correct answer should have been 'unknown'.
- Common incorrect answers were Na^+ and Cu^{2+} .

(iii) Comprehensive responses

- Some candidates successfully identified both anions present in **FA 7** and explicitly linked each anion to the evidence they recorded in **Question 3(b)(i)**.

Limited responses

- Some candidates correctly identified both ions without making a sufficiently clear link to the data in **Table 3.1** to justify their observations.
- Some candidates did not have sufficient evidence recorded in **Table 3.1** to be able to justify their identification of the anions.

(iv) Comprehensive responses

- Some candidates correctly identified the hydroxide ion.

Limited responses

- Many candidates incorrectly identified a halide ion as the anion present in **FA 8**.

CHEMISTRY

Paper 9701/38 Advanced Practical Skills
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Key messages

What candidates did well

- Comprehensive responses showed that candidates were able to:
 - plan experiments and investigations
 - collect, record and present observations, measurements and estimates
 - analyse and interpret experimental data to reach conclusions
 - evaluate methods and quality of experimental data and suggest improvements to experiments.
- Many candidates were able to present and label work clearly.
- In quantitative work, some results were presented to an appropriate level of precision. Some calculations were carried out correctly with clear working shown.
- In qualitative work, some responses clearly recorded at which stage in a test an observation was made using the terms given in the qualitative analysis notes as a guide.
- Some candidates were able to use the results of qualitative tests to identify ions and also appreciate the limitations of the tests carried out.

What candidates needed to improve

- Some candidates did not complete the paper using black or dark blue pen as indicated in the instructions. Pencil should only be used for diagrams and graphs.
- Some candidates did not write numbers and formulae clearly and unambiguously.
- Some candidates did not appear to read and follow the instructions carefully. For example, **Question 2** required only one heating and in **Question 3**, page 7 stated that 'No additional tests should be attempted'.
- When reporting burette readings, some candidates did not record volumes to 0.05 cm³.
- Some candidates were not familiar with the use of starch solution as an indicator added towards the end of a titration.
- Some candidates needed to make more use of the qualitative analysis notes and to use the precise language given there – e.g. white precipitate, not cloudy/milky solution, and where no change is observed, candidates should write 'no change'.

Comments on specific questions

Question 1

(a) Comprehensive responses

- In comprehensive responses, candidates provided initial and final readings for a rough titre either in the space provided on page 2 or clearly labelled in a table on page 3.
- Some candidates provided a single accurate table with correct headings and correctly displayed units.
- Some burette readings were given to an accuracy of 0.05 cm³ and concordant results (the final titre within 0.10 cm³ of another titre) were recorded.
- Many candidates were able to obtain results that demonstrated a high level of accuracy when compared to the Supervisor's results.

Limited responses

- In limited responses, no initial and final burette readings for the rough titre were provided. A small number of candidates recorded their titres in the marking boxes for examiner use only and did not produce a table.
- In a small number of responses, incorrect units, such as mL, were seen and some units were displayed incorrectly.
- Headings such as 'initial' and 'final' were provided by some candidates without '(burette) reading/volume' or 'initial titre' and 'final titre' recorded as headings.
- Some limited responses gave correct headings and units and then transposed the readings, making the headings invalid.
- Limited responses provided a heading 'volume of **FB 1**' in place of 'titre' without stating that this was the volume of **FB 1** used or added.
- Some limited responses stated the amount of **FB 1** used, which refers to moles rather than volume.
- Some limited responses did not give readings to the level of precision required by a comprehensive response, giving readings to 0.1 cm³ or integer values. The initial reading must show the precision of the burette; 0 cm³ was seen in some responses. Initial readings were sometimes given as 50.00 cm³ rather than 0.00 cm³.
- In some responses, results tables showed that two concordant titres were recorded followed by a third titration that was not concordant. The final titre recorded should be within 0.10 cm³ of a previously recorded titre.
- In this titration, candidates were instructed to run **FB 1** into the conical flask until a yellow colour was observed, then to add **FB 5** (starch indicator) to make the solution turn blue-black. The end point is reached when further addition of **FB 1** causes the solution to turn colourless.
- Limited responses did not record the correct initial volume of **FB 1**; instead used the point of addition of **FB 5** as the initial burette reading. This resulted in very small titres with an initial burette reading that was invalid. The volume of **FB 1** that had already reacted with the iodine produced up to the point of addition of **FB 5** was not measured and/or recorded.
- Titre values were more likely to be spread out and not close to the Supervisor's value.

(b) Comprehensive responses

- Comprehensive responses clearly showed two or more titres from the table within 0.20 cm³ and a calculation used to produce a mean value. If a calculation was not shown, the selected values were clearly indicated by use of a tick or other clear symbol in the table in (a). The mean was correctly rounded to two decimal places.

Limited responses

- Limited responses had selected values that were greater than 0.20 cm³ apart. This was often seen by the selection of more than two titres such as 22.20 cm³, 22.40 cm³ and 22.60 cm³, which has a total spread of 0.40 cm³. In this case, two of the closer values should be selected or a further titration carried out to obtain more concordant results.
- Limited responses used titres that had been incorrectly calculated in the results table or included the rough titre.
- Some mean values were provided to one or three decimal places rather than two.

(c) (i) Comprehensive responses

- Comprehensive answers to **Question 1(c)(ii)**, **1(c)(iii)** and **1(c)(iv)** were provided to three to four significant figures.

Limited responses

- Limited responses provided answers to two significant figures, five significant figures, left a question part blank or provided a three- to four-significant figure answer with no relevant working.

(ii) Comprehensive responses

- Comprehensive responses clearly displayed the use of the M_r of KIO_3 either via a number string of the A_r values used ($39.1 + 126.9 + (3 \times 16)$) or by 214.
- Correct use of the mass of KIO_3 stated on page 2 (3.35g) to work out the number of moles of KIO_3 in 1 dm³ of **FB 2** and hence the number of moles of KIO_3 in the 25.0 cm³ of **FB 2** used in the titration was also seen.

Limited responses

- Limited responses calculated the M_r of IO_3^- (174.9) rather than KIO_3 or calculated the mass of **FB 2** in 25.0 cm³ rather than the amount in moles.
- Some candidates carried out the calculation in two steps, rounding their answer to less than three significant figures after the first stage. This resulted in an inaccurate calculation.
- Many candidates did not use an M_r , giving $3.35 \times 25 \times 10^{-3}$ (0.08375) as their answer.

(iii) Comprehensive responses

- Comprehensive responses used the stoichiometry of the two equations provided and multiplied the answer to **(c)(ii)** by 6.

Limited responses

- Limited responses used the stoichiometry of the two equations provided incorrectly and multiplied **(c)(ii)** by factors such as 3, 2, 3/2, 2/3, 0.5 or 1.

(iv) Comprehensive responses

- Some candidates divided the answer to **(c)(iii)** by the titre in **(b)**. This was often accessed via an error carried forward.

Limited responses

- Some candidates divided the answer to **(c)(iii)** by an incorrect value such as 0.025.
- Some responses did not convert the titre to dm³, missing a factor of 1000.

Question 2

(a) (i) Comprehensive responses

- In comprehensive responses, the instructions in the method had clearly been read and followed.
- In these responses, the three masses and three calculated values were clearly provided in the results space, with units in grams correctly displayed for all.
- If masses were included, the inclusion of the crucible lid was consistent.
- After heating, the final heading was given by some candidates as the 'mass of crucible, (lid) and contents or residue'.
- Some candidates gave the three masses to a consistent number of decimal places (two to three).
- The mass of **FB 6**, residue and mass lost were correctly calculated by many candidates.
- Many candidates were able to demonstrate a high level of accuracy compared to the Supervisor results.

Limited responses

- Some responses did not provide three masses and it was not possible to calculate the data required.
- In limited responses, headings were not clear and included **FB 6** after heating when the residue is no longer **FB 6**. Numbers were difficult to read and ambiguous. Some headings included the lid with an initial crucible mass, but after heating the heading did not include the lid.
- Some candidates referred to weight rather than mass.
- Some candidates provided more than three masses; the method states that only one heating and cooling cycle should be completed rather than multiple cycles.
- The mass of residue and the mass loss were sometimes the wrong way round and often one of the values was not calculated.
- Some results were not possible, such as the final mass after heating being lower than that of the initial mass of the empty crucible.

(ii) Comprehensive responses

- The residue was a solid. Comprehensive responses included the need to first dissolve the residue in water (or nitric acid) to produce a solution for testing.
- In comprehensive responses, silver nitrate was selected to test for the halide ion, producing a white precipitate. The precipitate was tested with ammonia and anion **X** identified as chloride.

Limited responses

- Many responses described the addition of a solid residue to silver nitrate, which is not an appropriate test to assess whether a precipitate is formed. A precipitate is formed when two solutions are mixed. It is possible that candidates did dissolve the residue in water but did not include this in their answer. Very few responses included this step.
- When giving the details of a reagent, the correct formula should be used. Some responses gave only Ag^+ rather than AgNO_3 .
- Some limited responses gave the wrong formula for silver nitrate ($\text{Ag}(\text{NO}_3)_2$) or confused the two test reagents as AgNH_3 .
- Some tests were presented for non-halide ions suggesting that some candidates had not read the question carefully.
- Some responses recorded the precipitate as off-white rather than white and concluded that the anion was bromide or presented correct tests and then identified the anion as chlorine (rather than chloride) or Cl_2 .

(b)(i) Comprehensive responses

- The amount of water lost in mol was correctly calculated to an appropriate precision (two to four significant figures) by dividing the mass lost from **(a)(i)** by 18.

Limited responses

- Some responses used 2×18 rather than 18.
- Rounding errors were noted in some responses.
- Some responses were given to only one significant figure, which was not precise.

(ii) Comprehensive responses

- Some candidates presented a correct calculation of the moles of residue by use of the fact that two moles of water are produced for each mole of residue. The number of moles of residue or **FB 6** could be calculated via **(b)(i)** $\div 2$ and hence the M_r calculated by use of the mass of residue recorded in **(a)(i)** or the mass of **FB 6** recorded in **(a)(i)** followed by subtraction of $36 \times (2 \times 18)$.
- Many answers were provided to an appropriate precision (two to four significant figures).
- Many answers were clearly set out and correctly calculated.

Limited responses

- Incorrect use of stoichiometry was seen, with **(b)(i)** used as the moles of residue rather than **(b)(i)** $\div 2$.
- In some responses, the mass of **FB 6** was used rather than the mass of residue without subtraction of 36.
- Some answers were given to five significant figures.
- Some candidates selected a Group 2 metal chloride in **(b)(iii)** and worked backwards rather than using their experimental results as the question required.

(iii) Comprehensive responses

- Most candidates were able to use their answer to **(b)(ii)** and $2 \times$ the A_r of the halide deduced in **(a)(ii)** to calculate the A_r of the metal **M**.
- Comprehensive answers gave this value to an appropriate number of significant figures (two to four) and stated either the name of the metal or the ion with a +2 charge.

Limited responses

- In some responses, the question had not been read carefully as the A_r calculated was assigned to the closest element or metal, rather than the closest Group 2 metal. The cation was given as Ba or Ca rather than Ba^{2+} or Ca^{2+} .

(c) (i) Comprehensive responses

- Using the cation **M** identified in **(b)(iii)** and the anion in **(a)(ii)**, the actual M_r of **MX₂** was correctly calculated in comprehensive responses.
- In comprehensive responses, the difference between this value and **(b)(ii)** was calculated, divided by the actual M_r of **MX₂** and expressed as a percentage.
- Some responses had working that was displayed clearly.

Limited responses

- The question had not been read carefully enough in some cases, as answers expressed the percentage error as the difference in the A_r of **M** rather than the difference in M_r of **MX₂**.
- Some responses used equipment errors from the balance or used the mean of the actual and experimental values as the denominator in the calculation.

(ii) Comprehensive responses

- Some candidates recognised that the method only included one heating cycle and that to reduce the percentage error the sample should be heated again until there was a constant mass. This would ensure that all the water had been removed.

Limited responses

- Some limited responses recognised that further heating or longer heating was required to ensure all the water was lost. They did not suggest that a constant mass was required to confirm this.
- Responses such as repeating the experiment and taking a mean, using different masses of **FB 6** and using a more precise balance formed all or part of limited answers. These suggestions would not guarantee that all the water was lost.

Question 3

(a) (i) Comprehensive responses

- There were some very well organised responses to this question. Candidates clearly stated the colour and state of **FB 7** at the start and end of the experiment.
- In comprehensive responses, the gas was tested with a glowing splint which re-lit and was identified as oxygen.
- Some candidates noted that the solid moved around during heating.

Limited responses

- The initial and final colours of **FB 7** were often missing in limited responses.
- Some responses noted 'popping' rather than the solid moving around or did not explain this in enough detail.
- Some observations were not appropriate, for example 'fizzing' when there was no liquid present or a black gas.
- The description of the splint test was not precise in some responses, with it being stated to be 'burning' rather than glowing and some incorrect gas tests were noted.
- Many candidates only tested for and identified the gas.
- Hydrogen was commonly wrongly identified as the gas.

(ii) Comprehensive responses

- Some candidates had studied this reaction and were aware that the KMnO_4 decomposes into K_2MnO_4 , MnO_2 and O_2 .
- Precise descriptions of the reduction of manganese from +7 to +6 and / or +4 were given by many candidates.
- Other candidates were able to state that the reaction was a redox reaction as the manganese was reduced and the oxygen was oxidised or that the oxidation state of the oxygen changes from -2 to 0.

Limited responses

- Candidates writing about the reduction of manganese often stated that the final oxidation state was +2, which is the state reached when carrying out a redox titration rather than the oxidation state reached after a thermal decomposition.
- It was common to see manganate 'reduced' rather than manganese reduced.
- Some responses discussed only the loss of oxygen as a reason for the redox reaction and others suggested that the oxidation state of potassium was changing when it remains the same.
- Several responses referred to hydrogen, possibly due to a claim of its presence in **(a)(i)**.
- Many candidates were able to recognise that KMnO_4 was an oxidising agent. They did not then explain why a redox reaction was occurring.

(b)(i) Comprehensive responses

- This question required the candidates to carry out four tests on both **FB 8** and **FB 9**. **FB 8** was a mixture of ammonium chloride and sodium sulfite. **FB 9** was sulfuric acid.
- In Test 1, comprehensive responses detailed the changes to the (acidified aqueous) potassium manganate(VII) solution, stating that it decolourised (or changed from purple to colourless) with **FB 8** and did not with **FB 9**.
- In Test 2, comprehensive responses stated that **FB 9** produced effervescence of hydrogen gas with the Mg that was added and described a 'pop' with a lighted splint as stated in the qualitative analysis notes. Detailed answers noted that the test-tube became warm. **FB 8** was described as producing little or no effervescence.
- In Test 3, both **FB 8** and **FB 9** produced white precipitates in comprehensive responses.
- Some responses observed that in Test 4, no change was reported with **FB 8** and **FB 9** produced an off-white/pale yellow precipitate slowly.

Limited responses

- In Test 1, limited responses described changes (or lack of change) to **FB 8** and **FB 9**, not the potassium manganate(VII) solution. **FB 9** was described as 'turning purple' rather than the potassium manganate(VII) solution remaining purple and **FB 8** was described as 'remaining colourless' or 'no change' when a reaction was occurring.
- Many candidates noted effervescence. Some responses did not describe a lit splint popping or claimed another gas via an incorrect test, e.g. carbon dioxide, oxygen or ammonia.
- On page 7, there is an instruction that no additional tests should be attempted. Both **FB 8** and **FB 9** produced a white precipitate in Test 3. Limited responses described this as a white solution or carried out a further test such as adding a strong acid or potassium manganate(VII) solution. Infrequently, use of sulfuric acid was seen which invalidated this test for sulfate or sulfite ions.
- In Test 4, candidates added sodium thiosulfate, generally recording that **FB 8** produced no change. Limited responses described this as 'no observation' suggesting that no observations had been made rather than 'no change'. Many candidates noted a precipitate with **FB 9**; they did not then qualify that it was formed slowly. Vague statements such as a milky or cloudy solution were seen.

(ii) Comprehensive responses

- In comprehensive responses, it was clearly recorded at which stage in a test a change occurred.
- In these responses, appropriate reagents were selected to test for cations and no additional tests for anions were carried out.
- The results were reported in clear stages; no change or no precipitate with NaOH, then a gas produced on warming that turned damp red litmus blue.

Limited responses

- In limited responses, it was unclear whether NaOH was present at all stages of the test.
- Some responses described the test results with NaOH and ammonia, then heated the mixture. It was not then clear which reagent (if any) was included during the heating.
- Some responses gave no result on addition of NaOH. The solution was not warmed and/or the litmus paper was described as turning blue but it was not clear that it was the gas/ammonia that was the cause. The litmus paper would turn blue if dipped in the solution, so this distinction is required.
- Most issues with limited responses were due to the tests not being set out and explained clearly.
- Some responses described an additional test, usually for an anion such as chloride. No additional tests should be attempted.

(iii) Comprehensive responses

- Comprehensive responses used results from **(b)(i)** and **(b)(ii)** to identify the cation as ammonium/ NH_4^+ and the anions as sulfite/ SO_3^{2-} and unknown.

Limited responses

- Some responses gave the formula for ammonium as NH_4^+ .
- Some candidates did not carry out any tests to identify any other ions in **FB 8**, including chloride.

(iv) Comprehensive responses

- Many candidates used results from **(b)(i)** to correctly identify that **FB 9** was acidic, contained sulfate ions and was therefore H_2SO_4 .

Limited responses

- Some responses suggested that the anion was thiosulfate, perhaps recognising that acid produces sulfur slowly with thiosulfate, but confusing which reagent was **FB 9** and which was **FB 1**.
- Another common response was BaSO_4 .

(v) Comprehensive responses

- Good responses provided the reaction of H^+ with Mg to produce hydrogen gas with correct stoichiometry and state symbols or the production of barium sulfate from Ba^{2+} and SO_4^{2-} , again with correct stoichiometry and state symbols.

Limited responses

- Many responses were not ionic equations, using H_2SO_4 in the equation.
- State symbols were often omitted or incorrect (often $\text{BaSO}_4(\text{aq})$ rather than $\text{BaSO}_4(\text{s})$).
- The production of H_2 from a single H^+ was seen several times.
- No correct ionic equations using thiosulfate and acid to produce sulfur were reported.
- Some equations were provided for tests that had not been carried out, such as neutralisation.

CHEMISTRY

Paper 9701/41
A Level Structured Questions

Key messages

What candidates did well

- Many calculations were performed well with few rounding errors.
- The depiction of reaction mechanisms was correct, clear and unambiguous on many scripts.
- Many good answers were seen for the questions on proton NMR and carbon-13 NMR spectroscopy.

What candidates needed to improve

- The observations for the copper content of an alloy were not well known.
- The factors affecting the comparative magnitude of two lattice energies were not always known or stated without ambiguity.
- Where a question does not state that 'a buffer solution is made', it is necessary for the existence of a buffer solution to be recognised from its components. Having done this, the equations for adding H^+ ions or OH^- ions to the buffer solution can be deduced.
- An organic synthesis that gives the starting material and the final product must be carefully analysed to deduce the identity of the intermediate substances. All additional information provided should be taken into account.
- Where a question asks for a comparison between two compounds or two species – for example MgCO_3 and CaCO_3 or benzene and phenol – the use of 'it' should be avoided. The word 'it' nearly always leads to a limited response as 'it' is not clear what is being referenced.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates included the correct ionic charges and state symbols.

Limited responses

- One plus and one minus charge were seen, as were incorrect formulae for calcium sulfide in limited responses. The formula given on the question paper was the correct formula.

(b) Comprehensive responses

- Many candidates focused correctly on ionic bond formation.

Limited responses

- Limited responses restated the question with, 'it is exothermic'.
- The mention of the electrostatic attraction between the ions, without also stating that this process involves the ions coming together and bonding, was an insufficient answer.

(c) Comprehensive responses

- The two key factors – ionic charge and ionic radius – were focused on by some candidates.
- The ions that were being discussed and compared were specified and written with correct charges, e.g. the radius of Mg^{2+} was compared with that of Ca^{2+} and the radius of O^{2-} was compared with that of S^{2-} .

Limited responses

- Many candidates concentrated on descriptions of group trends without describing the factors involved.
- Some responses described the effect of nuclear charge rather than ionic charge.

(d)(i) Comprehensive responses

- Many candidates specified the two changes correctly.

Limited responses

- Where the energy changes were specified without precision – for example, ‘the enthalpy change of atomisation of chloride’ – this was not sufficient.
- Some candidates incorrectly identified the electron affinity of chloride ions.

(ii) Comprehensive responses

- Many candidates knew that they had to double the value for the enthalpy change of formation of chloride ions and were able to manipulate the three numbers algebraically to reach the correct answer.

Limited responses

- The answer -400 kJ mol^{-1} was often seen; this results from the use of -243 rather than (-2×243) .
- Other incorrect answers were reached after incorrect algebra. The manipulation of positive and negative numbers was incorrectly performed on a large number of scripts.

(e) Comprehensive responses

- A good calculation was provided by many. This included correct conversion of the temperature to Kelvin and a correct Gibbs equation. Most candidates knew that a negative value of ΔG means that a reaction is feasible at that temperature.

Limited responses

- The use of G , Gibbs or Gibbs free energy is insufficient. The term that must be calculated is ΔG , or the Gibbs free energy change.
- Some candidates calculated the value of ΔG as zero at 669 K. They did not go on to demonstrate numerically that it becomes negative above this temperature.
- The expression ‘ ΔG is more negative’ was seen; this is inferior to ‘ ΔG is negative’.

(f) Comprehensive responses

- Many candidates were able to state the explanation clearly and unambiguously.

Limited responses

- References were made to ionic radius or radii without specifying that the radii of Ca^{2+} and Mg^{2+} were being referred to.
- The use of ‘it’ in a question that asks for a comparison between two compounds or two species nearly always leads to a limited response as it is not clear what is being referenced.

Question 2

(a)(i) Comprehensive responses

- Many gave a correct expression with carefully drawn square brackets.

Limited responses

- Some answers were seen with round brackets, or with electric charges outside brackets.
- The minus sign was sometimes omitted.

(ii) Comprehensive responses

- Many gave a correct expression with carefully drawn square brackets.

Limited responses

- Some answers were seen with round brackets, or with electric charges outside brackets.
- Some candidates gave 1×10^{-14} , which is a value, not a mathematical definition.

(b)(i) Comprehensive responses

- Many candidates were able to demonstrate the correct use of the 10^x function and remembered the inclusion of the minus sign.

Limited responses

- Incorrect answers sometimes included misplacement of the decimal point, or incorrect use of standard form.
- 1.25×10^{-3} was a rounding error seen in some cases.

(ii) Comprehensive responses

- Many candidates used the K_a expression correctly.

Limited responses

- Methods were seen in which the assumption $(H^+) = (CH_3CH_2CH_2COO^-)$ was not made. It was very difficult to reach a correct answer after this.

(c)(i) Comprehensive responses

- Clear annotation of the mathematical method was very important here. This was seen on a small number of scripts. Where clear annotation was used, it appeared to help the candidate to reach the correct answer.
- Candidates who used the K_a expression were more likely to reach the correct answer or at least get part of the way there.

Limited responses

- Choosing to use the Henderson-Hasselbalch equation effectively made the question much more difficult.
- Many candidates did not show they appreciated that mixing two solutions inevitably involves the dilution of both.
- Many candidates showed working that alternated between the use of concentrations, and the use of amounts in moles, without clear annotations to explain what they were doing.

(ii) Comprehensive responses

- Many candidates appreciated that this involves adding H^+ ions to a buffer containing $CH_3CH_2CH_2COO^-$ ions and went on to write a correct equation.

Limited responses

- Attempts were seen to write an equation for the reaction between H^+ ions and $CH_3CH_2CH_2COOH$.
- Some candidates did not appreciate that solution **B** was a buffer and attempted an equation for the acidic hydrolysis of an ester.

(iii) Comprehensive responses

- Many candidates appreciated that this involves adding OH^- ions to a buffer containing $CH_3CH_2CH_2COOH$ and went on to write a correct equation.

Limited responses

- There were some responses showing similar misunderstandings to those seen in **(c)(ii)**.

(d) Comprehensive responses

- Many candidates appreciated the importance of the two chlorine atoms, their electronegative properties and consequent weakening of the O–H bond.
- A smaller number of good answers were seen that described the stabilisation of the anion formed when the chlorinated acid ionises.

Limited responses

- Answers that focused on the positive inductive effects of the alkyl groups, without reference to the chlorine atoms, were incomplete.
- The description of the bond that is weakened as ‘the –OH bond’ or ‘the C–O–H bond’ was ambiguous.

Question 3

(a) Comprehensive responses

- Many correct answers were seen.

Limited responses

- Some errors were seen in the overall order.

(b) Comprehensive responses

- Most candidates were able to calculate the rate constant.

Limited responses

- Units such as $\text{mol}^{-2} \text{dm}^6 \text{s}^{-1}$ and $\text{mol}^2 \text{dm}^{-6} \text{s}^{-1}$ were seen.

(c) (i) Comprehensive responses

- Many good answers were seen, giving the overall order as first order and specifying that the concentration of NO is constant, or almost constant.

Limited responses

- Some responses specified that the order with respect to H_2 was first order, without identifying that as the overall order.

(ii) Comprehensive responses

- Many correct answers were seen.

Limited responses

- Rounding errors were seen in the calculation of half-life.

(d) (i) Comprehensive responses

- Many candidates could deduce the reactants and products of step 2.

Limited responses

- Some responses were incorrect as they resulted in totals for steps 1, 2 and 3 that did not add up to the equation for the overall reaction.

(ii) Comprehensive responses

- Many good answers were seen focusing on the absence of H_2 in step 1, while this substance is present in the rate equation.

Limited responses

- Some responses focused on N_2O_2 as the product of step 1.
- Some responses stated that 'step 1 is not the slow step'. This is not a possible deduction from the information given in the question up to this point.

Question 4

(a) Comprehensive responses

- Many candidates gave the complete answer.

Limited responses

- Both the Nernst equation and the Gibbs equation were attempted by some.
- The more common omissions from partially correct attempts were the minus sign and 'cell'.

(b) Comprehensive responses

- The equation was usually correct.

Limited responses

- Some unbalanced equations were seen.
- Some candidates did not give the $E^\ominus_{\text{cell}}$ to two decimal places.

(c) Comprehensive responses

- The correct atoms or ions were seen on some scripts.

Limited responses

- Many candidates gave incorrect species.
- Some responses included an oxidised and a reduced species on the same part of the answer line, for example Cu^{2+}/Cu .

(d) Comprehensive responses

- The correct species were seen on some scripts.

Limited responses

- Some candidates gave the correct species the wrong way round.
- Some responses included an oxidised and a reduced species on the same answer line, for example V^{2+}/V .

- (e)** There was an error in **Question 4(e)**, which stated that oxygen is discharged at the cathode rather than at the anode. This has been corrected in the published version of the paper. To ensure that no candidates were disadvantaged by this error, full marks were awarded to all candidates for this question.

Question 5

(a) Comprehensive responses

- Many candidates knew that this is because of a similarity in energy of 3d and 4s orbitals.

Limited responses

- Definitions of transition elements, for example their behaviour as catalysts, were seen in some responses.

(b) Comprehensive responses

- Many candidates were able to describe the electronic configurations correctly.

Limited responses

- The electronic configuration for the Co atom was sometimes given as $3d^9$.
- Commonly seen incorrect electronic configurations for the Co^{2+} ion included $3d^7$ and $4s^1 3d^6$.

(c) Comprehensive responses

- Many good answers were seen. Characteristics of these answers included:
 - good descriptions of d-orbital splitting
 - use of correct vocabulary such as electron promotion or electron excitation
 - description of the complementary colour as either reflected or transmitted
 - a focus on the frequency or wavelength absorbed.

Limited responses

- Some answers missed out one or more of the three components of the answer.
- Some responses described the complementary colour as being emitted.

(d) Comprehensive responses

- The colour change was described as blue to pink.
- The equation gave $(\text{Co}(\text{H}_2\text{O})_6)^{2+}$ as one of the products.

Limited responses

- The colour change was described as pink to blue, dark blue to light blue, or some other incorrect combination of colours.
- The equation gave Cl_2 as one of the products or was not balanced for H_2O .

(e) (i) Comprehensive responses

- Some correct observations, including an off-white precipitate in a brown solution, were seen on a minority of scripts.

Limited responses

- Many responses included effervescence as an observation.
- Many responses described the iodine formed as violet coloured.

(ii) Comprehensive responses

- A small number of responses knew that starch is the indicator and that it changes from blue-black to colourless at the end-point.

Limited responses

- Many responses included acid-base indicators or MnO_4^- .
- Of those responses that began correctly with starch, some described the colour change at the end-point as brown to black or colourless to black.

(iii) Comprehensive responses

- Redox was commonly seen.

Limited responses

- Ligand exchange was seen on a small number of scripts.
- Reduction, without reference to oxidation, was seen on a small number of scripts.

(iv) Comprehensive responses

- A minority of very good responses were seen featuring excellent annotation and a well laid-out calculation.
- The stoichiometry included in the equations in the question was used correctly.
- The A_r value of copper was used correctly in many responses.

Limited responses

- Some responses were poorly laid out and included no annotation.
- The M_r value of HNO_3 or the formula mass of $\text{Cu}(\text{NO}_3)_2$ were used in some responses.

Question 6

(a) Comprehensive responses

- The correct answer had several components – two lone pairs, donated to form coordinate bonds, to a metal atom or ion – which were seen on many responses.

Limited responses

- Some responses described ‘two pairs of lone pairs’; this is not the same as two lone pairs.

(b) (i) Comprehensive responses

- $(\text{Fe}(\text{C}_2\text{O}_4)_3)^{3-}$ was the most commonly seen response.

Limited responses

- $(\text{FeC}_2\text{O}_4)^{3-}$, $(\text{Fe}(\text{C}_2\text{O}_4)_3)^{3+}$ and $(\text{FeC}_2\text{O}_4)^+$ were seen in some responses.

(ii) Comprehensive responses

- A large proportion of responses showed correct use of three-dimensional diagrams to describe the two isomers.

Limited responses

- Some responses only depicted one isomer.
- Some responses used no three-dimensional bonds, or made incorrect use of three-dimensional bonds, in the context of a diagram of an octahedral complex.
- Some responses depicted three or four structures; this meant that some of the structures drawn were repetitions of structures already drawn.

(iii) **Comprehensive responses**

- Many responses stated 'optical'.

Limited responses

- Some responses incorrectly stated 'geometrical' or '*cis-trans*'.

(c) **Comprehensive responses**

- Characteristics of comprehensive responses were:
 - expressions the right way up
 - carefully drawn square brackets
 - correct charges inside the square brackets.

Limited responses

- The most commonly seen inaccuracies were:
 - no charges on ions
 - expressions the wrong way up
 - no 4th power of (I⁻)
 - units of mol⁴ dm⁻¹² after a correct K_{stab} expression.

Question 7

(a) (i) **Comprehensive responses**

- Three components were all included in a comprehensive answer:
 - both acid formulae correct
 - both acids concentrated
 - a temperature in the correct range as stated in the syllabus.

Limited responses

- Some responses included 'reflux'. If the reaction mixture is heated under reflux, a significant amount of dinitrobenzene will form.

(ii) **Comprehensive responses**

- Two components were both included in a comprehensive answer:
 - either HNO₂ or NaNO₂ + HCl
 - a temperature between 0 °C and 10 °C.

Limited responses

- Some responses included the NO₃⁻ ion but not the NO₂⁻ ion.
- Some responses included 'heat' or 'warm'; this is incompatible with the correct temperature.

(iii) **Comprehensive responses**

- A small number of correct answers – benzenediazonium chloride or phenyldiazonium chloride – were seen.

Limited responses

- Answers that were considered limited include benzodiazonium chloride, benzyldiazonium chloride and diazonium chloride.

(b) (i) **Comprehensive responses**

- Many correct answers that recognised the number of hybridized carbon atoms of each type were seen.

Limited responses

- Some responses did not recognise the three sp³ hybridised carbon atoms of the side chain of G.

(ii) Comprehensive responses

- Many correct answers that recognised the number of different environments for carbon atoms in **G** were seen.

Limited responses

- The most commonly seen incorrect answers were 5 and 7.

(iii) Comprehensive responses

- A comprehensive response not only included the dipole, a curly arrow from the C=O bond to the O, and a curly arrow from the O to the H⁺, but also included a lone pair on the O.

Limited responses

- Some responses did not include the dipole.
- Some responses had a curly arrow from the H⁺ back towards the propanone.

(iv) Comprehensive responses

- Three components were all included in a comprehensive answer:
 - a curly arrow from the delocalised p electrons in phenol going directly to the C⁺ of the electrophile
 - the intermediate **K** was drawn with:
 - one + charge only
 - this + charge was in the right place
 - the broken delocalised p system was shown, including all of the carbon atoms that were part of the phenol molecule except for the sp³ hybridised carbon atom
 - a correct C(CH₃)₂OH side chain in the correct place
 - one hydrogen atom bonded to the sp³ hybridised carbon atom.
 - a curly arrow from the hydrogen atom bonded to the sp³ hybridised carbon atom going into the delocalised p system.

Limited responses

- In limited responses, the first curly arrow pointed to the O of the electrophile, not to the C⁺ of the electrophile.
- Sometimes the intermediate **K** was shown with two or more + charges.
- The + charge of the intermediate **K** was close to the sp³ hybridised carbon atom.
- The curly arrow from the hydrogen atom bonded to the sp³ hybridised carbon atom did not reach the delocalised p system.

(v) Comprehensive responses

- Many very good responses were seen, using clear, specific language to specify and describe all four components of the answer. Components of these comprehensive answers included:
 - the oxygen atom in phenol has lone pairs of electrons
 - one of these lone pairs is delocalised into the delocalised p system
 - this causes the delocalised p system to become more electron-rich.

Limited responses

- Some responses stated that benzene is more reactive than phenol toward an electrophile.
- Some responses specified that phenol causes more polarisation of the electrophile, but here the electrophile has a full + charge and does not need polarisation.
- Imprecise attempts to describe 'increased electron charge density in the delocalised p system' were present in some limited responses.

(c) (i) Comprehensive responses

- The structure of **H** was drawn correctly and the equation was balanced.

Limited responses

- In some responses, only one bromine atom was substituted into the ring of **H**.
- Sometimes two bromine atoms were substituted into the ring of **H** but on the wrong carbon atoms.
- Some responses showed four bromine atoms substituted into the ring of **H**.
- Occasionally, the equation was unbalanced.

(ii) Comprehensive responses

- Electrophilic substitution was often given as the answer.

Limited responses

- All other mechanisms were seen in responses.
- Some responses described reaction types that are not mechanisms.

Question 8

(a) (i) Comprehensive responses

- Many equations with correct substances, correctly balanced, were seen.

Limited responses

- CH_3COOCl was sometimes seen as a product.
- A very small number of equations were seen in which two CH_3COOH molecules reacted with each SOCl_2 molecule.

(ii) Comprehensive responses

- PCl_3 and PCl_5 were seen in most responses.

Limited responses

- NaCl was seen on a very small number of responses.

(iii) Comprehensive responses

- The correct structure was seen in a small number of responses.

Limited responses

- Ethanamide was seen in many responses. It would be very difficult to make substance **M** from ethanamide in step 3.

(iv) Comprehensive responses

- The correct structure was seen in a small number of responses.

Limited responses

- Ammonia was a common answer.

(v) Comprehensive responses

- Both addition-elimination and nucleophilic addition-elimination were seen in comprehensive answers.

Limited responses

- Condensation was seen in some responses. While it is true that step 2 is a condensation reaction, this is not the name of the mechanism.

(vi) Comprehensive responses

- LiAlH_4 will perform this reduction reaction successfully.

Limited responses

- $\text{Sn} + \text{conc HCl}$, heated under reflux, was seen in a number of responses.

(b) (i) Comprehensive responses

- Many candidates identified the splitting patterns and spelt them correctly.
- The splitting pattern of proton **u** was correctly identified by many as a multiplet, heptet or septet.

Limited responses

- The splitting pattern of proton **u** was sometimes loosely described as 'many peaks' or a 'seventet' rather than as a multiplet, heptet or septet.

(ii) Comprehensive responses

- A response that could be considered comprehensive identified or described carefully:
 - the solvent being discussed in each part of the answer
 - the number of peaks seen in each solvent
 - the NH functional group which is responsible for the difference in the number of peaks
 - the reason why the NH functional group does not give a peak in D₂O.

Limited responses

- The expression 'D₂O substitutes for the NH proton' is limited; 'D substitutes for the NH proton when D₂O is the solvent' is comprehensive.
- The use of 'it' made it unclear which solvent was being described.

Question 9

(a) Comprehensive responses

- A small proportion of candidates were able to:
 - select the two substances with stereoisomers, **P** and **Q**
 - draw the two optical isomers of **P** with the correct use of three-dimensional bonds
 - draw **Q** with the double bond that confers stereoisomerism on this molecule
 - name the two types of stereoisomerism in the correct places.

Limited responses

- The errors resulting in a limited response included:
 - choosing **R**, which does not have stereoisomers
 - drawing structures of **P** which were planar
 - drawing structural isomers of **Q**, for example NH₂CHC(NH₂)COOH.

(b)(i) Comprehensive responses

- The pH at which an amino acid exists as a zwitterion was specified on many scripts.
- The pH at which an amino acid has no overall charge was also a comprehensive response.

Limited responses

- Some responses described the amino acid as 'uncharged' at its isoelectric point.
- Some responses did not state that the isoelectric point is a pH value.

(ii) Comprehensive responses

- Such responses showed care and precision:
 - each structure drawn showed the correct groups either protonated or deprotonated according to the pH values in the headings of **Table 9.2** and the isoelectric point of each substance given in **Table 9.1**
 - the protonation or deprotonation was shown correctly

Limited responses

- NH groups in **T** or NH₂ groups in **U** were shown protonated twice at pH 4.0, leading to ions with 2+ charges.
- **T** was shown as a zwitterion at pH 5.5.
- On some scripts, **Table 9.2** was completed as if pH 4.0 is the pH at which all COOH groups are deprotonated and pH 8.0 is the pH at which all NH and NH₂ are protonated.

(c)(i) Comprehensive responses

- In many responses, the structure was fully correct with all amide links shown correctly displayed.

Limited responses

- A small number of responses showed the amide links with an extra oxygen atom, so they were rendered as –CO–O–NH–.
- A small number of responses drew a section of a polypeptide, with trailing bonds, rather than a tripeptide.
- A very small number of responses drew a **P–R** dipeptide rather than a **P–R–P** tripeptide.

(ii) Comprehensive responses

- 'Hydrolysis' was the answer seen on most scripts.

Limited responses

- A small number of responses stated 'addition' or 'condensation'.

(iii) Comprehensive responses

- 'Condensation' was the answer seen on most scripts.

Limited responses

- 'Addition' was the most commonly seen limited response.

CHEMISTRY

Paper 9701/42 A Level Structured Questions

Key messages

What candidates did well

- Some candidates responded appropriately to command words and followed instructions carefully.
- Many candidates showed a good knowledge of a wide range of chemistry topics.
- Many candidates set out the calculations clearly, labelling each of the steps.
- Many candidates were able to draw clear, accurate mechanisms using the correct terminology.

What candidates needed to improve

- Working should be shown clearly when answering questions involving calculations. The numbers should be linked to some text.
- Chemical equations, ionic equations and half-equations should always be balanced for substances and charge.
- If a candidate wishes to change an answer, they must cross out their original answer completely and a new answer should be written. If there is insufficient space to write their replacement answer, blank pages on the question paper can be utilised with clear indication as to where the answer is written.
- Candidates are advised to take care when writing words that could be read in more than one way – for example, exothermic or endothermic. This also happens with numbers; 1 and 2 can be written in a similar way, as can 4 and 9. Responses must be written in a legible way and must be unambiguous.

Comments on specific questions

Question 1

(a) (i) Comprehensive responses

- Most candidates gave two chemical properties of transition elements.

Limited responses

- Some candidates gave a physical property, for example high density, high melting points.

(ii) Comprehensive responses

- Most candidates could correctly explain that transition elements have variable oxidation states due to d and s sub-shells/orbitals having similar energy.

Limited responses

- Some candidates gave a reason for why transition elements can form complex ions.

(b) (i) Comprehensive responses

- Many candidates correctly completed the electrons-in-boxes diagrams.

Limited responses

- Some candidates incorrectly had paired 4s electrons or had an incorrect electronic structure.

(ii) Comprehensive responses

- Almost all candidates knew the type of bonding involved between a ligand and a transition element ion.

Limited responses

- Occasionally, hydrogen bonding and ionic bonding were suggested.

(c) Comprehensive responses

- Most candidates understood that the reason transition elements can form complexes was due to vacant d-orbitals that are energetically accessible.

Limited responses

- Some candidates did not explain that the d-orbitals needed to be completely empty and gave an answer in terms of partially filled d-orbitals.

(d)(i) Comprehensive responses

- Nearly all candidates gave NaOH or NH_3 as the reagent and stated a suitable reaction type.

Limited responses

- Very few errors were seen.

(ii) Comprehensive responses

- Many candidates gave a correct equation and most could recognise that the reaction type was ligand exchange.

Limited responses

- Some candidates were unable to balance the equation correctly, often giving $6\text{H}_2\text{O}$ as their product instead of $3\text{H}_2\text{O}$ and 3OH^- .
- Occasionally, the charge on the hydroxide ion was omitted.

(e) Comprehensive responses

- Most candidates were able to correctly draw two three-dimensional structures of the complex.

Limited responses

- Some candidates drew one correct isomer but repeated the same structure.
- A few candidates were unable to give a correct three-dimensional structure.
- Some incorrect formulas for ligands were seen like O_2H .

(f) (i) Comprehensive responses

- Some candidates gave a correct equation to show that Fe^{3+} in solution is acidic.

Limited responses

- The explanation of the ability of the Fe^{3+} to polarise/weaken the O-H bonds in the water ligands was less well understood.
- Many candidates suggested that the acidity was linked with a reaction of the complex with OH^- , instead of deprotonation of the water ligand.

(ii) Comprehensive responses

- Most candidates knew that the Fe^{3+} ion was more acidic than Fe^{2+} .

Limited responses

- Few suggested that the Fe^{3+} ion was more acidic than Fe^{2+} due to the higher charge of Fe^{3+} .
- Some candidates gave answers in terms of Fe^{3+} being more acidic as it reacted with more OH^- ions, or releasing more H^+ ions.
- A few candidates had issues with the concept that greater acidity means lower pH.

(g) Comprehensive responses

- Many candidates appreciated that the d-orbitals are full and hence no electron promotion takes place and that there is no light absorbed in the visible spectrum.

Limited responses

- Many candidates thought that the d-orbitals in the complex were still degenerate and this is why no d-d* transition was possible.

(h) Comprehensive responses

- Many candidates answered this question well and clearly set out their calculation using appropriate significant figures.
- Most candidates were able to use the titration results to calculate the moles of $\text{C}_2\text{O}_4^{2-}$ and the moles of $\text{H}_2\text{C}_2\text{O}_4$.
- Many candidates showed clear working, which enabled credit to be awarded for the moles of $\text{Na}_2\text{C}_2\text{O}_4$ and the final percentage by mass of $\text{Na}_2\text{C}_2\text{O}_4$ in the mixture.

Limited responses

- The key step in the calculation was to appreciate that the manganate ions would oxidise both the ethanedioate ions in sodium ethanedioate and ethanedioic acid dihydrate. Many candidates did not carry out the correct subtraction. Some others used the incorrect M_r of 90 (instead of 134).

Question 2

(a) Comprehensive responses

- Many candidates answered this question well and they were able to correctly use curly arrows to show the movement of electron pairs in this mechanism.

Limited responses

- Some candidates were not accurate with the positioning of their curly arrows, for example starting at the O^- and going to the C–O bond.
- Some candidates suggested the C=O bond would break in this process.

(b) Comprehensive responses

- This question was well answered by candidates.
- Many correctly linked the polarisation of the carbonate ion by the smaller cations to the trend in thermal stability.

Limited responses

- Some candidates discussed the ionic bond strength of the compounds rather than the weakening of the CO bond in the carbonate anions.

(c) Comprehensive responses

- Candidates answered this question well by correctly linking this trend to ΔH_{latt} , ΔH_{hyd} and ΔH_{sol} .

Limited responses

- Some candidates suggested that ΔH_{latt} became less exothermic to a greater extent than ΔH_{hyd} .
- Some others stated that ΔH_{sol} decreased, which is ambiguous.

(d)(i) Comprehensive responses

- Most candidates correctly deduced the correct expression and the corresponding units of K_{sp} .

Limited responses

- Some candidates included $[\text{Mg}(\text{OH})_2]$ as the denominator in their expressions.
- Some gave the incorrect charge on the magnesium ion or omitted charges completely in the expression, for example $K_{\text{sp}} = [\text{Mg}][\text{OH}]^2$.

(ii) Comprehensive responses

- Many candidates accurately calculated the OH^- concentration from the given pH value.

Limited responses

- Some candidates only used the pH value $10^{-10.35}$ in their calculation and stated $[\text{H}^+]$ equals $[\text{OH}^-]$ so the answer is 4.47×10^{-11} .

(iii) Comprehensive responses

- This question was well answered.
- Many successfully performed the correct calculation using their answers to **Questions 2(d)(i) and 2(d)(ii)**.

Limited responses

- Many candidates did not calculate $[\text{Mg}^{2+}]$ correctly, often multiplying their answer to **Question 2(d)(ii)** by two (instead of dividing by two).

Question 3

(a) (i) Comprehensive responses

- Most candidates were able to correctly deduce the orders of reaction of $[\text{CH}_3\text{OH}]$ and $[\text{H}^+]$ linking the data to appropriate experiments.
- Many rate equations were correct and some included the value for the rate constant k .

Limited responses

- Some candidates had difficulty calculating an order for $[\text{CH}_3\text{CHO}]$.
- Many suggested the order with respect to $[\text{CH}_3\text{CHO}]$ was zero order.

(ii) Comprehensive responses

- Most candidates could correctly state the units of the rate constant for their rate equation.

Limited responses

- Some candidates omitted s^{-1} from the units.

(iii) Comprehensive responses

- Most candidates were able to calculate the initial rate of experiment 5.

Limited responses

- Some candidates multiplied the three values given in the table to give 0.0156.

(b) Comprehensive responses

- Most candidates gave a correct equation for step 1.
- Some were also able to write a correct equation for step 3.

Limited responses

- Some candidates omitted a carbon atom in these structures.
- Some included H^+ as an additional reactant in step 3.

(c) Comprehensive responses

- Many candidates were able to describe the mode of action of a heterogeneous catalyst.

Limited responses

- Some described the bonds weakening **between** reactants (instead of in the reactants) and reactants being desorbed rather than products.

Question 4

(a) Comprehensive responses

- Many candidates could give a comprehensive definition of partition coefficient.

Limited responses

- Some candidates omitted 'at equilibrium' or 'concentration' in their answer.

(b) Comprehensive responses

- Many candidates were able to calculate the initial moles of $(\text{COOH})_2$ and moles of NaOH.
- Some candidates correctly calculated the value of K_{pc} .

Limited responses

- Many candidates omitted the step to calculate the moles of $(\text{COOH})_2$ in water.

(c) Comprehensive responses

- Most candidates were able to suggest how the two K_{pc} values compare to each other.
- Only some candidates were able to give full reasoning.

Limited responses

- Many candidates did not adequately link the higher value of K_{pc} for butanedioic acid to the increased non-polar hydrocarbon chain, which reduces its solubility in water.

Question 5

(a) Comprehensive responses

- The definition of 'standard electrode potential' was generally well answered.

Limited responses

- Some candidates defined in terms of 'cells' rather than half cells/electrodes.
- Some omitted one of the conditions in their answer.

(b)(i) Comprehensive responses

- Many candidates were able to write two correct equations and gave the correct explanation using E_{cell} or in terms of a comparable $E^\ominus$.

Limited responses

- Some candidates had difficulty with the equations and just quoted two half-equations from **Table 5.1**.
- Limited responses used E for E_{cell} with the numerical value of cell potential.

(ii) Comprehensive responses

- Some candidates answered this question correctly in terms of high activation energy.

Limited responses

- Some candidates answered in terms of non-standard conditions or incorrectly stated that ΔG would be positive.

(iii) Comprehensive responses

- Many candidates were able to complete a labelled diagram of the electrochemical cell.

Limited responses

- Some candidates omitted one of the constituents of the solution containing redox system 2 or used an incorrect electrode.

(c) Comprehensive responses

- Many candidates were able to correctly calculate the standard cell potential, E_{cell} .

Limited responses

- Common errors included:
 - 2.23×10^{-3} from use of -645.6 instead of -645600
 - -2.23 sign error in their Gibbs equation.

Question 6

(a) (i) Comprehensive responses

- Many candidates gave the expected observations of white precipitate and decolourisation of aqueous bromine.

Limited responses

- Some candidates only gave one of the expected observations.
- Some candidates included steamy fumes or effervescence in their observations.

(ii) Comprehensive responses

- Most candidates correctly gave the structure of 2,4,6-tribromophenol.

Limited responses

- Some candidates omitted the OH and gave the structure of 1,3,5-tribromobenzene.

(b) Comprehensive responses

- Many answers correctly identified phenol as more acidic, explaining the delocalisation of the oxygen lone pair into the benzene ring and the subsequent weakening of the O–H bond.

Limited responses

- Some answers described the π electron ring in benzene as electron withdrawing and omitted that the lone pair on oxygen was delocalised into the ring.

(c) (i) Comprehensive responses

- Many candidates were able to draw a clear, accurate repeat unit.

Limited responses

- Some common errors included:
 - omission of continuation bonds or hydrogen atoms in their repeat unit
 - drawing two or more repeat units
 - the OH group substituted in the incorrect ring position.

(ii) Comprehensive responses

- Many candidates were able to draw a clear structure showing two repeat units with an ester linkage.

Limited responses

- Some candidates gave structures showing three repeat units.
- Some candidates drew skeletal repeat units with continuation bonds drawn as straight lines. This was not accepted unless the line was intersected by a bracket, as it could represent a methyl group.

(d) Comprehensive responses

- Many candidates were able to draw the correct structures of the two organic products.

Limited responses

- Some candidates drew structures with two alcohol groups at the end of the substituent chain when reacting with LiAlH_4 .
- A common error was retaining the benzene ring structure when using H_2 and a Ni catalyst.

(e) (i) Comprehensive responses

- Many candidates were able to draw both products **D** and **E**, depending on their chosen synthetic route.

Limited responses

- Some candidates incorrectly suggested **D** was 2-hydroxybenzoic acid or 2-hydroxybenzonitrile.

(ii) Comprehensive responses

- Most candidates selected appropriate reagents and conditions based on their answers in (e)(i).

Limited responses

- The most common errors were omission of 'heat' with KMnO_4 in the oxidation reaction and suggesting the acylation reaction needed CH_3COCl and AlCl_3 .

Question 7

(a) (i) Comprehensive responses

- Many candidates stated clearly that plane polarised light was rotated.

Limited responses

- Some candidates stated that the molecule was rotated by (plane polarised) light.

(ii) Comprehensive responses

- Most candidates correctly stated that this is a mixture containing equal amounts of optical isomers.

Limited responses

- Some candidates only stated there was a mixture of isomers, omitting 'optical'.

(b) (i) Comprehensive responses

- Most candidates could correctly explain the meaning of the isoelectric point.

Limited responses

- Some candidates omitted 'pH' and just stated 'point', which was insufficient.

(ii) Comprehensive responses

- Most candidates gave the correct structure of alanine at pH 10.

Limited responses

- The most common error was to protonate the carboxylate group or the amine group, giving $-\text{COOH}$ and $-\text{NH}_3^+$ respectively.

(c) Comprehensive responses

- This question was well answered by candidates. Most were able to correctly represent a peptide linkage.

Limited responses

- The tripeptide structure was often represented as a polypeptide.

(d) (i) Comprehensive responses

- Many candidates were able to correctly identify both the carboxylic acid **G** and the acyl chloride **H** organic products.

Limited responses

- Some candidates incorrectly showed a $-\text{NO}_2$ group in their structures.

(ii) Comprehensive responses

- Most candidates correctly identified a reagent for step 2, but steps 1 and 3 were less commonly correct.

Limited responses

- Some common errors included:
 - in step 1, using CH_3COOH with HCl instead of CH_3COCl
 - in step 2, using HCl instead of a viable chlorinating agent
 - in step 3, using phenol instead of benzene.

Question 8

(a) Comprehensive responses

- Only a small number gave the correct name as tetramethylsilane.

Limited responses

- Some common errors included:
 - stating the reference as TMS instead of its full name
 - errors associated with the abbreviation TMS, for example use of tri- (instead of tetra-) and silicate (instead of silane).

(b)(i) Comprehensive responses

- Most candidates gave the correct answer.

Limited responses

- Very few errors were seen.

(ii) Comprehensive responses

- Many fully correct answers were seen.

Limited responses

- Some candidates stated the splitting pattern for x was a 'quartet'.
- Some responses used 'duplet' for doublet.

(iii) Comprehensive responses

- Many candidates could identify the chemical shift range and explain why the spectrum in CDCl_3 contains one more peak.

Limited responses

- The most common incorrect answer for the chemical shift range was 1.0 – 5.0 ppm.
- Some candidates stated that $-\text{NH}$ would exchange with D_2O instead of a proton exchanging with deuterium.

(c) Comprehensive responses

- Most candidates were able to identify the carboxylate salt.

Limited responses

- 2-aminoethanol was less commonly seen.
- Common errors included methylpropanoic acid and 2-aminoethyl chloride.

Question 9

(a) Comprehensive responses

- Many candidates were able to give the correct order of the relative basicity of these compounds and then clearly explain the reasoning for this order.

Limited responses

- Some answers discussed the lone pair on N but omitted its ability to accept a proton or referred to the lone pair attracting a proton.
- Some others neglected to explain that the lone pair needed to be on the nitrogen atom.

(b)(i) Comprehensive responses

- Most candidates knew the reaction conditions and reagents needed for this synthesis.

Limited responses

- Some candidates used 'dilute' acids instead of concentrated acids.
- A few candidates thought that tin metal was used as a catalyst.

(ii) Comprehensive responses

- Many candidates could balance this equation correctly.

Limited responses

- Some candidates incorrectly used H^+ instead of the required $[H]$.

(c)(i) Comprehensive responses

- Many candidates were able to correctly give the formula of the diazonium ion.

Limited responses

- Some candidates placed the positive charge on the incorrect nitrogen atom in their structure.

(ii) Comprehensive responses

- Most candidates correctly identified the reagents for step 1.

Limited responses

- Some candidates stated that nitric acid was used instead of nitrous acid in step 1.
- Step 2 was less commonly given than step 1.
- Many candidates omitted the phenolic structure in step 2 and provided only a formula, which was ambiguous.
- The alkaline conditions in step 2 were also often omitted.

CHEMISTRY

Paper 9701/41
A Level Structured Questions

Key messages

What candidates did well

- Many calculations were performed well with few rounding errors.
- The depiction of reaction mechanisms was correct, clear and unambiguous on many scripts.
- Many good answers were seen for the questions on proton NMR and carbon-13 NMR spectroscopy.

What candidates needed to improve

- The observations for the copper content of an alloy were not well known.
- The factors affecting the comparative magnitude of two lattice energies were not always known or stated without ambiguity.
- Where a question does not state that 'a buffer solution is made', it is necessary for the existence of a buffer solution to be recognised from its components. Having done this, the equations for adding H^+ ions or OH^- ions to the buffer solution can be deduced.
- An organic synthesis that gives the starting material and the final product must be carefully analysed to deduce the identity of the intermediate substances. All additional information provided should be taken into account.
- Where a question asks for a comparison between two compounds or two species – for example MgCO_3 and CaCO_3 or benzene and phenol – the use of 'it' should be avoided. The word 'it' nearly always leads to a limited response as 'it' is not clear what is being referenced.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates included the correct ionic charges and state symbols.

Limited responses

- One plus and one minus charge were seen, as were incorrect formulae for calcium sulfide in limited responses. The formula given on the question paper was the correct formula.

(b) Comprehensive responses

- Many candidates focused correctly on ionic bond formation.

Limited responses

- Limited responses restated the question with, 'it is exothermic'.
- The mention of the electrostatic attraction between the ions, without also stating that this process involves the ions coming together and bonding, was an insufficient answer.

(c) Comprehensive responses

- The two key factors – ionic charge and ionic radius – were focused on by some candidates.
- The ions that were being discussed and compared were specified and written with correct charges, e.g. the radius of Mg^{2+} was compared with that of Ca^{2+} and the radius of O^{2-} was compared with that of S^{2-} .

Limited responses

- Many candidates concentrated on descriptions of group trends without describing the factors involved.
- Some responses described the effect of nuclear charge rather than ionic charge.

(d)(i) Comprehensive responses

- Many candidates specified the two changes correctly.

Limited responses

- Where the energy changes were specified without precision – for example, ‘the enthalpy change of atomisation of chloride’ – this was not sufficient.
- Some candidates incorrectly identified the electron affinity of chloride ions.

(ii) Comprehensive responses

- Many candidates knew that they had to double the value for the enthalpy change of formation of chloride ions and were able to manipulate the three numbers algebraically to reach the correct answer.

Limited responses

- The answer -400 kJ mol^{-1} was often seen; this results from the use of -243 rather than (-2×243) .
- Other incorrect answers were reached after incorrect algebra. The manipulation of positive and negative numbers was incorrectly performed on a large number of scripts.

(e) Comprehensive responses

- A good calculation was provided by many. This included correct conversion of the temperature to Kelvin and a correct Gibbs equation. Most candidates knew that a negative value of ΔG means that a reaction is feasible at that temperature.

Limited responses

- The use of G , Gibbs or Gibbs free energy is insufficient. The term that must be calculated is ΔG , or the Gibbs free energy change.
- Some candidates calculated the value of ΔG as zero at 669 K. They did not go on to demonstrate numerically that it becomes negative above this temperature.
- The expression ‘ ΔG is more negative’ was seen; this is inferior to ‘ ΔG is negative’.

(f) Comprehensive responses

- Many candidates were able to state the explanation clearly and unambiguously.

Limited responses

- References were made to ionic radius or radii without specifying that the radii of Ca^{2+} and Mg^{2+} were being referred to.
- The use of ‘it’ in a question that asks for a comparison between two compounds or two species nearly always leads to a limited response as it is not clear what is being referenced.

Question 2

(a)(i) Comprehensive responses

- Many gave a correct expression with carefully drawn square brackets.

Limited responses

- Some answers were seen with round brackets, or with electric charges outside brackets.
- The minus sign was sometimes omitted.

(ii) Comprehensive responses

- Many gave a correct expression with carefully drawn square brackets.

Limited responses

- Some answers were seen with round brackets, or with electric charges outside brackets.
- Some candidates gave 1×10^{-14} , which is a value, not a mathematical definition.

(b)(i) Comprehensive responses

- Many candidates were able to demonstrate the correct use of the 10^x function and remembered the inclusion of the minus sign.

Limited responses

- Incorrect answers sometimes included misplacement of the decimal point, or incorrect use of standard form.
- 1.25×10^{-3} was a rounding error seen in some cases.

(ii) Comprehensive responses

- Many candidates used the K_a expression correctly.

Limited responses

- Methods were seen in which the assumption $(H^+) = (CH_3CH_2CH_2COO^-)$ was not made. It was very difficult to reach a correct answer after this.

(c)(i) Comprehensive responses

- Clear annotation of the mathematical method was very important here. This was seen on a small number of scripts. Where clear annotation was used, it appeared to help the candidate to reach the correct answer.
- Candidates who used the K_a expression were more likely to reach the correct answer or at least get part of the way there.

Limited responses

- Choosing to use the Henderson-Hasselbalch equation effectively made the question much more difficult.
- Many candidates did not show they appreciated that mixing two solutions inevitably involves the dilution of both.
- Many candidates showed working that alternated between the use of concentrations, and the use of amounts in moles, without clear annotations to explain what they were doing.

(ii) Comprehensive responses

- Many candidates appreciated that this involves adding H^+ ions to a buffer containing $CH_3CH_2CH_2COO^-$ ions and went on to write a correct equation.

Limited responses

- Attempts were seen to write an equation for the reaction between H^+ ions and $CH_3CH_2CH_2COOH$.
- Some candidates did not appreciate that solution **B** was a buffer and attempted an equation for the acidic hydrolysis of an ester.

(iii) Comprehensive responses

- Many candidates appreciated that this involves adding OH^- ions to a buffer containing $CH_3CH_2CH_2COOH$ and went on to write a correct equation.

Limited responses

- There were some responses showing similar misunderstandings to those seen in **(c)(ii)**.

(d) Comprehensive responses

- Many candidates appreciated the importance of the two chlorine atoms, their electronegative properties and consequent weakening of the O–H bond.
- A smaller number of good answers were seen that described the stabilisation of the anion formed when the chlorinated acid ionises.

Limited responses

- Answers that focused on the positive inductive effects of the alkyl groups, without reference to the chlorine atoms, were incomplete.
- The description of the bond that is weakened as ‘the –OH bond’ or ‘the C–O–H bond’ was ambiguous.

Question 3

(a) Comprehensive responses

- Many correct answers were seen.

Limited responses

- Some errors were seen in the overall order.

(b) Comprehensive responses

- Most candidates were able to calculate the rate constant.

Limited responses

- Units such as $\text{mol}^{-2} \text{dm}^6 \text{s}^{-1}$ and $\text{mol}^2 \text{dm}^{-6} \text{s}^{-1}$ were seen.

(c) (i) Comprehensive responses

- Many good answers were seen, giving the overall order as first order and specifying that the concentration of NO is constant, or almost constant.

Limited responses

- Some responses specified that the order with respect to H_2 was first order, without identifying that as the overall order.

(ii) Comprehensive responses

- Many correct answers were seen.

Limited responses

- Rounding errors were seen in the calculation of half-life.

(d) (i) Comprehensive responses

- Many candidates could deduce the reactants and products of step 2.

Limited responses

- Some responses were incorrect as they resulted in totals for steps 1, 2 and 3 that did not add up to the equation for the overall reaction.

(ii) Comprehensive responses

- Many good answers were seen focusing on the absence of H_2 in step 1, while this substance is present in the rate equation.

Limited responses

- Some responses focused on N_2O_2 as the product of step 1.
- Some responses stated that 'step 1 is not the slow step'. This is not a possible deduction from the information given in the question up to this point.

Question 4

(a) Comprehensive responses

- Many candidates gave the complete answer.

Limited responses

- Both the Nernst equation and the Gibbs equation were attempted by some.
- The more common omissions from partially correct attempts were the minus sign and 'cell'.

(b) Comprehensive responses

- The equation was usually correct.

Limited responses

- Some unbalanced equations were seen.
- Some candidates did not give the $E^\ominus_{\text{cell}}$ to two decimal places.

(c) Comprehensive responses

- The correct atoms or ions were seen on some scripts.

Limited responses

- Many candidates gave incorrect species.
- Some responses included an oxidised and a reduced species on the same part of the answer line, for example Cu^{2+}/Cu .

(d) Comprehensive responses

- The correct species were seen on some scripts.

Limited responses

- Some candidates gave the correct species the wrong way round.
- Some responses included an oxidised and a reduced species on the same answer line, for example V^{2+}/V .

- (e)** There was an error in **Question 4(e)**, which stated that oxygen is discharged at the cathode rather than at the anode. This has been corrected in the published version of the paper. To ensure that no candidates were disadvantaged by this error, full marks were awarded to all candidates for this question.

Question 5

(a) Comprehensive responses

- Many candidates knew that this is because of a similarity in energy of 3d and 4s orbitals.

Limited responses

- Definitions of transition elements, for example their behaviour as catalysts, were seen in some responses.

(b) Comprehensive responses

- Many candidates were able to describe the electronic configurations correctly.

Limited responses

- The electronic configuration for the Co atom was sometimes given as $3d^9$.
- Commonly seen incorrect electronic configurations for the Co^{2+} ion included $3d^7$ and $4s^1 3d^6$.

(c) Comprehensive responses

- Many good answers were seen. Characteristics of these answers included:
 - good descriptions of d-orbital splitting
 - use of correct vocabulary such as electron promotion or electron excitation
 - description of the complementary colour as either reflected or transmitted
 - a focus on the frequency or wavelength absorbed.

Limited responses

- Some answers missed out one or more of the three components of the answer.
- Some responses described the complementary colour as being emitted.

(d) Comprehensive responses

- The colour change was described as blue to pink.
- The equation gave $(\text{Co}(\text{H}_2\text{O})_6)^{2+}$ as one of the products.

Limited responses

- The colour change was described as pink to blue, dark blue to light blue, or some other incorrect combination of colours.
- The equation gave Cl_2 as one of the products or was not balanced for H_2O .

(e) (i) Comprehensive responses

- Some correct observations, including an off-white precipitate in a brown solution, were seen on a minority of scripts.

Limited responses

- Many responses included effervescence as an observation.
- Many responses described the iodine formed as violet coloured.

(ii) Comprehensive responses

- A small number of responses knew that starch is the indicator and that it changes from blue-black to colourless at the end-point.

Limited responses

- Many responses included acid-base indicators or MnO_4^- .
- Of those responses that began correctly with starch, some described the colour change at the end-point as brown to black or colourless to black.

(iii) Comprehensive responses

- Redox was commonly seen.

Limited responses

- Ligand exchange was seen on a small number of scripts.
- Reduction, without reference to oxidation, was seen on a small number of scripts.

(iv) Comprehensive responses

- A minority of very good responses were seen featuring excellent annotation and a well laid-out calculation.
- The stoichiometry included in the equations in the question was used correctly.
- The A_r value of copper was used correctly in many responses.

Limited responses

- Some responses were poorly laid out and included no annotation.
- The M_r value of HNO_3 or the formula mass of $\text{Cu}(\text{NO}_3)_2$ were used in some responses.

Question 6

(a) Comprehensive responses

- The correct answer had several components – two lone pairs, donated to form coordinate bonds, to a metal atom or ion – which were seen on many responses.

Limited responses

- Some responses described ‘two pairs of lone pairs’; this is not the same as two lone pairs.

(b) (i) Comprehensive responses

- $(\text{Fe}(\text{C}_2\text{O}_4)_3)^{3-}$ was the most commonly seen response.

Limited responses

- $(\text{FeC}_2\text{O}_4)^{3-}$, $(\text{Fe}(\text{C}_2\text{O}_4)_3)^{3+}$ and $(\text{FeC}_2\text{O}_4)^+$ were seen in some responses.

(ii) Comprehensive responses

- A large proportion of responses showed correct use of three-dimensional diagrams to describe the two isomers.

Limited responses

- Some responses only depicted one isomer.
- Some responses used no three-dimensional bonds, or made incorrect use of three-dimensional bonds, in the context of a diagram of an octahedral complex.
- Some responses depicted three or four structures; this meant that some of the structures drawn were repetitions of structures already drawn.

(iii) Comprehensive responses

- Many responses stated 'optical'.

Limited responses

- Some responses incorrectly stated 'geometrical' or '*cis-trans*'.

(c) Comprehensive responses

- Characteristics of comprehensive responses were:
 - expressions the right way up
 - carefully drawn square brackets
 - correct charges inside the square brackets.

Limited responses

- The most commonly seen inaccuracies were:
 - no charges on ions
 - expressions the wrong way up
 - no 4th power of (I⁻)
 - units of mol⁴ dm⁻¹² after a correct K_{stab} expression.

Question 7

(a) (i) Comprehensive responses

- Three components were all included in a comprehensive answer:
 - both acid formulae correct
 - both acids concentrated
 - a temperature in the correct range as stated in the syllabus.

Limited responses

- Some responses included 'reflux'. If the reaction mixture is heated under reflux, a significant amount of dinitrobenzene will form.

(ii) Comprehensive responses

- Two components were both included in a comprehensive answer:
 - either HNO₂ or NaNO₂ + HCl
 - a temperature between 0 °C and 10 °C.

Limited responses

- Some responses included the NO₃⁻ ion but not the NO₂⁻ ion.
- Some responses included 'heat' or 'warm'; this is incompatible with the correct temperature.

(iii) Comprehensive responses

- A small number of correct answers – benzenediazonium chloride or phenyldiazonium chloride – were seen.

Limited responses

- Answers that were considered limited include benzodiazonium chloride, benzyldiazonium chloride and diazonium chloride.

(b) (i) Comprehensive responses

- Many correct answers that recognised the number of hybridized carbon atoms of each type were seen.

Limited responses

- Some responses did not recognise the three sp³ hybridised carbon atoms of the side chain of G.

(ii) Comprehensive responses

- Many correct answers that recognised the number of different environments for carbon atoms in **G** were seen.

Limited responses

- The most commonly seen incorrect answers were 5 and 7.

(iii) Comprehensive responses

- A comprehensive response not only included the dipole, a curly arrow from the C=O bond to the O, and a curly arrow from the O to the H⁺, but also included a lone pair on the O.

Limited responses

- Some responses did not include the dipole.
- Some responses had a curly arrow from the H⁺ back towards the propanone.

(iv) Comprehensive responses

- Three components were all included in a comprehensive answer:
 - a curly arrow from the delocalised p electrons in phenol going directly to the C⁺ of the electrophile
 - the intermediate **K** was drawn with:
 - one + charge only
 - this + charge was in the right place
 - the broken delocalised p system was shown, including all of the carbon atoms that were part of the phenol molecule except for the sp³ hybridised carbon atom
 - a correct C(CH₃)₂OH side chain in the correct place
 - one hydrogen atom bonded to the sp³ hybridised carbon atom.
 - a curly arrow from the hydrogen atom bonded to the sp³ hybridised carbon atom going into the delocalised p system.

Limited responses

- In limited responses, the first curly arrow pointed to the O of the electrophile, not to the C⁺ of the electrophile.
- Sometimes the intermediate **K** was shown with two or more + charges.
- The + charge of the intermediate **K** was close to the sp³ hybridised carbon atom.
- The curly arrow from the hydrogen atom bonded to the sp³ hybridised carbon atom did not reach the delocalised p system.

(v) Comprehensive responses

- Many very good responses were seen, using clear, specific language to specify and describe all four components of the answer. Components of these comprehensive answers included:
 - the oxygen atom in phenol has lone pairs of electrons
 - one of these lone pairs is delocalised into the delocalised p system
 - this causes the delocalised p system to become more electron-rich.

Limited responses

- Some responses stated that benzene is more reactive than phenol toward an electrophile.
- Some responses specified that phenol causes more polarisation of the electrophile, but here the electrophile has a full + charge and does not need polarisation.
- Imprecise attempts to describe 'increased electron charge density in the delocalised p system' were present in some limited responses.

(c) (i) Comprehensive responses

- The structure of **H** was drawn correctly and the equation was balanced.

Limited responses

- In some responses, only one bromine atom was substituted into the ring of **H**.
- Sometimes two bromine atoms were substituted into the ring of **H** but on the wrong carbon atoms.
- Some responses showed four bromine atoms substituted into the ring of **H**.
- Occasionally, the equation was unbalanced.

(ii) Comprehensive responses

- Electrophilic substitution was often given as the answer.

Limited responses

- All other mechanisms were seen in responses.
- Some responses described reaction types that are not mechanisms.

Question 8

(a) (i) Comprehensive responses

- Many equations with correct substances, correctly balanced, were seen.

Limited responses

- CH_3COOCl was sometimes seen as a product.
- A very small number of equations were seen in which two CH_3COOH molecules reacted with each SOCl_2 molecule.

(ii) Comprehensive responses

- PCl_3 and PCl_5 were seen in most responses.

Limited responses

- NaCl was seen on a very small number of responses.

(iii) Comprehensive responses

- The correct structure was seen in a small number of responses.

Limited responses

- Ethanamide was seen in many responses. It would be very difficult to make substance **M** from ethanamide in step 3.

(iv) Comprehensive responses

- The correct structure was seen in a small number of responses.

Limited responses

- Ammonia was a common answer.

(v) Comprehensive responses

- Both addition-elimination and nucleophilic addition-elimination were seen in comprehensive answers.

Limited responses

- Condensation was seen in some responses. While it is true that step 2 is a condensation reaction, this is not the name of the mechanism.

(vi) Comprehensive responses

- LiAlH_4 will perform this reduction reaction successfully.

Limited responses

- $\text{Sn} + \text{conc HCl}$, heated under reflux, was seen in a number of responses.

(b) (i) Comprehensive responses

- Many candidates identified the splitting patterns and spelt them correctly.
- The splitting pattern of proton **u** was correctly identified by many as a multiplet, heptet or septet.

Limited responses

- The splitting pattern of proton **u** was sometimes loosely described as 'many peaks' or a 'seventet' rather than as a multiplet, heptet or septet.

(ii) Comprehensive responses

- A response that could be considered comprehensive identified or described carefully:
 - the solvent being discussed in each part of the answer
 - the number of peaks seen in each solvent
 - the NH functional group which is responsible for the difference in the number of peaks
 - the reason why the NH functional group does not give a peak in D₂O.

Limited responses

- The expression 'D₂O substitutes for the NH proton' is limited; 'D substitutes for the NH proton when D₂O is the solvent' is comprehensive.
- The use of 'it' made it unclear which solvent was being described.

Question 9

(a) Comprehensive responses

- A small proportion of candidates were able to:
 - select the two substances with stereoisomers, **P** and **Q**
 - draw the two optical isomers of **P** with the correct use of three-dimensional bonds
 - draw **Q** with the double bond that confers stereoisomerism on this molecule
 - name the two types of stereoisomerism in the correct places.

Limited responses

- The errors resulting in a limited response included:
 - choosing **R**, which does not have stereoisomers
 - drawing structures of **P** which were planar
 - drawing structural isomers of **Q**, for example NH₂CHC(NH₂)COOH.

(b)(i) Comprehensive responses

- The pH at which an amino acid exists as a zwitterion was specified on many scripts.
- The pH at which an amino acid has no overall charge was also a comprehensive response.

Limited responses

- Some responses described the amino acid as 'uncharged' at its isoelectric point.
- Some responses did not state that the isoelectric point is a pH value.

(ii) Comprehensive responses

- Such responses showed care and precision:
 - each structure drawn showed the correct groups either protonated or deprotonated according to the pH values in the headings of **Table 9.2** and the isoelectric point of each substance given in **Table 9.1**
 - the protonation or deprotonation was shown correctly

Limited responses

- NH groups in **T** or NH₂ groups in **U** were shown protonated twice at pH 4.0, leading to ions with 2+ charges.
- **T** was shown as a zwitterion at pH 5.5.
- On some scripts, **Table 9.2** was completed as if pH 4.0 is the pH at which all COOH groups are deprotonated and pH 8.0 is the pH at which all NH and NH₂ are protonated.

(c)(i) Comprehensive responses

- In many responses, the structure was fully correct with all amide links shown correctly displayed.

Limited responses

- A small number of responses showed the amide links with an extra oxygen atom, so they were rendered as –CO–O–NH–.
- A small number of responses drew a section of a polypeptide, with trailing bonds, rather than a tripeptide.
- A very small number of responses drew a **P–R** dipeptide rather than a **P–R–P** tripeptide.

(ii) Comprehensive responses

- 'Hydrolysis' was the answer seen on most scripts.

Limited responses

- A small number of responses stated 'addition' or 'condensation'.

(iii) Comprehensive responses

- 'Condensation' was the answer seen on most scripts.

Limited responses

- 'Addition' was the most commonly seen limited response.

CHEMISTRY

Paper 9701/44
A Level Structured Questions

Key messages

What candidates did well

- Many candidates showed good knowledge across a wide range of chemistry topics.
- Candidates responded appropriately to command words and tended to follow instructions carefully.
- Many candidates were able to draw organic reaction mechanisms clearly and correctly.
- Many candidates set out their calculations clearly and labelled each step.
- Candidates tackled the rate equation question particularly well.

What candidates needed to improve

- Candidates should avoid stylised handwriting, and care should be used to represent letters (including capital letters) and numbers in a way that is unambiguous.
- Candidates should cross through incorrect work and provide a replacement answer. If there is not enough space to do this, candidates should use the blank page in the question paper or extra paper. This work should be clearly identified with the question number. Candidates should never overwrite incorrect work as it makes the correct work unclear.
- Definitions need to be recalled correctly and completely. For example, there is a difference between 'an electron is added to one mole of atoms' and 'one mole of electrons is added to one mole of atoms'.
- 3D drawings should correctly represent the 3D shape of the species. If the 3D shape is incorrect, optical isomers cannot be assessed.
- Use of the terms 'increase' or 'decrease' are, in many cases, ambiguous. Candidates should be encouraged to use 'more positive' or 'more negative', especially when discussing electrode potentials. Use of 'more exothermic' or 'more endothermic' is acceptable if appropriate, e.g. for enthalpy/energy changes, but not for Gibbs free energy or entropy changes.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates were able to identify that the gas released was oxygen.

Limited responses

- Hydrogen was often given as the wrong gas.
- Some equations were unbalanced or included the hydrogen ion or missed out the hydroxide ions.
- Some candidates produced both hydrogen and oxygen at the same electrode.

(b)(i) Comprehensive responses

- Many candidates managed to use the data to correctly calculate the number of moles of bromine.

Limited responses

- A few candidates calculated the amount of bromine atoms rather than molecules of Br₂.

(ii) Comprehensive responses

- Most candidates managed to correctly calculate the volume of Br₂ gas under the given conditions.

Limited responses

- Some candidates did not give a value to three significant figures or forgot that the ideal gas equation gives volumes in m³ rather than dm³.

(c) Comprehensive responses

- Many candidates correctly gave various stages in their working and good answers were common.

Limited responses

- Some candidates either used *L*, the Avogadro number, in their calculations, or *F*, the Faraday constant, which incorporates *L*.
- Some candidates used the *M_r* of NaCl rather than the *A_r* of Na.

Question 2

(a) Comprehensive responses

- Many candidates were able to define strong and weak acids correctly.

Limited responses

- Some candidates missed that acids were proton donors.
- Some candidates used incorrect words for dissociated, such as 'dissolved' or 'delocalised'.

(b) Comprehensive responses

- Some candidates were able to identify the acid-base pairs and write their correct formulae.

Limited responses

- Most candidates included H₂O, H₃O⁺, OH⁻ or H⁺.
- Some candidates used incorrect formulae, for example missing out a carbon to give HOOCOOH rather than HOCCOOH.

(c) (i) Comprehensive responses

- Most candidates answered well, giving reagents that would react to give calcium ethanoate, and wrote a correct balanced equation for the reaction.

Limited responses

- Some candidates used Ca²⁺ or a calcium salt as a reactant.
- A few candidates used calcium ethanoate as a reactant.

(ii) Comprehensive responses

- Most candidates gave a comprehensive definition of a buffer solution.

Limited responses

- Some candidates neglected to mention pH or discussed the solution's response to the addition of moderate, rather than small, amounts of acid or base.
- Some candidates thought that buffer solutions keep pH constant, which is not the case.

(iii) Comprehensive responses

- Most candidates could write equations to show the buffer solution's response to the addition of acid or base.

Limited responses

- Some candidates made the equations more complicated than they needed to be, with the addition of just H⁺ or OH⁻.

(d) Comprehensive responses

- Some candidates included all working steps, correctly labelled, which helped them towards the correct answer.
- Various methods were seen, working through pH and through pOH.

Limited responses

- Some candidates did not correctly consider the effect of two OH^- ions and multiplied (H^+) by two instead. This results in the pH becoming more negative rather than more positive.

(e) (i) Comprehensive responses

- Some correct definitions of K_{pc} were seen.

Limited responses

- Some candidates did not mention 'ratio' or 'at equilibrium' in their definition.
- Some candidates confused 'solute' and 'solvent'.

(ii) Comprehensive responses

- Most candidates gave the correct answer.

Limited responses

- A few candidates gave the inverse of the correct answer, having not read the question carefully, which stated that the answer should be less than 1.00.

(iii) Comprehensive responses

- Some candidates gave clear, well-ordered responses, which showed a good understanding of the question.
- Some candidates started by determining the polarity of **A**, then the polarity of cyclohexane and then the solubility of **A** in cyclohexane, making it clear what they were referring to at each step.

Limited responses

- Most candidates were unable to clearly articulate their answer.
- Some candidates lacked understanding of polarity, thinking that water was non-polar.
- Some candidates were unclear about the solute and solvent when talking about dissolving.

Question 3

(a) Comprehensive responses

- Most candidates correctly completed the table.

Limited responses

- A few candidates did not get the correct orders of reaction.

(b) (i) Comprehensive responses

- Most candidates correctly completed the table.

Limited responses

- A few candidates did not get the correct power of ten in the rate column.

(ii) Comprehensive responses

- Most candidates were able to calculate the rate constant and give correct units.

Limited responses

- Some candidates gave the units as $\text{mol dm}^{-3} \text{s}^{-1}$ rather than $\text{mol}^{-1} \text{dm}^3 \text{s}^{-1}$, being either unable to calculate them from their expression or confusing them with the units for the rate.

(c) Comprehensive responses

- Most candidates were able to calculate the half-life correctly.

Limited responses

- A few candidates used log rather than ln, or inverted the equation needed to calculate the half-life.

(d) Comprehensive responses

- Many fully correct responses were seen, starting with the rate-determining step as step one, matching the rate equation and simply combining all the elements into one intermediate.

Limited responses

- Some candidates used charged species without balancing the equation for charge, for instance generating a neutral species and F^- in step 1.
- A few candidates introduced reactants into step 1 that were not in the overall equation, such as O_2 or F_2 .

Question 4

(a) (i) Comprehensive responses

- Comprehensive responses gave a clear definition, such as 'one mole of electrons added to one mole of gaseous atoms'.

Limited responses

- Some candidates omitted moles in their answer.
- Some candidates omitted gaseous when mentioning atoms.
- A few candidates generated cations rather than anions.
- A few candidates used incorrect terms such as the energy 'needed' when electron affinity values are negative.

(ii) Comprehensive responses

- Some candidates were able to talk correctly about atoms gaining electrons, with the trend identified and the explanation including attraction of the nucleus to the incoming electron.

Limited responses

- Many candidates used ionic radii rather than atomic radii in their answer.
- For many candidates it was unclear that the nucleus was attracting the electron, or that it was the incoming electron being attracted.
- A few candidates gave the trend in terms of the molecules rather than the atoms.

(b) Comprehensive responses

- Most candidates could choose appropriate numbers for the lattice enthalpies.
- Many candidates compared both ions in both parts of the question, referring to charge and/or radius correctly, as appropriate.

Limited responses

- Some candidates compared only one of the two ions involved in each part of the question.
- Some candidates talked in terms of charge density rather than radius and charge. Changes in charge density are consequences of changes in radius and/or charge.
- Some candidates referred to atomic rather than ionic radius.

(c) (i) Comprehensive responses

- Many candidates quoted the full syllabus description.

Limited responses

- Some candidates gave the older definition of 'a measure of disorder', which is no longer accepted.
- Some candidates left out the word 'number'.

(ii) Comprehensive responses

- Most candidates correctly referred to the reduction in the number of gaseous particles.

Limited responses

- Some candidates did not see the importance of the state of the particles and only referred to the decrease in their number.
- Some candidates only stated that a reactant was gaseous, neglecting to mention that the product was solid.

(iii) Comprehensive responses

- Most candidates could see that the reaction became less spontaneous and could clearly explain why with correct references to the negative value of ΔS or the positive value of $T\Delta S$, and the subsequent effect on ΔG .

Limited responses

- Some candidates thought the reaction is more spontaneous with a more positive ΔG .
- Some candidates used incorrect terminology, such as 'more endothermic', when talking about the change to ΔG .
- Some candidates used the words increase or decrease, which were ignored.

Question 5

(a) (i) Comprehensive responses

- Most candidates recalled the equation and could balance it correctly.

Limited responses

- Some candidates were unable to balance the equation or could not give the correct formula for the nitrate.

(ii) Comprehensive responses

- Most candidates could describe the trend in the thermal stability of the nitrates correctly and explain it in terms of the radius of the cation and the polarisation of the anion.

Limited responses

- Some candidates were not clear what was being polarised.
- Some candidates thought the ionic bond between M^{2+} and the nitrate ion becomes stronger down the group.
- Many candidates talked about 'polarising power', which was ignored.

(b) (i) Comprehensive responses

- Some candidates simply compared the solubility of the sulfates.

Limited responses

- Many candidates discussed the solubilities in terms of the energy changes involved, which was not required here.
- Some candidates did not see that the sulfates, rather than the hydroxides, were being compared.

(ii) Comprehensive responses

- Many responses were concise, with some presented in bullet-point form, showing good recall of this part of the syllabus.

Limited responses

- Some candidates gave contradictory responses.

Question 6

(a) Comprehensive responses

- Many candidates quoted the full syllabus definition.

Limited responses

- Some candidates missed either 'metal' or 'atom/ion'.

(b)(i) Comprehensive responses

- Most candidates were able to deduce the numbers of the ligands in each species from the charges correctly.

Limited responses

- A few candidates reversed the numbers.

(ii) Comprehensive responses

- Almost all candidates could see that with six mono-dentate ligands, the coordination number would be six.

Limited responses

- A few candidates incorrectly thought the coordination number was 3.

(iii) Comprehensive responses

- Most candidates could draw a correct 3D octahedral shape.
- Most candidates knew the answer involved *cis* and *trans* isomers and could draw them correctly.

Limited responses

- Some candidates could not draw a correct 3D octahedral shape.
- Some candidates drew mirror images, thinking the isomers were optical.
- A few candidates repeated the same isomer as their second structure.

(iv) Comprehensive responses

- Many candidates could identify the isomerism correctly.

Limited responses

- Some candidates, especially those who drew mirror images in **6(b)(iii)**, thought **D** showed optical isomerism.

(c) (i) Comprehensive responses

- Some candidates could correctly give the syllabus definition of K_{stab} .

Limited responses

- Some candidates either missed the word 'equilibrium' or did not mention 'from ions' or 'in a solvent'.
- Some candidates tried to describe a ratio of concentrations (that is in the question) rather than give a definition.

(ii) Comprehensive responses

- Almost all candidates gave the correct units.

Limited responses

- A few candidates gave incorrect signs on the indices and put $\text{mol}^6 \text{dm}^{-18}$ rather than $\text{mol}^{-6} \text{dm}^{18}$.

(iii) Comprehensive responses

- Most candidates were able to rearrange the expression correctly, substitute the values from the question and evaluate to give the correct answer.

Limited responses

- A few candidates neglected to include the power of ten in their answer.

(iv) Comprehensive responses

- Most candidates were able to complete and balance the equation correctly.

Limited responses

- A few candidates were unable to balance the equation.

(v) Comprehensive responses

- Almost all candidates gave a correct type of reaction.

Limited responses

- A few candidates only put 'substitution', which is insufficient.

Question 7

(a) (i) Comprehensive responses

- Almost all candidates gave the correct angle and type of hybridisation.

Limited responses

- A few candidates thought the bond angle was 180° or 109.5° .

(ii) Comprehensive responses

- Most candidates knew that σ bonds resulted from head-on overlap of orbitals and π bonds resulted from lateral overlap of orbitals.
- Many candidates knew the answer and correctly identified both the hybrid orbitals involved and how they interacted.

Limited responses

- Many candidates did not read the question and included information about the C–H bond.

(b) (i) Comprehensive responses

- Many candidates could recall the reagent and conditions, including the temperature range, correctly.

Limited responses

- Some candidates did not recall that the sulfuric acid needed to be concentrated.
- Some candidates could not recall the temperature range and either gave a temperature outside the range or an open range (e.g. $T > 25^\circ\text{C}$).
- A few candidates used nitrous acid rather than nitric acid.

(ii) Comprehensive responses

- Almost all candidates saw that aniline was the product of reaction 2.

Limited responses

- A few candidates had $-\text{NH}_3$ as the side group.

(iii) Comprehensive responses

- Most candidates knew reaction 3 should be $<10^{\circ}\text{C}$ and reaction 4 should be $>10^{\circ}\text{C}$.
- Many candidates could recall the sequence of reactions that produces an azo ion and then converts it into a phenolic hydroxide group.

Limited responses

- Many candidates used nitrous acid and hydrochloric acid, which is unnecessary.
- Some candidates used nitric rather than nitrous acid or a nitrate rather than a nitrite ion.
- Some candidates reacted the azo group with aqueous sodium hydroxide rather than water without realising this would form the phenoxide ion rather than phenol.

(c) (i) Comprehensive responses

- Many could recall the steps in an electrophilic substitution reaction and drew clear, accurate diagrams of the intermediate and electron movements.

Limited responses

- Some candidates placed the positive charge too close to the sp^3 carbon in the intermediate or incorrectly began their curly arrow for breaking the C–H bond from the H atom rather than the bond.
- A few candidates gave the initial electron movement from the electrophile to the ring, rather than the correct way round.
- A few candidates gave HCl as their other product rather than the H^+ generated by their mechanism.

(ii) Comprehensive responses

- Most knew that CO_2 and H_2O were the products and went on to give a correctly balanced equation.

Limited responses

- Some candidates put various carboxylic acids in place of CO_2 .

(d) Comprehensive responses

- A few candidates saw that the iodoform reaction was appropriate and knew that alkaline iodine was added, followed by acid to protonate the carboxylate produced.

Limited responses

- Most candidates could not see that the iodoform reaction could be a synthetic route step.
- Some candidates did not combine the reagents for the iodoform reaction and so formed the carboxylate ion only.

Question 8

(a) Comprehensive responses

- Most candidates knew that TMS was responsible for the calibrant line at $\delta = 0$.

Limited responses

- Some candidates thought that the line was due to the solvent and then typically gave CDCl_3 .

(b) (i) Comprehensive responses

- Almost all candidates identified **Q** as the correct spectrum and could explain why, referring to both the Ar–H and Ar–OH peaks.

Limited responses

- Most candidates referred to the Ar–OH peak only without referencing the Ar–H peaks. The question asked for identification of the protons responsible for the peaks in the spectrum.

(ii) Comprehensive responses

- Almost all candidates could correctly name the splitting patterns shown by the two peaks and could also clearly explain why they arose.

Limited responses

- Some candidates were not clear that the hydrogens responsible for the splitting pattern were located on a neighbouring carbon.
- A few candidates appeared to look at the wrong spectrum.

(c) Comprehensive responses

- Most candidates made it clear that the –OH peak had disappeared and the H had been replaced by D.

Limited responses

- Many candidates knew that the –OH peak disappeared but could not clearly state why.
- Some candidates did not identify the peak that disappeared.

(d) Comprehensive responses

- Most candidates gave the correct order of acidity and explained carefully the effect of the group(s) around the acidic proton on the O–H bond strength in each compound, correctly linking it to the acidity.

Limited responses

- Some candidates used abbreviations such as EDG/EWG without defining them.
- Some candidates referred to the –OH bond strength rather than the OH or O–H bond strength.
- Some candidates did not refer to the lone pair on O in phenol as part of their answer.

Question 9

(a) Comprehensive responses

- Most candidates were able to deduce from the data both the directions of movement (if any) of the amino acids under the conditions given and the reason why.

Limited responses

- Some candidates gave only the directions of movement without explaining with the charges on the species.
- Many candidates talked about the pH being above, below or at the isoelectric point, which was unnecessary.

(b)(i) Comprehensive responses

- Many candidates could draw a correct 3D representation of a tetrahedral carbon with the correct groups around it and gave both optical isomers.

Limited responses

- Some candidates could not draw a correct 3D representation of a tetrahedral, commonly putting an in-plane bond between the two out-of-plane bonds.

(ii) Comprehensive responses

- Most candidates knew that this was a racemic mixture, or a racemate.

Limited responses

- Some candidates incorrectly referred to the mixture as ‘enantiomers’.

(iii) Comprehensive responses

- Many candidates knew that different enantiomers rotate the plane of polarised light differently and have different biological activity, recalling directly from the syllabus.

Limited responses

- Some candidates were unfamiliar with or could not recall the effect on plane polarised light.
- Some candidates referred to the efficacy of drugs or side effects.

(iv) Comprehensive responses

- Some candidates could see that the SOCl_2 would react with both the alcohol and the carboxylic acid groups to form the haloalkane and acyl chloride groups and could write a balanced equation for the reaction.

Limited responses

- Most candidates considered only the carboxylic acid group and ignored the alcohol group.
- Some candidates correctly reacted both groups but could not construct a balanced equation for the reaction.
- A few candidates thought a reaction with SOCl_2 formed H_2O rather than HCl .

Question 10

(a) Comprehensive responses

- A few candidates used their knowledge of naming diacids and acyl chlorides to give ethandioyl chloride.

Limited responses

- Most candidates gave incorrect answers such as ethanoyl dichloride or diethanoyl chloride.

(b)(i) Comprehensive responses

- Most candidates could draw a section of the polymer chain showing only one repeat unit and including the amide group correctly displayed.

Limited responses

- A few candidates omitted atoms, usually hydrogens.
- A few candidates did not use leading or trailing bonds in their diagrams.
- A few candidates did not realise that leading or trailing bonds in skeletal formulae are interpreted as methyl groups.

(ii) Comprehensive responses

- Most candidates knew that this was a condensation reaction producing amide groups.

Limited responses

- Some candidates thought that peptide bonds were formed, not understanding that this refers only to the joining of amino acids.
- A few candidates drew an amide group rather than naming it.

(c) Comprehensive responses

- Most candidates could see this was a reduction reaction and identified LiAlH_4 as a suitable reducing agent.

Limited responses

- A few candidates misunderstood the question and gave a dihalo compound.

(d) Comprehensive responses

- Some candidates correctly identified ammonia as the reagent, and heat and pressure as the conditions.

Limited responses

- Most candidates did not put pressure as a condition.
- Although a solvent was not required, ethanol was commonly seen.
- A few candidates incorrectly used water.

CHEMISTRY

Paper 9701/51 Planning, Analysis and Evaluation
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Key messages

What candidates did well

- Most candidates were able to identify apparatus suitable for carrying out a single step in an experimental method.
- Most candidates were able to identify why a fume cupboard is required to keep risks to a minimum.
- Some candidates showed an understanding of why a chosen procedure is effective.
- Most candidates were able to describe standard laboratory practice to ensure complete thermal decomposition.
- Most candidates were able to identify the independent variable in the experiment.
- Most candidates were able to calculate the percentage by mass of $\text{Ca}(\text{NO}_3)_2$ in mixture X.
- Most candidates were able to suggest how the percentage error in the measurement of mass could be reduced.
- Most candidates were able to use a given equation to calculate values to three significant figures.
- Most candidates were able to read the calibration graph to find the concentration for a given resistance reading.
- Some candidates were able to explain how a change to the gradient of a graph would change a conclusion drawn from the graph.

What candidates needed to improve

- Some candidates understood that, when a reason or explanation was requested, their response should be specific to the practical information provided rather than too general, for example in **Questions 1(c)** and **1(f)(ii)**. Candidates are recommended to read the information provided about each experiment carefully and use it when answering the questions.
- Candidates could improve on drawing diagrams. In drawing an apparatus to collect a gas by condensation, there should be a clear pathway from where the gas is generated, to an unsealed and cooled collection vessel without loss of the gas on the way. Using a sharp pencil and a ruler to produce a neat diagram and adding clear labels to the diagram is recommended.
- Some candidates are aware that significant figures should be carried through calculations without rounding until applying suitable rounding to the final answer. The number of significant figures given after rounding should match the number of significant figures of the data provided, unless the question specifies how many significant figures or decimal places are to be given.

Comments on specific questions

Question 1

(a) **Comprehensive responses**

- Many candidates identified a pipeclay triangle.

Limited responses

- Some candidates named a tripod, gauze or triangular holder.

(b) Comprehensive responses

- Some candidates recognised that the solid could jump out of the crucible on heating and referred to this as spitting.

Limited responses

- Some answers mentioned the loss of water.

(c) Comprehensive responses

- Some answers stated that a fume cupboard is used for hazardous/toxic gases or that NO_2 is a toxic gas.

Limited responses

- Some responses did not refer to either NO_2 or gas.
- A few candidates used harmful instead of hazardous or toxic.

(d)(i) Comprehensive responses

- Comprehensive responses gave the answer to three significant figures and included clear working.

Limited responses

- Some calculations were based on the assumption that all the gas released was NO_2 .
- Some candidates used some of the data from the table to calculate a mass which was assumed to be one of the solids. This calculated mass was converted to an amount in mol and then used along with the chemical equation to calculate an answer.
- Occasionally, an intermediate calculated value was rounded to too few significant figures.

(ii) Comprehensive responses

- Comprehensive responses presented the correct working as well as the numerical answer. For example, writing $(2 \times 0.005/17.81) \times 100\%$ is full working.

Limited responses

- Some candidates wrote 0.01 instead of 2×0.005 .
- Some candidates wrote 0.05 or 0.01 instead of 0.005.

(iii) Comprehensive responses

- Some candidates specified an increase in the mass of mixture **X**.

Limited responses

- Limited responses described collecting multiple readings and taking the average.
- Some candidates described changing the balance.
- Some answers specified an increase in $\text{Ca}(\text{NO}_3)_2$ alone.

(e) Comprehensive responses

- Some candidates gave the correct answer to three significant figures with clear working.

Limited responses

- Some answers did not account for the ratio of $\text{Ca}(\text{NO}_3)_2$ to NO_2 as 1 : 2 leading to a calculation of double the answer.

(f) (i) Comprehensive responses

- Comprehensive responses suggested that $\text{Ca}(\text{NO}_3)_2$ is reheated and then reweighed repeatedly until there is no change in mass.

Limited responses

- Limited responses included either the idea of heating or the idea of weighing to constant mass, not both.

(ii) Comprehensive responses

- A statement that the percentage by mass decreases supported by an explanation about how the mass of gas lost or the mass of solid remaining would change was given by some candidates.

Limited responses

- Limited answers did not refer to the mass of gas lost, for example writing 'not all NO₂ released' or omitted a reference to the 'gas' lost (or 'solid' remaining).
- Some answers only referred to the loss of NO₂ gas and did not include the loss of O₂.

(g) Comprehensive responses

- Comprehensive responses presented a neat diagram which showed an uninterrupted pathway from the test-tube to a collection vessel kept at a low enough temperature, without loss of NO₂ gas.
- These diagrams showed a way for the O₂ gas to escape from the apparatus without a build-up of pressure.

Limited responses

- Some diagrams showed a condenser with iced water as the coolant and angled downwards towards a suitably cooled collection vessel.
- Some condensers were drawn angled upwards or horizontally which would not allow the collection of NO₂.

Question 2

(a) Comprehensive responses

- Comprehensive responses suggested that outside light should not be allowed to reach the photocell detector.
- Some candidates suggested that the black box prevents internal reflections of the LED light reaching the photocell.

Limited responses

- Limited answers referred to other light without specifying what light.
- Some answers discussed absorbance of the solution without mentioning detecting the light.
- Some candidates gave general answers, for example, light from sunlight or laboratory lighting does not affect the results.

(b)(i) Comprehensive responses

- Some candidates completed the **Table 2.1** with correct relative absorbances which were calculated to three significant figures.

Limited responses

- Limited responses gave answers to two significant figures or truncated the final digit instead of rounding, for example writing 0.838 not 0.839 as the entry for the first row of **Table 2.1**.

(ii) Comprehensive responses

- Many candidates suggested distilled water.

Limited responses

- Some responses suggested water or starch solution alone.
- A few answers gave a piece of physics equipment which might be used when measuring resistance, such as an ohmmeter, ammeter or voltmeter.

(iii) Comprehensive responses

- Some candidates stated the concentration of I₃⁻.

Limited responses

- Limited responses referred to the concentration of I⁻ or the resistance of the photocell or the absorbance.

(iv) Comprehensive responses

- Well drawn graphs included five points plotted correctly to the nearest half square.
- These graphs had lines of best fit drawn through the origin with a sharp pencil and ignored the anomalous point completely.

Limited responses

- Graphs that were less well drawn were plotted without point 5, which was written in the **Table 2.1** with a different power of ten.
- Some graphs were plotted with point 4 at a concentration of $1.70 \times 10^{-6} \text{ mol dm}^{-3}$ instead of $1.52 \times 10^{-6} \text{ mol dm}^{-3}$.

(v) Comprehensive responses

- Some candidates circled the anomalous point and gave a valid reason.
- Good responses explained why the absorbance was higher than the value recorded, for example, because less than 10.0 cm^3 of solution was transferred from the boiling tube to the measuring cylinder.

Limited responses

- Limited answers only discussed the absorbance change or suggested mis-readings or faulty equipment.
- Some answers described how the anomalous point was selected from the graph.

(c) (i) Comprehensive responses

- Comprehensive responses suggested that all the I_3^- ions react with starch to form a coloured complex.
- Some candidates suggested that a full or complete reaction took place.

Limited responses

- Limited responses suggested that all the starch reacts.
- Some candidates suggested that the reaction reaches either equilibrium or an end-point.

(ii) Comprehensive responses

- Many candidates identified a 10 cm^3 volumetric pipette.

Limited responses

- Some candidates referred to a pipette, without specifying that it was volumetric.
- A few responses identified a burette, syringe or measuring cylinder.

(iii) Comprehensive responses

- Some candidates were able to calculate the absorbance correctly and gave their answer to three significant figures (0.640).
- Some candidates read the correct value of concentration from the plotted graph to the nearest half square and gave this answer to three significant figures. Three significant figures are expected because this matches the number of significant figures for the absorbance data in **Table 2.1**.

Limited responses

- A few candidates truncated the absorbance value of 0.6399 to 0.639.
- Some candidates stated the concentration value without the 10^{-6} factor.

(iv) Comprehensive responses

- Some candidates correctly multiplied their answer to **2c(iii)** by 0.015 and gave this to three significant figures.

Limited responses

- Some candidates multiplied their answer to **2(c)(iii)** by 0.010.
- A few candidates calculated the correct answer in the working and subsequently divided this by 3.

(v) Comprehensive responses

- Some candidates correctly divided their answer to **2c(iv)** by 7.5 and gave this to three significant figures.

Limited responses

- Some candidates gave their answer to the wrong power of ten, usually a factor of 10^3 out.

(vi) Comprehensive responses

- Comprehensive responses stated that calculations showed that the percentage uncertainties, when applied to the two given resistance values, gave ranges that did not overlap and led to the conclusion that the concentration of $O_3(g)$ in the air was different.

Limited responses

- Limited responses stated that calculations did not take into account that the percentage error applies to both values of resistance and applied the percentage error to only one value.
- Some candidates stated that calculations applied the percentage error to absorbance instead of resistance.

(viii) Comprehensive responses

- Some responses stated that the resistance of the photocell increases because the light has a longer path length through the solution.

Limited responses

- Limited responses stated that the resistance either stayed the same or decreased.
- Many candidates thought that the value of resistance stayed the same because the volume of the solution does not change.
- Some candidates stated that the value decreased because the surface area decreased.

(ix) Comprehensive responses

- Some candidates suggested that the concentration of I_3^- ions will be higher resulting in a lower percentage uncertainty.

Limited responses

- Limited answers did not provide a sufficiently detailed explanation or gave an explanation that was too general, for example stating that the percentage uncertainty is lower or that the accuracy is higher.
- Some candidates suggested that all the I^- ions react (with O_3).

CHEMISTRY

Paper 9701/52 Planning, Analysis and Evaluation
--

Key messages

What candidates did well

- Most calculations were carried out correctly.
- Many candidates were able to correctly plot the points on a graph and draw accurate lines of best fit.
- The majority of candidates knew how to collect a measured volume of a water-soluble gas.

What candidates needed to improve

- Candidates needed to take time to read carefully the question. For example, in **Question 1(a)(ii)** where the question told candidates that iodine was dissolved in methanol, many assumed distilled water was to be used.
- Some candidates did not read through the steps of an experiment carefully before answering questions on that step. For example, in **Question 1(b)(iii)** many suggested heating the crystals to dryness in step 6 when no heating took place in step 6.
- A common error when plotting a line of best fit was not indicating that a point was anomalous.

Comments on specific questions

Question 1

(a) (i) **Comprehensive responses**

- Most candidates correctly calculated the mass of iodine.

Limited responses

- A few candidates used the relative atomic mass of iodine in their calculation.

(ii) **Comprehensive responses**

- Most candidates gave full, accurate descriptions of the steps needed to prepare $I_2(\text{meth})$.

Limited responses

- Some candidates assumed distilled water would be the solvent instead of the stated methanol.

(b) (i) **Comprehensive responses**

- A few candidates suggested that if direct heating with a Bunsen burner did not occur, then there must be a flammable substance present.

Limited responses

- Many candidates suggested (thermal) decomposition may occur or that the conical flask would crack.

(ii) **Comprehensive responses**

- Many candidates suggested the precipitate was washed to remove methanol-soluble impurities from the residue.

Limited responses

- A few candidates suggested that washing would remove solids.

(iii) Comprehensive responses

- A few candidates suggested continually allowing the crystals to dry without heating until constant mass was achieved.

Limited responses

- Most candidates did not read that the crystals were not heated in step 6 and suggested heating the crystals until constant mass was reached.

(iv) Comprehensive responses

- A few candidates described how dry crystals could be obtained in step 6.
- Many were able to produce a results table.

Limited responses

- Most candidates suggested using a second container such as a weighing boat.

(c) (i) Comprehensive responses

- Most candidates stated that the burette was rinsed with $0.00200 \text{ mol dm}^{-3}$ sodium thiosulfate solution.

Limited responses

- Limited responses suggested rinsing with distilled water.

(ii) Comprehensive responses

- Most candidates could calculate the percentage error and showed the correct expression in their working.

Limited responses

- Some candidates did not show the correct expression in their working or assumed that half a graduation of a burette was 0.0005 cm^3 .

(iii) Comprehensive responses

- Most candidates correctly selected two concordant titres to determine a mean titre.

Limited responses

- Some candidates selected all three or all four titres to determine a mean titre, therefore including non-concordant values.

(iv) Comprehensive responses

- Most candidates correctly determined the number of moles of sodium thiosulfate in the mean titre.
- Many correctly applied the stoichiometry to find the number of moles of iodine in 10.0 cm^3 of solution **A** and used this to determine the number of moles of iodine in 100.0 cm^3 of solution **A**.
- Most candidates correctly determined the mass of iodine to three significant figures.

Limited responses

- Some candidates used the volume of solution **A** (10.0 cm^3) to determine the number of moles of sodium thiosulfate.
- Some candidates used the relative atomic mass of iodine in their calculation.

(v) Comprehensive responses

- Some candidates calculated the value of n as an integer by determining the ratio of moles of I_2 to $(\text{CH}_3)_4\text{NI}$.

Limited responses

- Many candidates did not utilise the mass of $(\text{CH}_3)_4\text{NI}$ given in the question or gave answers that were not integers.

Question 2

(a) Comprehensive responses

- Many candidates drew a gas syringe attached to the side arm and sealed the flask with a bung.

Limited responses

- Some candidates did not apply the information given in the question and attempted to collect CO₂ by displacement of water or used the side arm to introduce reagents.

(b) Comprehensive responses

- Most candidates identified the independent variable.

Limited responses

- Some candidates suggested the concentration or the volume of either aqueous solution.

(c) Comprehensive responses

- Some candidates suggested that the volume of CO₂ was read at a time less than 1000 s.

Limited responses

- Many candidates gave vague answers such as 'the time was measured early', which focused on time being measured rather than the volume of CO₂.

(d) Comprehensive responses

- Most candidates drew a correct second curve.

Limited responses

- Some candidates drew second curves that produced in excess of 10 cm³ of CO₂ or finished producing CO₂ at a similar time to the original curve.

(e) (i) Comprehensive responses

- Most candidates recorded the values correctly to two decimal places.

Limited responses

- A few candidates did not round correctly or used fewer than two decimal places.

(ii) Comprehensive responses

- Most candidates plotted all 6 points correctly and drew suitable lines of best fit.

Limited responses

- Some candidates misplotted some points and drew lines of best fit which did not have approximately equal numbers of points on each side.

(iii) Comprehensive responses

- Many candidates chose suitable pairs of coordinates and correctly calculated a gradient to three significant figures.

Limited responses

- Some candidates chose pairs of coordinates that were not points on the line of best fit or were too close to each other.

(iv) Comprehensive responses

- Most candidates were able to apply $y = mx + c$ to determine a value for k .

Limited responses

- Some candidates used x and y values that were not from the line of best fit or assumed that $\log k$ was $\ln k$.

(v) Comprehensive responses

- Some candidates were able to determine correctly the percentage error of their gradient value from the true value.
- Some stated the origin of that error or compared their value to a 4.5% difference from the true value and correctly stated the cause of that difference.

Limited responses

- Many candidates did not attempt any calculation.
- Many candidates did a correct calculation and then assigned the wrong reason.

(vi) Comprehensive responses

- Most candidates gave a correct statement about reliability and related their statement to the presence, or lack of, anomalous points.

Limited responses

- Some candidates stated that anomalous points were present when there were none.
- Some candidates gave a contradictory statement such as 'the results were reliable as **most** points were close to the line of best fit'. If 'most' were close to the line, at least one must not have been and therefore would be regarded as anomalous.

CHEMISTRY

Paper 9701/53 Planning, Analysis and Evaluation
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Key messages

What candidates did well

- Most candidates were able to identify apparatus suitable for carrying out a single step in an experimental method.
- Most candidates were able to identify why a fume cupboard is required to keep risks to a minimum.
- Some candidates showed an understanding of why a chosen procedure is effective.
- Most candidates were able to describe standard laboratory practice to ensure complete thermal decomposition.
- Most candidates were able to identify the independent variable in the experiment.
- Most candidates were able to calculate the percentage by mass of $\text{Ca}(\text{NO}_3)_2$ in mixture X.
- Most candidates were able to suggest how the percentage error in the measurement of mass could be reduced.
- Most candidates were able to use a given equation to calculate values to three significant figures.
- Most candidates were able to read the calibration graph to find the concentration for a given resistance reading.
- Some candidates were able to explain how a change to the gradient of a graph would change a conclusion drawn from the graph.

What candidates needed to improve

- Some candidates understood that, when a reason or explanation was requested, their response should be specific to the practical information provided rather than too general, for example in **Questions 1(c)** and **1(f)(ii)**. Candidates are recommended to read the information provided about each experiment carefully and use it when answering the questions.
- Candidates could improve on drawing diagrams. In drawing an apparatus to collect a gas by condensation, there should be a clear pathway from where the gas is generated, to an unsealed and cooled collection vessel without loss of the gas on the way. Using a sharp pencil and a ruler to produce a neat diagram and adding clear labels to the diagram is recommended.
- Some candidates are aware that significant figures should be carried through calculations without rounding until applying suitable rounding to the final answer. The number of significant figures given after rounding should match the number of significant figures of the data provided, unless the question specifies how many significant figures or decimal places are to be given.

Comments on specific questions

Question 1

(a) **Comprehensive responses**

- Many candidates identified a pipeclay triangle.

Limited responses

- Some candidates named a tripod, gauze or triangular holder.

(b) Comprehensive responses

- Some candidates recognised that the solid could jump out of the crucible on heating and referred to this as spitting.

Limited responses

- Some answers mentioned the loss of water.

(c) Comprehensive responses

- Some answers stated that a fume cupboard is used for hazardous/toxic gases or that NO_2 is a toxic gas.

Limited responses

- Some responses did not refer to either NO_2 or gas.
- A few candidates used harmful instead of hazardous or toxic.

(d)(i) Comprehensive responses

- Comprehensive responses gave the answer to three significant figures and included clear working.

Limited responses

- Some calculations were based on the assumption that all the gas released was NO_2 .
- Some candidates used some of the data from the table to calculate a mass which was assumed to be one of the solids. This calculated mass was converted to an amount in mol and then used along with the chemical equation to calculate an answer.
- Occasionally, an intermediate calculated value was rounded to too few significant figures.

(ii) Comprehensive responses

- Comprehensive responses presented the correct working as well as the numerical answer. For example, writing $(2 \times 0.005/17.81) \times 100\%$ is full working.

Limited responses

- Some candidates wrote 0.01 instead of 2×0.005 .
- Some candidates wrote 0.05 or 0.01 instead of 0.005.

(iii) Comprehensive responses

- Some candidates specified an increase in the mass of mixture **X**.

Limited responses

- Limited responses described collecting multiple readings and taking the average.
- Some candidates described changing the balance.
- Some answers specified an increase in $\text{Ca}(\text{NO}_3)_2$ alone.

(e) Comprehensive responses

- Some candidates gave the correct answer to three significant figures with clear working.

Limited responses

- Some answers did not account for the ratio of $\text{Ca}(\text{NO}_3)_2$ to NO_2 as 1 : 2 leading to a calculation of double the answer.

(f) (i) Comprehensive responses

- Comprehensive responses suggested that $\text{Ca}(\text{NO}_3)_2$ is reheated and then reweighed repeatedly until there is no change in mass.

Limited responses

- Limited responses included either the idea of heating or the idea of weighing to constant mass, not both.

(ii) **Comprehensive responses**

- A statement that the percentage by mass decreases supported by an explanation about how the mass of gas lost or the mass of solid remaining would change was given by some candidates.

Limited responses

- Limited answers did not refer to the mass of gas lost, for example writing 'not all NO₂ released' or omitted a reference to the 'gas' lost (or 'solid' remaining).
- Some answers only referred to the loss of NO₂ gas and did not include the loss of O₂.

(g) **Comprehensive responses**

- Comprehensive responses presented a neat diagram which showed an uninterrupted pathway from the test-tube to a collection vessel kept at a low enough temperature, without loss of NO₂ gas.
- These diagrams showed a way for the O₂ gas to escape from the apparatus without a build-up of pressure.

Limited responses

- Some diagrams showed a condenser with iced water as the coolant and angled downwards towards a suitably cooled collection vessel.
- Some condensers were drawn angled upwards or horizontally which would not allow the collection of NO₂.

Question 2

(a) **Comprehensive responses**

- Comprehensive responses suggested that outside light should not be allowed to reach the photocell detector.
- Some candidates suggested that the black box prevents internal reflections of the LED light reaching the photocell.

Limited responses

- Limited answers referred to other light without specifying what light.
- Some answers discussed absorbance of the solution without mentioning detecting the light.
- Some candidates gave general answers, for example, light from sunlight or laboratory lighting does not affect the results.

(b)(i) **Comprehensive responses**

- Some candidates completed the **Table 2.1** with correct relative absorbances which were calculated to three significant figures.

Limited responses

- Limited responses gave answers to two significant figures or truncated the final digit instead of rounding, for example writing 0.838 not 0.839 as the entry for the first row of **Table 2.1**.

(ii) **Comprehensive responses**

- Many candidates suggested distilled water.

Limited responses

- Some responses suggested water or starch solution alone.
- A few answers gave a piece of physics equipment which might be used when measuring resistance, such as an ohmmeter, ammeter or voltmeter.

(iii) **Comprehensive responses**

- Some candidates stated the concentration of I₃⁻.

Limited responses

- Limited responses referred to the concentration of I⁻ or the resistance of the photocell or the absorbance.

(iv) Comprehensive responses

- Well drawn graphs included five points plotted correctly to the nearest half square.
- These graphs had lines of best fit drawn through the origin with a sharp pencil and ignored the anomalous point completely.

Limited responses

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- Some graphs were plotted with point 4 at a concentration of $1.70 \times 10^{-6} \text{ mol dm}^{-3}$ instead of $1.52 \times 10^{-6} \text{ mol dm}^{-3}$.

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- Some candidates circled the anomalous point and gave a valid reason.
- Good responses explained why the absorbance was higher than the value recorded, for example, because less than 10.0 cm^3 of solution was transferred from the boiling tube to the measuring cylinder.

Limited responses

- Limited answers only discussed the absorbance change or suggested mis-readings or faulty equipment.
- Some answers described how the anomalous point was selected from the graph.

(c) (i) Comprehensive responses

- Comprehensive responses suggested that all the I_3^- ions react with starch to form a coloured complex.
- Some candidates suggested that a full or complete reaction took place.

Limited responses

- Limited responses suggested that all the starch reacts.
- Some candidates suggested that the reaction reaches either equilibrium or an end-point.

(ii) Comprehensive responses

- Many candidates identified a 10 cm^3 volumetric pipette.

Limited responses

- Some candidates referred to a pipette, without specifying that it was volumetric.
- A few responses identified a burette, syringe or measuring cylinder.

(iii) Comprehensive responses

- Some candidates were able to calculate the absorbance correctly and gave their answer to three significant figures (0.640).
- Some candidates read the correct value of concentration from the plotted graph to the nearest half square and gave this answer to three significant figures. Three significant figures are expected because this matches the number of significant figures for the absorbance data in **Table 2.1**.

Limited responses

- A few candidates truncated the absorbance value of 0.6399 to 0.639.
- Some candidates stated the concentration value without the 10^{-6} factor.

(iv) Comprehensive responses

- Some candidates correctly multiplied their answer to **2c(iii)** by 0.015 and gave this to three significant figures.

Limited responses

- Some candidates multiplied their answer to **2(c)(iii)** by 0.010.
- A few candidates calculated the correct answer in the working and subsequently divided this by 3.

(v) Comprehensive responses

- Some candidates correctly divided their answer to **2c(iv)** by 7.5 and gave this to three significant figures.

Limited responses

- Some candidates gave their answer to the wrong power of ten, usually a factor of 10^3 out.

(vi) Comprehensive responses

- Comprehensive responses stated that calculations showed that the percentage uncertainties, when applied to the two given resistance values, gave ranges that did not overlap and led to the conclusion that the concentration of $O_3(g)$ in the air was different.

Limited responses

- Limited responses stated that calculations did not take into account that the percentage error applies to both values of resistance and applied the percentage error to only one value.
- Some candidates stated that calculations applied the percentage error to absorbance instead of resistance.

(viii) Comprehensive responses

- Some responses stated that the resistance of the photocell increases because the light has a longer path length through the solution.

Limited responses

- Limited responses stated that the resistance either stayed the same or decreased.
- Many candidates thought that the value of resistance stayed the same because the volume of the solution does not change.
- Some candidates stated that the value decreased because the surface area decreased.

(ix) Comprehensive responses

- Some candidates suggested that the concentration of I_3^- ions will be higher resulting in a lower percentage uncertainty.

Limited responses

- Limited answers did not provide a sufficiently detailed explanation or gave an explanation that was too general, for example stating that the percentage uncertainty is lower or that the accuracy is higher.
- Some candidates suggested that all the I^- ions react (with O_3).

CHEMISTRY

Paper 9701/54 Planning, Analysis and Evaluation
--

Key messages

What candidates did well

- Many candidates showed a good understanding of the steps necessary to carry out the experiments described.
- Most candidates could identify the dependent variable.
- Most candidates described standard laboratory practice well.
- Many candidates were able to carry out successfully the mathematical calculations required.
- Many candidates plotted graph points accurately on the provided grid.

What candidates needed to improve

- Candidates should seek to expand their experience of practical methods used in chemistry.
- Candidates should critically question why the steps in a practical procedure are necessary for a successful outcome.
- Candidates should gain experience in selecting and drawing the most appropriate line of best fit from a variety of types of data sets.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates either knew the term 'heat to constant mass' or were able to describe the steps needed.

Limited responses

- A few candidates suggested weighing until constant mass without the required reheating.

(b)(i) Comprehensive responses

- Most candidates calculated the masses required and completed Table 1.1 correctly and were then able to calculate correctly the mass of water lost.

Limited responses

- Very few candidates were unable to determine the mass of water lost correctly.

(ii) Comprehensive responses

- Most candidates understood that the measurement of a larger mass of $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}(\text{s})$ would have a smaller percentage error.

Limited responses

- Common examples of incorrect responses included repeating the experiment or increasing the time of heating, both of which would not have any effect on the percentage error in the measurement of the mass of water lost.

(c) Comprehensive responses

- Most candidates were able to use a suitable method of calculation to determine the value of x .

Limited responses

- A very small minority were unable to complete this calculation correctly.

(d)(i) Comprehensive responses

- Most candidates were able to describe in detail the standard laboratory practice required to prepare a standard solution.

Limited responses

- Common errors included missing out one or two important details, most commonly washing the beaker into the volumetric flask or inverting the flask to mix the final solution.
- A few responses had the wrong piece of apparatus in which to produce an exact volume of solution **A**, e.g. conical flask.

(ii) Comprehensive responses

- Most candidates identified the titrant, 0.0100 mol dm⁻³ hydrochloric acid, as the correct substance to rinse the burette with before carrying out step 2 in Method 2.

Limited responses

- The most common substance suggested in the few incorrect responses was distilled water.

(e)(i) Comprehensive responses

- Most candidates identified the two concordant titres and understood that they should be within 0.10 cm³ of each other.

Limited responses

- Some candidates indicated which titre values had been used; they did not then explain why.

(ii) Comprehensive responses

- Most candidates completed this multi-step calculation successfully.

Limited responses

- Common mistakes were to miss the scaling factor ($\times 10$) and to assume an incorrect stoichiometry for the reaction taking place in the titration.

(iii) Comprehensive responses

- Most candidates gave the correct expression to calculate the percentage error.

Limited responses

- Some candidates only used the uncertainty in measuring one burette reading in their calculation.
- A few candidates used a total uncertainty of ± 0.01 cm³, leading to an answer ten times too small.

(f) Comprehensive responses

- Some candidates made a correct prediction of the effect on the calculated value of **x** and backed this up with a logical explanation involving the calculated amount of sodium carbonate or water.

Limited responses

- Some candidates gave explanations that did not refer to the calculated amount of sodium carbonate or water.

Question 2

(a)(i) Comprehensive responses

- Most candidates completed this calculation correctly and expressed their answer to three significant figures.

Limited responses

- The most common errors were not considering the 2 : 1 stoichiometry to give 6.93 g and applying the 2 : 1 ratio the wrong way around to give 13.9 g.

(ii) Comprehensive responses

- Most candidates correctly linked fume hood use to the production of a hazardous gas, usually stating 'toxic' or 'irritant'.

Limited responses

- A small number of candidates did not mention that a gas was produced.

(iii) Comprehensive responses

- Many candidates were able to use the information given in the question to suggest that the purpose of tube **B** was to remove water produced as a by-product in the reaction to produce ammonia.

Limited responses

- Incorrect responses included to remove ammonia and to ensure smooth boiling.

(iv) Comprehensive responses

- Most candidates gave a comparison of the density of ammonia with the density of air.

Limited responses

- In describing ammonia as lighter than air, some candidates did not use appropriate scientific terminology.

(b) Comprehensive responses

- Most candidates were able to suggest either that ammonia gas is soluble in water and would dissolve, or that it would react with the water.

Limited responses

- There were few incorrect responses.

(c) (i) Comprehensive responses

- Most candidates plotted points using neat crosses, located within the allowed tolerance.
- Some candidates drew a suitable smooth curve for the line of best fit.

Limited responses

- Some candidates chose to draw a straight line of best fit even though the points clearly fitted a curve. The straight line for tungsten already printed on the grid may have influenced their choice.

(ii) Comprehensive responses

- Most candidates identified NH_3 concentration as the dependent variable.

Limited responses

- Incorrect responses included 'rate of decomposition', 'time' and 'type of catalyst'.

(d) (i) Comprehensive responses

- Most candidates understood that c in the equation for a straight line ($y = mx + c$) is the intercept of the line on the y -axis and read the correct value from the graph.

Limited responses

- There were very few incorrect answers.

(ii) Comprehensive responses

- Most candidates explained that the absence of an anomalous point meant that the results for tungsten were reliable.
- Some responded that all the plotted data points were on the line of best fit.

Limited responses

- A common incorrect answer was the suggestion that most of the points were on the line of best fit.

(iii) Comprehensive responses

- Many candidates stated that the results supported the candidate's conclusion because the concentration versus time graph was a straight line.
- Other common explanations were that the gradient of the line was constant.

Limited responses

- Some candidates did not state whether the results supported the student's conclusion.

(e) Comprehensive responses

- Some candidates determined the half-life beginning at $t = 0$ by measuring the time when NH_3 concentration had fallen to half of its original value directly from their graph.
- A few candidates arrived at the correct value by means of more complex mathematical methods.
- Most candidates were able to read and express (x, y) coordinates accurately from their line of best fit.

Limited responses

- Some candidates measured half-lives that started at times other than $t = 0$.

(f) Comprehensive responses

- Most candidates determined that the time for the concentration to reduce would be equal to four half-lives.

Limited responses

- A few candidates determined the wrong time.