CHEMISTRY

Paper 9701/11
Multiple Choice

Question Number	*Key*	*Question Number*	*Key*
1	**C**	21	**D**
2	**B**	22	**A**
3	**C**	23	**D**
4	**A**	24	**C**
5	**B**	25	**D**
6	**C**	26	**B**
7	**B**	27	**C**
8	**A**	28	**A**
9	**B**	29	**D**
10	**C**	30	**A**
11	**C**	31	**A**
12	**B**	32	**D**
13	**B**	33	**A**
14	**A**	34	**D**
15	**C**	35	**B**
16	**C**	36	**A**
17	**D**	37	**B**
18	**D**	38	**C**
19	**C**	39	**A**
20	**D**	40	**B**

General comments

This examination paper provided a suitable challenge to the candidates. The majority of candidates were able to finish the paper within the hour allowed.

The majority of candidates chose the correct response to **Questions 2**, **5**, **8**, **12**, **15**, **18**, **22**, **28**, **30**, **35** and **40**. Five questions can be said to have been found to be particularly challenging; few candidates chose correct responses to **Questions 3**, **19**, **20**, **31** and **32**. The questions that were found to be more challenging will now be looked at in greater detail.

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Comments on specific questions

Question 3

The most commonly chosen incorrect answer was **B**.
The products of the nuclear reaction described have a total mass number of 33 and a total atomic number of 16. The named reactant, ^{32}S, has a mass number of 32 and an atomic number of 16. The second reactant, particle X, therefore has a mass number of 1 and an atomic number of zero. Particle X is therefore a neutron and statement **C** is correct.

Question 19

The most commonly chosen incorrect answer was **D**.
This is an acid-base reaction, not a redox reaction. An aqueous solution of SO_2 can be thought of as $H_2SO_3(aq)$, so the salt formed is $CaSO_3$, meaning statement **C** is the correct answer.

Question 20

The most commonly chosen incorrect answer was **A**.
The isomers of C_3H_7ClO that are alcohols, in addition to those shown on the question paper, are:

- the two optical isomers of 2-chloropropan-1-ol
- 3-chloropropan-1-ol
- the two optical isomers of 1-chloropropan-2-ol.

This gives a total of five other isomers, making statement **D** the correct answer.

Question 31

The most commonly chosen incorrect answers were **B** and **C**. The correct answer is **A**.

- Statement 1 is correct. A Hess' Law cycle allows us to calculate a $\Delta H^{\ominus}$ of –16 kJ per mole of N_2O.
- Statement 2 is correct. $\Delta H^{\ominus}_f[N_2O(g)]$ is endothermic. This means that the decomposition of N_2O to its elements must be exothermic.
- Statement 3 is correct. A Hess' Law cycle allows us to calculate a $\Delta H^{\ominus}$ of –57 kJ per mole of NO for the reaction described.

Question 32

The most commonly chosen incorrect answer was **A**. The correct answer is **D**.

- Statement 1 is correct. The complete combustion of one mole of hydrogen produces one mole of water.
- Statement 2 is incorrect. the enthalpy of formation of any element is defined as zero, while the enthalpy of atomisation of any element that consists of diatomic molecules requires the absorption of a finite and measurable amount of energy to break bonds.
- The enthalpy of solution of HCl requires the breaking of the H–Cl bond as well as the hydration of the two ions mentioned, so statement 3 is also incorrect.

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Paper 9701/12
Multiple Choice

Question Number	Key	Question Number	Key
1	**A**	21	**C**
2	**A**	22	**B**
3	**C**	23	**A**
4	**D**	24	**B**
5	**D**	25	**A**
6	**A**	26	**D**
7	**C**	27	**D**
8	**C**	28	**D**
9	**C**	29	**A**
10	**B**	30	**C**
11	**C**	31	**B**
12	**B**	32	**B**
13	**B**	33	**D**
14	**B**	34	**A**
15	**D**	35	**A**
16	**B**	36	**D**
17	**C**	37	**B**
18	**D**	38	**C**
19	**D**	39	**A**
20	**B**	40	**C**

General comments

This examination paper provided a suitable challenge to candidates. The majority of candidates were able to finish the paper within the hour allowed.

Only six questions can be said to have been found to be easier. the majority of candidates chose the correct response to each of **Questions 1**, **3**, **9**, **15**, **21** and **31**. Only five questions can be said to have been found to be particularly difficult. Few candidates chose the correct response to each of **Questions 14**, **20**, **27**, **28**, and **36**.

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Comments on specific questions

Question 14

The most commonly chosen incorrect answer was **C**.
If the concentration of ammonia is increased the position of equilibrium 2 moves to the right, this reduces the concentration of Ag^+, therefore the position of equilibrium 1 moves to the left. Therefore, statement **B** is correct. K_c for equilibrium 2 is a mathematical expression that is independent of either $[Cl^-]$ or $[I^-]$, so neither of these ions has an effect on the value of K_c.

Question 20

The most commonly chosen incorrect answer was **C**.
The double bonds at positions 1 and 7 each have a CH_2 group. This will not give rise to geometric isomers, so these two bonds need not be considered. The double bonds at positions 3 and 5 both give rise to geometric isomers. The possible isomers might be named, giving the configuration at position 3 first, as *cis-cis*, *cis-trans*, *trans-cis* and *trans-trans*. However, if skeletal formulae are drawn and compared carefully it can be seen that *cis-trans* and *trans-cis* are in fact identical. There are therefore three isomers and statement **B** is correct.

Question 27

The most commonly chosen incorrect answer was **C**.
Since we are looking for compounds that give a red precipitate with Fehling's solution, the structural isomers must all be aldehydes. There are four isomers with aldehyde groups, therefore statement **D** is correct. The four isomers are:

- pentanal
- 2-methylbutanal
- 3-methylbutanal
- dimethylpropanal.

Question 28

The most commonly chosen incorrect answer was **A**.
Statement **A** is not true as octane does not react with nitrogen gas. Statement **D** is correct as it correctly names two gases which contribute to the formation of photochemical smog.

Question 36

The most commonly chosen incorrect answer was **B**.
The majority of candidates knew that statement 1 is true, and that statement 3 is untrue. The difficulty of the question therefore lay in the truth of statement 2. The molecular formula of phosphorus(V) oxide is P_4O_{10}, and although the empirical formula of phosphorus(V) oxide would be correctly given as P_2O_5, statement **2** refers only to the molecular formula and is therefore incorrect.

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Paper 9701/13
Multiple Choice

Question Number	*Key*	*Question Number*	*Key*
1	**C**	21	**D**
2	**B**	22	**A**
3	**C**	23	**D**
4	**A**	24	**C**
5	**B**	25	**D**
6	**C**	26	**B**
7	**B**	27	**C**
8	**A**	28	**A**
9	**B**	29	**D**
10	**C**	30	**A**
11	**C**	31	**A**
12	**B**	32	**D**
13	**B**	33	**A**
14	**A**	34	**D**
15	**C**	35	**B**
16	**C**	36	**A**
17	**D**	37	**B**
18	**D**	38	**C**
19	**C**	39	**A**
20	**D**	40	**B**

General comments

This examination paper provided a suitable, accessible, challenge to the candidates. The vast majority of candidates were able to finish the paper within the hour allowed.

Twelve questions can be said to have been found to be easier. The majority of candidates chose the correct responses to each of **Questions 2**, **5**, **8**, **9**, **12**, **18**, **22**, **23**, **27**, **28**, **30** and **34**. Five questions can be said to have been found to be particularly difficult. Few candidates chose the correct responses to each of **Questions 1**, **20**, **31**, **32** and **33**. The questions that were found to be particularly difficult will now be looked at in greater detail.

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Comments on specific questions

Question 1

The most commonly chosen incorrect answers were **A** and **B**.
It is possible that this question was found difficult by some due to the unfamiliarity of ICl, a covalent molecule. ICl does indeed have a relative molecular mass of 35.5 + 126.9, which equals 162.4. Therefore, statement **C** is correct.

Question 20

The most commonly chosen incorrect answer was **B**.
The isomers of C_3H_7ClO that are alcohols, in addition to those shown on the question paper, are:

- the two optical isomers of 2-chloropropan-1-ol
- 3-chloropropan-1-ol
- the two optical isomers of 1-chloropropan-2-ol.

This gives a total of five other isomers, making statement **D** the correct answer. It is possible that some of the candidates who chose answer **B** – three other isomers – were not including the optical isomers described above.

Question 31

The most commonly chosen incorrect answers was **C**. The correct answer is **A**.

- Statement 1 is correct. A Hess' Law cycle allows us to calculate a $\Delta H^{\ominus}$ of –16 kJ per mole of N_2O.
- Statement 2 is correct. $\Delta H^{\ominus}_f[N_2O(g)]$ is endothermic. This means that the decomposition of N_2O to its elements must be exothermic.
- Statement 3 is correct. A Hess' Law cycle allows us to calculate a $\Delta H^{\ominus}$ of –57 kJ per mole of NO for the reaction described.

Question 32

Each of the answers was chosen by approximately equal numbers of candidates.

- Statement 1 is correct. The complete combustion of one mole of hydrogen produces one mole of water.
- Statement 2 is incorrect. The enthalpy of formation of any element is defined as zero, while the enthalpy of atomisation of any element that consists of diatomic molecules requires the absorption of a finite and measurable amount of energy to break bonds.
- Statement 3 is also incorrect. The enthalpy of solution of HCl requires the breaking of the $H–Cl$ bond as well as the hydration of the two ions mentioned.

Question 33

The most commonly chosen incorrect answer was **C**.
Statement 1 is the key consideration in this question. Since the state given for substance C is solid, the units of K_c for the equilibrium described in statement 1 will be $mol^{-1}\,dm^3$. This means all three statements are correct and therefore the correct answer is **A**.

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Paper 9701/21
AS Structured Questions

General comments

The concepts relating to equilibrium and intermolecular forces still cause problems with candidates showing frequent incorrect use of chemical terminology.

One such example is the mention of ionic bonding in compounds and then using the term 'intermolecular' to describe the interactions relating to boiling point and volatility.

It is essential to understand the basic concepts of bonding, equilibrium, and intermolecular forces so these concepts can be applied to a variety of chemical questions throughout the paper.

Comments on specific questions

Question 1

(a) The *first* ionisation of magnesium requires the '*gaseous*' state symbol to be present for both Mg and Mg^+.

The majority of incorrect answers either omitted state symbols or used the incorrect state symbols. Some answers removed 2 electrons from magnesium in the equation.

(b) The trend in *first* ionisation energies, shown by the graph, is dependent on the outer/valence electron being removed from a valence shell which is progressively further away from the nucleus. Down the group, there is an increase in shielding of the outer/valence electron by the additional electron shells, leading to a decreased nuclear attraction of this outer/valence electron.

Many appreciated that the nuclear charge increases down the group and that the outer/valence electron/valence electron shell was further from the nucleus. Linking these two statements to a decreased nuclear attraction on this outer/valence electron was often overlooked.

(c) From the Data Booklet, the second ionisation energy of Be is almost double that of the first ionisation energy. It was clear that many candidates did not realise that there is now a greater nuclear attraction for the remaining outer/valence electron because the Be^+ ion is significantly smaller than the Be atom. The electron removed during the second ionisation is in the same 2s shell as the electron lost during the first ionisation. Several answers referred to inter-electron repulsion and shielding effects, both of which have a much smaller impact on ionisation energy than that seen in this question.

Question 2

(a) (i) The molecular formula for phosphorus(V) oxide, P_4O_{10}, as quoted in the syllabus, was not evident in many answers. The majority of incorrect answers gave P_2O_5, which is regarded as the empirical formula rather than its molecular formula.

(ii) The descriptions of the reaction of phosphorus(V) oxide with water were quite vague, and often incorrect, and included responses such as 'phosphoric acid is formed'. A more accurate description would be that 'an acid solution is formed'.

(iii) Solid phosphorus(V) oxide is a simple molecule with covalent bonding between the P and O atoms. Incorrect answers included giant ionic, metallic and van der Waals to describe the bonding.

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(b) (i) The explanation of the term *weak Brønsted-Lowry acid'* required two distinct answers. Candidates were required to define both the terms, '*weak*' and '*acid*', to gain full credit.

The definition of the acid, as a proton donor, was often well answered; however, the '*weak*' aspect of this definition, requiring 'partially dissociated/partially ionised', was less well defined with several answers mentioning 'partially dissolved' or 'gives few H^+ ions', as answers.

(ii) When SO_2 reacts with water, there are no changes in oxidation numbers when sulfuric(IV) acid, H_2SO_3, is formed. The majority of candidates answered correctly. The predominant incorrect answers included the formation of SO_3 and H_2 or sulfuric(VI) acid, H_2SO_4.

(iii) NO_2 is a reactant in the first equation and is regenerated, as a product, in the second equation. The overall role of NO_2 is, therefore, as a catalyst. Incorrect answers tended to refer to its role in terms of redox reactions for each stage of the two equations.

(c) (i) In equation 1, when limestone, was heated to form CaO, the type of reaction it undergoes is '*thermal* decomposition'. A common error was the omission of the word 'thermal'.

(ii) The enthalpy change for the formation of $CaSO_4(s)$ was very well answered. The enthalpy terms required no multiples of the given enthalpy values.

Incorrect answers were seen when candidates introduced other enthalpy terms, such as the bond energy for $O_2(g)$, into the enthalpy calculation. The calculation only required the use of the ΔH_f values given in the data table.

(d) (i) The 'dot-and-cross' diagram for Cl_2O, showing only the outer electrons, was well answered. The principal error was the omission of the outer electrons in either the O or C*l* atoms.

(ii) This question was very well answered by almost all candidates.

(iii) Candidates were asked to state and explain the effect on the yield of $Cl_2O_6(g)$ when either the temperature or the pressure was changed from the default values of 500 K and 100 kPa. The majority of incorrect responses failed to identify which of the two default values had changed, e.g. when the experiment was carried out at 1000 K and 100 kPa. Many candidates, incorrectly, gave answers which indicated that both default values of this reaction had changed.

Many descriptions of the **direction of movement** of the equilibrium were too vague and therefore unable to gain full credit.

If the position of equilibrium has changed resulting in the formation of more products, then the position of the equilibrium '***moves to the right'***. Conversely, if the change in the position of the equilibrium results in the formation of more reactants, then the position of the equilibrium '***moves to the left'.***

Statements relating to the yield for each experiment were frequently correct. However, *explanations* for these requisite change in yields were often not clear enough to gain credit.

(e) (i) Many answers suggested that candidates did not make full use of the information in the stem of the question.

A significant number of candidates focused on the high melting point of the insoluble white oxide, which tended to steer answers towards a 'covalent' type of bonding. The second statement regarding the electrical conductivity of the liquid oxide of **E** was often overlooked. Candidates who assimilated the second piece of information often opted, correctly, for 'ionic' bonding and referenced the associated electrical conductivity linked to the mobility of the free ions, in the liquid state.

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(e) (ii) Candidates who recognised that the exothermic reaction of the chloride of E with water was hydrolysis of the **E**–C*l* bonds in the **covalent** chloride of **E**, tended to give creditworthy answers.

The majority of incorrect responses tended to focus on the reaction of the Cl^- ion with aqueous $AgNO_3$.

Question 3

(a) (i) When candidates elected to use sticks to represent both covalent and dative covalent bonds in diagrams of Al_2Cl_6, it was often clear which atom provided the lone pairs of electrons associated with the dative bond.

However, 'dot-and-cross' representations for Al_2Cl_6, frequently contained inaccuracies such as incorrect annotations of the dative bonds and overlap of A*l* atoms' outer shells.

(ii) The bond angle of the trigonal planar $AlCl_3$(g) is 120°. This question was well answered.

(iii) The electronic configurations of Li^+ and H^- are **both** $1s^2$. This question was well answered.

(iv) The syllabus definition of 'metallic bonding' specifies: 'a lattice of positive ions surrounded by delocalised electrons'. This question was well answered.

(b) $LiAlH_4$ undergoes a vigorous reaction in the presence of water, producing hydrogen gas and forming LiOH and $Al(OH)_3$. The amphoteric $Al(OH)_3$ will dissolve in excess NaOH.

A very large number of answers incorrectly identified the white precipitate as Al_2O_3.

(c) (i) The [O] above the arrow in reaction 1, indicates an oxidation reaction. In reaction 1, a 1° and 2° alcohol are both oxidised. The typical reagent for this type of reaction is potassium dichromate(VI), $Cr_2O_7^{2-}$, in the presence of acid and 'heated under reflux' as the required conditions. This question was well answered.

(ii) The formation of **R**, 2-hydroxybutanoic acid, from **P**, 2-oxobutanoic acid, involves the reduction of only the carbonyl group, requiring the use of the weaker reducing agent, $NaBH_4$ (reaction 3).

If the stronger reducing agent, $LiAlH_4$, is used, both the carbonyl and carboxyl functional groups, of **P**, are reduced to form **Q**, butane-1,2-diol.

Candidates familiar with these two reducing agents and their relative strengths tended to present creditworthy answers.

(iii) The nucleophilic addition mechanism involving propanal, requires the initial use of the CN^- ion showing a lone pair, on the C atom, attacking the carbonyl C atom, of the aldehyde group, which has the correct polarity.

The attack on the aldehyde carbon is followed by the breaking of the π bond, of the carbonyl group, to form an intermediate with a CN group attached and a positively charged O atom.

Many precise, correct, answers showed curly arrows starting from the lone pair, from the middle of the π bond, and directed towards a specific atom with the correct polarity.

(iv) Heating the hydroxynitrile, **S**, with HCl(aq) under reflux, involves the hydrolysis of the nitrile group to form a carboxylic acid. The equation requires the use of both HCl and H_2O.

Very few candidates recognised these requirements to give a correct balanced equation to form the given $C_2H_5CH(OH)COOH$ and NH_4Cl.

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(v) **S**, $C_2H_5CH(OH)CN$, is readily distinguishable from 2-hydroxypropanoic acid, $C_2H_5CH(OH)COOH$, in an infrared spectrum.

Many candidates did not appreciate that **S** and 2-hydroxypropanoic acid, both have an O-H stretch absorption in the same region of the infrared spectrum, between 3200–3600 cm^{-1}.

The distinguishing feature in the infrared spectrum of **S** was the presence of a C≡N absorption between 2200–2250 cm^{-1}; the absence of C=O and O-H absorptions, of a COOH functional group, at 1680–1730 and 2500–3000 cm^{-1} respectively, further supported that the organic compound is **S**.

Question 4

(a) (i) The *decrease* in the volatility of the halogens, from gas (Cl_2) to liquid (Br_2) to solid (I_2), is directly linked to the strength of the intermolecular forces of attraction ***between*** the halogen molecules.

The intermolecular forces present here are London Dispersion forces/instantaneous dipole-induced dipole forces. The expression '*van der Waals'* is a generic term used to describe a number of non-covalent interactions such as London Dispersion forces/instantaneous dipole-induced dipole forces.

Many candidates stated that the volatility 'decreases', from Cl_2 to I_2, but did not link this decrease in volatility to the increase in the strength of the intermolecular forces of attraction.

Candidates who used only the term 'van der Waals forces' need to further state that the van der Waals forces were **between** molecules.

(ii) Thermal stability of the hydrogen halides is the ease with which the covalent bond, H–X, splits into hydrogen and the halogen, and is linked to the value of the bond energy of the hydrogen halide. HI has the *weakest* bond and will thus have the *lowest* bond energy of the three hydrogen halides.

(iii) The table of electronegativity values, given in the question, can be used to deduce the *specific* intermolecular forces of attraction between HI and HF molecules, respectively.

The hydrogen halide with the weaker IMF's will have the lower boiling point.

Many candidates appreciated that HF has strong intermolecular hydrogen bonds but tended to use the generic term 'van der Waals' for the intermolecular forces of attraction between HI molecules. However, candidates were often failed to specify that HI molecules have weaker dipole-dipole forces of attraction that HF molecules.

(iv) The reaction of iodine with hot aqueous NaOH, parallels that of Cl_2 with hot NaOH(aq), and forms the iodate(V) salt and iodide:

$3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$

Many found this equation challenging; there were few correctly balanced equations.

(b) (i) Many candidates mistakenly identified NaOH and I_2, as the reagents for converting CH_3OH to CH_3I, clearly confusing iodomethane, CH_3I, with tri-iodomethane, CHI_3.
The reagent required was HI(g), or P and I_2.

(ii) The name of the mechanism, *electrophilic addition,* for the reaction of ethene and liquid iodine, was very well answered.

(c) (i) The systematic name of the halogenoalkane, **J**, is 2-iodo-2-methylbutane.

(ii) The name of the mechanism for the reaction of **J** with NaOH(aq) is *nucleophilic substitution.*

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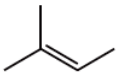
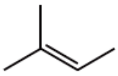
(iii) When NaOH, dissolved in ethanol, is reacted with **J**, a mixture of two alkenes, **L** and **M**, are formed by the elimination of HI.

L is given as:  and **M** is:

This question was well answered.

(iv) Alkene **L**, , does **not** exhibit geometric (cis-trans) isomerism because **each** C in the C=C, does not contain **two** different atoms/groups. (one C atom, in the C=C double bond, contains two methyl groups, and the other C atom, contains a methyl group and a hydrogen atom).

Many answers incorrectly used expressions such ‘one side/same side, of the double bond to describe the lack of cis/trans isomerism in **L**.

(v) When the alkene, **L**, is reacted with hot, concentrated, acidified $KMnO_4(aq)$, the double bond is ruptured producing a ketone and a carboxylic acid.

Propanone is given as one of the products from the oxidation of **L**, and the other is ethanoic acid, CH_3COOH.

Many incorrect answers included CO_2, H_2O, ethanal and propane.

(vi) The equation representing the reaction of propanone with excess alkaline aqueous iodine, to form tri-iodomethane, CHI_3, proved challenging for many candidates. A high proportion of candidates were not familiar with the chemical formula of tri-iodomethane, CHI_3, which was the only product not given in the question.

A typical **incorrect** answer was:

$CH_3COCH_3 + 2I_2 + 4OH^- \rightarrow CH_3COO^- + 3H_2O + I^- + CHI_3$

The equation above is balanced in terms of the number of atoms on each side; however, in redox terms, the charges are imbalanced.

$CH_3COCH_3 + \mathbf{3}I_2 + \mathbf{4}OH^- \rightarrow CH_3COO^- + \mathbf{3}H_2O + \mathbf{3}I^- + CHI_3$

is the correctly balanced equation.

(vii) Frequently, candidates who recognised that tri-iodomethane, CHI_3, was the product from the reaction, in **(c)(vi)**, stated the correct observation here of a ‘pale solid’ (with an antiseptic smell).

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Paper 9701/22
AS Structured Questions

Key messages

To score full marks on this paper candidates needed to:

- make appropriate use of key terms specific to the syllabus
- give correct formulae for chemical species and balance all equations
- identify key functional groups on novel organic molecules and apply relevant knowledge of the reactions and chemical tests for these functional groups.

General comments

Answers did not always address the question asked, for example, in **2c** and **3a(ii)**.

Questions which required application of knowledge to new situations, for example, **1b(iv)** and **2d(iii)** and **4d(iii)** proved to be particularly demanding.

Many candidates demonstrated a good knowledge of trends in the behaviour of Period 3 elements and some knowledge of the chemical reactions associated with these elements and their compounds.

Comments on specific questions

Question 1

(a) (i) This item was answered correctly by the majority of candidates.

(ii) This item was answered correctly by the majority of candidates.

(b) (i) Only a relatively small number of candidates correctly identified the number of occupied orbitals in an atom of $_{36}Kr$. Some confusion of the terms sub-level and orbital was seen.

(ii) Many answers showed a correct understanding of the Aufbau Principle. It was common for the electrons to be added to the correct sub-levels, in some cases a pair of electrons in one 3p orbital was shown.

(iii) Many answers correctly described a total of 5 electrons in all the p orbitals of a $_{9}F$ atom.

(iv) Application of the factors that determine ionisation energy to the first ionisation energies of elements in the first row of the d-block was challenging; precise use of vocabulary was essential. Many answers gave explanations in terms of *'an overall increase in nuclear charge across the d-block'* and '*similar nuclear attraction*'. Excellent answers discussed the effect of additional electrons in the third shell to produce an increase in shielding.

(c) Many references were made to the similarities and differences of the ions in terms of the number of electrons, atomic number and mass number. Fewer responses gave answers in terms of the subatomic particles in the nucleus.

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Question 2

(a) The trend in acid/base behaviour across the Period 3 elements was well known. A relatively small number of candidates stated the opposite trend.

(b) The best answers gave concise explanations that related the increase in maximum oxidation number to the number of outer electrons in the atoms of each element.

Many answers that indicated the trend correctly did not go on to explain the trend. Some candidates, incorrectly, answered in terms of the common oxidation number of the elements rather than the maximum oxidation number.

(c) Many answers identified the correct product formed in both reactions. Few responses named the products as the question required.

(d) Excellent answers identified the type of bonds broken in magnesium oxide and the intermolecular forces broken in phosphorus(V) oxide and also appreciated that the relative difference in the strength of these attractions accounted for the difference in melting point.

Common misconceptions included the idea that covalent bonds in phosphorus oxide were broken during melting or that the bonding in magnesium oxide was covalent or metallic. Reference to intermolecular forces in magnesium oxide was also seen.

(e) (i) The equation for the reaction of aluminium oxide with excess aqueous hydrochloric acid was well known. Some equations were not balanced correctly.

(ii) The formula of the correct aluminium containing product was not well known. Not all equations which correctly identified the correct species involved in the reaction were correctly balanced.

(f) Some candidates showed a good understanding of the lattice structure of silicon(IV) oxide and described the giant structure in terms of the tetrahedral arrangement of covalently bonded atoms of silicon and oxygen. Occasionally there were incorrect descriptions of the lattice as an arrangement of discrete SiO_2 molecules with double covalent bonds between the atoms, or silicon atoms bonded to only two oxygen atoms.

(g) (i) The equation for sodium oxide and silicon(IV) oxide was well known. Some responses gave an incorrect formula of the product.

(ii) Correct equations were given by those that knew the formulae of sodium carbonate and sodium oxide.

Question 3

(a) (i) Balanced equations showing the reaction of phosphorus with chlorine were common. Weaker responses used monatomic chlorine instead of Cl_2 or did not produce balanced equations.

(ii) The type of structure and bonding in PCl_5 was well known. Some answers described the intermolecular forces present between the molecules rather than described the structure as '*simple molecular*'.

(b) (i) A common incorrect answer seen was stating observation of a green gas.

(ii) Good answers produced correctly balanced equations to describe the reaction of PCl_5 with excess water. The correct product, HCl, was identified frequently but often alongside a formula for phosphorus oxide, which is not a product of this reaction.

(iii) A suitable pH was often seen. Occasionally answers were given which stated that the solution made is acidic rather than an estimate of the pH value, these answers were not credited.

(c) (i) A significant number of answers correctly described the strong reducing agent $LiAlH_4$. The most common incorrect reagent identified was the weaker reducing agent $NaBH_4$.

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(ii) Good answers applied knowledge that an optical isomer must have a chiral centre to identify the appropriate carbon atom on **T**. Some answers did not identify the appropriate atom or identified more than one. Clear, concise explanations which described an optical isomer existing as one of a pair of non-superimposable mirror images were often seen.

(iii) Many unambiguous answers, which represented the correct structure, were produced. Incorrect answers did not apply Markovnikov's rule appropriately or produced structures where only one of the double bonds had reacted.

(d)(i) Correct predictions for the shape and bond angle of this novel molecule, analogous to NH_3, were often seen.

(ii) Clear explanations of weak Brønsted-Lowry acid were seen and generally well known. Weaker responses were vague, including expressions like '*formation of hydrogen ions*' or used inappropriate vocabulary such as '*partial dissolving of acids*'.

(iii) Many different approaches were seen based on the application of the ideal gas equation. Some answers did not take account of the stoichiometry of the reaction to find the amount of gas produced. The majority rearranged the ideal gas equation correctly and converted the units to the correct SI units to calculate a value for the pressure of gas produced during the reaction. Excellent responses went on to calculate the overall pressure of the container after the reaction by adding this value to the original pressure of the container. The weakest responses did not appreciate that the volume of the container was fixed and attempted to calculate the volume of gas produced when NCl_3 decomposed.

Question 4

(a)(i) Descriptions of reaction 1 as 'oxidation' were common.

(ii) Identification of potassium dichromate was seen frequently. Relevant details regarding the conditions required for this reaction were not always included.

(iii) Some candidates were able to apply knowledge of the reaction of carboxylic acids and alcohols with sodium to draw the correct structure of **H**. Care was needed to ensure that the correct number of carbon atoms in the backbone of the molecule was shown and that, if included, both charges were shown on the –ONa part of the molecule.

(iv) The majority of answers identified the presence of a silver mirror or a black precipitate. Weaker answers described a range of colour changes to the solution, effervescence or no visible change.

(v) Many responses identified the reaction as an esterification or condensation reaction. Incorrect answers included oxidation and hydrolysis.

(b)(i) These isomers were commonly identified as position isomers. Incorrect answers included the range of other types of structural isomers and stereoisomers.

(ii) A relatively small number of candidates recognised that **J** could be distinguished from **G** by adding alkaline aqueous iodine. Some, incorrectly, described the *addition of aqueous iodine* but were still able to give appropriate test results based on the tri-iodomethane reaction.

(iii) Correct answers that described the role of $NaBH_4$ as a reducing agent were seen frequently. '*Catalyst*' was a common incorrect answer.

(iv) This question proved challenging. Many appreciated that **K** was an alkene but only rarely was **K** identified correctly, as either an unambiguous structure or a name.

(c) Candidates were required to interpret the skeletal formulae of **P** and **Q** to identify their functional groups and then give appropriate observations for the reactions of the three reagents. A small number of candidates were able to apply knowledge to give appropriate observations for all six reactions.

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(d) (i) Commonly seen was the correct identification of the bonds responsible for the absorptions marked as **X** and **Z**.

(ii) Many answers, correctly, named molecule **M** as hexanoic acid. Common incorrect answers, based on the correct identification of the functional group, included '*pentanoic acid*' '*methyl pentanoic acid*' '*propanoic acid*'.

(iii) This question proved extremely challenging. Correct answers were seen by those that used all the information in the question to deduce the structure of the alkyl group –R and interpret the skeletal formula of **L** and combine these details to deduce the molecular formula of **L**.

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Paper 9701/23
AS Structured Questions

General comments

The concepts relating to equilibrium and intermolecular forces still cause problems with candidates showing frequent incorrect use of chemical terminology.

One such example is the mention of ionic bonding in compounds and then using the term 'intermolecular' to describe the interactions relating to boiling point and volatility.

It is essential to understand the basic concepts of bonding, equilibrium, and intermolecular forces so these concepts can be applied to a variety of chemical questions throughout the paper.

Comments on specific questions

Question 1

(a) The *first* ionisation of magnesium requires the '*gaseous*' state symbol to be present for both Mg and Mg^+.

The majority of incorrect answers either omitted state symbols or used the incorrect state symbols. Some answers removed 2 electrons from magnesium in the equation.

(b) The trend in *first* ionisation energies, shown by the graph, is dependent on the outer/valence electron being removed from a valence shell which is progressively further away from the nucleus. Down the group, there is an increase in shielding of the outer/valence electron by the additional electron shells, leading to a decreased nuclear attraction of this outer/valence electron.

Many appreciated that the nuclear charge increases down the group and that the outer/valence electron/valence electron shell was further from the nucleus. Linking these two statements to a decreased nuclear attraction on this outer/valence electron was often overlooked.

(c) From the Data Booklet, the second ionisation energy of Be is almost double that of the first ionisation energy. It was clear that many candidates did not realise that there is now a greater nuclear attraction for the remaining outer/valence electron because the Be^+ ion is significantly smaller than the Be atom. The electron removed during the second ionisation is in the same 2s shell as the electron lost during the first ionisation. Several answers referred to inter-electron repulsion and shielding effects, both of which have a much smaller impact on ionisation energy than that seen in this question.

Question 2

(a) (i) The molecular formula for phosphorus(V) oxide, P_4O_{10}, as quoted in the syllabus, was not evident in many answers. The majority of incorrect answers gave P_2O_5, which is regarded as the empirical formula rather than its molecular formula.

(ii) The descriptions of the reaction of phosphorus(V) oxide with water were quite vague, and often incorrect, and included responses such as 'phosphoric acid is formed'. A more accurate description would be that 'an acid solution is formed'.

(iii) Solid phosphorus(V) oxide is a simple molecule with covalent bonding between the P and O atoms. Incorrect answers included giant ionic, metallic and van der Waals to describe the bonding.

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(b) (i) The explanation of the term *weak Brønsted-Lowry acid'* required two distinct answers. Candidates were required to define both the terms, '*weak*' and '*acid*', to gain full credit.

The definition of the acid, as a proton donor, was often well answered; however, the '*weak*' aspect of this definition, requiring 'partially dissociated/partially ionised', was less well defined with several answers mentioning 'partially dissolved' or 'gives few H^+ ions', as answers.

(ii) When SO_2 reacts with water, there are no changes in oxidation numbers when sulfuric(IV) acid, H_2SO_3, is formed. The majority of candidates answered correctly. The predominant incorrect answers included the formation of SO_3 and H_2 or sulfuric(VI) acid, H_2SO_4.

(iii) NO_2 is a reactant in the first equation and is regenerated, as a product, in the second equation. The overall role of NO_2 is, therefore, as a catalyst. Incorrect answers tended to refer to its role in terms of redox reactions for each stage of the two equations.

(c) (i) In equation 1, when limestone, was heated to form CaO, the type of reaction it undergoes is '*thermal* decomposition'. A common error was the omission of the word 'thermal'.

(ii) The enthalpy change for the formation of $CaSO_4(s)$ was very well answered. The enthalpy terms required no multiples of the given enthalpy values.

Incorrect answers were seen when candidates introduced other enthalpy terms, such as the bond energy for $O_2(g)$, into the enthalpy calculation. The calculation only required the use of the ΔH_f values given in the data table.

(d) (i) The 'dot-and-cross' diagram for Cl_2O, showing only the outer electrons, was well answered. The principal error was the omission of the outer electrons in either the O or C*l* atoms.

(ii) This question was very well answered by almost all candidates.

(iii) Candidates were asked to state and explain the effect on the yield of $Cl_2O_6(g)$ when either the temperature or the pressure was changed from the default values of 500 K and 100 kPa. The majority of incorrect responses failed to identify which of the two default values had changed, e.g. when the experiment was carried out at 1000 K and 100 kPa. Many candidates, incorrectly, gave answers which indicated that both default values of this reaction had changed.

Many descriptions of the **direction of movement** of the equilibrium were too vague and therefore unable to gain full credit.

If the position of equilibrium has changed resulting in the formation of more products, then the position of the equilibrium '***moves to the right'***. Conversely, if the change in the position of the equilibrium results in the formation of more reactants, then the position of the equilibrium '***moves to the left'.***

Statements relating to the yield for each experiment were frequently correct. However, *explanations* for these requisite change in yields were often not clear enough to gain credit.

(e) (i) Many answers suggested that candidates did not make full use of the information in the stem of the question.

A significant number of candidates focused on the high melting point of the insoluble white oxide, which tended to steer answers towards a 'covalent' type of bonding. The second statement regarding the electrical conductivity of the liquid oxide of **E** was often overlooked. Candidates who assimilated the second piece of information often opted, correctly, for 'ionic' bonding and referenced the associated electrical conductivity linked to the mobility of the free ions, in the liquid state.

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(e) (ii) Candidates who recognised that the exothermic reaction of the chloride of E with water was hydrolysis of the **E**–C*l* bonds in the **covalent** chloride of **E**, tended to give creditworthy answers.

The majority of incorrect responses tended to focus on the reaction of the Cl^- ion with aqueous $AgNO_3$.

Question 3

(a) (i) When candidates elected to use sticks to represent both covalent and dative covalent bonds in diagrams of Al_2Cl_6, it was often clear which atom provided the lone pairs of electrons associated with the dative bond.

However, 'dot-and-cross' representations for Al_2Cl_6, frequently contained inaccuracies such as incorrect annotations of the dative bonds and overlap of A*l* atoms' outer shells.

(ii) The bond angle of the trigonal planar $AlCl_3$(g) is 120°. This question was well answered.

(iii) The electronic configurations of Li^+ and H^- are **both** $1s^2$. This question was well answered.

(iv) The syllabus definition of 'metallic bonding' specifies: 'a lattice of positive ions surrounded by delocalised electrons'. This question was well answered.

(b) $LiAlH_4$ undergoes a vigorous reaction in the presence of water, producing hydrogen gas and forming LiOH and $Al(OH)_3$. The amphoteric $Al(OH)_3$ will dissolve in excess NaOH.

A very large number of answers incorrectly identified the white precipitate as Al_2O_3.

(c) (i) The [O] above the arrow in reaction 1, indicates an oxidation reaction. In reaction 1, a 1° and 2° alcohol are both oxidised. The typical reagent for this type of reaction is potassium dichromate(VI), $Cr_2O_7^{2-}$, in the presence of acid and 'heated under reflux' as the required conditions. This question was well answered.

(ii) The formation of **R**, 2-hydroxybutanoic acid, from **P**, 2-oxobutanoic acid, involves the reduction of only the carbonyl group, requiring the use of the weaker reducing agent, $NaBH_4$ (reaction 3).

If the stronger reducing agent, $LiAlH_4$, is used, both the carbonyl and carboxyl functional groups, of **P**, are reduced to form **Q**, butane-1,2-diol.

Candidates familiar with these two reducing agents and their relative strengths tended to present creditworthy answers.

(iii) The nucleophilic addition mechanism involving propanal, requires the initial use of the CN^- ion showing a lone pair, on the C atom, attacking the carbonyl C atom, of the aldehyde group, which has the correct polarity.

The attack on the aldehyde carbon is followed by the breaking of the π bond, of the carbonyl group, to form an intermediate with a CN group attached and a positively charged O atom.

Many precise, correct, answers showed curly arrows starting from the lone pair, from the middle of the π bond, and directed towards a specific atom with the correct polarity.

(iv) Heating the hydroxynitrile, **S**, with HC*l*(aq) under reflux, involves the hydrolysis of the nitrile group to form a carboxylic acid. The equation requires the use of both HC*l* and H_2O.

Very few candidates recognised these requirements to give a correct balanced equation to form the given $C_2H_5CH(OH)COOH$ and NH_4Cl.

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(v) **S**, $C_2H_5CH(OH)CN$, is readily distinguishable from 2-hydroxypropanoic acid, $C_2H_5CH(OH)COOH$, in an infrared spectrum.

Many candidates did not appreciate that **S** and 2-hydroxypropanoic acid, both have an O-H stretch absorption in the same region of the infrared spectrum, between 3200–3600 cm^{-1}.

The distinguishing feature in the infrared spectrum of **S** was the presence of a C≡N absorption between 2200–2250 cm^{-1}; the absence of C=O and O-H absorptions, of a COOH functional group, at 1680–1730 and 2500–3000 cm^{-1} respectively, further supported that the organic compound is **S**.

Question 4

(a) (i) The *decrease* in the volatility of the halogens, from gas (Cl_2) to liquid (Br_2) to solid (I_2), is directly linked to the strength of the intermolecular forces of attraction ***between*** the halogen molecules.

The intermolecular forces present here are London Dispersion forces/instantaneous dipole-induced dipole forces. The expression '*van der Waals'* is a generic term used to describe a number of non-covalent interactions such as London Dispersion forces/instantaneous dipole-induced dipole forces.

Many candidates stated that the volatility 'decreases', from Cl_2 to I_2, but did not link this decrease in volatility to the increase in the strength of the intermolecular forces of attraction.

Candidates who used only the term 'van der Waals forces' need to further state that the van der Waals forces were **between** molecules.

(ii) Thermal stability of the hydrogen halides is the ease with which the covalent bond, H–X, splits into hydrogen and the halogen, and is linked to the value of the bond energy of the hydrogen halide. HI has the *weakest* bond and will thus have the *lowest* bond energy of the three hydrogen halides.

(iii) The table of electronegativity values, given in the question, can be used to deduce the *specific* intermolecular forces of attraction between HI and HF molecules, respectively.

The hydrogen halide with the weaker IMF's will have the lower boiling point.

Many candidates appreciated that HF has strong intermolecular hydrogen bonds but tended to use the generic term 'van der Waals' for the intermolecular forces of attraction between HI molecules. However, candidates were often failed to specify that HI molecules have weaker dipole-dipole forces of attraction that HF molecules.

(iv) The reaction of iodine with hot aqueous NaOH, parallels that of Cl_2 with hot NaOH(aq), and forms the iodate(V) salt and iodide:

$3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$

Many found this equation challenging; there were few correctly balanced equations.

(b) (i) Many candidates mistakenly identified NaOH and I_2, as the reagents for converting CH_3OH to CH_3I, clearly confusing iodomethane, CH_3I, with tri-iodomethane, CHI_3.
The reagent required was HI(g), or P and I_2.

(ii) The name of the mechanism, *electrophilic addition,* for the reaction of ethene and liquid iodine, was very well answered.

(c) (i) The systematic name of the halogenoalkane, **J**, is 2-iodo-2-methylbutane.

(ii) The name of the mechanism for the reaction of **J** with NaOH(aq) is *nucleophilic substitution.*

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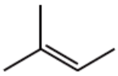
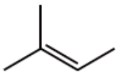
(iii) When NaOH, dissolved in ethanol, is reacted with **J**, a mixture of two alkenes, **L** and **M**, are formed by the elimination of HI.

L is given as:  and **M** is:

This question was well answered.

(iv) Alkene **L**, , does **not** exhibit geometric (cis-trans) isomerism because **each** C in the C=C, does not contain **two** different atoms/groups. (one C atom, in the C=C double bond, contains two methyl groups, and the other C atom, contains a methyl group and a hydrogen atom).

Many answers incorrectly used expressions such 'one side/same side, of the double bond to describe the lack of cis/trans isomerism in **L**.

(v) When the alkene, **L**, is reacted with hot, concentrated, acidified $KMnO_4(aq)$, the double bond is ruptured producing a ketone and a carboxylic acid.

Propanone is given as one of the products from the oxidation of **L**, and the other is ethanoic acid, CH_3COOH.

Many incorrect answers included CO_2, H_2O, ethanal and propane.

(vi) The equation representing the reaction of propanone with excess alkaline aqueous iodine, to form tri-iodomethane, CHI_3, proved challenging for many candidates. A high proportion of candidates were not familiar with the chemical formula of tri-iodomethane, CHI_3, which was the only product not given in the question.

A typical **incorrect** answer was:

$CH_3COCH_3 + 2I_2 + 4OH^- \rightarrow CH_3COO^- + 3H_2O + I^- + CHI_3$

The equation above is balanced in terms of the number of atoms on each side; however, in redox terms, the charges are imbalanced.

$CH_3COCH_3 + \mathbf{3}I_2 + \mathbf{4}OH^- \rightarrow CH_3COO^- + \mathbf{3}H_2O + \mathbf{3}I^- + CHI_3$

is the correctly balanced equation.

(vii) Frequently, candidates who recognised that tri-iodomethane, CHI_3, was the product from the reaction, in **(c)(vi)**, stated the correct observation here of a 'pale solid' (with an antiseptic smell).

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Paper 9701/31
Advanced Practical Skills 1

Key messages

- Candidates should thoroughly read all the information and instructions given in the paper. Use of a highlighter to emphasise important points may help candidates produce more focused answers.
- When recording observations in qualitative analysis questions, candidates should employ precise language to describe changes in colour and state.
- Candidates should be given the opportunity to discuss, during lesson time, the validity of experimental procedures, errors arising in different methods and possible improvements.
- Candidates should practise writing ionic equations, including use of state symbols.

Centres are reminded that the following documentation for each session, and each laboratory within a session, should be included in the script packet:

- a list of the candidates present and a seating plan for the laboratory
- a copy of the examination paper with the Supervisor's experimental results, including those for the question on qualitative analysis
- a Supervisor's report relevant to each session or laboratory using different batches of chemicals.

Invigilators/Supervisors at centres running more than one session, or using more than one laboratory, should instruct their candidates to complete the Session/Laboratory boxes on the front of the examination paper.

General comments

This paper proved accessible to all candidates, though challenging to many, and generated a wide range of marks. Most candidates completed the paper, indicating that there were no time constraints. It appeared that many candidates had only limited access to the laboratory prior to the exam, possibly due to the impact of Covid-19 on teaching time. Candidates should ensure they thoroughly read and follow the general instructions given at the start of both the **Quantitative** and **Qualitative Analysis** sections.

Comments on specific questions

Question 1

(a) Most candidates were aware of the skills necessary to perform and record the results of this titration exercise. The majority of candidates displayed data in a table with unambiguous headings, recorded burette readings to the nearest 0.05 cm^3 and ensured the final titre was within 0.10 cm^3 of an earlier titre.

Three marks were available for carrying out the titration competently, with this being assessed by comparison of the candidate's results with those of the Supervisor. Nearly all candidates obtained at least one of these accuracy marks.

(b) To score this mark it was necessary for candidates to use titration volumes that were within 0.20 cm^3 of each other, and to indicate, by showing a calculation or ticks by, the relevant volumes that were used to give their final answer to two decimal places.

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(c) (i) Awareness of the need to give final answers to an appropriate number of significant figures was assessed in this question. The number of significant figures required must be judged by candidates by considering the accuracy to which the data in the question are given and the accuracy to which pieces of apparatus can be read. This generally means that answers should be quoted, correctly rounded, to 3 – 4 significant figures.

(ii) Most candidates correctly calculated the number of moles of iodine.

(iii) The majority of candidates realised that the number of moles of iodine was doubled when calculating the number of moles of thiosulfate ions. Far fewer candidates successfully calculated the moles of hydrated thiosulfate weighed in **(a)** with many merely multiplying by ten.

(iv) For full credit, it was necessary to use an accurate value of the M_r of sodium thiosulfate, (158.2) and give the value of x as an integer. Some unlikely answers, e.g. of several hundred moles of water of crystallisation were not uncommon, but such answers were credited if they correctly interpreted earlier incorrectly calculated values.

(d) (i) Since different centres use balances that read to a different number of decimal places the correctness of the maximum error in a single reading was judged by looking back at the numbers quoted in the masses in **(a).** Regardless of the value given for a single reading, it must be doubled when considering the maximum percentage error in the mass of **FA 1**. Very few candidates were able to calculate the minimum value for the relative formula mass.

(e) Many candidates recognised that the lack of water of crystallisation in the anhydrous salt meant that this solution was more concentrated and therefore that less volume would be needed.

(f) Very few candidates appeared to have considered the practical difficulties associated with titrations. A small number did point out that a burette is difficult to read if the solution in it is darkly coloured, but most answers discussed which solution was of a known concentration.

Question 2

(a) Most candidates gave their readings in a suitable form and with correct units. However, a significant number did not follow the rubric in the question and did not round the time to the nearest second or gave an incorrect unit for rate. It was expected that the ratio of the times should be 1:2, and most candidates obtained this value within experimental limits.

(b) Most candidates gave answers that were not sufficiently precise to be credited. Many simply stated that 'as the concentration increased so did the rate', which is too vague a response for credit. Few candidates used their results from **(a)** to comment on whether direct proportionality of the concentration of thiosulfate ions was present.

(c) Most candidates correctly recognised the need to keep the overall volume of solution constant. The most common error was omitting the of the volume of **FA 4**.

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Question 3

Some candidates gained high marks in this question with detailed observations and use of the information provided in the question and/or the Qualitative Analysis Notes. Candidates should be reminded that a dash or blank box is not credit-worthy, that ‘no observation’ is not the same as ‘no visible reaction’ and that ‘colourless solution’ is ambiguous when one colourless solution is added to another.

(a) (i) Most candidates gained at least one mark here.

(ii) Most candidates gained at least one mark here.

(iii) While it was evident that most candidates knew which tests they should use, a number mistakenly chose to add sulfuric acid to test the solubility in acid of the precipitate with barium chloride/nitrate.

(iv) Candidates found this a challenging question. The most common errors were omission/incorrect state symbols or quoting a more familiar, incorrect, ionic equation such as the reaction of silver nitrate with chloride ions. A mark was allowed for candidates who identified sulfate in **(iii)** and then gave a corresponding equation.

(b) (i) Most candidates gained the mark for the addition of ammonia, but few gave enough detail in their observations for the reaction with hydrogen peroxide. It should be noted that gas produced is a conclusion and not an alternative to fizzing/bubbles/effervescence.

(ii) Nearly all candidates recognised copper(II) as the cation in **FA 8**.

(iii) The colours of the solution and precipitate were difficult to describe for some candidates. A range of suggestions were accepted.

(iv) This part proved very challenging, with many candidates merely rewriting their observations from **(iii)** rather than attempting to explain them.

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Paper 9701/33
Advanced Practical Skills 1

Key messages

- Candidates should thoroughly read all the information and instructions given in the paper. Use of a highlighter to emphasise important points may help candidates more focused answers.
- When recording observations in qualitative analysis questions, candidates should employ precise language to describe changes in colour and state.
- Candidates should be given the opportunity to discuss, during lesson time, the validity of experimental procedures, errors arising in different methods and possible improvements.
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General comments

This paper proved accessible to most candidates and generated a wide range of marks. Almost all candidates completed the paper, indicating that there were no undue time constraints. It appeared that many candidates had only limited access to the laboratory prior to the exam, possibly because of Covid-19's impact on teaching time. Candidates should ensure they thoroughly read and follow the general instructions given at the start of both the **Quantitative** and **Qualitative Analysis** sections.

Comments on specific questions

Question 1

Candidates should be aware that lines of best fit may be smooth curves rather than straight lines. This error, and failure to assimilate information given in the question, made it difficult for some candidates to gain high marks throughout question 1.

(a) Many candidates gained at least half the marks in this part. The most frequent errors in the tabulation of results were not stating volumes to the accuracy inherent in the apparatus and stating time to the nearest second. Burettes are read to the nearest 0.05 cm^3 so all volumes of **FA 1** and water should be stated to .00 (or .05) cm^3. Candidates should be reminded that a time of '29.0 s' is displayed to one decimal place and is, therefore, is not an integer.

Candidates were expected to select volumes for the extra three experiments using the whole range available. Those selecting volumes only 1.00 cm^3 from any other or all between 10.00 and 20.00 cm^3 could not access the mark. Candidates were generally successful in calculating the rates of reaction, although some rounding errors and answers quoted to only one significant figure were seen in candidate responses. Almost all candidates gained at least one mark for accuracy though the awarding of all four marks was rare.

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(b) Almost all candidates chose linear scales so that their points covered more than half the grid. Candidates should be encouraged to use straightforward scales such as 2, 4 or 5 units per large square as use of difficult scales leads to errors in plotting. However, the plotting of points by many candidates using a small x or small dot was accurate. Many arrays of points clearly indicated that a curve should be drawn, but the majority of candidates ignored this. The point for the rate using 20.00 cm3 of **FA 1** was marked as an anomaly by many. Those who included (0,0) as a point on their graph were more likely to draw the expected curve. Candidates should be aware that when drawing lines of best fit, lines should have more than two points close to the line and other points, not marked as anomalous, should be balanced either side of the line.

(c) Many candidates drew a vertical line from 5.00 cm^3 of **FA 1** to their line of best fit and then drew a horizontal line to the *y*-axis. Of these, the majority were able to convert their rate to time successfully.

(d) (i) Few candidates gained this mark. The importance of using a constant total volume for all five experiments was appreciated by very few. However, some candidates worked towards the answer by successfully calculating the number of moles of **FA 1** used in **Experiments 1** and **2**.

(ii) The answers tended to be vague rather than using precise terms correctly. A sizable minority of candidates answered in terms of collision rates rather than using the ratios of volumes and rates from their tables. Many used the shape of the graph to answer the question but needed greater clarity: 'they are proportional' does not indicate 'rate is proportional to concentration' nor 'proportional as (the straight) line has a positive gradient'. Candidates should understand that a straight-line graph that does not go through the origin cannot show direct proportionality. The increasing gradient was commented on by only a few.

(e) (i) Candidates must thoroughly read through the question stem as, in this example, all the required information was given. Few candidates were able to give all the correct products and the correct state symbols. The most common errors were providing incorrect state symbols 'S(aq)' and 'H_2O(aq)'.

(ii) Few candidates gained the mark for this question as many did not supply sufficiently detailed explanations.

(f) (i) This question required candidates to thoroughly read the stem. However, a large minority of candidates left the volumes of **FA 1**, **FA 3** and **FA 4** unchanged so gained the first mark. Fewer ensured the volumes of **FA 2** and distilled water totalled 20.00 cm^3.

(ii) Candidates who answered **(f)(i)** correctly usually also used the ratio successfully and gained the mark. However, it appeared that some candidates were employing guesswork rather than ratios to arrive at an answer.

Question 2

Candidates should be reminded that the general instructions at the start of the section help them provide full and accurate observations. The Qualitative Analysis Notes are also a helpful guide.

(a) (i) Most candidates gained at least one mark in this part. The more commonly awarded marks were, observing condensation, the solid melting, a gas turning litmus red and the darkening of the solid on stronger heating. Some candidates could not be awarded the mark for the change in colour due to calling the solid a precipitate. Candidates should be aware that precipitates form on mixing two solutions or bubbling a gas through a solution. Few candidates noted the initial colour of the crystalline solid. Centres should be aware that spirit burners do not provide a sufficiently high temperature for many decomposition reactions.

(ii) The majority of candidates reported effervescence though far fewer went on to test the gas either here or in **(a)(iii)**. 'Gas evolved' is a deduction and not an observation so cannot be credited.

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(iii) Most candidates gained at least one mark in this question. Typical errors were describing the precipitate on adding aqueous sodium hydroxide to **FA 5** as white rather than off-white, and not completing the observation as detailed in the Qualitative Analysis Notes. Only a few candidates incorrectly reported a precipitate on adding hydrogen peroxide to **FA 5**. Many correctly reported a dark brown or black precipitate on adding aqueous sodium hydroxide

(b) (i) The majority of candidates correctly selected (aqueous) silver nitrate and (aqueous) barium chloride or barium nitrate with which to test the anions. However, fewer candidates suggested using (aqueous) ammonia after the silver nitrate or hydrochloric or nitric acid after the barium salt. A substantial minority did not indicate for which anions the reagents were used. Some candidates mistakenly suggested using sulfuric acid after the barium salt.

(ii) Many candidates correctly reported no visible reaction with either **FA 5** or **FA 7** with the barium salt. The colours of the precipitates with silver nitrate included were often correct though many responses stated ‘cream or off-white precipitate’ for **FA 7** rather than the expected (pale) yellow. The most common error was to describe the white precipitate with **FA 5** to be soluble in aqueous ammonia rather than report a change of colour as the insoluble hydroxide formed.

(iii) A large proportion of candidates gained at least one of the two marks in this part. Typical errors were giving names of ions instead of formulae or not identifying one of the anions correctly. As no tests to identify a potassium ion were performed during the exam, identification of this ion could not be credited.

(iv) The mark for ‘no reaction’ for aqueous chlorine added to a solution containing the chloride ion was commonly awarded. However, many candidates mistakenly suggested that a white precipitate would be formed with other ions. Those describing the outcome of the displacement reaction successfully suggested the solution would turn brown.

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Paper 9701/34
Advanced Practical Skills 2

Key messages

- Candidates should thoroughly read all the information and instructions given in the paper. Use of a highlighter to emphasise important points may help candidates produce more focused answers.
- When recording observations in qualitative analysis questions, candidates should employ precise language to describe changes in colour and state.
- Candidates should be given the opportunity to discuss, during lesson time, the validity of experimental procedures, errors arising in different methods and possible improvements.
- Candidates should practise writing ionic equations, including use of state symbols.

Centres are reminded that the following documentation for each session, and each laboratory within a session, should be included in the script packet:

- a list of the candidates present and a seating plan for the laboratory
- a copy of the examination paper with the Supervisor’s experimental results, including those for the question on qualitative analysis
- a Supervisor’s report relevant to each session or laboratory using different batches of chemicals.

Invigilators/Supervisors at centres running more than one session, or using more than one laboratory, should instruct their candidates to complete the Session/Laboratory boxes on the front of the examination paper.

General comments

This paper proved accessible to all candidates, though challenging to many, and generated a wide range of marks. Most candidates completed the paper, indicating that there were no time constraints. It appeared that many candidates had only limited access to the laboratory prior to the exam, possibly due to the impact of Covid-19 on teaching time. Candidates should ensure they thoroughly read and follow the general instructions given at the start of both the **Quantitative** and **Qualitative Analysis** sections.

Comments on specific questions

Question 1

Candidates should be reminded to follow the instructions and to use the information given in the questions. Thought should also be given to the appropriate number of significant figures to use in the final answers. Candidates should also be encouraged to consider whether improvements in the procedure could better the results they obtain.

(a) The majority of candidates recorded four weighings to the same number of decimal places in the space provided. Those who ignored the instruction to reheat the crucible and contents limited the marks available in this section. Fewer candidates gave appropriate headings for the data though most supplied correctly displayed units. Common errors were misnaming the contents of the crucible after heating, as ‘**FB 1** after heating’, the inconsistent listing of the lid and ‘weight’ instead of ‘mass’. A substantial number of candidates calculated the mass of water lost instead of the mass of residue, and this had consequences for the calculation. Most candidates gained at least one mark for accuracy.

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(b) (i) Most candidates gained this mark as it was either fully correct or 'error carried forward' was employed from their results in **(a)**. However, a small proportion of candidates gave their answers to 1 or 5 significant figures: neither was appropriate given the precision of the apparatus used.

(ii) Most candidates successfully divided by 16.

(iii) The majority of candidates used their mass of residue correctly in this calculation. Confusing 'mass of residue' and 'mass of water lost' caused problems for the next parts of the question as the value was usually less than 288.3. Candidates should be encouraged to check earlier work for errors if this type of situation arises.

(iv) Many of the candidates attempting this part did so successfully. However, others did not use the formula for a group 13 sulfate or did not show sufficient working for the use of 32.1 to be identified or manipulated their values to give an answer that corresponded to the relative atomic mass of aluminium.

(v) Those completing **(iv)** were almost all successful in identifying the corresponding group 13 metal. Candidates who manipulated their values to fit with the relative atomic mass of a known metal could not be credited.

(c) (i) Few candidates showed an understanding of why the initial gentle heating was carried out with the lid on the crucible (as the water of crystallisation is vapourised the solid may also be lost from the crucible). Typical incorrect statements were that 'it was to prevent water vapour from escaping', 'to prevent water vapour from the air being absorbed' or 'to prevent heat loss'.

(ii) Candidates needed to use the results from their two weighings after heating to make a valid comment on whether more water was likely to be driven off.

Question 2

Candidates were able to perform the practical work to a high degree of accuracy. However, they appeared to lack practice in drawing suitable graphs. Candidates should be encouraged to take note of units, especially those required in calculations.

(a) Many candidates gained over half the marks in this part. Almost all recorded data for six experiments, though a few omitted the initial temperature or data for experiment 6. While most recorded their thermometer readings to 0.5 ºC slightly fewer recorded their burette readings to the expected precision of 0.00 or 0.05 cm^3. Candidates were expected to select volumes of **FB 3** and water to help determine the volume of **FB 3** at which **FB 2** was neutralised: hence 0.00 or 9.00 cm^3 were inappropriate. Most candidates gained at least one mark for accuracy.

(b) Almost all candidates chose linear scales, but many could not access the mark as their points covered less than half the grid. Candidates should be encouraged to use straightforward scales such as 2, 4 or 5 units per large square as use of difficult scales leads to errors in plotting. However, the plotting of points by many candidates using a small x or small dot was accurate. Candidates should be aware that when drawing lines of best fit, lines should have more than two points close to the line and other points, not marked as anomalous, should be balanced either side of the line. Candidates are expected to read the volume at the intersect to an appropriate number of decimal places: those recording values to two decimal places where the point was off the line for this value were not credited.

(c) (i) Few candidates gained the mark for the energy change as the volume of solution was rarely given as 20(.00) cm^3.

(ii) This was frequently well answered.

(iii) Most candidates with answers for **(c)(i)** and **(ii)** were successful in this calculation with the majority showing the negative sign in the answer. However, some candidates did not convert J to kJ.

(iv) Only a minority of candidates gained this mark. Common errors were omitting state symbols, writing $H_2O(aq)$ or giving the formula of sodium sulfate as $NaSO_4$.

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(v) Candidates who had given the product of the reaction as the acid salt, $NaHSO_4$, were able to access this mark.

(d) Only a minority of candidates gained this mark. Teachers should attempt to build the discussion of errors in, and improvements to, experimental procedures into practical exercises throughout the Chemistry course. A significant number of candidates answered in terms of improving the insulation, contrary to the instructions in the question.

Question 3

Some candidates gained high marks in this question with detailed observations and use of the information provided in the question and/or the Qualitative Analysis Notes. Candidates should be reminded that a dash or blank box is not credit-worthy, that 'no observation' is not the same as 'no visible reaction' and that 'colourless solution' is ambiguous when one colourless solution is added to another.

(a) Most candidates gained at least two of the four marks in this section. Candidates should carefully consider the tests they are carrying out and write relevant observations. As all the nitrates candidates have encountered are soluble in water, the response of 'no ppt' on adding nitric acid to a solution was not credited. Another error was not adding aqueous ammonia to excess once the white precipitate was observed with **FB 4**.

(b) A typical error seen in candidate responses was the failure to add aqueous sodium hydroxide to excess when a precipitate was observed. Another common error was a lack of distinction between the few bubbles formed if the solution was heated, rather than warmed, and the vigorous effervescence once the aluminium foil started to react. Candidates should state it is the gas that changes the colour of litmus paper. 'Gas turns red litmus blue' in the final stage of testing **FB 5** showed poor technique: this was from the sodium hydroxide rather than from the hydrogen being evolved. Only a small number successfully tested for this gas.

(c) Only a minority of candidates used the redox information given on page 8 and suggested using a named oxidising agent. Candidates should be aware that the correct formula or full name of the reagent must be quoted. The observations in this type of test should involve the change (or not) of the colour of the reagent.

(d) Few candidates identified all four ions correctly. Some wrote names instead of giving formulae. Some 'identified' the cation in **FB 5** as Na^+ even though no test for this had been given. The ions identified most often were Zn^{2+} and NO_3^-.

(e) Few candidates gained this mark, many of those that did sate the correct formulae either omitted state symbols or did not balance the equation.

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Paper 9701/35
Advanced Practical Skills 1

Key messages

- Candidates should thoroughly read all the information and instructions given in the paper. Use of a highlighter to emphasise important points may help candidates produce more focused answers.
- When recording observations in qualitative analysis questions, candidates should employ precise language to describe changes in colour and state.
- Candidates should be given the opportunity to discuss, during lesson time, the validity of experimental procedures, errors arising in different methods and possible improvements.
- Candidates should practise writing ionic equations, including use of state symbols.

Centres are reminded that the following documentation for each session, and each laboratory within a session, should be included in the script packet:

- a list of the candidates present and a seating plan for the laboratory
- a copy of the examination paper with the Supervisor's experimental results, including those for the question on qualitative analysis
- a Supervisor's report relevant to each session or laboratory using different batches of chemicals.

Invigilators/Supervisors at centres running more than one session, or using more than one laboratory, should instruct their candidates to complete the Session/Laboratory boxes on the front of the examination paper.

General comments

This paper proved accessible to all candidates, though challenging to many, and generated a wide range of marks. Most candidates completed the paper, indicating that there were no time constraints. It appeared that many candidates had only limited access to the laboratory prior to the exam, possibly due to the impact of Covid-19 on teaching time. Candidates should ensure they thoroughly read and follow the general instructions given at the start of both the **Quantitative** and **Qualitative Analysis** sections.

Comments on specific questions

Question 1

(a) Most candidates were aware of the skills necessary to perform and record the results of this titration exercise. The majority of candidates displayed data in a table with unambiguous headings, recorded burette readings to the nearest 0.05 cm^3 and ensured the final titre was within 0.10 cm^3 of an earlier titre.

Three marks were available for carrying out the titration competently, with this being assessed by comparison of the candidate's results with those of the Supervisor. Nearly all candidates obtained at least one of these accuracy marks.

(b) To score this mark it was necessary for candidates to use titration volumes that were within 0.20 cm^3 of each other, and to indicate, by showing a calculation or ticks by, the relevant volumes that were used to give their final answer to two decimal places.

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(c) (i) Awareness of the need to give final answers to an appropriate number of significant figures was assessed in this question. The number of significant figures required must be judged by candidates by considering the accuracy to which the data in the question are given and the accuracy to which pieces of apparatus can be read. This generally means that answers should be quoted, correctly rounded, to 3 – 4 significant figures.

(ii) Most candidates correctly calculated the number of moles of iodine.

(iii) The majority of candidates realised that the number of moles of iodine was doubled when calculating the number of moles of thiosulfate ions. Far fewer candidates successfully calculated the moles of hydrated thiosulfate weighed in **(a)** with many merely multiplying by ten.

(iv) For full credit, it was necessary to use an accurate value of the M_r of sodium thiosulfate, (158.2) and give the value of x as an integer. Some unlikely answers, e.g. of several hundred moles of water of crystallisation were not uncommon, but such answers were credited if they correctly interpreted earlier incorrectly calculated values.

(d) (i) Since different centres use balances that read to a different number of decimal places the correctness of the maximum error in a single reading was judged by looking back at the numbers quoted in the masses in **(a).** Regardless of the value given for a single reading, it must be doubled when considering the maximum percentage error in the mass of **FA 1**. Very few candidates were able to calculate the minimum value for the relative formula mass.

(e) Many candidates recognised that the lack of water of crystallisation in the anhydrous salt meant that this solution was more concentrated and therefore that less volume would be needed.

(f) Very few candidates appeared to have considered the practical difficulties associated with titrations. A small number did point out that a burette is difficult to read if the solution in it is darkly coloured, but most answers discussed which solution was of a known concentration.

Question 2

(a) Most candidates gave their readings in a suitable form and with correct units. However, a significant number did not follow the rubric in the question and did not round the time to the nearest second or gave an incorrect unit for rate. It was expected that the ratio of the times should be 1:2, and most candidates obtained this value within experimental limits.

(b) Most candidates gave answers that were not sufficiently precise to be credited. Many simply stated that 'as the concentration increased so did the rate', which is too vague a response for credit. Few candidates used their results from **(a)** to comment on whether direct proportionality of the concentration of thiosulfate ions was present.

(c) Most candidates correctly recognised the need to keep the overall volume of solution constant. The most common error was omitting the of the volume of **FA 4**.

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Question 3

Some candidates gained high marks in this question with detailed observations and use of the information provided in the question and/or the Qualitative Analysis Notes. Candidates should be reminded that a dash or blank box is not credit-worthy, that ‘no observation’ is not the same as ‘no visible reaction’ and that ‘colourless solution’ is ambiguous when one colourless solution is added to another.

(a) (i) Most candidates gained at least one mark here.

(ii) Most candidates gained at least one mark here.

(iii) While it was evident that most candidates knew which tests they should use, a number mistakenly chose to add sulfuric acid to test the solubility in acid of the precipitate with barium chloride/nitrate.

(iv) Candidates found this a challenging question. The most common errors were omission/incorrect state symbols or quoting a more familiar, incorrect, ionic equation such as the reaction of silver nitrate with chloride ions. A mark was allowed for candidates who identified sulfate in **(iii)** and then gave a corresponding equation.

(b) (i) Most candidates gained the mark for the addition of ammonia, but few gave enough detail in their observations for the reaction with hydrogen peroxide. It should be noted that gas produced is a conclusion and not an alternative to fizzing/bubbles/effervescence.

(ii) Nearly all candidates recognised copper(II) as the cation in **FA 8**.

(iii) The colours of the solution and precipitate were difficult to describe for some candidates. A range of suggestions were accepted.

(iv) This part proved very challenging, with many candidates merely rewriting their observations from **(iii)** rather than attempting to explain them.

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Paper 9701/36
Advanced Practical Skills 2

Key messages

- Candidates should thoroughly read all the information and instructions given in the paper. Use of a highlighter to emphasise important points may help candidates produce more focused answers.
- When recording observations in qualitative analysis questions, candidates should employ precise language to describe changes in colour and state.
- Candidates should be given the opportunity to discuss, during lesson time, the validity of experimental procedures, errors arising in different methods and possible improvements.
- Candidates should practise writing ionic equations, including use of state symbols.

Centres are reminded that the following documentation for each session, and each laboratory within a session, should be included in the script packet:

- a list of the candidates present and a seating plan for the laboratory
- a copy of the examination paper with the Supervisor’s experimental results, including those for the question on qualitative analysis
- a Supervisor’s report relevant to each session or laboratory using different batches of chemicals.

Invigilators/Supervisors at centres running more than one session, or using more than one laboratory, should instruct their candidates to complete the Session/Laboratory boxes on the front of the examination paper.

General comments

This paper proved accessible to all candidates, though challenging to many, and generated a wide range of marks. Most candidates completed the paper, indicating that there were no time constraints. It appeared that many candidates had only limited access to the laboratory prior to the exam, possibly due to the impact of Covid-19 on teaching time. Candidates should ensure they thoroughly read and follow the general instructions given at the start of both the **Quantitative** and **Qualitative Analysis** sections.

Comments on specific questions

Question 1

(a) Most candidates recorded masses and the volume of gas in an unambiguous way, many scored the mark available for competent completion of the practical. Because it is difficult to avoid some loss of gas, a range of values of volume of gas collected was allowed.

(b) (i) The calculation of moles of carbon dioxide was correctly carried out by most candidates with only occasional rounding errors seen. Answers throughout this section had to be given to 2 to 4 significant figures to be credited although the use of an inappropriate number was only penalised once.

(ii) and (iii) For full credit it was necessary to use accurate values of relative atomic masses, including 39.1 for potassium, as this is the value shown in the Periodic Table.

It was also necessary to give the final value of x as an integer. This section was marked using the candidate’s data, so even very unrealistic answers could be awarded credit if data were used correctly.

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(c) This showed the importance of candidates being encouraged to think about possible sources of error and how to minimise them. Many candidates correctly suggested the use of a gas syringe, but few gave another acceptable modification. A number did suggest replacing the water with another solvent, but few stated a specific liquid.

Question 2

(a) Most candidates gave their readings in a suitable form and with correct units. A few used ‘weight’ rather than ‘mass’ and a significant number did not read the thermometer to the correct degree of accuracy, i.e. the reading should end in .0 °C or .5 °C.

The competence of candidates to carry out the practical exercise was assessed by comparing the candidate’s temperature changes with that of the Supervisor. Nearly all candidates scored some marks, and a significant number gained all the available marks.

(b) (i) Most candidates were familiar with $mc\Delta T$, but a number used ‘m’ as the mass of solid rather than the mass of solution.

(ii) Most candidates recognised how to change heat energy, from **(i),** into the enthalpy change per mole.

(iii) Answers based on using Hess’ diagram or relevant equations were both seen and accepted.

However, in many Hess’ diagrams, arrows were either unlabelled or in the reverse direction. For full credit, it was necessary to show some justification of an answer.

(c) This was a challenging question, and credit was rarely awarded. Many answers tried to describe, erroneously, that one reagent was in excess so that the temperature change would be the same. Very rarely was it recognised that it was the same number of moles of H^+ that was significant.

Question 3

Some candidates gained high marks in this question with detailed observations and use of the information provided in the question and the Qualitative Analysis Notes. Candidates should be reminded that a dash or blank box is not credit-worthy, that ‘no observation’ is not the same as ‘no visible reaction’ and that ‘colourless solution’ is ambiguous when one colourless solution is added to another.

(a) (i) All candidates scored some of the marks available, but very few gained all. In this type of question, observations must be precise so that, for example, ‘grey-green’ is not the same as ‘green’. Care should also be taken, for example, when acidified potassium manganate(VII) is used in making clear whether the purple remains or decolouration occurs.

(ii) A significant number of candidates recognised that a carbonate was present, but fewer were able to give an ionic equation for the reaction with sulfuric acid. Many candidates omitted state symbols, gave an unbalanced equation or included spectator ions.

(iii) The presence of Cr^{3+} and Fe^{2+} was stated by many candidates but only a small number, correctly, said that the cation in **FB 6** could not be identified from the test carried out.

(b) (i) Although most candidates realised that it was necessary to use silver nitrate and barium chloride/nitrate, very few were awarded the mark because most did not state which ions they were testing for.

(ii) Some marks were gained by nearly all candidates, although very few gained full credit.

(iii) Many correctly identified the presence of chloride and sulfate.

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Paper 9701/41
A Level Structured Questions

Key messages

- Candidates need to ensure that corrected work is clear to read; work that is crossed out should be very clearly crossed out and never overwritten with the new answer.
- Chemical equations, ionic equations and half-equations should always be balanced for substances and charge.
- In organic reaction mechanisms, the starting and finishing point of a curly arrow should be clear, as this is a key part in the description of the mechanism.

General comments

Candidates who had prepared well for the examination were able to attempt all questions. Many candidates were able to work through to the end of the paper, with very few blank responses seen.

Comments on specific questions

Question 1

(a) Most candidates could give the correct orders of reaction.

(b) (i) The majority of candidates were able to calculate the correct answer and state the correct units.

(ii) Most candidates could do this successfully.

(c) This was well known.

(d) (i) This question discriminated well. There were many good and inventive mechanisms suggested. However, some candidates did not link their mechanism with the given rate equation and overall equation.

(ii) This question was usually answered well. A common error was 9.75×10^{-4} (from the use of only three half-lives).

Question 2

(a) (i) This was generally well answered. Common errors were
- omitting 1 mole with ionic compound formed, and
- starting from 1 mole of gaseous ions.

(ii) This was found to be difficult. Answers needed to focus on the charges of both the cation and anion.

(iii) This question was usually fully credited.

(b) (i) This was answered well. Common errors were omitting state symbols or forming $H_2(g)$ as a product.

(ii) This explanation was well known and clearly described by many candidates.

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(c) Many candidates completed this calculation successfully. Candidates should be reminded to show their working as credit is available for the method used. Common errors involved an incorrect multiplier with '158' or '348', for example answers of −3245 (use of 1 × 348), −3166 (use of 1 × 348 and 0.5 × 158) and −3055 (use of 2 × 158).

(d) (i) This was usually done well. Some candidates confused the definition of electron affinity with ionisation energy.

(ii) This was not well known. A common error was an explanation in terms of their difference in electronegativity.

Question 3

(a) Candidates generally answered this question well. Common errors were SO_2 at the anode and Na at the cathode.

(b) Many excellent answers to this calculation were seen, including many different approaches. The methods of better performing candidates were clearly explained. The commonest sources of error included:

- calculations that stopped after reaching 24 300 C and 0.2518 mol of electrons
- volume of Cl_2 = 6.04 dm^3
- mass of Na = 2.90 g.

(c) (i) This question was generally answered well. The most common omissions were $H^+(aq)$ ions in the half-cell with MnO_4^- and Mn^{2+}, a label for the platinum electrode and pressure (1 atm) for hydrogen gas.

(ii) Many candidates were able to deduce a substance that could be used to oxidise Mn^{2+} to MnO_4^- and were able to write an equation for this reaction.

Question 4

(a) (i) Most candidates gave a correct mathematical expression for pH and K_w.

(ii) This answer was usually correct.

(b) Most candidates could calculate the correct pH.

(c) (i) This was usually answered well.

(ii) Many candidates found this challenging. Common errors included

- 0.82 g (from 14.4 = (x/50)/(0.935-x/100)) and
- 0.13 g (from 14.4 = ((0.935)/50)/(x/100)).

Question 5

(a) (i) Candidates found this question demanding. Most candidates included $CuSO_4.5H_2O$ in their K_{stab} expression.

(ii) Most candidates gave a correct answer.

(b) This question was often found to be difficult. A common error was $[Cu(NH_3)_4]^{2+} + 2OH^- \rightarrow Cu(OH)_2 + 4NH_3$.

(c) Many candidates correctly identified **Y** as $[CuCl_4]^{2-}$, however they had difficulty in completing the rest of the equation. A common error was $Cu(OH)_2 + 4Cl^- \rightarrow [CuCl_4]^{2-} + 2OH^-$.

(d) Candidates did not perform well on this question. Many were unable to recall the correct colour and geometry of **Y** and of **Z**. The formula $Cu(H_2O)_4(OH)_2$ was a common error for **Z**.

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(e) This was well known. Some candidates stated that light energy is emitted or did not clearly mention why **Y** and **Z** are different colours. This is due to the d–d energy gap being different, so the frequency of light absorbed is different.

Question 6

(a) (i) This definition was well known. Some candidates did not specify that only **one** lone pair from the ligand formed a dative covalent bond to the central metal ion.

(ii) This proved difficult for some candidates. Some did not appreciate that a linear complex must have two $S_2O_3^{2-}$ ligands bonded to the Ag^+ ion. A common error was $[Ag(S_2O_3)]^-$.

(b) (i) This question was found to be difficult by most candidates.

(ii) Most candidates answered this question correctly. A common error was stating the common ion effect as the explanation.

(iii) This question was usually fully credited.

(c) (i) This was answered well by many candidates. Common errors were diagrams in which three-dimensional bonds were drawn but where the complex could not be square planar, or by drawing two cis–isomers or two trans-isomers.

(ii) Candidates often gave the correct answer here.

(iii) Most candidates recognised geometrical isomerism. Optical was a common incorrect answer.

Question 7

(a) This was found to be difficult. Candidates needed to state the reagents and conditions to form the corresponding diazonium salt and recall that this salt decomposes on warming under aqueous conditions.

(b) This was usually answered well. Many candidates stated that 2-nitrophenol and 4-nitrophenol would be formed.

(c) (i) Most candidates gave the correct structure of 2,4,6-tribromophenol, however 'tri' was often omitted in its name.

(ii) This was not well known. Common errors were effervescence and/or white fumes being observed.

(d) Most candidates answered this well. The commonest answer was an equation for the reaction of phenol with hydroxide ions: $C_6H_5OH + OH^- \rightarrow C_6H_5O^- + H_2O$.

(e) This discriminated well. Some good and clear answers were seen. Candidates had to give a clear statement for phenol and for ethanol about how and why the anion is stabilised or destabilised or how and why the O–H bond is strengthened or weakened. They had to relate the acidity of these substances to the ease of proton donation.

Question 8

(a) (i) Most candidates gave the correct answer here.

(ii) Many good answers were seen; however, some errors were frequently seen:
- drawing of the partly delocalised ring which should not include the sp^3 carbon
- position of the positive charge on the intermediate – this should be inside the partially delocalised ring system rather than on the sp^3 carbon
- drawing of the curly arrow as the C–H bond breaks – this should start on or near the C–H bond, not on the hydrogen atom.

(iii) Most candidates answered this correctly.

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(b) (i) This was generally well answered. The most common error was stating an incorrect formula for chloroethane as CH_2CH_3Cl.

(ii) Many candidates found this question challenging. A common error was $C_6H_5CH_2COOH$.

(iii) Most candidates answered this question well and suggested a suitable reducing agent for step 3 and for step 4.

(iv) This was generally well answered. Common errors were stating 4 or 6 peaks.

Question 9

(a) Many correct answers were seen. A common error was $CDCl_3$ is a better solvent than $CHCl_3$.

(b) This question was usually fully credited.

(c) This was usually well known. A common error was carboxylic acid.

(d) (i) This discriminated well. Approximately half the candidates correctly identified the two splitting patterns. It was less common to see a clear explanation in terms of number of hydrogen atoms on the neighboring carbon atom.

(ii) Most candidates answered this correctly.

(iii) This was generally well answered. A common error was the ester $CH_3CH_2COOC_6H_5$.

(e) Many candidates could identify the fragments. The most common error was omitting the positive charges.

Question 10

(a) Most candidates answered this correctly.

(b) (i) This question discriminated well. Common errors were

- omission of identifying the repeat unit
- inclusion of a trivalent carbon
- drawing a section of a polymer chain with only one or two monomer residues
- an incorrect linkage bond such as –COO–NH–.

(ii) Most candidates identified optical isomerism and gave two correct optical isomers with correct connectivity. The quality of the diagrams was generally good although some drew incorrect tetrahedral stereochemical structures.

(c) (i) This was well known.

(ii) Many candidates gave a suitable alkyl diamine such as $H_2NCH_2CH_2NH_2$ or $H_2NCH_2CH_2CH_2NH_2$. A common error was suggesting a diamine with the two NH_2 groups bonded to the same carbon atom such as $H_2NCH_2NH_2$.

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Paper 9701/42
A Level Structured Questions

Key messages

- Candidates should be discouraged from using non-standard abbreviations, as without explanation these cannot be awarded credit.
- Where a question asks for a comparison of the properties of two substances or ions, candidates should always make it very clear which of the two they are describing in each part of their answer. An example of such a question on this paper is **3(a)(v)**. The use of the word 'it' should be strongly discouraged in such answers.
- Chemical equations, ionic equations and half-equations should always be balanced for substances and charge.

General comments

Candidates who had prepared well for the examination were able to attempt all questions. Many candidates were able to work through to the end of the paper, with very few blank responses seen.

Comments on specific questions

Question 1

(a) (i) Many candidates gave answers in the context of limiting reagents, or the need for all hydrogen to be consumed, but did not appreciate the need to keep the concentration of one reagent effectively constant in an investigation of this type.

(ii) This question discriminated well, many candidates appreciating the importance of the curve's constant half-life. When a question like this requires candidates to 'use data from the graph' it is strongly recommended that candidates use a ruler to draw lines on the graph, showing clearly how at least two half-life periods have been arrived at.

(b) (i) The explanation part of a question such as this can be found to be very difficult. Candidates were able to provide concise and correct answers, showing both excellent chemistry and clear communication. In addition, some excellent mathematically based answers were seen. For a good answer it was essential that the information in the question – that the reaction is first order with respect to $[H_2]$ – was used. Therefore, if the data for experiments 1 and 2 is considered, when $[H_2]$ increases x10, this would cause the rate to increase x10. It can be deduced that the additional x10 increase in rate is due to the x10 increase in $[I_2]$. Some candidates ignored the change in $[H_2]$ and stated that a 10x increase in $[I_2]$ caused a 100x increase in rate, concluding that the reaction is 2nd order with respect to $[I_2]$.

(ii) This was usually answered well. Some candidates did not include *k*.

(iii) Many correct answers were seen, gaining full credit.

(c) (i) This was a good discriminating question. Many candidates wrongly assumed that because all concentrations at the start are equal, the starting position must also be in dynamic equilibrium. This assumption misses the information given that *k* for the forward reaction is much greater than *k* for the backward reaction, so equilibrium will only be reached when [HI] is much greater than $[I_2]$ and $[H_2]$.

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(ii) The mark for 'forward reaction has a negative value of ΔH, backward reaction has a positive value of ΔH.' was often awarded. The explanation was less often given credit. A good answer explained that, although elevated temperature increases the rate of both the forward and the backward reactions, in this case it increases the rate of the backward reaction more, so the position of equilibrium moves towards H_2 and I_2. Some candidates wrongly stated that elevated temperature decreases the rate of the forward reaction.

Question 2

(a) This was answered correctly by a majority of candidates.

(b) (i) This was answered correctly by a majority of candidates. Many candidates showed good mathematical skills in **Question 2(b)** and **(c);** there were very few calculator errors, rounding errors, or significant figure errors.

(ii) This was answered correctly by a majority of candidates.

(c) This was found to be more difficult. Some candidates approached the question as if 1.1×10^{-11} *was* the solubility. The fact that the OH^- concentration is twice the Mn^{2+} concentration was not well appreciated.

Question 3

(a) (i) **Questions 3(a)(i)**, **(ii)** and **(iii)** were highly discriminating. It was necessary for candidates to understand and apply the energy cycle with precision. The direction of each arrow, and therefore the particular changes signified, was relevant to each question. Transformation **W** included several parts of a Born-Haber cycle. Common errors included $\frac{1}{2} \times 242$, 2×242, the omission of 242 and the use of 1×-349.

(ii) Not all candidates followed the instruction to use their answer to **(a)(i)** here. Those that did needed to appreciate that the sign of the answer to **(a)(i)** should be reversed.

(iii) Not all candidates followed the instruction to use their answer to **(a)(ii)** here; 1×-364 was a common error.

(iv) Many candidates did not read the question and attempted to use three, or all four, of **W, X, Y** and **Z.** This was not possible.

(v) Since the ions in MgF_2 and $CaCl_2$ have the same charges, any difference must be due to the ionic radii. The ionic radii of the anions and of the cations is relevant. Many candidates mentioned the radii of the anions, or of the cations, but not both.

(b) (i) This was usually well answered however some points should be noted.

- Barium carbonate is insoluble.
- Barium and barium oxide both react with water to produce barium hydroxide. It is not correct to talk about a solution of barium in water or a solution of barium oxide in water.
- Hydrogen sulfate is not an accepted name for sulfuric acid.
- The question asked for names. Credit was allowed for correct formulae, but not incorrect formulae such as BaOH or $BaCl$.

(ii) This was answered well. The use of correct and specific terms such as 'more exothermic', 'less exothermic' and '$\Delta H^{\ominus}_{sol}$' was commonly seen.

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Question 4

(a) Candidates found this question difficult. The commonest error was stating that potassium metal is discharged at the cathode.

(b) Most candidates calculated the amount of charge correctly. Many then converted the 675 C into moles of electrons using 96,500 for partial credit. Full credit was much more rarely awarded as it was rarely appreciated that four moles of electrons have to pass for the discharge of one mole of O_2 gas. 168 cm^3 and 84 cm^3 were both commonly seen answers.

(c) (i) Most candidates gained credit here. It should be noted that those candidates who did not give their answers in the order in the question – chlorine, then bromine, then iodine – had to identify clearly which voltage was the value for which halogen.

(ii) Candidates found this very difficult, with full credit rarely being awarded. Many candidates quoted the $E^\ominus$ for $Sn^{2+} + e^- \rightleftharpoons Sn$, incorrectly believing that a halogen can reduce Sn^{2+} ions. Where a question involving oxidation and reduction asks for an explanation, candidates should, if possible, use $E^\ominus$ values.

(iii) The role of chlorine as an oxidising agent seems not to have been appreciated by many candidates, despite the clear reference at the start of **(c)**.

(d) (i) This was answered well.

(ii) This was answered well, although 'iron' was sometimes seen as the electrode in the Fe^{3+} / Fe^{2+} half-cell.

(iii) This mark was rarely credited. Both stated changes needed to be correct for credit to be awarded.

Question 5

(a) Many candidates found it difficult to provide the full definition.

(b) (i) This was answered well. The commonest error was an electronic configuration ending either $3d^3\ 4s^2$ or $4s^2\ 3d^3$.

(ii) Some correct answers were seen.

(c) (i) Many candidates did not know the formula of the cobalt complex in the blue solution. Candidates' drawings of the correct three-dimensional structure of a tetrahedral complex were generally good.

(ii) This mark was scored by many candidates.

(iii) A very many good answers were seen here. Candidates often gave all of the key details here – for example the importance of d-orbitals, the fact that colour is due to the absorption of light and not emission – and also at constructing an explanation in a logical order. However, it should be noted that some candidates need to be more careful to use specific vocabulary correctly – for example 'degenerate' and 'non-degenerate'.

(iv) This was also answered well.

(d) (i) Candidates were not confident in answering this question.

(ii) This was very discriminating. A significant number of candidates drew a planar structure.

(iii) While most candidates gave one of the types of stereoisomerism, a large proportion did not give the correct 'optical'.

(iv) This was very discriminating. Two, three and four were all commonly seen wrong answers.

(e) (i) Great care was required here to ensure that correct species were used in the answer and that no charges were written outside the square brackets around each species.

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(ii) Most candidates were able to identify the complex ions in highest and lowest concentrations and were able to explain their decision by reference to either K_{stab} values or stability.

Question 6

(a) This question was found challenging but the central theme of acidity – the ability to donate H^+ ions – was understood by a large number of candidates and was used as the basis for their answers.

(b) (i) The reactivity of methanoic acid with Fehling's reagent was not well known.

(ii) The reactivity of methanoic acid and of ethanedioic acid with acidified manganate(VII) ions was not well known.

(c) (i) The structural formula was well known but the name was less well known. Incorrect names such as ethyl chloride and chloroethanoic acid were seen.

(ii) This discriminated well. It should be noted that in specifying reagents for step 2, candidates needed to show appreciation that any water present will also react with the ethanoyl chloride.

(d) (i) This discriminated well. Common incorrect answers included '$CDCl_3$ gives the reference peak at zero' and 'because $CDCl_3$ is a better solvent'.

(ii) Although answered well by many candidates, others found this difficult. Answers were often seen that included δ values not associated with any peaks in the proton NMR spectrum on page 14.

(iii) Some candidates described the disappearance of a peak but did not specify which peak disappears. The replacement of a labile hydrogen with deuterium was seen in many answers.

(e) This was answered well.

(f) (i) Most candidates knew that the answer is $LiAlH_4$. Candidates should be reminded of the convention of upper case and lower-case use for chemical symbols.

(ii) Very many different answers were seen here, including 1, 3, 4 and 5 in addition to the correct answer, which was 2.

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Question 7

(a) This question was found to be very difficult. Many candidates stated the hexagonal shape, 120° bond angle, equal length C–C bonds and sp^2 hybridisation, and therefore received partial credit. However, good descriptions of the orbital overlaps – for example s with sp^2 to form the C–H bonds – were very rarely seen. Many candidates seemed to know that all C–C bonds are the same length but did not state it clearly. There was some confusion over the meaning of p, which is a type of orbital, and π or pi, which is a bonding type caused by p-orbital overlap.

(b) (i) This was answered well with many good diagrams of the intermediate. Some candidates did not appreciate that a curly arrow should have been drawn in the first box to indicate the first step of the reaction.

(ii) This was answered well.

(iii) Some candidates answered this well. Omissions included 'concentrated' with reference to the acids, and balancing of equations.

(iv) This discriminated well.

(c) (i) Although many candidates knew the formula of the 2,4,6-tribromophenylamine product, many did not balance the equation with 3HBr.

(ii) This discriminated well.

(iii) This discriminated well. When observing this reaction, the decolourisation of bromine, and the formation of the white precipitate, are both apparent.

(d) This question was found to be difficult by many candidates. However, as with **Question 6(a)**, good answers showed a grasp of a central theme – the relative abilities of lone pairs in different environments to accept H^+ ions. This was appreciated by a significant number of candidates and was used as the basis for their answers.

(e) (i) This discriminated well.

(ii) Candidates who did not specify a compound such as ethanedioic acid in 7**(e)(i)** found this very difficult. If a suitable dioic acid had been specified, full credit was often awarded here.

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Paper 9701/43
A Level Structured Questions

There were too few candidates for a meaningful report to be produced.

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Paper 9701/51
Planning, Analysis and Evaluation

Key messages

The illegibility of many scripts poses problems when assessing and crediting candidate working.

Candidates would benefit from reading questions thoroughly to ensure they are answering the question posed.

The plotting of graphs was often problematic for candidates. Many issues related to inaccurate graphs were seen and included, points being too faint or too big, lines being too faint or too thick and dots used instead of crosses.

General comments

In common with previous years there was no evidence that candidates were short of time as the majority of scripts were complete.

Calculations should be set out in a logical sequence rather than spread about. The quality of the calculation responses varied tremendously, but there is no doubt that candidates who were able to set out the steps in a clear and logical manner had an advantage over those who did not.

A common fault was stating an answer but failing to give an explanation when asked. If the question only had one mark allocated to it, then a failure to give a reason/explanation meant that no mark could be awarded.

When a question requests a single response, candidates should avoid giving either/or answers or lists as a response. Good answers are characterised by succinct responses. Longer responses frequently suffered by contradicting themselves. For example, in **Question 1(c)(v)**, ‘sulfuric acid acts as a proton donor and as a reducing agent.’

Candidates should be advised never to approximate, round or truncate intermediate values within a calculation.

Candidates should be strongly encouraged to reconsider their responses in order to avoid non-specific responses. Answers such as ‘the mass was recorded wrongly’, or in **Question 2(b)(iii)** ‘the reading was taken too early’ without stating if the reading was of mass or volume.

Comments on specific questions

Question 1

(a) (i) A very straightforward moles-based calculation in which most candidates were successful.

(ii) Many responses erroneously suggested making up the solution directly in the volumetric flask or failed to specify the use of distilled (de-ionised) water. A significant minority of responses incorrectly suggested the use of non-volumetric apparatus such as conical flasks or beakers.

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(b) A common error was to approach the question by using a formulaic approach such as $c_1v_1 = c_2v_2$ without fully appreciating the information in the question stem. Candidates who used this approach often failed to apply the 2:5 stoichiometry so could not gain full credit. A better approach to these calculations is to use an understanding of the logical sequence involved in determining the moles of one reagent, using the stoichiometric ratio to the moles of the other, and then with M_r to produce the answer.

(c) (ii) Whilst most candidates were correct here, too many chose only one titre, or some chose Titre 2 on the grounds it was nearest to the rough.

(iii) This algebraic calculation proved to be a challenging question. Some answers ignored *x* & *y*, confused them, or used numerical values from earlier in the question.
This is essentially a two-stage calculation:

Step 1: use the *x* cm^3 titre of 0.02 mol dm^{-3} manganate(VII) to give moles of manganate(VII); then multiply by 5 to give moles of Fe^{2+} in 25 cm^3; multiply by 10 to give moles of Fe^{2+} in 250 cm^3.

Step 2: multiply moles of Fe^{2+} in 250 cm^3 by the M_r of Fe and, finally, multiply by 100/y.

Most errors were in failing to multiply by 10 or omitting the 1000 in the manganate(VII) moles calculation. Others failed to multiply by 100 to get percentage Fe^{2+}.

(iv) Most candidates realised that iron(II) would be oxidised by the oxygen in air to iron(III). However, some incorrect answers revealed a misunderstanding of chemical basics. Such answers included, Fe^{2+} was reduced, Fe^{2+} evaporated, Fe^{2+} reacts with the acid, and more.

(v) Better responses noted the role of the sulfuric acid in enabling the manganate(VII) to behave as an oxidising agent by providing hydrogen ions for that to happen. A common error was to say the sulfuric acid was an oxidising agent or a reducing agent.

(d) The acid was in excess and therefore did not require accurate measurement.

Question 2

(a) Completion of the table required subtracting each value in column A from 164.02. Some candidates missed this necessary step, resulting in data that was inappropriate for the supplied grid. When plotting calculated values on preformed grids, it is prudent to double-check the axis labels and calculated data before completing the plot.

(b) (i) The plotting on the preformed grid was usually correct. However, the majority of candidates would benefit from ensuring plotted points are clear without overdoing the cross. Most errors seen were a failure to plot the origin (0,0). The origin, on this occasion, represents an error-free point and probably the most significant point in the table.

(ii) Whilst the intended anomalous point was fairly close to the line, most candidates were successful in identifying it. Other points were accepted in the event of a mis-plot.

(iii) This proved to be a challenging question for most candidates. Answers such as ‘The reading was taken too early’ often failed to specify whether the reading was of mass or volume and could not, therefore, be credited. In the same way, answers such as ‘the temperature was wrong’ often failed to explain the significance of temperature. Candidates should desist from answers as ‘the balance was broken’ or similar responses.

(c) (i) The gradient determination typically performed well. Only a few answers did not present the coordinates in the correct *x,y* format and only a few inverted the *x* and *y* values to calculate an inverted gradient value. For the gradient to be representative of the *x* value, it had to cover at least half of the plot (500 cm^3) and many, but not all, managed this. It was pleasant to see that virtually all candidates provided answers to three significant figures.

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(ii) This calculation proved very difficult for many candidates. There was a large variation in the quality of answers seen, ranging from correct answer with clear working to incorrect answers with a jumble of working, which was difficult to decipher. Candidates should have used an expression derived from the ideal gas equation that featured M_r and the gradient, such as:

$$M_r = \frac{m}{V} \times \frac{RT}{p} \text{ where } \frac{m}{v} \text{ is the gradient}$$

An alternative approach was by way of calculating moles (n). The major problem encountered in this question was the use of incorrect units. To use the ideal gas equation correctly, the volume had to be in cubic meters and the pressure in pascals. Failure to convert the data often resulted in errors in the order of magnitude leading to unrealistic M_r values like 5.8×10^{-5}.

(iii) The correctly calculated M_r of 56 – 59 gave C_4H_{10} butane with M_r 58. Many who had the correct identification failed to explain their answer (as requested). Some erroneously matched the M_r of butane to match their calculation, e.g. C_4H_9. Other identifications were acceptable provided they matched the calculated M_r, e.g. heptane for M_r calculated around 100.

(d) (i) Many candidates struggled to gain both marks to this question. Most candidates realised that a balance reading to 3 or more decimal places would improve accuracy. However, Answers often showed a misunderstanding of the question in so far as 'repeat for consistent results' or 'use a thermostatically controlled water bath' which are irrelevant for this question. Often candidates used words like, accurate, sensitive and precise out of context. Many candidates suggested 'use a gas syringe' but did not make a comment about the need for graduations.

(ii) The alkane is described as flammable on page 6. However, a significant majority of answers failed to state 'keep away from naked flames'. Many generic answers specified using gloves and fume cupboards without the necessary thought or interpretation of the information provided.

(iii) It was apparent that many candidates realised that having a more volatile contaminant would produce a higher volume at that temperature but did not realise for that, to affect the gradient, the mass would have to be constant. Whilst only very few candidates combined these two, many correctly stated the gradient would be less.

(iv) Many answers suggested, incorrectly, that the ideal gas equation only worked at room temperature.

(v) Many candidates answered in terms of how to make the experiment accurate rather than reliable, for example, by using a 3 decimal place balance. A small majority correctly stated that the experiment needed to be repeated but did not follow that statement with the idea of using repeats to calculate a mean value for gradient or M_r.

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Paper 9701/52
Planning, Analysis and Evaluation

Key messages

Candidates should be aware that lines of best fit need to split the plotted points in such a way as to have an approximately equal number of points (excluding anomalies) either side of the line. Drawing a line from the origin to the last point may not necessarily result in this outcome.

If a candidate wishes to cross out work, this should be done. A significant number of candidates chose to put brackets around work they did not want to be marked with only the smallest of crosses (x) above whole sentences. Examiners had difficulty interpreting the wishes of the candidate. Unwanted responses should have a definite line through them, but not so thick as to mask what was written as, in the absence of other responses, credit may still be given.

Candidates need to be made aware that offering lists of answers beyond the number of responses asked for will most likely incur a penalty if any of the additional answers are incorrect. For instance, many questions asked for **one** variable or reason or **two** reasons. The number of responses is clearly in bold, yet many candidates supplied more than this required number of responses.

General comments

Questions 1(b)(ii) and **2(d)(iv)** had multi-step calculations. It is important that candidates do not round in early steps and do their rounding to the required number of significant figures after calculating the final answer.

Candidates should be aware of the need to use an appropriate number of significant figures in numerical answers even when a question does not specify an exact number of significant figures.

Comments on specific questions

Question 1

Question 1 was based upon a method to find the concentration of saturated $Ca(OH)_2(aq)$. Saturated $Ca(OH)_2(aq)$ was prepared by adding excess $Ca(OH)_2(s)$ to distilled water followed by filtration. The filtrate (saturated $Ca(OH)_2(aq)$) was titrated against standard hydrochloric acid.

Candidates were told $Ca(OH)_2(aq)$ is known as limewater.

(a) (i) Candidates were asked why a flask containing limewater had to be stoppered. This was meant as a simple introductory question for candidates as it was expected most would realise that it was imperative to prevent limewater from reacting with atmospheric carbon dioxide.

The majority answers seen were incorrectly based around the prevention of the escape of gas or water (via evaporation) from the flask or the prevention of air entering the flask. This suggested that the context of the question had not been fully appreciated in relation to the method outlined.

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(ii) Candidates were asked why the preparation of saturated $Ca(OH)_2(aq)$ required a flask containing excess $Ca(OH)_2(s)$ needed to be left for 24 hours prior to filtration.

Many responses did not fully articulate that enough time was needed to achieve saturation. A common error was to state something such as 'To allow **all** the $Ca(OH)_2(s)$ to dissolve' when step 3 (filtration) clearly indicated **all** the $Ca(OH)_2(s)$ would not dissolve. Responses such as 'To allow all the $Ca(OH)_2(s)$ that is going to dissolve, to dissolve' gained credit.

Responses which talked about allowing enough time for $Ca(OH)_2(s)$ to *react* with water once again indicated that the context of the question had not been appreciated and received no credit.

(b) (i) Most candidates used the correct stoichiometry and were able to compute the number of moles of $Ca(OH)_2$ in 25.0 cm^3 of saturated $Ca(OH)_2(aq)$. Ideally, answers should be to 3 significant figures, but, as well as the expected answer of 5.33×10^{-4} mol, alternatives such as 5.3×10^{-4} mol or 5.325×10^{-4} mol gained credit. A surprisingly significant number of candidates incorrectly rounded 5.325×10^{-4} mol to 5.35×10^{-4} mol.

(ii) Most candidates were able to gain both marks by:

1 converting the answer in **1(b)(i)** from mol to g by multiplication by 74.1
2 scaling this value up by a factor of 1000 / 25

Ideally, the answer used from **1(b)(i)** should have been what the calculator read (i.e. 5.325×10^{-4} mol) rather than any rounded value, but these were allowed.

One significant source of error here was for candidates to round their answer in step 1 before computing step 2, which led to incorrect final answers.

(iii) Candidates were asked why a value for solubility obtained in a practical was lower a value quoted in a data book. Candidates were told the data book value was measured at 293 K. Many seized upon this big clue and wrote that the practical was carried out at a different temperature (to 293 K). As the solubility of Ca(OH)2 with temperature does not follow typical trends, the idea of the temperature being 'lower than', 'higher than' or simply 'is different to' 293 K gained credit.

Only the strongest responses stated that if solubility at saturation was lower than the data book value, 24 hours was not a long enough period for saturation to take place. Although not correct, the response 'The flask was not left for 24 hours' was given credit as this too suggested saturation had not been achieved.

A significant number of candidates focused on why the data book value would be correct, rather than what the student would have done incorrectly during the practical.

(c) Many candidates realised that the presence of extra undissolved calcium hydroxide in the 25 cm^3 sample would need more HCl to achieve neutralisation.

Many candidates seemed to misunderstand the concept of the question and suggested a greater number of moles of $Ca(OH)_2$ had *dissolved* as a result of the bungled titration.

Some suggested there was less $Ca(OH)_2$ present.

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(d) The method of preparing a standard solution starting from a more concentrated solution was well known. Nearly all candidates were able to calculate that 25.0 cm^3 of 1.00 $mol\,dm^{-3}$ HCl was needed to make 250.0 cm^3 of 0.100 $mol\,dm^{-3}$ HCl.

The vast majority knew that a piece of volumetric apparatus (i.e. a pipette or a burette) was needed to measure and transfer 25.0 cm^3 of 1.00 $mol\,dm^{-3}$ HCl as a first step, and, as a second step this should be transferred into a 250 cm^3 volumetric flask, followed by topping up to the mark with distilled water.

Transfer in step 1 was allowed to be into an intermediate vessel (e.g. a beaker) prior to transfer into the volumetric flask as long as rinsing of the intermediate vessel was described.

Centres should make candidates aware that a measuring cylinder is not considered to be of volumetric standard.

Question 2

(a) Most candidates realised that toxic sulfur dioxide was the problem and correctly suggested a fume cupboard, although a well-ventilated room was also acceptable. Masks would not be a sufficient precaution, as the room would still accumulate a toxic gas.

(b) This question proved more difficult for candidates than anticipated. A volume such as 10.00 cm^3 of $Na_2S_2O_3(aq)$ needs volumetric apparatus, (i.e. pipette or a burette) whereas 10 cm^3 of $HCl(aq)$ can readily be measured in a measuring cylinder. The appropriateness of a measuring cylinder was enhanced by the information that the HCl was in excess.

(c) The vast majority of candidates completed the table correctly. A few ignored or did not understand the ‘3 significant figures’ instruction in bold. There were also rounding errors, usually associated with the reciprocal of 323.

(d) (i) Plotting of the points was good, as was the straight line of best-fit and the vast majority of candidates secured both marks. The line of best fit did not quite go through the first and last points, but it was close enough, so those candidates who opted for drawing a line of best fit through the first and last points secured credit on this graph. This is not likely to be the case in most graphs.

(ii) This was a challenging question. It asked ‘errors in the procedure’ which could have caused the anomalous point, which was below the plotted line.

As the axes were time-related (*y*-axis) and temperature-related (*x*-axis), it would be procedural errors in timing and temperature which caused the erroneous outcome. Better candidates realised that the recorded time had to be greater than the actual time taken for the cross to disappear. This could have been caused by the procedural error of the timer being started too early (before solutions were mixed) or stopped too late (after the cross had disappeared).

Harder to appreciate was what happened with the temperature reading. The recorded temperature for the anomalous point was 309 K, but the line of best fit suggested it was actually close to 303 K, so candidates had to produce statements that qualified this. No candidate said that the actual temperature was 303 K, not 309 K, but credit was given for statements such as ‘the actual temperature was lower than the recorded temperature’, (or for the reverse argument) or for reasons why the actual temperature was too low, e.g. ‘the mixture cooled down during the reaction after the temperature had been recorded.’

Many candidates gave vague responses such as ‘the temperature was too low’ without indicating whether it was the recorded temperature or the temperature at which the reaction took place and did not gain a mark.

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(iii) The gradient was calculated correctly by most candidates, although some misread the points or forgot that the *y*-axis involved negative values. Occasionally, some significant figure conversions introduced unusual errors where a typical value of –5625 would be changed to –563 to three significant figures.

(iv) The given equation made this a challenging calculation for candidates. The most difficult part was relating E_a and R to the gradient. Better answers stated that the gradient was $-E_a$ / R.

The less difficult step of converting from J to kJ was omitted frequently, as was the final step of rounding to two significant figures and inserting a '+' sign in their answer.

(e) This very straightforward rate question, which most candidates got right, needed the simple premise that because the reaction took longer, solution B must be less concentrated.

(f) This was an unusual question which caused difficulties for many candidates. The reason that times should not be recorded to 0.01 s is that human reaction time (needed twice when starting and stopping the timer) is far in excess of 0.01 s so recording a time to the nearest second is much more realistic.

Question 3

(a)(i) Completion of the results table was well attempted. Most candidates gave the correct headings for the two volumes and time, although a few did not realise that the unit of time is 's'.

Once the values in the first row of the table had been completed (50 cm^3 of HCl and 0 cm^3 of water – as per experimental instructions given) a choice of suitable further volumes proved more difficult, but most candidates still gained this mark.

Although candidates did not need to keep the total volume constant to answer the question, most did, showing good practical technique. A small minority of candidates erroneously suggested timing a reaction in which the volume of acid was 0 cm^3 or using a total volume greater than 100 cm^3.

(ii) Nearly all candidates knew the dependent variable was time.

(iii) Nearly all candidates knew that temperature was the other variable that needed to be controlled.

(b) In the question, a student was timing how long it took for 'the magnesium ribbon to disappear'. So, inaccuracies in timing the experiment would arise because as the magnesium slowly got smaller and smaller, possibly obscured by the small bubbles of hydrogen, it would be difficult to observe exactly when there was no magnesium left.

(c) Alternative variables that could be followed included collecting hydrogen and measuring its *volume*, or the loss in *mass* of the reaction mixture, or the change in *concentration* of the hydrochloric acid, (all against time). But loose phrases such as 'the amount' of hydrogen failed to gain credit as did impractical methods such as measuring the mass of the magnesium ribbon.

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There were too few candidates for a meaningful report to be produced.

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