CHEMISTRY

Paper 9701/11
Multiple Choice

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

General comments

This examination paper provided a suitable, but difficult, challenge to the candidates. Most candidates were able to finish the paper within the hour allowed.

Many candidates chose the correct response to each of **Questions 5**, **6**, **11**, **14**, **19**, **27** and **31**. Seven questions were found to be particularly challenging; **Questions 1**, **8**, **13**, **15**, **22**, **37** and **38**. These will now be looked at in greater detail.

Comments on specific questions

Question 1

The most common incorrect answer was **D**.
The total abundance of the three peaks is 108.3. The sum which gives the A_r is therefore $((100 \times 20) + (0.3 \times 21) + (8 \times 22)) / 108.3$. The answer to this sum is 20.15.

Question 8

The most common incorrect answer was **B**.
The equation representing the enthalpy change of atomisation of an element must produce one mole of atoms. This rules out option **B** and **D**. The element must be in its standard state, for iodine this is solid, so the answer is **C**.

Question 13

The most common incorrect answer was **B**.
Of the four elements given only magnesium and aluminium will produce a precipitate with NaOH(aq). Of these two elements only aluminium has a hydroxide that dissolves in an excess of NaOH(aq), so the answer is **C**.

Question 15

The most common incorrect answer was **C**.
The equation for the reaction involved is $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$. The ratio X / Y is therefore 184 / 32 which is equal to 1 / 0.174.

Question 22

The most common incorrect answer was **C**. Each answer will be treated separately.

A does not exist as a mixture of two optical isomers.
B gives three alkenes under the conditions described, pent-1-ene and *cis* pent-2-ene and *trans* pent-2-ene.
C does not exist as a mixture of two optical isomers.
D gives two alkenes under the conditions described, 3-methylbut-1-ene and 2-methylbut-2-ene.

Question 37

The most common incorrect answer was **C**. Each statement will be treated separately.

Statement 1 is true.
Statement 2 is true. When the upper C=C bond is oxidised both limonene and terpinolene give a product with a ketone group and an acid group in the same positions on the carbon skeleton. However, when the lower C=C bond is oxidised the ketone group forms on a different carbon atom.
Statement 3 is untrue. Limonene forms a compound with four chiral carbon atoms, as the carbon atom at the 4 position of the six-membered ring becomes chiral. Terpinolene forms a compound with three chiral carbon atoms.

Question 38

The most common incorrect answer was **B**. Each statement will be treated separately.

Statement 1 is true. The three compounds given could form by the cracking of $C_{12}H_{26}$.
Statement 2 is untrue. If Y and Z have different M_r values one of them must be ethene or propene, neither compound shows *cis-trans* isomerism.
Statement 3 is untrue. If X is octane, Y and Z would both have to be ethene, therefore they would not have different M_r values.

CHEMISTRY

Paper 9701/12
Multiple Choice

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

General comments

This examination paper provided a suitable challenge to the candidates. Some candidates may have experienced time pressure towards the end of the hour allowed.

Most candidates chose the correct response to **Questions 1**, **3**, **4**, **8**, **10**, **13**, **20** and **24.** Five questions were found to be particularly challenging; **Questions 2**, **7**, **11**, **27** and **39** These questions will now be looked at in greater detail.

Comments on specific questions

Question 2

The most common incorrect answer was **D**.

Since the formula of carbon dioxide is CO_2 one mole of carbon dioxide contains three moles of atoms, so **D** is wrong. However, since the formula of methane is CH_4 one mole of methane contains five moles of atoms, so **C** is correct.

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Question 7

The most common incorrect answer was **B**.
Answer **B** is incorrect because it refers to bond energies, not intermolecular forces. One molecule of PH_3 and HCl each has 18 electrons, and the similar boiling points show that both molecules have similar intermolecular forces, so **D** is correct.

Question 11

The most common incorrect answer was **B**.
Both NO and NO_2 take part in reactions and are regenerated in subsequent steps, so both are acting as catalysts.

Question 27

The most common incorrect answer was **B**. The four choices will be looked at separately.

A will be dehydrated under the conditions described to form pent-2-ene. This has *cis* and *trans* isomers, so two organic products are formed.
B will be dehydrated under the conditions described to form pent-1ene and pent-2-ene, so three organic products are formed.
C will be dehydrated under the conditions described to form 3-methylpent-2-ene and 2-ethylbut-1-ene. 3-methylpent-2-ene has *cis* and *trans* isomers so three organic products are formed.
D will be dehydrated under the conditions described to form several organic products, including 3-hydroxypent-1-ene, 4-hydroxypent-2-ene and pent-1,3-diene. This is already more than two.

Question 39

The most common incorrect answer was **D**. The three statements will be looked at separately.

Reaction 1 produces $CH_2(OH)C^*(OH)(CN)CO_2H$, which is chiral.
Reaction 1 produces $CH_2(OH)C^*H(OH)CO_2H$, which is chiral.
Reaction 1 produces $CH_2(OH)CH(OH)CH_2OH$, which is not chiral.

CHEMISTRY

Paper 9701/13
Multiple Choice

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

General comments

This examination paper provided a suitable challenge to the candidates, many of whom did well. Most candidates were able to finish the paper within the hour allowed.

Many candidates chose the correct response to each of **Questions 2**, **9**, **11**, **12**, **14**, **17**, **18**, **27**, **30**, **31** and **35**. Five questions can be said to have been found to be particularly challenging; **Questions 16**, **21**, **22**, **37** and **38**. These will now be looked at in greater detail.

Comments on specific questions

Question 16

The most common incorrect answer was **C**.
Since iodine is displaced by chlorine and bromine from sodium iodide experiments 3 and 6 produce a purple layer. Since iodine cannot displace chlorine or bromine from sodium chloride or sodium bromide experiments 7 and 8 produce a purple layer. When we include experiment 9 this is five test-tubes that contain a purple upper hexane layer.

Question 21

The most common incorrect answer was **C**.
In this explanation it will be considered that HBr adds on to the central C=C bond first.

Since the molecule is symmetrical it does not matter how the first HBr adds to the central C=C bond. When the second HBr adds on, the bromine atom can go on either the 2 or the 3 position of the left hand ring. When the third HBr adds on, the bromine atom can go on either the 2 or the 3 position of the right hand ring. The four compounds that form can therefore be called '2,2', '2,3', '3,2' and '3,3'. Since the addition of the first HBr made the molecule asymmetrical '2,3' and '3,2' are different, giving four different products.

Question 22

The most common incorrect answer was **B**. Each answer will be treated separately.

A does not exist as a mixture of two optical isomers.
B gives three alkenes under the conditions described, pent-1-ene and *cis* pent-2-ene and *trans* pent-2-ene.
C does not exist as a mixture of two optical isomers.
D gives two alkenes under the conditions described, 3-methylbut-1-ene and 2-methylbut-2-ene.

Question 37

The most common incorrect answer was **A**. Each statement will be treated separately.

Statement 1 is true.
Statement 2 is true. When the upper C=C bond is oxidised both limonene and terpinolene give a product with a ketone group and an acid group in the same positions on the carbon skeleton. However, when the lower C=C bond is oxidised the ketone group forms on a different carbon atom.
Statement 3 is untrue. Limonene forms a compound with four chiral carbon atoms, as the carbon atom at the 4 position of the six-membered ring becomes chiral. Terpinolene forms a compound with three chiral carbon atoms.

Question 38

The most common incorrect answer was **B**. Each statement will be treated separately.

Statement 1 is true. The three compounds given could form by the cracking of $C_{12}H_{26}$.
Statement 2 is untrue. If Y and Z have different M_r values one of them must be ethene or propene, neither compound shows *cis-trans* isomerism.
Statement 3 is untrue. If X is octane, Y and Z would both have to be ethene, therefore they would not have different M_r values.

CHEMISTRY

Paper 9701/21
AS Structured Questions

Key messages

It is important to emphasise to all students that, in questions requiring any form of calculation, it is often unwise to round figures during the intermediate steps of determining a final answer.

Rounding errors for any mathematical numbers can be avoided if the process of rounding is left to the end of a question, unless specified elsewhere in the question.

Comments on specific questions

Question 1

(a) (i) Many candidates found it difficult to explain the meaning of the word *volatile* which may be defined as *a substance that easily evaporates.*

Many answers suggested that volatility was the ability or tendency for a liquid to vaporise, without considering the ease with which, or how readily this evaporation occurs.

(ii) Many correct answers showing a sigma and a pi bond from the C atom to each of the two S atoms, leaving each S with a further two lone pairs of electrons, in the outer shell.

(iii) The central C atom, in CS_2, has two pairs of electrons, in sigma bonds, leading to a linear shape with a bond angle of 180°. Many candidates gave a correct bond angle.

(iv) Many candidates correctly linked the increasing strength of the induced dipole intermolecular forces, in CS_2, with an increase in the number of electrons in CS_2 or S, compared to CO_2.

There was confusion, in some answers, between the induced dipoles and size / M_r of the respective molecules; also, a number of candidates incorrectly stated that the breaking of covalent bonds was responsible for the difference in physical properties between CS_2 and CO_2.

(b) (i) The enthalpy change of combustion definition requires 1 mole of a compound to be used and to be completely combusted in oxygen or combusted in excess oxygen.

The most common errors included the omission of oxygen or stating that ‘energy was required’ for a combustion reaction.

(ii) Several candidates gave answers showing a Born-Haber cycle for the combustion of $CS_2(l)$ and included the correct stoichiometry for an answer of $-1077.7\ kJ\ mol^{-1}$.

The question required the use of the enthalpy changes of formation data from the table; common errors included the introduction of the bond energy value for O_2 (496) into the calculation and the omission of 2 x $\Delta H_f\ (SO_2)$.

(c) (i) Hydrogen sulphide acts as a weak acid by partially dissociating into $H^+(aq)$ ions. Some candidates confused dissolving with dissociation and several mentioned that H_2S gave a low concentration of H^+ ions, which is a consequence of the partial dissociation.

(ii) Few answers gave the correct conjugate base of H_2S as HS^-.

The concept of the loss of H^+ from H_2S to give a conjugate base, was not often seen and many answers gave the conjugate base ranging from S / S^- / HS or HS^+.

(iii) The reaction between H_2S and O_2 to form S and H_2O is a redox reaction as illustrated by the increase in oxidation number of S from –2 (in H_2S) to 0 (in S), an *oxidation*, and the decrease in oxidation number of O from 0 (in O_2) to –2 (in H_2O), a *reduction*.

A quite well answered question; many candidates gained full marks. A common error was the omission of the terms oxidation/ reduction for the change in oxidation number for specific elements.

(d) (i) The key to gaining full marks for this question appeared to be by identifying that the 0.100 dm^3 of oxygen was an excess; the volume of gas present at the end of this experiment, therefore, consisted of SO_2 formed in this reaction plus the excess oxygen.

Correct calculation of the original moles of As_2S_3 was then essential in order to calculate the final volume of SO_2 and to establish how much O_2 had been used and how much O_2 remained, at the end of the experiment.

Candidates found the determination of the moles of oxygen remaining challenging. The use of the stoichiometry of the balanced equation:

$2As_2S_3(s) + 9O_2(g) \rightarrow As_4O_6(s) + 6SO_2(g)$

also led to confusion with many using a ratio of 1:6 for $2As_2S_3 : 6SO_2$.

(ii) It was widely recognised by candidates that the environmental consequence of releasing $SO_2(g)$ into the atmosphere is '*acid rain'*.

(iii) When $SO_2(g)$ is removed from air using NaOH(aq) it is an *acid-base* reaction.

The equation including state symbols is:

$SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3(aq) + H_2O(l)$

Very many answers gave the products as Na_2SO_4 and $H_2(g)$ which would involve the S changing its oxidation number from (IV) to (VI).

Question 2

(a) (i) The one other product that is produced when calcium metal is reacted with HNO_3 to form $Ca(NO_3)_2$, is hydrogen gas. This question was generally well answered.

(ii) The correct equation to represent the thermal decomposition of $Ca(NO_3)_2$ is:

$$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + \frac{1}{2}O_2$$

Often the candidates stated the correct decomposition equation, but incorrectly balanced the equation.

(iii) There is an ***increase*** in the thermal stability of Group 2 nitrates down the group, the option selected by many candidates.

(iv) A balanced equation was required to represent the reaction between $CaCO_3$ and CO_2 in aqueous solution, to form $Ca(HCO_3)_2(aq)$.

$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$

Most candidates gave a correctly balanced equation.

(b) $Ca(OH)_2$ is used in agriculture to reduce the acidity of soil; this was recognised by many candidates.

(c) (i) Hybridisation describes how different atomic orbitals of similar energies combine to form a set of equivalent hybrid orbitals which can then overlap with orbitals of other atoms.

Each carbon in the C_2^{2-} anion contains an *sp* hybridised orbital; these sp hybridised orbitals are formed by the overlap of one s and one p orbital.

Many candidates found the explanation of hybridisation difficult; several answers often discussed the use of orbitals to generate sigma and pi bonds rather than how the hybrids are formed.

(ii) Very, very few answers correctly showed two *sp* hybrids overlapping to form a sigma bond as illustrated below

(d) (i) The 1.50×10^6 tonnes of ammonia was often correctly calculated by converting this value to grammes and then using the $M_r(NH_3)$.

Many candidates then divided this number by 2 (as per the balanced equation given) and used the $M_r(CaCN_2)$ to calculate the mass of $CaCN_2$ which was then successfully converted back to tonnes.

The most common errors included the use of 80 instead of 80.1, for the M_r of $CaCN_2$, and the omission of the division of the moles of NH_3 by 2, to determine the correct mass of $CaCN_2$.

(ii) Several candidates gave the correct structure for the formation of CH_3CH_2CN, from the reaction between CH_3CH_2Br and NaCN. The sequential acid hydrolysis to the carboxylic acid, propanoic acid, C_2H_5COOH, using $H_2SO_4(aq)$, was less well known. The addition of HCN, in the presence of NaCN, to propanone to form $CH_3C(OH)(CN)CH_3$ was also challenging for many. Correct skeletal representations of the three organic products were often given.

Question 3

(a) (i) This question on the difference in melting points of two allotropes of phosphorus, white phosphorus (P_4) and red phosphorus(P), is directly linked to their structures.

White phosphorus (P_4) is a simple molecule held together by covalent bonds between the four P atoms, whereas red phosphorus (P), is a giant three-dimensional structure of P atoms joined by covalent bonds.

The melting point of the simple molecule, P_4, will thus be associated with overcoming the intermolecular forces of attraction, whilst the red phosphorus, P, will melt when the covalent bonds throughout the giant three-dimensional arrangement of the P atoms are broken.

The few candidates who gave the correct structures for both white and red phosphorus tended to give a correct explanation for what was happening when P_4 and P melted.

Common errors included describing white P_4 as 'simple covalent' and incorrectly comparing IMF's in P_4 with IMF's in red P.

(ii) Diagrams showing the reaction pathway for the exothermic reaction

$$\frac{1}{4}P_4(s) \rightarrow P(s) \quad \Delta H = -17.6\ \text{kJ mol}^{-1}$$

was well answered.

(b) (i) The oxidation number of phosphorus, in P_4O_{10}, is V; a well answered question.

(ii) The reaction of water with both PCl_5 and P_4O_{10}, to form **Q**, is a hydrolysis reaction forming phosphoric (V) acid, H_3PO_4, **Q**, in both instances. HCl is also formed in the reaction of PCl_5 with water:

$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$

$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$

Some candidates identified **Q**, H_3PO_4, in both reactions, but were then unable to correctly balance either equation.

Frequently answers contained phosphorus containing compounds where the oxidation number of the P had changed on going from reactant to product.

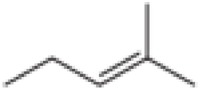
(c) (i) The empirical formula of triphenylphosphine was often correctly given as $C_{18}H_{15}P$. A common error seen regularly was $P(C_6H_5)_3$.

(ii) Many answers were able to state the type of reaction as *reduction* when $NaBH_4$ was used in stage 1, where an aldehyde functional group is reduced to an alcohol group (**G**). The *substitution* reaction, in stage 2, where an alcohol functional group is treated with red P and I_2 to form $C_2H_5CH_2I$ was less well known.

(iii) A range of responses was seen for the structures of **G** and **H**. Many correctly identified **G** as $C_2H_5CH_2OH$, from the reduction of C_2H_5CHO, using $NaBH_4$. The structure of **H** proved more challenging for many; there was a requirement to match the reaction in stage 3 with the unbalanced equation given in the stem. Candidates who opted to use skeletal formulae, as in the stem, tended to give an accurate and correct structure of $C_2H_5CH{=}CHC_2H_5$, for **H**.

(d) Several candidates recognised that hot, concentrated acidified $KMnO_4$ is used to cleave the C=C double bond, in **J**, to produce products dependent upon the groups/atoms attached to the C atoms in the C=C.

J



The first stage of this reaction is to replace the C=C with two carbon-oxygen double bonds which may then be further oxidised, if appropriate.

Here propanone is one product, $(CH_3)_2CO$, and the other is propanoic acid, C_2H_5COOH, which is formed from the propanal formed in the first stage of this extended oxidation process.

Common incorrect structures given did not fully oxidise propanal to propanoic acid.

Question 4

(a) (i) Most candidates gained full credit here for giving the correct reagent and conditions for the oxidation of C_2H_5OH to CH_3COOH, often using acidified $K_2Cr_2O_7$ and heating under reflux.

Errors here tended to include omitting reflux or acidified.

(ii) Surprisingly, the equation to represent the oxidation of C_2H_5OH to CH_3COOH, using [O] to denote the oxidising agent was poorly answered.

$C_2H_5OH + 2[O] \rightarrow CH_3CO_2H + H_2O$

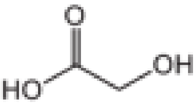
Many answers included either hydrogen as a product or omitted the H_2O as a product.

(iii) In the reaction scheme, given in the question paper, reaction 2 involves the conversion of CH_3COOH to $CH_2BrCOOH$

Many candidates correctly state that this type of reaction is a *substitution* reaction.

(iv) The description of H_2SO_4 behaving as a *homogeneous* catalyst, in an esterification reaction, because it was in the same phase / in the same state as the reactant, C_2H_5OH, was very well answered.

(b) This question required the identification of a functional group (containing no O-H bonds), which is present, twice, in a product formed from the presence of a 2-hydroxyethanoic acid, in the reaction mixture.



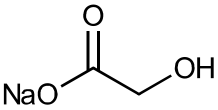
Two absorptions were given from an infrared spectrum of 1100 cm^{-1} and 1720 cm^{-1} linked to C—O and to C=O bonds.

Many candidates correctly identified the functional group as an ***ester*** from the infrared absorptions.

Very few candidates, however, went on to explain why one could eliminate the choices of alcohols and carboxylic acid functional groups as there were **no** O-H bonds, and deduce that an ester must be the only functional group present here, based on the IR data.

A common error was for the mention of the presence of the alcohol and carboxylic acid groups, by stating what was in the Data Booklet for the absorptions 1100 and 1720 cm^{-1}, identifying the presence of an O-H group, but then adding further comments that contradicted this statement.

(c) (i) The reaction between 2-hydroxyethanoic acid and Na_2CO_3 solution gave only the sodium salt of the carboxylic acid functional group



Many incorrectly suggested the alcohol group would also react with Na_2CO_3.

(ii) The reduction of the hydroxy acid to the diol, $(CH_2OH)_2$, can be achieved using a strong reducing agent.

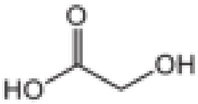
$NaBH_4$ is a weak reducing agent and will not reduce the COOH group to an alcohol group.

(iii) An equation for the reaction of $(CH_2OH)_2$ with $SOCl_2$ to form $(CH_2Cl)_2$ proved quite challenging for some candidates.

$(CH_2OH)_2 + SOCl_2 \rightarrow (CH_2Cl)_2 + SO_2 + H_2O$

A common error was to form H_2SO_4 as a by-product.

(d) The hydroxyl acid



contains two polar O-H groups, thus interactions between hydroxy acid molecules include hydrogen bonding; water is a polar molecule that can form intermolecular hydrogen bonds.

When the hydroxy acid and water are mixed the interactions between the hydroxy acid and water are hydrogen bonding, so the hydroxy acid dissolves in water.

Many answers referred to the polarity of the individual but did not make the link of the interactions between the water and hydroxy acid and solubility in water.

CHEMISTRY

Paper 9701/22
AS Structured Questions

Key messages

The most successful candidates produce answers which include all relevant details for key definitions, explanations and chemical reactions in a succinct fashion, with appropriate use of key vocabulary and use of information given in a question.

Representation of chemical symbols must not be ambiguous and where applicable the correct oxidation states should be included when naming compounds.

Candidates should be discouraged from using previous mark scheme details as their only basis for revision. They should be encouraged to respond in terms of the context of the question given.

General comments

The term 'reflux' is being used indiscriminately whenever a question asks for conditions to be identified; not all answers which need to be heated require heat under reflux and reactions carried out in the cold or room temperature should not involve reflux.

Candidates should be reminded that any working out or attempts to answer a question which the candidate does not wish the Examiner to mark must be crossed out.

Comments on specific questions

Question 1

(a) (i) Many answers identified the type of intermolecular forces responsible for the difference in boiling point and explained this difference in terms of the number of electrons. The most common incorrect responses were in terms of the difference in electronegativity and the difference in strength of permanent dipoles.

(ii) Good answers indicated an appropriate boiling point for HF based on the presence of hydrogen bonds and gave an explanation in terms of the relative strength of hydrogen bonds compared to the other intermolecular forces present in the different samples. The weakest responses did not use the information provided; these answers described the boiling point of HF following the trend shown by the rest of the group.

(b) Answers tended to appreciate that the process involved the enthalpy change which occurs when 1 mole of compound is made from elements under standard conditions. The best answers included the idea that the elements are in their standard states.

(c) (i) Correct expressions for K_p were common. Some answers were given in terms of the concentration of the species rather than the partial pressures.

(ii) This question was answered well with many answers correctly rounded to an appropriate number of significant figures.

(iii) Many explained the difference in the value of K_p in terms of the relevant shift in the position of equilibrium. A smaller proportion of responses related the effect of the change in K_p, at a reduced temperature, on the endothermic/exothermic nature of the reaction.

(d) (i) Common errors included showing iodine as monatomic or not balancing the number of oxygen molecules correctly.

(ii) In general, this question was answered well. Weaker responses produced ambiguous statements which referred to the change in oxidation number of I_2 or incorrectly referred to the change in oxidation number of the hydrogen species.

(e) Some excellent answers were seen which identified the change in pressure that occurs when iodine and hydrazine react together and explained this either by identifying the relationship between number of moles of gas reacting compared to number of moles of gas produced or by stating that pressure is proportional to the number of moles of gas in the container.

Weaker responses were given in general terms rather than specific to the given reaction.

Some descriptions of a change in the volume of gas were seen even though the question stated that the container was sealed.

(f) (i) The majority showed a correct dot-and-cross diagram for the molecule PI_3.

(ii) Hydration and redox were common incorrect answers.

(iii) The meaning of the term *strong Bronsted-Lowry acid* was well known.

(iv) Few answers were able to describe the formula of the conjugate base of H_3PO_3. Identification of one of the species in step 2 of the laboratory preparation of hydrogen iodide was a common incorrect answer.

(g) (i) There were some well-constructed responses which demonstrated an excellent understanding of the factors responsible for producing the major product and gave answers specific to the reaction of hydrogen iodide with propene.

Some gave an explanation in terms of the stability of the halogenoalkane product rather than the stability of the carbocation. The inductive effect of alkyl groups was frequently quoted in general terms. The best answers compared the number of alkyl groups present on the two carbocations and the resulting inductive effect.

(ii) There were some excellent responses which demonstrated understanding of Markownikov's rule and the correct convention for representing mechanisms using lone pairs and curly arrows. Weaker answers showed a lack of familiarity when using the conventions for describing a mechanism appropriately or did not understand what steps occurred during this mechanism.

Arrows from the carbon atom of C=C, a non-existent lone pair shown on the hydrogen of hydrogen iodide, δ+ rather than + shown as the charge on the carbocation and no lone pair on the iodide ion were common incorrect details.

Question 2

(a) (i) The bonding of the elements across Period 3 was well known.

(ii) Explanations of the difference in ionisation energy values in terms of nuclear charge and shielding were common. Many answers made no reference to the removal of an electron even though it is key to the ionisation process.

(iii) The majority appreciated that the difference in ionisation energy was because of 'spin pair repulsion' and good answers identified the location of the pair of electrons involved. Some responses were vague and referred to the repulsion involving a pair of electrons in the valence shell. Other statements suggested a pair of electrons was involved in the repulsion of other electrons rather than between the pair.

(iv) Identification of the maximum oxidation number of the elements was common.

(v) This question proved challenging. A very small proportion of excellent responses was seen which described the isoelectronic nature of the anions and appreciated that it was the effect of increasing nuclear charge which was responsible for the increased attraction of the nucleus to the outer electrons.

Misunderstanding of the term anion was seen quite often. Some answers described the effect of losing electrons to form the ion. Others described an increase in electron repulsion as more electrons are added to the shell even though the table shows the anions getting smaller from atomic number 14 to 17.

(b) Many sketches showed knowledge of the trend in melting point from element 11 to 17. Some sketches did not account for the difference in melting point of elements 15, 16 and 17 using knowledge of the relative difference in strength of their intermolecular forces.

(c) Candidates recognised that there should be a general trend in properties down Group 13 and, for the most part, predicted appropriate values for the relevant density, boiling point and cationic radius.

(d) (i) In general, the correct formula of indium chloride was predicted. Equations were often described when the question only required the formula of the salt.

(ii) Many equations were given with the correct indium containing product. However, there were few correct balanced equations.

(iii) A significant number of candidates were able to show the correct connectivity and bond type present in the dimer. Common mistakes included the two indium atoms joined by a covalent bond or described a lone pair of electrons on each indium atom responsible for the formation of the dative covalent bonds.

Question 3

(a) This was a difficult structure to name. Ambiguity arose in those answers that did not identify the position of the double bond or gave the incorrect numbers to show the position of the two methyl groups on but-2-ene.

(b) Some structures drawn were structural isomers of **T** that would not show cis-trans isomerism. Any formulae which are used by candidates to work out the skeletal formula must be crossed out.

(c) (i) The most common incorrect answer showed 2 vertical p orbitals with no overlap.

(ii) Identification of the type of hybridisation between the two carbon atoms was well known.

(d) (i) The correct reagent, potassium manganate (VII), was often described. The conditions required to make the diol were generally confused with the conditions which would rupture the carbon –carbon double bond. Contradictory answers stated that cold conditions were required with ‘heat under reflux’.

(ii) The reaction of compounds like **V**, which contain a carbonyl group, with 2, 4-dinitrophenylhydrazine was generally well known. Weaker answers did not state that a precipitate was made in the reaction.

(iii) Excellent answers interpreted the details given for reaction 3 and described the disappearance of appropriate absorptions that indicated a C-O bond was lost and the appearance of appropriate absorptions that indicated the formation of a C=O bond.

(e) (i) Familiarisation with the triiodomethane reaction was apparent in many answers and identification of a yellow precipitate was quite common.

(ii) Answers did not always refer to the reactants involved in reaction 3. Oxygen and **V** were common incorrect answers. Descriptions of a purple gas or effervescence were also seen.

(iii) Candidates found it difficult to interpret the skeletal formulae given to construct an equation for reaction 4. Incorrect equations included those that were not balanced or showed a product with molecular formula $C_6H_{13}O$.

(iv) Many answers demonstrated a good understanding of optical isomerism. The two optical isomers of X were shown with correct bond shapes to indicate the three-dimensional tetrahedral structures, with one structure as the non-superimposable mirror image of the other. The weakest responses made no attempt to show three-dimensional structures or to show a tetrahedral shape around the chiral carbon.

(v) Some answers which referred to sulfuric acid or phosphoric acid as the reagent did not state that the acid should be concentrated.

(vi) The representation of the repeat unit for polymer **Z** proved challenging for many.

(vii) The idea of reaction 6 involving a high activation energy was commonly seen in candidate response.

CHEMISTRY

Paper 9701/23
AS Structured Questions

Key messages

It is important to emphasise to all students that, in questions requiring any form of calculation, it is often unwise to round figures during the intermediate steps of determining a final answer.

Rounding errors for any mathematical numbers can be avoided if the process of rounding is left to the end of a question, unless specified elsewhere in the question.

Comments on specific questions

Question 1

(a) (i) Many candidates found it difficult to explain the meaning of the word *volatile* which may be defined as *a substance that easily evaporates.*

Many answers suggested that volatility was the ability or tendency for a liquid to vaporise, without considering the ease with which, or how readily this evaporation occurs.

(ii) Many correct answers showing a sigma and a pi bond from the C atom to each of the two S atoms, leaving each S with a further two lone pairs of electrons, in the outer shell.

(iii) The central C atom, in CS_2, has two pairs of electrons, in sigma bonds, leading to a linear shape with a bond angle of 180°. Many candidates gave a correct bond angle.

(iv) Many candidates correctly linked the increasing strength of the induced dipole intermolecular forces, in CS_2, with an increase in the number of electrons in CS_2 or S, compared to CO_2.

There was confusion, in some answers, between the induced dipoles and size / M_r of the respective molecules; also, a number of candidates incorrectly stated that the breaking of covalent bonds was responsible for the difference in physical properties between CS_2 and CO_2.

(b) (i) The enthalpy change of combustion definition requires 1 mole of a compound to be used and to be completely combusted in oxygen or combusted in excess oxygen.

The most common errors included the omission of oxygen or stating that ‘energy was required’ for a combustion reaction.

(ii) Several candidates gave answers showing a Born-Haber cycle for the combustion of CS_2(l) and included the correct stoichiometry for an answer of $-1077.7\ \text{kJ mol}^{-1}$.

The question required the use of the enthalpy changes of formation data from the table; common errors included the introduction of the bond energy value for O_2 (496) into the calculation and the omission of 2 x ΔH_f (SO_2).

(c) (i) Hydrogen sulphide acts as a weak acid by partially dissociating into H^+(aq) ions. Some candidates confused dissolving with dissociation and several mentioned that H_2S gave a low concentration of H^+ ions, which is a consequence of the partial dissociation.

(ii) Few answers gave the correct conjugate base of H_2S as HS^-.

The concept of the loss of H^+ from H_2S to give a conjugate base, was not often seen and many answers gave the conjugate base ranging from S / S^- / HS or HS^+.

(iii) The reaction between H_2S and O_2 to form S and H_2O is a redox reaction as illustrated by the increase in oxidation number of S from –2 (in H_2S) to 0 (in S), an *oxidation*, and the decrease in oxidation number of O from 0 (in O_2) to –2 (in H_2O), a *reduction*.

A quite well answered question; many candidates gained full marks. A common error was the omission of the terms oxidation/ reduction for the change in oxidation number for specific elements.

(d) (i) The key to gaining full marks for this question appeared to be by identifying that the 0.100 dm^3 of oxygen was an excess; the volume of gas present at the end of this experiment, therefore, consisted of SO_2 formed in this reaction plus the excess oxygen.

Correct calculation of the original moles of As_2S_3 was then essential in order to calculate the final volume of SO_2 and to establish how much O_2 had been used and how much O_2 remained, at the end of the experiment.

Candidates found the determination of the moles of oxygen remaining challenging. The use of the stoichiometry of the balanced equation:

$2As_2S_3(s) + 9O_2(g) \rightarrow As_4O_6(s) + 6SO_2(g)$

also led to confusion with many using a ratio of 1:6 for $2As_2S_3 : 6SO_2$.

(ii) It was widely recognised by candidates that the environmental consequence of releasing $SO_2(g)$ into the atmosphere is '*acid rain*'.

(iii) When $SO_2(g)$ is removed from air using NaOH(aq) it is an *acid-base* reaction.

The equation including state symbols is:

$SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3(aq) + H_2O(l)$

Very many answers gave the products as Na_2SO_4 and $H_2(g)$ which would involve the S changing its oxidation number from (IV) to (VI).

Question 2

(a) (i) The one other product that is produced when calcium metal is reacted with HNO_3 to form $Ca(NO_3)_2$, is hydrogen gas. This question was generally well answered.

(ii) The correct equation to represent the thermal decomposition of $Ca(NO_3)_2$ is:

$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + \frac{1}{2}O_2$

Often the candidates stated the correct decomposition equation, but incorrectly balanced the equation.

(iii) There is an ***increase*** in the thermal stability of Group 2 nitrates down the group, the option selected by many candidates.

(iv) A balanced equation was required to represent the reaction between $CaCO_3$ and CO_2 in aqueous solution, to form $Ca(HCO_3)_2(aq)$.

$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$

Most candidates gave a correctly balanced equation.

(b) $Ca(OH)_2$ is used in agriculture to reduce the acidity of soil; this was recognised by many candidates.

(c) (i) Hybridisation describes how different atomic orbitals of similar energies combine to form a set of equivalent hybrid orbitals which can then overlap with orbitals of other atoms.

Each carbon in the C_2^{2-} anion contains an *sp* hybridised orbital; these sp hybridised orbitals are formed by the overlap of one s and one p orbital.

Many candidates found the explanation of hybridisation difficult; several answers often discussed the use of orbitals to generate sigma and pi bonds rather than how the hybrids are formed.

(ii) Very, very few answers correctly showed two *sp* hybrids overlapping to form a sigma bond as illustrated below

(d) (i) The 1.50×10^6 tonnes of ammonia was often correctly calculated by converting this value to grammes and then using the $M_r(NH_3)$.

Many candidates then divided this number by 2 (as per the balanced equation given) and used the $M_r(CaCN_2)$ to calculate the mass of $CaCN_2$ which was then successfully converted back to tonnes.

The most common errors included the use of 80 instead of 80.1, for the M_r of $CaCN_2$, and the omission of the division of the moles of NH_3 by 2, to determine the correct mass of $CaCN_2$.

(ii) Several candidates gave the correct structure for the formation of CH_3CH_2CN, from the reaction between CH_3CH_2Br and NaCN. The sequential acid hydrolysis to the carboxylic acid, propanoic acid, C_2H_5COOH, using $H_2SO_4(aq)$, was less well known. The addition of HCN, in the presence of NaCN, to propanone to form $CH_3C(OH)(CN)CH_3$ was also challenging for many. Correct skeletal representations of the three organic products were often given.

Question 3

(a) (i) This question on the difference in melting points of two allotropes of phosphorus, white phosphorus (P_4) and red phosphorus(P), is directly linked to their structures.

White phosphorus (P_4) is a simple molecule held together by covalent bonds between the four P atoms, whereas red phosphorus (P), is a giant three-dimensional structure of P atoms joined by covalent bonds.

The melting point of the simple molecule, P_4, will thus be associated with overcoming the intermolecular forces of attraction, whilst the red phosphorus, P, will melt when the covalent bonds throughout the giant three-dimensional arrangement of the P atoms are broken.

The few candidates who gave the correct structures for both white and red phosphorus tended to give a correct explanation for what was happening when P_4 and P melted.

Common errors included describing white P_4 as 'simple covalent' and incorrectly comparing IMF's in P_4 with IMF's in red P.

(ii) Diagrams showing the reaction pathway for the exothermic reaction

$$\frac{1}{4}P_4(s) \rightarrow P(s) \quad \Delta H = -17.6\ \text{kJ mol}^{-1}$$

was well answered.

(b) (i) The oxidation number of phosphorus, in P_4O_{10}, is V; a well answered question.

(ii) The reaction of water with both PCl_5 and P_4O_{10}, to form **Q**, is a hydrolysis reaction forming phosphoric (V) acid, H_3PO_4, **Q**, in both instances. HCl is also formed in the reaction of PCl_5 with water:

$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$

$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$

Some candidates identified **Q**, H_3PO_4, in both reactions, but were then unable to correctly balance either equation.

Frequently answers contained phosphorus containing compounds where the oxidation number of the P had changed on going from reactant to product.

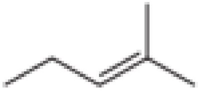
(c) (i) The empirical formula of triphenylphosphine was often correctly given as $C_{18}H_{15}P$. A common error seen regularly was $P(C_6H_5)_3$.

(ii) Many answers were able to state the type of reaction as *reduction* when $NaBH_4$ was used in stage 1, where an aldehyde functional group is reduced to an alcohol group (**G**). The *substitution* reaction, in stage 2, where an alcohol functional group is treated with red P and I_2 to form $C_2H_5CH_2I$ was less well known.

(iii) A range of responses was seen for the structures of **G** and **H**. Many correctly identified **G** as $C_2H_5CH_2OH$, from the reduction of C_2H_5CHO, using $NaBH_4$. The structure of **H** proved more challenging for many; there was a requirement to match the reaction in stage 3 with the unbalanced equation given in the stem. Candidates who opted to use skeletal formulae, as in the stem, tended to give an accurate and correct structure of $C_2H_5CH=CHC_2H_5$, for **H**.

(d) Several candidates recognised that hot, concentrated acidified $KMnO_4$ is used to cleave the C=C double bond, in **J**, to produce products dependent upon the groups/atoms attached to the C atoms in the C=C.

J



The first stage of this reaction is to replace the C=C with two carbon-oxygen double bonds which may then be further oxidised, if appropriate.

Here propanone is one product, $(CH_3)_2CO$, and the other is propanoic acid, C_2H_5COOH, which is formed from the propanal formed in the first stage of this extended oxidation process.

Common incorrect structures given did not fully oxidise propanal to propanoic acid.

Question 4

(a) (i) Most candidates gained full credit here for giving the correct reagent and conditions for the oxidation of C_2H_5OH to CH_3COOH, often using acidified $K_2Cr_2O_7$ and heating under reflux.

Errors here tended to include omitting reflux or acidified.

(ii) Surprisingly, the equation to represent the oxidation of C_2H_5OH to CH_3COOH, using [O] to denote the oxidising agent was poorly answered.

$C_2H_5OH + 2[O] \rightarrow CH_3CO_2H + H_2O$

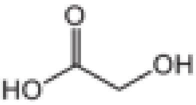
Many answers included either hydrogen as a product or omitted the H_2O as a product.

(iii) In the reaction scheme, given in the question paper, reaction 2 involves the conversion of CH_3COOH to $CH_2BrCOOH$

Many candidates correctly state that this type of reaction is a *substitution* reaction.

(iv) The description of H_2SO_4 behaving as a *homogeneous* catalyst, in an esterification reaction, because it was in the same phase / in the same state as the reactant, C_2H_5OH, was very well answered.

(b) This question required the identification of a functional group (containing no O-H bonds), which is present, twice, in a product formed from the presence of a 2-hydroxyethanoic acid, in the reaction mixture.



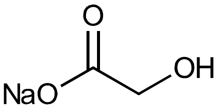
Two absorptions were given from an infrared spectrum of 1100 cm^{-1} and 1720 cm^{-1} linked to C—O and to C=O bonds.

Many candidates correctly identified the functional group as an ***ester*** from the infrared absorptions.

Very few candidates, however, went on to explain why one could eliminate the choices of alcohols and carboxylic acid functional groups as there were **no** O-H bonds, and deduce that an ester must be the only functional group present here, based on the IR data.

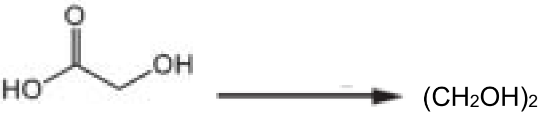
A common error was for the mention of the presence of the alcohol and carboxylic acid groups, by stating what was in the Data Booklet for the absorptions 1100 and 1720 cm^{-1}, identifying the presence of an O-H group, but then adding further comments that contradicted this statement.

(c) (i) The reaction between 2-hydroxyethanoic acid and Na_2CO_3 solution gave only the sodium salt of the carboxylic acid functional group



Many incorrectly suggested the alcohol group would also react with Na_2CO_3.

(ii) The reduction of the hydroxy acid to the diol, $(CH_2OH)_2$, can be achieved using a strong reducing agent.



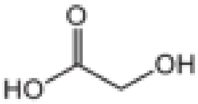
$NaBH_4$ is a weak reducing agent and will not reduce the COOH group to an alcohol group.

(iii) An equation for the reaction of $(CH_2OH)_2$ with $SOCl_2$ to form $(CH_2Cl)_2$ proved quite challenging for some candidates.

$(CH_2OH)_2 + SOCl_2 \rightarrow (CH_2Cl)_2 + SO_2 + H_2O$

A common error was to form H_2SO_4 as a by-product.

(d) The hydroxyl acid



contains two polar O-H groups, thus interactions between hydroxy acid molecules include hydrogen bonding; water is a polar molecule that can form intermolecular hydrogen bonds.

When the hydroxy acid and water are mixed the interactions between the hydroxy acid and water are hydrogen bonding, so the hydroxy acid dissolves in water.

Many answers referred to the polarity of the individual but did not make the link of the interactions between the water and hydroxy acid and solubility in water.

CHEMISTRY

Paper 9701/31
Advanced Practical Skills 1

Key messages

- It is essential that candidates and supervisors enter the information regarding session and laboratory on the front cover of the paper so that candidates' results can be matched with the relevant supervisor values.
- Candidates should be reminded to read the full method before starting an experiment so that they record all the required data in a suitable manner.
- Candidates should be encouraged to reflect on the precision of apparatus used when providing numerical answers.
- Candidates should be given opportunities to discuss the reasons for carrying out practical procedures in a particular way.

General comments

This paper tested all the practical assessment objectives listed in the syllabus. There appeared to be no time constraints with almost all candidates completing the paper. Candidates should give all their written answers in black or dark blue ink as some answers in pencil were very difficult to decipher.

The supervisors in some centres did not supply results for the qualitative analysis question. This makes it less likely for them to be aware of any errors in the supply of reagents: problems listed in the supervisor's report are taken into consideration by the principal examiner.

Comments on specific questions

Question 1

The accuracy of the experimental work tended to be centre-dependent with some excellent results seen. Candidates should be reminded to read through the method carefully to ensure they do not miss recording important information.

(a) Very few candidates wrote 'weight' instead of mass and most included a correctly displayed unit with all the entries in the tables of data. A few omitted the calculated value of the mass of residue and some confused the mass of residue with the mass of water lost. Many candidates gained at least one of the two marks available for carrying out the practical procedures accurately. This was judged by comparing the candidate and supervisor results.

(b) **(i)** Almost all candidates gained this mark with those who had confused mass of residue and mass of water being credited if they used the values they gave in **(a)**.

(ii) Most candidates gave a correct answer to between two and four significant figures and gained this mark.

(iii) Most candidates correctly calculated relative formula mass of $\mathbf{X}_2CO_3$.

(iv) Many also subtracted 60 from their answer to **(iii)** though not all then divided by 2 to account for the formula being $\mathbf{X}_2CO_3$. Some candidates chose elements that were not members of Group 1 whilst others did not match their numerical answer with Group 1 elements shown on the Periodic Table.

(c) Candidates were instructed to use evidence from their results in **(a)** so that the correct answer could be that decomposition was complete or not complete. The answer had to concentrate on whether a further loss of mass occurred between the first and second weighing of crucible + lid + residue.

Question 2

Almost all candidates appear secure in their use of titration apparatus and most were aware of many of the methods used in calculations associated with volumetric analysis.

(a) Most candidates presented their data in the manner required and scored well in terms of accuracy marks. Just a few omitted burette readings for the rough titration, and a small number read burettes to only 0.1 cm^3.

(b) Most candidates gained this mark. Only a few gave the answer to fewer than 2 decimal places or selected titres with a spread of greater than 0.20 cm^3.

(c) (i) Many candidates realised that numerical answers should be to 3 or 4 significant figures.

(ii) Most candidates gained this mark. Very few omitted dividing by 1000 to convert cm^3 to dm^3.

(iii) Far fewer gained this mark as candidates did not realise that they needed to use the stoichiometry of the reaction **and** the fact that the solution had been diluted. Many considered one of these factors but only the most able considered both. This perhaps shows the importance of reading the information given in the question carefully.

(iv) Many candidates gained this mark from correctly using their answer to **(iii)**.

(v) The method needed to identify **Z** was similar to that used in**1(b)(iv)** although this was somewhat easier in that it was not necessary to divide by 2.

(d) This part was only answered correctly by the most able candidates. Very few realised that to calculate the percentage difference the **difference** between the value of the A_r of the element calculated in **(c)(v)** and the value given in the Periodic Table must be used as a percentage of the Periodic Table value.

Question 3

Candidates should be encouraged to follow the instructions given at the start of the qualitative analysis question as many lost marks through incomplete testing of the ‘unknowns’. A conclusion, even if a correct identity of an ion, cannot be accepted unless there is supporting evidence. Precision in the use of scientific language is also required: ‘soluble precipitate’ is a contradiction in terms.

(a) (i) Nearly all candidates gave at least some correct observations. Many correctly reported an effervescence in **Test 2** with **FA 6** but few bubbled the gas into limewater to identify the gas. It should be noted that ‘milky’ and ‘cloudy white’ were accepted as observations in this test but that only ‘white precipitate’ will be allowed from 2022.

(ii) Many candidates correctly identified at least one ion but few identified all three. Both H^+ and OH^- proved problematic.

(iii) Although most candidates seem able to use the tests in the Qualitative Analysis Notes few apparently recognised that, rather than aqueous sodium hydroxide being used as a test for $Mg^{2+,}$ aqueous magnesium chloride can be used as a test for OH^-. This meant that only the most able candidates gave a correct test for OH^-. The inclusion, in the question, that the use of indicators was not acceptable might have given candidates a clue to the fact that indicators had some significance.

(iv) Since so few candidates correctly identified OH^- in **(iii)**, a significant number did not attempt this question.

(b) This question proved problematic for nearly all candidates.

(i) In **Test 1** it was expected that the purple manganate(VII) would be decolorised/go yellow. The formation of a brown coloration reported by a significant number of candidates suggests that, contrary to the instruction in the question of 'add a few drops of acidified aqueous potassium manganate(VII)', an excessive volume of this reagent was actually added.

In **Test 2** many candidates noticed the fizzing but very few gave a positive test for hydrogen.

(ii) There was not enough evidence to find the specific identity of **FA 8** but in **Test 1** it can be deduced that **FA 8** reduces manganate(VII) and in **Test 2** that **FA 8** is an acid.

CHEMISTRY

Paper 9701/33
Advanced Practical Skills 1

Key messages

- It is essential that candidates and Supervisors enter the information regarding session and laboratory on the front cover of the paper so that candidates' results can be matched with the relevant Supervisor values.
- Candidates should be reminded to read the full method before starting an experiment so that they record all the required data in a suitable manner.
- Candidates should be encouraged to reflect on the precision of apparatus used when providing numerical answers.
- Candidates should be given opportunities to discuss the reasons for carrying out practical procedures in a particular way.

General comments

This paper tested all the practical assessment objectives listed in the syllabus. There appeared to be no time constraints with almost all candidates completing the paper. The candidates achieved a wide spread of marks though relatively few gained marks above 35 or lower than 5. Candidates should give all their written answers in black or dark blue ink as some answers in pencil were very difficult to decipher.

The Supervisors in some centres did not supply results for the qualitative analysis question. This makes it less likely for them to be aware of any errors in the supply of reagents: problems listed in the Supervisor's report are taken into consideration by the principal examiner.

Comments on specific questions

Question 1

The accuracy of the experimental work tended to be centre-dependent with some excellent results seen. Candidates should be reminded to read through the method carefully to ensure they do not miss recording important information.

(a) Very few candidates wrote 'weight' instead of mass, and most included a correctly displayed unit with all the entries in the tables of data. However, some appeared to have ignored the instruction to 'read through the whole method before starting practical work'. Had they done so, and prepared a table for their data, fewer would have omitted necessary information or given an incorrect value for 'theoretical initial mass'. Many candidates gained the mark for accuracy.

(b) (i) Almost all candidates gained this mark. A few did not give the answer to an acceptable number of significant figures.

(ii) Most candidates gained this mark.

(iii) Most candidates correctly subtracted 60 from their answer to **(ii)** though not all then divided by 2 to account for the formula being $\mathbf{M_2CO_3}$. Some candidates did not match their numerical answer with the correct Group 1 cation.

(c) (i) While some candidates understood that heating the acid would decrease the solubility of the carbon dioxide many did not make it plain that the heating should be done before the **M_2CO_3** was added. Some candidates did not answer the question as they suggested a modification in the equipment such as collecting the gas in a gas syringe which was not used in **(a)**.

(ii) Many candidates correctly calculated the amount of acid used in the experiment or required by the reaction. However, not all showed use of the stoichiometry and omitted the factor of 2.

Question 2

Almost all candidates appear secure in their use of titration apparatus though slightly less so with the calculation. Very few candidates were able to explain their answer in **part (d)** indicating they would benefit from greater discussion of errors and improvements linked to the various practical techniques.

(a) Most candidates presented their data in the manner required and also scored well in terms of accuracy marks. Just a few omitted burette readings for the rough titration, and a small number read burettes to only 0.1 cm^3.

(b) Most candidates gained this mark. Only a few gave the answer to fewer than 2 decimal places or selected titres with a spread of greater than 0.20 cm^3.

(c) (i) Many candidates realised that numerical answers should be to 3 or 4 significant figures though not all gained the mark as they provided insufficient answers.

(ii) Most candidates gained this mark. Very few omitted dividing by 1 000 to convert cm^3 to dm^3.

(iii) Slightly fewer gained this mark as not all candidates realised they should use the stoichiometry of the reaction.

(iv) Almost all candidates attempting this part used the mass of M_2CO_3 correctly. The scale up from 25 cm^3 to 1 dm^3 caused problems for weaker candidates. It is important that candidates are reminded to read information given in the questions carefully.

(v) Many candidates gained this mark from correctly using their answer to **(iv)**.

(d) This part was the most demanding in the paper and only the most able candidates were able to supply a fully correct answer.

One way of answering this type of question is to follow the logic of answers given in **part (c)**. For example, if the acid is less concentrated then the titre will be greater. A greater titre (assuming the stated concentration of acid) will result in the amount of **M_2CO_3** being a greater number of moles so the M_r will be smaller. As the A_r of Rb is greater than that of K an acid of lower concentration gives the incorrect answer. Hence the acid provided is more concentrated than stated.

(In summary: concentration ↑ => titre ↓ => n(**M_2CO_3**) ↓ => M_r ↑)

Question 3

Candidates should be encouraged to follow the instruction given at the start of the qualitative analysis question as many lost marks through incomplete testing of the 'unknowns'. A conclusion, even if a correct identity of an ion, cannot be accepted unless there is supporting evidence. Precision in the use of scientific language is also required: 'soluble precipitate' is a contradiction in terms.

(a) (i) Most candidates successfully tested for ammonia so gained at least 1 mark. Only a few noted the condensation at the mouth of the test-tube on gentle warming. A sizable minority reported melting of the solid which was unlikely.

(ii) Almost all candidates correctly reported effervescence but few bubbled the gas into limewater either here or in **part (b)(i)** or **(b)(ii)**. It should be noted that 'milky' and 'cloudy white' were accepted observations but only 'white precipitate' will be allowed from 2022.

(b) (i) Candidates need to consider the precision of their descriptions and limit their descriptions to whether there is a change of colour or state. When none is apparent the expected response is no change or no reaction. Candidates sometimes assumed a reaction had taken place when a slight change in colour or thickness of a precipitate was due to dilution.

(ii) Most candidates gained at least 2 marks. Very few scored all 5 marks as the mixture of **FA 6** with NaOH(aq) was rarely warmed nor damp red litmus used to test any gas being evolved. Use of the **Qualitative Analysis Notes** on page 10 would have helped more candidates to remember to test **FA 7** with excess NaOH(aq). These **Notes** also help with describing the accepted colour of the precipitate (grey-green). Candidates who tested with additional reagents were unable to access one of the marks as that was contrary to instructions.

(c) (i) Few candidates gained more than 1 mark in drawing conclusions. Some ignored the instruction to give formulae. The ions most commonly identified correctly were NH_4^+ and Cl^-. However, there were some candidates who scored all 3 marks.

(ii) Very few candidates gave a correct ionic equation with that for $Ag^+(aq)$ and $Cl^-(aq)$ being the one seen most. Some candidates included 'spectator' ions, some wrote equations for reactions where no precipitate would be formed and others omitted state symbols.

CHEMISTRY

Paper 9701/34
Advanced Practical Skills 2

Key messages

- Candidates should be reminded to read the full method before starting an experiment so that they record all the required data in a suitable manner.
- Candidates should be encouraged to reflect on the precision of apparatus used when providing numerical answers.
- Candidates should be given the opportunity to carry out practical exercises which lead to the graphical representation of results so that the plotting of points is to the required standard.
- Candidates should be given opportunities to discuss the reasons for carrying out practical procedures in a particular way.

General comments

This paper tested all the practical assessment objectives listed in the syllabus. There appeared to be no time constraints with almost all candidates completing the paper. Candidates should give all their written answers in black or dark blue ink as some answers in pencil were very difficult to decipher.

The Supervisors in some centres did not supply results for the qualitative analysis question. This makes it less likely for them to be aware of any errors in the supply of reagents: problems listed in the Supervisor's report are taken into consideration by the principal examiner.

Comments on specific questions

Question 1

Almost all candidates completed the practical tasks, usually to a high standard. However, many found parts of the rest of the question more demanding.

(a) (i) Almost all candidates constructed a single table for their results.

(ii) The lack of the correct unit for rate of s^{-1} was the reason for some candidates to lose this mark.

(iii) One relatively common error was to give the volumes as integers instead of reflecting the accuracy of the burette. Another was not to give the time to the nearest second: candidates should be reminded that values such as 93.0 and 34.00 are not integers.

(iv) Almost all candidates selected suitable volumes for the additional experiments.

(v) As the rates were to be used for plotting a graph it was sufficient to record these to 1 decimal place. Integer values were allowed provided these were to a minimum of 2 significant figures.

(vi) Almost all candidates reported a decrease in time for an increase in volume of **FB 1**.

(vii) and **(viii)** The acquisition of accuracy marks was partly centre-dependent which suggested that some candidates had little experience of this type of procedure (whether owing to Covid or for other reasons). However, the majority of candidates gained at least 1 mark.

(b) (i) Almost all candidates assigned the correct variable to each axis and gained this mark. Those who lost mark II in **(a)** generally gained the mark here as ecf.

(ii) The majority correctly selected scales that led to plotted points covering more than half the available length on the two axes. Candidates should be encouraged to use simple scales such as 1, 2, 4 or 5 units to a 20 mm square wherever possible.

(iii) A poor choice of scale usually led to errors in plotting. Some candidates were too imprecise for this mark to be awarded. Candidates should be reminded to use a sharp pencil and ensure any point that should be on a line is on that line and points within a square should be plotted in the correct portion of the square.

(iv) Lines of best fit may be straight or a smooth curve but it is important in either case that anomalous points are clearly indicated. Candidates should either ring points they consider anomalous or otherwise label them. A line of best fit should have points balanced on either side and not be improved by rotation.

(c) This mark was gained by a minority of candidates. Many candidates appeared to ignore their graphs as a common response was that the rate was directly proportional to the concentration of **FB 1** when there was no extrapolation of the line to the origin. The other common error was that rate increased as concentration increased without mention of 'proportional'

(d) (i) Few candidates gained this mark as, although some were aware that a neutralisation reaction was taking place, many thought the sodium carbonate was reacting with sulfur dioxide.

(ii) There were many vague statements about pH or neutralisation but precise answers about sodium carbonate being used up were rare. It was clear that the reasons (health and safety) for using a quenching bath had not been discussed in class.

(e) (i) Many candidates gained 1 mark for calculating the amount of hydrogen ions and thiosulfate ions. Fewer used the stoichiometry from the balanced equation to gain both.

(ii) This part was the most demanding in the paper and only the most able candidates were able to supply a fully correct answer. The task was to investigate how the concentration of the thiosulfate ions affects the rate so the concentration of the acid must remain almost constant so it does not affect the rate too.

Question 2

The standard of experimental work, manipulation of results and demonstration of understanding the underlying chemistry varied considerably with a wide spread of marks seen.

(a) Most candidates gained the mark for headings and units. However, not all candidates gave thermometer readings to .0 or to .5 °C. It was clear from some small increases in temperature that not all candidates stirred the reactants for sufficient time.

(b) (i) While the majority of candidates used mcΔT successfully some gave the answer to an inappropriate number of significant figures. Candidates should always use the value for the specific heat capacity that is given in the question or, from 2022, in the data section.

(ii) Fewer candidates gained both marks here. Some omitted the conversion from J to kJ and others did not scale their amount of **FB 4** in 25 cm^3 to satisfy the required unit of mol dm^{-3}.

(c) (i) Many candidates omitted the factor of 2, owing to 2 readings being needed, in their calculation of maximum percentage error in the temperature rise.

(ii) Few candidates gained the mark for stating the rise in temperature would not change. Far fewer gained the second mark: many confused heat and temperature.

Question 3

Candidates should be aware that the provision of reagents in addition to those normally supplied indicates they are likely to be useful in obtaining observations. Precision of language in the description of changes in state and colour can be aided by use of the **Qualitative Analysis Notes**.

(a) (i) All candidates tested **FB 5** with aqueous sodium hydroxide and/or aqueous ammonia so gained mark I. Of these many also gained mark III for describing the colour of the precipitate and its solubility with excess alkali or change of colour on standing. A number of grey-green precipitates were reported even though the insolubility of the ppt on adding excess NaOH(aq) ruled out Cr^{3+}(aq). Few warmed the mixture of **FB 5** and NaOH(aq) or did not state that it was the gas that turned red litmus blue so could not access mark **IV**.

Very few selected to use the magnesium ribbon or aqueous sodium carbonate supplied or to use a named pH indicator so could not access mark **II**. Of those who correctly noted effervescence with either of the additional reagents fewer tested the gas. This is contrary to the instructions at the start of the **Qualitative analysis** section of the paper so normally these candidates would not be able to access mark **V**. However, as this section was deemed to be demanding the observation of effervescence was awarded the mark. It should be noted that 'milky' and 'cloudy white' were accepted observations on bubbling the gas through limewater but only 'white precipitate' will be allowed from 2022.

Owing to the lack of testing few candidates gained more than 1 of marks **VI** and **VII** with many incorrectly selecting Cr^{3+} as well as Fe^{2+}.

(ii) Most candidates selected (aqueous) barium chloride or (aqueous) barium nitrate. However, some candidates merely wrote Ba^{2+} which is an incomplete formula so was not acceptable. Some candidates omitted the addition of acid to the precipitate or chose to use sulfuric acid to test its solubility so could not access the marks. A minority of candidates claimed the white precipitate was soluble in hydrochloric or nitric acid. The use of acidified aqueous potassium manganate(VII) was not appropriate in this case as most candidates had already noted the presence of Fe^{2+} which would decolourise the purple solution.

(b) (i) Many candidates only gave 1 observation for each of **FB 6** and **FB 7** so could only access 1 mark. For **FB 6** the most common correct observation was the change of state. A few candidates noted effervescence but that the gas relit a glowing splint was rarely seen. It is probable that **FB 6** was not heated sufficiently strongly or for sufficient time.

For **FB 7** the most commonly seen correct observations were white fumes/smoke and the blue litmus paper turning red. Some candidates noted sublimation but very few tested for ammonia gas.

(ii) Many candidates suggested a physical change such as melting rather than a chemical reaction. While some suggested decomposition not all noted this only occurred on heating. 'Redox' was rarely seen which was not surprising given the limited observations written in **(b)(i)**.

CHEMISTRY

Paper 9701/35
Advanced Practical Skills 1

Key messages

- It is essential that candidates and supervisors enter the information regarding session and laboratory on the front cover of the paper so that candidates' results can be matched with the relevant supervisor values.
- Candidates should be reminded to read the full method before starting an experiment so that they record all the required data in a suitable manner.
- Candidates should be encouraged to reflect on the precision of apparatus used when providing numerical answers.
- Candidates should be given opportunities to discuss the reasons for carrying out practical procedures in a particular way.

General comments

This paper tested all the practical assessment objectives listed in the syllabus. There appeared to be no time constraints with almost all candidates completing the paper. Candidates should give all their written answers in black or dark blue ink as some answers in pencil were very difficult to decipher.

The supervisors in some centres did not supply results for the qualitative analysis question. This makes it less likely for them to be aware of any errors in the supply of reagents: problems listed in the supervisor's report are taken into consideration by the principal examiner.

Comments on specific questions

Question 1

The accuracy of the experimental work tended to be centre-dependent with some excellent results seen. Candidates should be reminded to read through the method carefully to ensure they do not miss recording important information.

(a) Very few candidates wrote 'weight' instead of mass and most included a correctly displayed unit with all the entries in the tables of data. A few omitted the calculated value of the mass of residue and some confused the mass of residue with the mass of water lost. Many candidates gained at least one of the two marks available for carrying out the practical procedures accurately. This was judged by comparing the candidate and supervisor results.

(b) (i) Almost all candidates gained this mark with those who had confused mass of residue and mass of water being credited if they used the values they gave in **(a)**.

(ii) Most candidates gave a correct answer to between two and four significant figures and gained this mark.

(iii) Most candidates correctly calculated relative formula mass of $\mathbf{X}_2CO_3$.

(iv) Many also subtracted 60 from their answer to **(iii)** though not all then divided by 2 to account for the formula being $\mathbf{X}_2CO_3$. Some candidates chose elements that were not members of Group 1 whilst others did not match their numerical answer with Group 1 elements shown on the Periodic Table.

(c) Candidates were instructed to use evidence from their results in **(a)** so that the correct answer could be that decomposition was complete or not complete. The answer had to concentrate on whether a further loss of mass occurred between the first and second weighing of crucible + lid + residue.

Question 2

Almost all candidates appear secure in their use of titration apparatus and most were aware of many of the methods used in calculations associated with volumetric analysis.

(a) Most candidates presented their data in the manner required and scored well in terms of accuracy marks. Just a few omitted burette readings for the rough titration, and a small number read burettes to only 0.1 cm^3.

(b) Most candidates gained this mark. Only a few gave the answer to fewer than 2 decimal places or selected titres with a spread of greater than 0.20 cm^3.

(c) (i) Many candidates realised that numerical answers should be to 3 or 4 significant figures.

(ii) Most candidates gained this mark. Very few omitted dividing by 1000 to convert cm^3 to dm^3.

(iii) Far fewer gained this mark as candidates did not realise that they needed to use the stoichiometry of the reaction **and** the fact that the solution had been diluted. Many considered one of these factors but only the most able considered both. This perhaps shows the importance of reading the information given in the question carefully.

(iv) Many candidates gained this mark from correctly using their answer to **(iii)**.

(v) The method needed to identify **Z** was similar to that used in**1(b)(iv)** although this was somewhat easier in that it was not necessary to divide by 2.

(d) This part was only answered correctly by the most able candidates. Very few realised that to calculate the percentage difference the **difference** between the value of the A_r of the element calculated in **(c)(v)** and the value given in the Periodic Table must be used as a percentage of the Periodic Table value.

Question 3

Candidates should be encouraged to follow the instructions given at the start of the qualitative analysis question as many lost marks through incomplete testing of the 'unknowns'. A conclusion, even if a correct identity of an ion, cannot be accepted unless there is supporting evidence. Precision in the use of scientific language is also required: 'soluble precipitate' is a contradiction in terms.

(a) (i) Nearly all candidates gave at least some correct observations. Many correctly reported an effervescence in **Test 2** with **FA 6** but few bubbled the gas into limewater to identify the gas. It should be noted that 'milky' and 'cloudy white' were accepted as observations in this test but that only 'white precipitate' will be allowed from 2022.

(ii) Many candidates correctly identified at least one ion but few identified all three. Both H^+ and OH^- proved problematic.

(iii) Although most candidates seem able to use the tests in the Qualitative Analysis Notes few apparently recognised that, rather than aqueous sodium hydroxide being used as a test for $Mg^{2+,}$ aqueous magnesium chloride can be used as a test for OH^-. This meant that only the most able candidates gave a correct test for OH^-. The inclusion, in the question, that the use of indicators was not acceptable might have given candidates a clue to the fact that indicators had some significance.

(iv) Since so few candidates correctly identified OH^- in **(iii)**, a significant number did not attempt this question.

(b) This question proved problematic for nearly all candidates.

(i) In **Test 1** it was expected that the purple manganate(VII) would be decolorised/go yellow. The formation of a brown coloration reported by a significant number of candidates suggests that, contrary to the instruction in the question of 'add a few drops of acidified aqueous potassium manganate(VII)', an excessive volume of this reagent was actually added.

In **Test 2** many candidates noticed the fizzing but very few gave a positive test for hydrogen.

(ii) There was not enough evidence to find the specific identity of **FA 8** but in **Test 1** it can be deduced that **FA 8** reduces manganate(VII) and in **Test 2** that **FA 8** is an acid.

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Paper 9701/36
Advanced Practical Skills 2

Key messages

- It is essential that candidates and supervisors enter the information regarding session and laboratory on the front cover of the paper so that candidates' results can be matched with the relevant supervisor values.
- Candidates should be reminded to read the full method before starting an experiment so that they record all the required data in a suitable manner.
- Candidates should be encouraged to reflect on the precision of apparatus used when providing numerical answers.
- Candidates should be given opportunities to discuss the reasons for carrying out practical procedures in a particular way.

General comments

This paper tested all the practical assessment objectives listed in the syllabus. There appeared to be no time constraints with almost all candidates completing the paper. Candidates should give all their written answers in black or dark blue ink as some answers in pencil were very difficult to decipher.

The supervisors in some centres did not supply results for the qualitative analysis question. This makes it less likely for them to be aware of any errors in the supply of reagents: problems listed in the supervisor's report are taken into consideration by the principal examiner.

Comments on specific questions

Question 1

Almost all candidates appear secure in their use of titration apparatus, and most were aware of many of the methods used in calculations associated with volumetric analysis.

(a) Most candidates presented their data for both the mass of **FB 1** added and the volume of **FB 4** needed to neutralise the unreacted acid in the manner required.
The marks gained for the accuracy of the exercise tended to be centre dependent with some whole centres scoring well and others where the range of titration volumes given was very large. This lack of consistency in titres could indicate that, for a variety of reasons, candidates had not had sufficient experience in exercises of this type.
Just a few gave masses to an inconsistent number of significant figures, omitted burette readings for the rough titration, or read burettes to only 0.1 cm^3.

(b) Most candidates gained this mark. Only a few gave the answer to fewer than 2 decimal places or selected titres with a spread of greater than 0.20 cm^3.

(c) (i) Many candidates realised that numerical answers should be to 3 or 4 significant figures.

(ii) Most candidates gained this mark.

(iii) Many candidates gained this mark although a significant minority omitted one of the two steps needed in the calculation.

(iv) Although many candidates recognised that a simple subtraction was all that was needed, a small number attempted more complex calculations.

(v) Most candidates wrote equations that showed the correct stoichiometry of the reaction. A number however omitted or gave incorrect state symbols. It should be noted that H_2CO_3 is not an acceptable alternative for CO_2 and H_2O.

(vi) Most candidates recognised the 2:1 stoichiometry in the equation and correctly divided their answer to **(c)(iv)** by 2.

(vii) Although a variety of methods for finding the value of **x** were seen, many of these methods led to a correct answer.

(d) Since questions involving the maximum percentage error have been set in a variety of contexts it was disappointing that very few candidates gained the mark. Whilst the maximum error in a single balance reading differed according to the number of decimal places to which the balance was calibrated, this number must always be doubled when the mass of **FB 1** was considered. This was rarely seen in candidates' responses.

(e) It is important that, when candidates carry out practical exercises, they consider sources of error and the effect of making changes to the apparatus or procedures.

In this case many candidates correctly said that the titre volume would be smaller but, to be awarded the mark, it was necessary to explain **why** this change occurred. It was insufficient merely to state that the solution was more (or less) concentrated since reference had to be made to there being less hydrochloric acid left after the addition of **FB 1**.

Question 2

The accuracy of the experimental work tended to be centre-dependent with some excellent results being seen but some centres' results showing massive variations in values measured. Centres are reminded that spirit burners do not produce enough heat for many thermal decomposition reactions – portable gas burners are suitable for such reactions.

(a) Very few candidates wrote 'weight' instead of mass and most included a correctly displayed unit with all the entries in the tables of data. A few omitted the calculated value of the mass of residue or mass lost and some confused these two masses. Many candidates gained the mark available for carrying out the practical procedures accurately. This was judged by comparing the candidate and supervisor results.

(b) Many candidates gained this mark with those who had confused mass of residue and mass of water being credited, if they used the values they gave in **(a)**. Several different correct methods of carrying out this calculation were seen and allowed.

(c) A precise answer was required so that vague answers such as 'heat for longer' / heat with a hotter flame were not credit-worthy. In this case the heating should be carried out until a constant mass was obtained.

Question 3

Candidates should be encouraged to follow the instructions given at the start of the qualitative analysis question as many lost marks through incomplete testing of the 'unknowns'. A conclusion, even if a correct identity of an ion, cannot be accepted unless there is supporting evidence. Precision in the use of scientific language is also required: 'soluble precipitate' is a contradiction in terms.

(a) (i) Nearly all candidates gave at least some correct observations. Many correctly reported an effervescence in **Test 1** but few used a glowing splint to identify the gas.

In **Test 2** many candidates reported seeing a green or a purple solution but few reported both.

In **Test 3** an initial yellow coloration followed by a brown precipitate were expected. Noting the effervescence was also an observation at this stage.

In **Test 4** nearly all candidates observed the formation of the white precipitate with aqueous barium ions.

Test 5 was perhaps the test which had several possible observations, most of which were not reported by a large number of candidates.

Test 6 was the usual test for a halide and the expected results were generally reported by most candidates.

(ii) A significant number of candidates gave two correct identities bur few gave all three. The most common error was the omission of 'unknown' for **FB 8**. The inclusion in the question that it might not be possible to identify an anion positively from the information available should at least be considered.

(b) This part was not well-answered. The instructions stated quite clearly that the answer should include conclusions as well as tests and observations. Many candidates failed to include the conclusions from their suggested tests.

One mark was available for recording the data in clear manner with relevant headings, etc. Apart from the candidates who omitted any conclusions, most scored this mark. Many also scored the mark for recording the formation of a green precipitate that turned brown on standing. Very few however **heated** with the aqueous sodium hydroxide to test for the ammonium ion.

(c) (i) A precise answer was needed to score this mark. Acceptable answers were based either on **FB 7** being a reducing agent or on **FB 7** being a catalyst. In either case it was necessary to explain how the data led to the conclusion.

(ii) Several answers involving Ag^+, Ba^{2+} or Fe^{3+} were correct. However, a significant number of candidates did not balance their equation or omitted state symbols.

CHEMISTRY

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. Cancellable species should be removed.
- In organic reaction mechanisms, the starting and finishing points of curly arrows is a key part in the description of the mechanisms.

General comments

This paper gave candidates of all abilities the opportunity to demonstrate their knowledge and understanding of a wide range of chemistry topics. Candidates who had prepared well for the examination were able to attempt all the questions. Many candidates were able to work through to the end of the paper.

Comments on specific questions

Question 1

(a) This was answered well. Some candidates mistakenly only calculated the number of moles of hydrogen and did not use Avogadro's constant.

(b) The omission of *x* 2 was a common error.

(c) This mark was often scored.

(d) Most candidates could do this successfully.

(e) (i) Most candidates calculated the correct entropy change of reaction.

(ii) Candidates often gave the correct answer here. A common error was the use of 327 instead of 0.327 in their calculation.

(iii) This proved difficult for some candidates. Some gave a clear explanation why the reaction becomes more spontaneous with increasing temperature. However, a common error was to omit $T\Delta S$ in their explanation.

Question 2

(a) (i) Many candidates gave the correct expression.

(ii) This was well known.

(iii) This answer was usually correct.

(iv) Most candidates found this question difficult. Some did not use their K_a expression from **(a)(i)** to calculate $[Cl(CH_2)_3CO_2H]$. Another common error was 3.31 (from the ratio $[Cl(CH_2)_3CO_2H] / [HCl]$).

(b) Many candidates found this question challenging. Most were able to use the pH to calculate the [H^+] and to correctly evaluate the mass of sodium propanoate for their calculated moles of propanoate ions. However, many candidates were not able to correctly calculate the moles of propanoate ions using their K_a expression or Henderson-Hasselbalch equation.

(c) The award of both marks was rare. Some candidates did recognise that all the propanoate ions would have been neutralised by the sulfuric acid. However, most did not explain why the final pH of the solution would be close to 1.

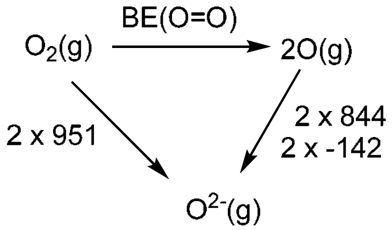
Question 3

(a) This was generally well answered. Common errors were:

- omitting ‘gaseous’ linked to atoms and
- omitting ‘1 mole’ linked to atoms (or ions).

(b) Candidates performed well on this question. Common errors included the use of (aq) instead of (g) or omitting state symbols altogether.

(c) Many candidates found this question challenging. It was necessary for candidates to understand and select relevant data for this energy cycle calculation. Many correct answers were seen.

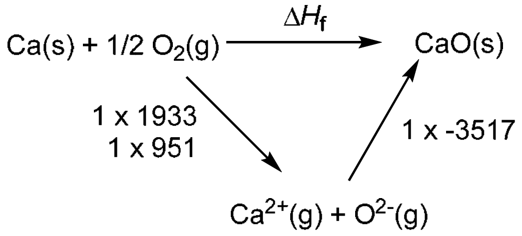


A common error was 249 (no × 2).

(d) (i) Many candidates found it difficult to provide a suitable explanation. Some incorrect responses gave answers in terms of stability.

(ii) This question discriminated well. Many good answers were seen. Weaker candidates omitted to reference the repulsion between the incoming electron and the negative ion.

(e) This question discriminated well. Candidates were more successful here than **part (c)**. They had to select the relevant data for this calculation and evaluate it to give the correct answer for the enthalpy of formation of –633 kJ mol^{-1}.



(f) This discriminated well. Many candidates were able to identify the ionic charge or charge density of the ions as the main factor. However, some did not provide an adequate explanation for this difference in lattice energy. Weaker candidates incorrectly suggested ionic radii.

Question 4

(a) Most candidates answered this question well. Many candidates correctly identified barium carbonate linking to its larger cationic radius. Some gave a clear explanation in terms of the anion being less polarised down Group 2. A few candidates suggested there was polarisation of the cation, or that polarisation was caused by the anion.

(b) This was generally well-answered. Some candidates misunderstood the question and compared the solubility of $Ca(OH)_2$ and of $Ba(OH)_2$ in water instead of the corresponding sulfates in water. The trend and its explanation were well understood by candidates. It was common to see a statement regarding decreasing solubility due to ΔH_{latt} and ΔH_{hyd} decreasing down Group 2. The decrease in ΔH_{hyd} is more was less frequently seen.

(c) (i) This answer was usually correct.

(ii) Many candidates gave the correct answer. The commonest error was not giving their answer to three significant figures.

Question 5

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

(ii) This was answered well by many candidates. The errors most commonly seen were:
- omission of a value for the bond angle
- diagrams without any 3–D bonds
- diagrams in which 3–D bonds were drawn but where the complex was not tetrahedral.

(b) (i) This was generally well answered. Many candidates correctly identified the cobalt-containing species as $[Co(OH)_2(H_2O)_4]$ or $Co(OH)_2$ however they had difficulty in completing the rest of the equation.

(ii) Candidates did not perform well on this question. Many were unable to recall the correct colour of $[Co(NH_3)_6]^{2+}$ or incorrectly identified the cobalt-containing species as $[Co(NH_3)_4]^{2+}$.

(iii) This proved difficult for many candidates. Many correctly identified the cobalt-containing species as $[CoCl_4]^{2-}$ however they had difficulty in completing the rest of the equation.

(iv) This answer was usually correct. Redox or omission of 'ligand' were common errors.

(c) (i) This was generally well known. Omission of the lone pair was a common error.

(ii) Many candidates answered this well. Common errors included drawing the trans isomer of $[Co(NH_3)_2(en)_2]$ or two optical isomers of $[Co(en)_3]$.

Question 6

(a) This was generally well-answered.

(b) (i) Most candidates had prepared well for this question. Many of the explanations were in a logical order and included all the key details.
- the importance of d-orbitals
- electron promotion
- colour seen is complementary to the frequency of visible light absorbed.

(ii) This answer was usually correct.

(c) Many candidates answered this well.

(d) Candidates found this difficult. Common errors were
- omitting how E (Cu^{2+} / Cu^{+}) changes or
- stating that E° (I_2 / I^{-}) changes.

Question 7

(a) Most candidates answered this correctly. A common incorrect answer was three peaks.

(b) This discriminated well. Some good and clear answers were seen. Many candidates gave the correct trend but did not explain the relative acidity in terms of the strength of the O–H bond or the stability of the conjugate base. They had to relate the acidity of these substances to the ease of proton donation.

(c) (i) This question was usually fully credited.

(ii) Many very 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.

(d) (i) This answer was usually correct.

(ii) Candidates often gave the correct answer here. Common errors were $C_6H_5CH_2OH$ and $C_6H_5CH_2CH_2OH$.

(iii) This was generally answered well. Candidates seemed to be better at recalling the reagents and conditions for the substitution reaction than that for the hydrolysis reaction.

(iv) This question discriminated well. Many correct answers were seen. HBr was a common error.

Question 8

(a) Many fully correct answers were seen.

(b) This was usually well known. A common error was decolourisation of the bromine water.

(c) Most candidates gave the correct structure of 2,4,6-tribromophenylamine.

(d) This was generally answered well, however ‘tri’ was often omitted in the name.

Question 9

(a) Most candidates gave a correct answer. HCl was a common error.

(b) (i) This question was usually fully credited.

(ii) This was usually well known. A common error was hydrochloric acid.

(c) (i) Candidates often gave the correct answer here.

(ii) This question was usually fully credited.

(d) (i) This was generally well answered. A common error was 0.68.

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

(e) (i) Most candidates answered this correctly.

(ii) This question was usually fully credited.

(iii) This proved difficult for some candidates. Most candidates recognised one or two environments that would give triplets normally b and c, but a fully correct answer was less frequent.

(iv) This was generally well answered.

Question 10

(a) Most candidates gave the correct structure of the zwitterion.

(b) Most candidates found this challenging. Candidates had to deduce that ions **A** and **B** had a net single positive charge and **C** a 2+ charge. Some incorrectly suggested that **A** was the zwitterion of lysine and that **B** had a net single negative charge.

(c) This question discriminated well. Many good answers were seen. Common errors were inclusion of a trivalent carbon or an incorrect peptide linkage such as –COO–NH–.

CHEMISTRY

Paper 9701/42
A Level Structured Questions

Key messages

- This has continued to be a difficult time for many candidates in many schools across the world and it can be assumed that much lesson time had been missed by some candidates. There were a significant number of scripts where candidates were unable to attempt parts of certain questions. Those candidates whose papers were particularly good deserve to be highly commended.
- 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 **Question 1(e)(ii)**.
- Chemical equations, ionic equations and half-equations should always be balanced for substances and charge. This was a significant issue for candidates when answering **Questions 5** and **6**.
- Candidates should never cross out an answer and attempt to write another answer over the top of the crossing out, or in any other way that introduces doubt as to whether an answer is being presented or not. This was a significant problem in marking chemical formulae.
- It is essential for candidates to read the questions carefully. **Question 4a** is about Group 2 nitrates while **Question 4b** is about Group 2 oxides. However, a significant number of candidates answered **Question 4b** as if it was about Group 2 nitrates.

General comments

This paper examined the material outlined in the syllabus, often incorporating novel contexts into the questions. Many candidates found this difficult. Nevertheless, we saw many very good scripts and a significant number of excellent ones.

The great majority of candidates were able to work through to the end of the paper, suggesting that they had sufficient time to complete the examination.

Comments on specific questions

Question 1

(a) This was generally answered well. Some candidates wrongly stated that ΔH_{latt} is an amount of energy *needed* or *required*.

(b) This was generally answered well. Some candidates confused electron affinity with ionisation energy, others missed the instruction to include state symbols.

(c) This was found difficult. The use of the data values 555, –200 and 532 was not appreciated by many candidates.

(d) This was answered better than **part c**, yet a very significant number of candidates were confused by the data values in the table and wanted to construct a Born-Haber cycle in the manner that they had practiced.

(e) (i) It was pleasing to note how many candidates know that ionic charge and ionic radius are the only factors that affect lattice energy. Some confusion was evident in answers such as 'ionic radius and charge density' since ionic radius is a contributory factor to charge density.

(ii) This question required careful answering. Good answers included the two clear statements:

- since the ions in RaS are more highly charged this factor (ionic charge) tends to make the lattice energy of RaS larger than that of NaC*l*
- since the ions in RaS have larger radii this factor (ionic radius) tends to make the lattice energy of RaS smaller than that of NaC*l*.

(iii) Some candidates were able to work through to the deduction that the larger lattice energy of RaS means that ionic charge is the dominant factor. This was good to see.

Question 2

(a) Many candidates could suggest that the concentration of ethoxyethane in water was too high, or that the concentration of ethoxyethane in octan-1-ol was too low. However, the statement that 'the system was not at equilibrium', or an equivalent statement, was much more rarely seen. No credit was given for answers suggesting experimental errors that were not specified in the question.

(b) (i) This was generally answered well.

(ii) This was found to be very difficult. The award of three marks was rare. Many candidates ignored the reference to '100 cm^3 of water' and believed that the concentration in the aqueous layer was the same as they calculated in 2bi.

(c) (i) This was generally answered well. 4.0×10^9 was a commonly seen wrong answer for K_{sp}.

(ii) Many candidates did not understand what should be a familiar situation – the addition of a high concentration of a common ion to saturated solution X – and described a result involving redox reactions leading to the production of iodine.

Question 3

Candidates who followed the scheme in the question did well on **Questions 3a** to **3d**.

(a) Involved the use of the molar gas volume and the Avogadro constant.

(b) Required application of the knowledge that the transfer of two electrons is required to produce each chlorine molecule.

(c) Many candidates were confused because they expected the Faraday constant to be used. Although there is a possible correct method using the Faraday constant the question can be solved without it.

(d) Use of 3.1 A and a conversion from seconds into minutes to calculate the time taken.

If candidates made a mistake in **Question 3a** all marks in **Question 3b**, **Question 3c** and **Question 3d** Were still available to those who used their previous answer correctly.

(e) (i) This was generally answered well.

(ii) This was generally answered well, although the value of the entropy change in $J\,K^{-1}\,mol^{-1}$ was not always converted into $kJ\,K^{-1}\,mol^{-1}$. It was pleasing to see how many candidates went straight to the Gibbs equation, and that the Gibbs equation was nearly always quoted correctly. Candidates who used expressions involving for example ΔS_{total} or $\Delta S_{surroundings}$ were much less likely to score marks, even when the expressions they began with were correct.

(iii) It was good to see the use of precise terminology, such as 'TΔS becomes more negative as T increases' or '–TΔS becomes more positive as T increases', as part of the explanations submitted.

Question 4

(a) This was generally answered well although some candidates found it difficult to use their knowledge of stability to predict which compound requires the higher temperature.

(b) Some very good answers were seen. However, some candidates got stuck here because they failed to appreciate that magnesium oxide and strontium oxide form magnesium hydroxide and strontium hydroxide when they are added to water.

(c) (i) The commonest error seen here was a failure to appreciate that the decomposition of one formula unit of $Sr(NO_3)_2$ produces two molecules of NO_2. If they thought that the decomposition of one formula unit of $Sr(NO_3)_2$ produces one molecule of NO_2 this lead to the incorrect answer 0.0667 mol dm^{-3}.

(ii) In general, this technique is well known at AS level but the mark was rarely scored here. Some candidates who could do the calculation ignored the instruction to give their answer to three significant figures.

Question 5

(a) (i) This was generally answered well.

(ii) This was generally answered well although some believed that the molybdenum complex must be charged.

(iii) This was generally answered well although poor three-dimensional renditions are still seen. Some of the angles labelled were 90° not 180°.

(b) (i) This equation required precise and careful work, many good answers were seen.

(ii) Some confused and imprecise answers were seen in which d-orbitals, electrons and the absorption of light were not mentioned. Several answers were seen where it was stated that the splitting of the d-orbitals, rather than the excitation of electrons, is responsible for the absorption of light. However, the knowledge required was often demonstrated, resulting in the award of four marks.

(c) (i) This equation also required precise and careful work. The mark for the formula of the $CuCl_4^{2-}$ complex was awarded more often than the mark for balancing the equation.

(ii) This was generally answered well.

(iii) This was generally answered well.

(iv) This was generally answered well.

(v) Most candidates scored this mark. This was another question in which the ability to use precise terminology such as 'd-orbital splitting' or 'ΔE' greatly assisted candidates.

Question 6

(a) The two colours were not well known.

(b) The answers to questions like this are getting better, but a significant number are still being seen in which ionic charges are written outside the final set of square brackets.

(c) This was generally answered well. It was pleasing to see a greater number of answers that gave a comparison between the stability of the two complex ions involved.

(d) (i) This was generally answered correctly.

(ii) Candidates often struggled here. Many answers were seen with equations for oxidation under acidic conditions, rather than alkaline conditions as specified in the question.

(iii) Despite the instruction in the question many answers were seen that did not refer to data. The data in the Data Booklet is all presented as reduction potentials. If a candidate wishes to reverse the sign of a reduction potential, e.g. changing +1.82 V to –1.82, giving an oxidation potential, they should make it clear that this is what they've done. The best way to do this would be with a half-equation, e.g. $(Co(H_2O)_6)^{2+} \rightleftharpoons (Co(H_2O)_6)^{2+} + e^-$, $E^\ominus = -1.82$ V.

Question 7

(a) This was generally answered correctly although many molecular formulae were seen.

(b) It was a surprise to see very few answers '5 and 3' that scored two marks.

(c) (i) This was generally answered correctly.

(ii) This was generally answered correctly, with many candidates focussing on the directing effect of the –COOH side chain.

(iii) This was generally answered correctly.

(iv) Candidates are getting better at showing such mechanisms, this is very pleasing to report. However, some candidates were still unable to start this question. On other scripts, where difficulties were seen they included curly arrows going in the wrong direction, poorly drawn intermediates, and the new substituent being joined to the ring through the CH_3 group not the CO group.

(v) Candidates found this to be difficult. Where the reagent – acidified or neutral $KMnO_4$ – was known the need for heat was sometimes omitted. Some candidates gave alkaline aqueous iodine as their answer but did not say that the product should be acidified to give the carboxylic acid groups, so no mark could be awarded.

Question 8

(a) This was generally answered correctly. Some candidates used four different symbols for bonds, e.g. —, - - -, ▲and Δ. This made understanding the candidate's meaning, and therefore accurate marking, very difficult. Only three symbols for bonds should be used on any one three-dimensional diagram. The following symbols can be used:

1. '—' for a bond in the plane of the paper
2. '- - -' or 'lllll' for a bond into the plane of the paper (receding from the observer)
3. '▲' for a bond out of the plane of the paper (approaching the observer.)

(b) Candidates found this difficult. The answer that this cannot be the spectrum of glutamic acid because that would have three peaks, was rarely seen. The answer that this cannot be the spectrum of glutamic acid because that would have a triplet peak, was also rarely seen. However, the explanations for the presence of a doublet, and of a quartet, were often clearly expressed, this was pleasing. Where clear expression was not used answers were difficult to mark. For example, 'the doublet is caused by protons attached to CH' did not score a mark. This is not as clearly expressed as 'the doublet is caused by a $-CH_3$ group with one proton on the neighbouring carbon atom' which did score.

(c) (i) Few correct answers were seen.

(ii) Few correct answers were seen. Some candidates tried to match the masses given in the question, 88 and 131, without realising that fragments are caused by the breaking of one σ bond. Answers that involved the breakage of more than one σ bond, or those involving rearrangements, did not score marks. It should also be noted that the question asks for ions so positive charges were needed.

(d) (i) This was generally answered correctly.

(ii) Although most answers showed use of electrophoresis paper or gel, and the sample mixture was usually applied correctly in the middle or nearer to the cathode, the correct drawing of an external circuit with a DC power supply was less common.

(iii) The number of correct answers here was disappointing. Perhaps some candidates had forgotten the information, given at the start of **part (d)**, that both alanine and glutamic acid exist as negative ions at pH 11.

(iv) For the award of the two marks here the answer had to be detailed, so that it explained the difference in distances travelled, not just that 'glutamic acid travels further than alanine'. Good answers referred to the difference in ionic charges, 1^- and 2^-, and the fact that alanine has a smaller molecular mass than glutamic acid.

Question 9

(a) Some candidates misunderstood the question, thinking it required a sequence of three reactions giving butylamine as *final* product only. This was regrettable. The hoped-for three starting materials were $CH_3CH_2CH_2CH_2Br$, $CH_3CH_2CH_2CN$ and $CH_3CH_2CH_2CONH_2$. However, candidates who suggested the use of $CH_3CH_2CH_2CH_2NO_2$ or $CH_3CH_2CH_2CONHCH_2CH_3$, for example, were also able to score full marks. In a question like this it should be noted that candidates are much safer giving their answers as structural or displayed formulae, rather than as names where many slips were seen that cost marks.

(b) Some excellent answers were seen here. The use of specific vocabulary, for example the positive inductive effect of the $–C_4H_9$ group, or the delocalisation of the lone pair on nitrogen into the benzene ring, helped many candidates to gain marks. The use of imprecise vocabulary, such as 'the lone pair attracts protons' should be avoided. A precise term such as 'the lone pair forms a coordinate bond to a proton' is much better.

Question 10

(a) This was generally answered correctly. Errors seen included:

- attributing incorrect charges to the salts in lines 1 and 2 e.g. $C_6H_5O^+Na^-$
- missing off the –OH group from the azo dye in line 3. (Due to the alkaline conditions this group could be shown as $–O^-$)
- drawing part of a polymer chain in line 4, rather than the trimer, $C_6H_5OCOC_6H_4COOC_6H_5$, that contains two phenol residues.

(b) This mark was scored only by a small proportion of candidates.

CHEMISTRY

Paper 9701/43
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. Cancellable species should be removed.
- In organic reaction mechanisms, the starting and finishing points of curly arrows is a key part in the description of the mechanisms.

General comments

This paper gave candidates of all abilities the opportunity to demonstrate their knowledge and understanding of a wide range of chemistry topics. Candidates who had prepared well for the examination were able to attempt all the questions. Many candidates were able to work through to the end of the paper.

Comments on specific questions

Question 1

(a) This was answered well. Some candidates mistakenly only calculated the number of moles of hydrogen and did not use Avogadro's constant.

(b) The omission of *x* 2 was a common error.

(c) This mark was often scored.

(d) Most candidates could do this successfully.

(e) (i) Most candidates calculated the correct entropy change of reaction.

(ii) Candidates often gave the correct answer here. A common error was the use of 327 instead of 0.327 in their calculation.

(iii) This proved difficult for some candidates. Some gave a clear explanation why the reaction becomes more spontaneous with increasing temperature. However, a common error was to omit $T\Delta S$ in their explanation.

Question 2

(a) (i) Many candidates gave the correct expression.

(ii) This was well known.

(iii) This answer was usually correct.

(iv) Most candidates found this question difficult. Some did not use their K_a expression from **(a)(i)** to calculate $[Cl(CH_2)_3CO_2H]$. Another common error was 3.31 (from the ratio $[Cl(CH_2)_3CO_2H] / [HCl]$).

(b) Many candidates found this question challenging. Most were able to use the pH to calculate the [H^+] and to correctly evaluate the mass of sodium propanoate for their calculated moles of propanoate ions. However, many candidates were not able to correctly calculate the moles of propanoate ions using their K_a expression or Henderson-Hasselbalch equation.

(c) The award of both marks was rare. Some candidates did recognise that all the propanoate ions would have been neutralised by the sulfuric acid. However, most did not explain why the final pH of the solution would be close to 1.

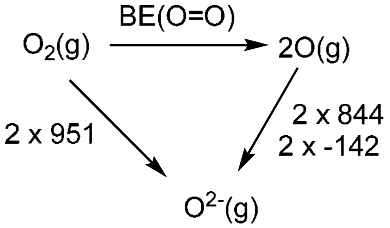
Question 3

(a) This was generally well answered. Common errors were:

- omitting 'gaseous' linked to atoms and
- omitting '1 mole' linked to atoms (or ions).

(b) Candidates performed well on this question. Common errors included the use of (aq) instead of (g) or omitting state symbols altogether.

(c) Many candidates found this question challenging. It was necessary for candidates to understand and select relevant data for this energy cycle calculation. Many correct answers were seen.

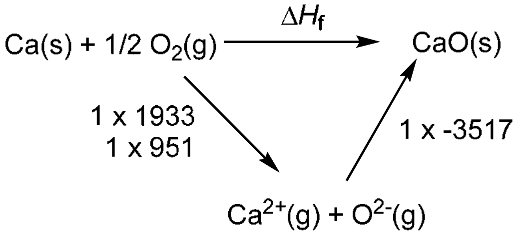


A common error was 249 (no × 2).

(d) (i) Many candidates found it difficult to provide a suitable explanation. Some incorrect responses gave answers in terms of stability.

(ii) This question discriminated well. Many good answers were seen. Weaker candidates omitted to reference the repulsion between the incoming electron and the negative ion.

(e) This question discriminated well. Candidates were more successful here than **part (c)**. They had to select the relevant data for this calculation and evaluate it to give the correct answer for the enthalpy of formation of –633 kJ mol^{-1}.



(f) This discriminated well. Many candidates were able to identify the ionic charge or charge density of the ions as the main factor. However, some did not provide an adequate explanation for this difference in lattice energy. Weaker candidates incorrectly suggested ionic radii.

Question 4

(a) Most candidates answered this question well. Many candidates correctly identified barium carbonate linking to its larger cationic radius. Some gave a clear explanation in terms of the anion being less polarised down Group 2. A few candidates suggested there was polarisation of the cation, or that polarisation was caused by the anion.

(b) This was generally well-answered. Some candidates misunderstood the question and compared the solubility of $Ca(OH)_2$ and of $Ba(OH)_2$ in water instead of the corresponding sulfates in water. The trend and its explanation were well understood by candidates. It was common to see a statement regarding decreasing solubility due to ΔH_{latt} and ΔH_{hyd} decreasing down Group 2. The decrease in ΔH_{hyd} is more was less frequently seen.

(c) (i) This answer was usually correct.

(ii) Many candidates gave the correct answer. The commonest error was not giving their answer to three significant figures.

Question 5

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

(ii) This was answered well by many candidates. The errors most commonly seen were:
- omission of a value for the bond angle
- diagrams without any 3–D bonds
- diagrams in which 3–D bonds were drawn but where the complex was not tetrahedral.

(b) (i) This was generally well answered. Many candidates correctly identified the cobalt-containing species as $[Co(OH)_2(H_2O)_4]$ or $Co(OH)_2$ however they had difficulty in completing the rest of the equation.

(ii) Candidates did not perform well on this question. Many were unable to recall the correct colour of $[Co(NH_3)_6]^{2+}$ or incorrectly identified the cobalt-containing species as $[Co(NH_3)_4]^{2+}$.

(iii) This proved difficult for many candidates. Many correctly identified the cobalt-containing species as $[CoCl_4]^{2-}$ however they had difficulty in completing the rest of the equation.

(iv) This answer was usually correct. Redox or omission of 'ligand' were common errors.

(c) (i) This was generally well known. Omission of the lone pair was a common error.

(ii) Many candidates answered this well. Common errors included drawing the trans isomer of $[Co(NH_3)_2(en)_2]$ or two optical isomers of $[Co(en)_3]$.

Question 6

(a) This was generally well-answered.

(b) (i) Most candidates had prepared well for this question. Many of the explanations were in a logical order and included all the key details.
- the importance of d-orbitals
- electron promotion
- colour seen is complementary to the frequency of visible light absorbed.

(ii) This answer was usually correct.

(c) Many candidates answered this well.

(d) Candidates found this difficult. Common errors were
- omitting how E (Cu^{2+} / Cu^{+}) changes or
- stating that E^{o} (I_2 / I^{-}) changes.

Question 7

(a) Most candidates answered this correctly. A common incorrect answer was three peaks.

(b) This discriminated well. Some good and clear answers were seen. Many candidates gave the correct trend but did not explain the relative acidity in terms of the strength of the O–H bond or the stability of the conjugate base. They had to relate the acidity of these substances to the ease of proton donation.

(c) (i) This question was usually fully credited.

(ii) Many very 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.

(d) (i) This answer was usually correct.

(ii) Candidates often gave the correct answer here. Common errors were $C_6H_5CH_2OH$ and $C_6H_5CH_2CH_2OH$.

(iii) This was generally answered well. Candidates seemed to be better at recalling the reagents and conditions for the substitution reaction than that for the hydrolysis reaction.

(iv) This question discriminated well. Many correct answers were seen. HBr was a common error.

Question 8

(a) Many fully correct answers were seen.

(b) This was usually well known. A common error was decolourisation of the bromine water.

(c) Most candidates gave the correct structure of 2,4,6-tribromophenylamine.

(d) This was generally answered well, however ‘tri’ was often omitted in the name.

Question 9

(a) Most candidates gave a correct answer. HCl was a common error.

(b) (i) This question was usually fully credited.

(ii) This was usually well known. A common error was hydrochloric acid.

(c) (i) Candidates often gave the correct answer here.

(ii) This question was usually fully credited.

(d) (i) This was generally well answered. A common error was 0.68.

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

(e) (i) Most candidates answered this correctly.

(ii) This question was usually fully credited.

(iii) This proved difficult for some candidates. Most candidates recognised one or two environments that would give triplets normally b and c, but a fully correct answer was less frequent.

(iv) This was generally well answered.

Question 10

(a) Most candidates gave the correct structure of the zwitterion.

(b) Most candidates found this challenging. Candidates had to deduce that ions **A** and **B** had a net single positive charge and **C** a 2+ charge. Some incorrectly suggested that **A** was the zwitterion of lysine and that **B** had a net single negative charge.

(c) This question discriminated well. Many good answers were seen. Common errors were inclusion of a trivalent carbon or an incorrect peptide linkage such as –COO–NH–.

CHEMISTRY

Paper 9701/51
Planning, Analysis and Evaluation

General comments

In general, most responses were well structured and legible. There were few very low marks and the paper proved to be accessible to all but a very small number. There were very few unattempted (no response) items.

Some sections of this paper demand knowledge and understanding of experimental methods. It is possible that a reduction of practical activities owing to the COVID pandemic was a contributing factor in candidate's reduced experience of practical activities.

It is most unfortunate when marks are lost for reasons other than lack of chemical knowledge and understanding. Close reading of the question and heeding the instructions given when forming answers would avoid such unnecessary losses. Examples in this paper included:

- Using the correct number of significant figures or decimal places in a numerical answer.
- Showing working where requested.

There is also no credit to be gained for rewriting the question as part of the answer.

The command word **'suggest'** appears often in this paper and is used in two main contexts. It may imply either that there is no unique answer (e.g. two or more substances may satisfy the given conditions describing an 'unknown'), or that candidates are expected to apply their general knowledge to a new situation. It is important that candidates bear this in mind when answering.

Two areas that appear frequently in this paper and were not widely understood by candidates this series are:

- calculation of percentage error **1(b)(ii)**
- and the initial separation of reagents in the reaction vessel when producing a gas whose volume is to be measured **2(a)**.

Comments on specific questions

Question 1

(a) Very few responses gained credit here. The difficulty in measuring the temperature of a solid while heating it was not widely appreciated. Incorrect responses relating to the speed of the reaction and the concurrence of the two reactions were common. A good number doubted that it would be possible to achieve a high enough temperature to decompose $KHCO_3$ in the laboratory or that the reaction would be incomplete. In fact, the decomposition takes place easily between 100 and 400°C.

(b) (i) The vast majority of candidates followed the instruction in the question to give answers to three decimal places and produced the correct responses. A small number incorrectly answered to two or four decimal places.

(ii) Candidate's struggled to answer this straightforward question. The uncertainty in the measurement of a mass is estimated as half of the smallest scale division. If a weighing is made using a balance that displays mass to three decimal places, then there is a $\pm$ **0.0005 g** uncertainty in that measurement. The mass of the sample of solid is calculated as the difference between two mass measurements. Therefore, the absolute uncertainty in the mass of the sample is (**2** × $\pm$ **0.0005 g**) = $\pm$ **0.001 g**.

Working that clearly showed the candidate had used these steps was essential to gain the mark here. Common answers which were not mark worthy included:

$$\frac{0.001\times100}{2.503}=0.04\% \quad \frac{0.0005\times100}{2.503}=0.02\% \quad \frac{0.005\times2\times100}{2.503}=0.4\%$$

(c) (i) The responses given to this question were either excellent, showing clear understanding of the calculation steps, or rather haphazard, indicating a poor or incomplete grasp.

Some common errors in the calculation of q were:

- Using (50 + 2.503) g instead of 50 g for mass of the solution.
- Using (273 $\pm$ 3.5) K in place of 3.5°C as the temperature change.
- Units were not required, but had to be correct if given. J mol^{-1} or kJ mol^{-1} were commonly incorrectly used.

Errors in the calculation of ΔH_1 included:

- Failing to give the correct sign (+) for the endothermic process.
- Not dividing by the number of moles of $KHCO_3$

(ii) Candidates made similar errors here to those made in **(c)(i)**.

Common errors in the calculation of q were:

- Using (50 + 3.455) g instead of 50 g for mass of the solution.
- Using (273 $\pm$ 1.5) K in place of 3.5°C as the temperature change.
- Units were not required but had to be correct if given. J mol^{-1} or kJ mol^{-1} were commonly incorrectly used.

Errors in the calculation of ΔH_2 included:

- Failing to give the correct sign (–) for the exothermic process.
- Not dividing by the number of moles of K_2CO_3

(d) This was generally well answered by candidates assisted by the Hess cycle provided for them in the question. Incorrect responses usually involved a failure to multiply ΔH_1 by two, multiplying ΔH_2 by 2 or a confusion of signs (e.g. adding ΔH_2 rather than subtracting it).

(e) Heat loss and/or heat gain was the predominant creditworthy response given. Heat exchange with the surroundings is complicated as the final value is calculated using ΔH values for an endothermic reaction, during which heat energy would be gained from the surroundings, and an exothermic reaction, during which heat energy would be lost to the surroundings. A correct description of heat exchange associated with each reaction was needed if they were specifically mentioned in the response.

Few managed to give a sensible second reason for the discrepancy. Impure solid(s) was a popular incorrect response. Vague answers such as '*inaccurate weighing of the solid*' and '*the reaction may not have finished*' were common but not creditworthy.

(f) This question asked for a suggested improvement to the apparatus given, not a wholesale replacement of it. The most popular correct responses involved adding a lid to or extra insulation around the polystyrene cup. Some candidates struggled with the distinction between apparatus and reagents, suggesting the use of powdered solids or acid of a different concentration.

(g) The experiment is designed so that the acid is in excess, thus a measuring cylinder might seem the obvious choice to measure the volume of the acid here. However, the experimental procedure states 'Transfer 50.00 cm^3 …' and the volume of the solution is used in the later calculation of q, so it is important to choose a measurement method capable of achieving this degree of precision and accuracy. Burette was the most popular acceptable response, followed by pipette. The acid being in excess appeared to lead many candidates into thinking a measuring cylinder, the most popular incorrect response, would suffice.

(h) The irritant nature of all three substances means that chemical resistant gloves are required. The explanation of this choice required reference to the hazard information given earlier in the question. A significant number of responses suggested the use of goggles, even though the question began 'Apart from wearing safety glasses…'.

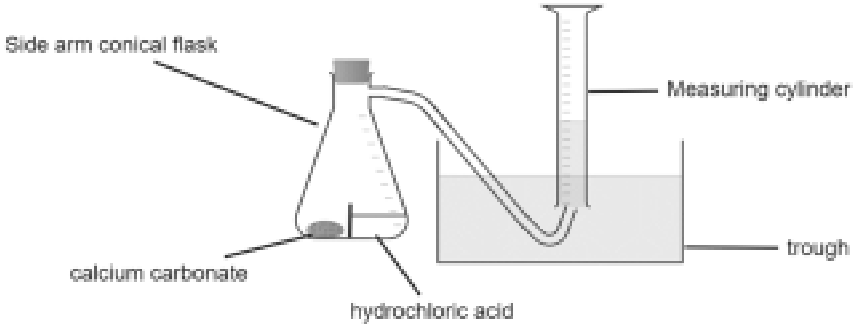
Question 2

(a) Diagrams

Candidates who have carried out experiments like the one described in the question are at a great advantage when drawing experimental diagrams. The diagrams were not graded in terms of their neatness and a degree of latitude was allowed in their construction. This said, neat and well-presented diagrams are to be encouraged.

Most candidates drew a reaction vessel connected to a gas collection device.

This set-up would have gained all three marks.



The most commonly missing element in the reaction vessel was a device keeping the two reagents (calcium carbonate and hydrochloric acid) apart prior to mixing and reaction, for example, by using a divided flask. The reactants had to be shown separate from each other in the flask

The addition of hydrochloric acid from a funnel with a tap was not awarded the mark as gas displaced from the reaction vessel by addition of the acid would be collected in the measuring cylinder introducing inaccuracy in measurement.

Several candidates included a gas syringe to collect the carbon dioxide even though the question requires collection by displacement of water.

(b) (i) The table of results was completed correct in most cases.

(ii) Selection of suitable scales for the axes caused few problems. There were two obvious scales for the *x*-axis; the first has one large square equal to 50 s and the other 30 s. The best scale for the *y*-axis has one large square equal to 10 cm^3.

The points plotted easily and were generally located accurately on the grid.

Drawing a curved line of best fit freehand in an exam requires a good deal of skill and some allowance is made for this. Overall, these lines were drawn well. There were, however, some poor examples and candidates would benefit from plenty of practice in this technique.

(iii) The most anomalous point was clear and well recognised. Very few failed to circle this point.

(iv) This proved to be an elusive mark for most candidates who had to recognise that the reason for the anomaly lay in reading volume of carbon dioxide before 240 s. Many candidates had the correct idea but lost the mark because they did not say exactly what was being measured. '*The recorded volume was too low*' was a common response without any reason being offered. Vague responses such as '*read too early*' were not credited. Candidates are expected to explain their answers fully and with precision at this level.

(v) Many candidates recognised which lines to construct, and some drew horizontal and vertical lines with great precision. Frequently, the lines were correctly drawn at 46.5 cm^3 and 23.25 cm^3.

A common error was to give the first half life correctly, e.g. 78 s, and then the second half life incorrectly as the sum of the first two, e.g. 160 s instead of 82 s. Calculation of the average was done well.

(vi) This calculation was successfully executed by most candidates. Credit was given, error carried forward, for the correct use of any calculated value from **(b)(v)**.

(c) Nearly all candidates stated correctly that k would increase, with the majority of these giving half-life decreasing as the correct explanation. Credit was given for explaining in terms of increased rate of reaction. Some candidates gave an extended answer, including unnecessary extra points which sometimes lost the mark. List answers are best avoided.

(d) (i) The candidates completed the first two columns of the table very well. Marks were lost here by:

- using a volume of HCl less than 10.0 cm^3 as this would not be an excess or
- using a volume such as 13.125 cm^3 which could not be measured by a standard piece of volumetric glassware, e.g. a burette.

Most candidates calculated the concentration of the diluted hydrochloric acid correctly. Common problems included:

- Listing the initial concentration of HCl, 2.0moldm^{-3}, rather than the diluted concentration
- Being unable to correctly calculate the concentration.

(ii) There was a good understanding of variables shown. '*Time taken for the fizzing to stop*' was given by almost all candidates. A few incorrectly suggested '*the volume of distilled water*' or '*concentration of the acid*.'

(iii) Simply '*taking more readings*' or '*repeating the experiment*' does not improve reliability. These extra experimental measurements must be used to obtain a mean or eliminate anomalies to have an effect and gain the mark.

CHEMISTRY

Paper 9701/52
Planning, Analysis and Evaluation

Key messages

Candidates should read through the methodology of the experiment upon which the following questions are based. Many candidates gave responses which suggested they had not appreciated the aim of the experiment being carried out and asked about.

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

In general, many candidates appeared under-prepared for this exam, but in mitigation, disruption linked to the COVID pandemic may have contributed to this.

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. One significant figure will usually be insufficient at A level.

Comments on specific questions

Question 1

(a) Nearly all candidates were able to complete the simple subtractions and were able to produce correct answers and with numbers of decimal places commensurate to the data provided.

(b) Nearly all candidates were able to divide the mass of ethanol calculated by its molar mass to arrive at a correct answer to three significant figures, although some candidates confused number of significant figures with number of decimal places and 0.012 was seen on more than one occasion.

(c) About half of the candidates scored both marks in this calculation in which they needed to determine *q* and then had to scale *q* up to molar quantities by dividing by the answer to **1(b)**.

Many candidates used incorrect figures in determining *q* such as:

- using the mass of ethanol (0.53 g) combusted as *m*, rather than the mass of water heated
- using 293.1 as ΔT, presumably in an incorrect attempt to convert ΔT in Celsius into ΔT in Kelvin by adding 273 to the correct value of 20.1.

A significant number of candidates omitted the minus sign in their answer.

(d) Candidates were asked to show their working in this question. Determining a percentage error involves the use of half a graduation, rather than the graduation itself. Thus $(2 \times 0.05) / 20.1$ expressed as a percentage (0.498 per cent) gains credit whereas $0.1 / 20.1$ does not. Candidates need to make it clear that 0.1 was derived from multiplying half the graduation by 2 (because two readings were taken in obtaining ΔT) and not using the graduation itself.

(e) Only a few candidates scored the mark for this question. Despite a strong clue about percentage errors in **1(d)**, most candidates failed to appreciate that a bigger value of *m* or of ΔT would lead to a reduced percentage error and therefore increased accuracy.

Credit was also awarded to those who suggested a great ΔT would lead to greater heat loss leading to decreased accuracy

(f) A substantial number of candidates assumed the spirit burner continued to burn after the flame was extinguished, possibly as a result of misunderstanding the term ‘extinguished’. In terms of describing the change in ΔH, candidates should avoid using phrases such as ‘lower’ as a lower value than, say, $-730\ \text{kJ mol}^{-1}$ would be $-830\ \text{kJ mol}^{-1}$.

The correct way to describe a change in ΔH would be to use terms such as ‘less exothermic’,

(g) (i) It was expected that candidates would focus upon the two main sources of experimental error, i.e. heat loss (via radiation into the surrounding atmosphere or by conduction into the apparatus) and incomplete combustion of the ethanol.

Most candidates correctly identified heat loss as a source of experimental error, but few identified incomplete combustion as a source of error.

(ii) Candidates found this a challenging question. Both values required for comparison were theoretical values, therefore experimental error was not the cause of the difference.

Very few candidates were able to communicate that bond enthalpies vary according to the environment they happen to be in (stating that ‘bond enthalpies were an average value’ was simply restating the wording of the question). The alternative explanation bond enthalpies assume all reactants and products to be gaseous or that ethanol exhibits hydrogen bonding was very rarely seen.

Question 2

(a) Most candidates realised that an electrically heated water bath would allow temperature control, but fewer realised that the heating had to be by electrical means due to the flammability of organic substances.

(b) Almost all candidates stated chemically resistant gloves were the safety precaution to be used.

(c) Most candidates realised that the organic solvent was used to dissolve the halogenoalkanes or to act as a medium for the reaction to take place in.

(d) Many candidates did not appreciate that sodium hydroxide was the limiting reagent in this reaction. Therefore the indicator would change colour when the sodium hydroxide had reacted, thus allowing the reaction to be timed.

(e) (i) The vast majority of candidates could correctly perform the three easy calculations. However, some candidates gave answers with too few a number of significant figures (three were expected) or made elementary rounding errors.

(ii) Most candidates appreciated that bond enthalpies for hydrogen halides decrease down Group 7, although some thought that they increased.

(f) Many candidates understood that the additional variable to be controlled was the concentration of the reactants, although a common error seen was 'heat' which suggested these candidates had not appreciated the nature of the experiment.

(g) (i) The plotting of the points on the graph was done well but a significant number of candidates attempted to include the clear anomaly into the line of best fit.

(ii) Nearly all candidates circled the most anomalous point, although some erroneously insisted on circling more than one point.

(iii) This was a challenging question and very few candidates realised that omission of step 4 was responsible for causing the anomaly. Many giving vague or rote learnt answers based around poor practice, rather than an answer that suggested something which could have actually caused the anomaly to be where it was.

(iv) Candidates were asked to draw construction lines to show two consecutive half-lives, and most did this, often using 1.00 mol dm^{-3} as their initial concentration followed by construction lines at 0.50 mol dm^{-3} and 0.25 mol dm^{-3}. This led to half-lives of about 180 s and 170 s in most cases.

However, some candidates incorrectly combined the values of their first and second half-lives, producing second half-lives with values of approximately 350 s.

(v) This was well answered. The answer accepted was dependent upon the half-life values calculated and candidates were allowed to consider half-lives of 180 s and 170 s as being either different or constant as a difference of only 10 s could be allowed to be thought of as similar under practical conditions.

Surprisingly many of the candidates who gave half-lives as 180 s and 350 s in **2(g)(iv)** gave answers in **2(g)(v)** that indicated they knew the second half-life to be 170 s and answered **2(g)(v)** based upon this.

(h) (i) Most candidates realised that a piece of volumetric apparatus was required to measure the 10.00 cm^3 sample of the reaction mixture. Although burette is typically an acceptable alternative to pipette for measuring volumes to this degree of accuracy, in this instance, the sample was extracted from the reaction mixture, so pipette was the only acceptable answer.

(ii) Only the more able candidates were able to appreciate that 25.00 cm^3 samples would require a total volume of reaction mixture in excess of the 250 cm^3 used.

(iii) The idea of cooling to prevent significant reaction occurring during and after the extraction process was well understood.

CHEMISTRY

Paper 9701/53
Planning, Analysis and Evaluation

General comments

In general, most responses were well structured and legible. There were few very low marks and the paper proved to be accessible to all but a very small number. There were very few unattempted (no response) items.

Some sections of this paper demand knowledge and understanding of experimental methods. It is possible that a reduction of practical activities owing to the COVID pandemic was a contributing factor in candidate's reduced experience of practical activities.

It is most unfortunate when marks are lost for reasons other than lack of chemical knowledge and understanding. Close reading of the question and heeding the instructions given when forming answers would avoid such unnecessary losses. Examples in this paper included:

- Using the correct number of significant figures or decimal places in a numerical answer.
- Showing working where requested.

There is also no credit to be gained for rewriting the question as part of the answer.

The command word **'suggest'** appears often in this paper and is used in two main contexts. It may imply either that there is no unique answer (e.g. two or more substances may satisfy the given conditions describing an 'unknown'), or that candidates are expected to apply their general knowledge to a new situation. It is important that candidates bear this in mind when answering.

Two areas that appear frequently in this paper and were not widely understood by candidates this series are:

- calculation of percentage error **1(b)(ii)**
- and the initial separation of reagents in the reaction vessel when producing a gas whose volume is to be measured **2(a)**.

Comments on specific questions

Question 1

(a) Very few responses gained credit here. The difficulty in measuring the temperature of a solid while heating it was not widely appreciated. Incorrect responses relating to the speed of the reaction and the concurrence of the two reactions were common. A good number doubted that it would be possible to achieve a high enough temperature to decompose $KHCO_3$ in the laboratory or that the reaction would be incomplete. In fact, the decomposition takes place easily between 100 and 400°C.

(b) (i) The vast majority of candidates followed the instruction in the question to give answers to three decimal places and produced the correct responses. A small number incorrectly answered to two or four decimal places.

(ii) Candidate's struggled to answer this straightforward question. The uncertainty in the measurement of a mass is estimated as half of the smallest scale division. If a weighing is made using a balance that displays mass to three decimal places, then there is a ± **0.0005 g** uncertainty in that measurement. The mass of the sample of solid is calculated as the difference between two mass measurements. Therefore, the absolute uncertainty in the mass of the sample is (**2** × ± **0.0005 g**) = ± **0.001 g**.

Working that clearly showed the candidate had used these steps was essential to gain the mark here. Common answers which were not mark worthy included:

$$\frac{0.001\times100}{2.503}=0.04\% \quad \frac{0.0005\times100}{2.503}=0.02\% \quad \frac{0.005\times2\times100}{2.503}=0.4\%$$

(c) (i) The responses given to this question were either excellent, showing clear understanding of the calculation steps, or rather haphazard, indicating a poor or incomplete grasp.

Some common errors in the calculation of q were:
- Using (50 + 2.503) g instead of 50 g for mass of the solution.
- Using (273 ± 3.5) K in place of 3.5°C as the temperature change.
- Units were not required, but had to be correct if given. J mol^{-1} or kJ mol^{-1} were commonly incorrectly used.

Errors in the calculation of ΔH_1 included:
- Failing to give the correct sign (+) for the endothermic process.
- Not dividing by the number of moles of $KHCO_3$

(ii) Candidates made similar errors here to those made in **(c)(i)**.

Common errors in the calculation of q were:
- Using (50 + 3.455) g instead of 50 g for mass of the solution.
- Using (273 ± 1.5) K in place of 3.5°C as the temperature change.
- Units were not required but had to be correct if given. J mol^{-1} or kJ mol^{-1} were commonly incorrectly used.

Errors in the calculation of ΔH_2 included:
- Failing to give the correct sign (–) for the exothermic process.
- Not dividing by the number of moles of K_2CO_3

(d) This was generally well answered by candidates assisted by the Hess cycle provided for them in the question. Incorrect responses usually involved a failure to multiply ΔH_1 by two, multiplying ΔH_2 by 2 or a confusion of signs (e.g. adding ΔH_2 rather than subtracting it).

(e) Heat loss and/or heat gain was the predominant creditworthy response given. Heat exchange with the surroundings is complicated as the final value is calculated using ΔH values for an endothermic reaction, during which heat energy would be gained from the surroundings, and an exothermic reaction, during which heat energy would be lost to the surroundings. A correct description of heat exchange associated with each reaction was needed if they were specifically mentioned in the response.

Few managed to give a sensible second reason for the discrepancy. Impure solid(s) was a popular incorrect response. Vague answers such as '*inaccurate weighing of the solid*' and '*the reaction may not have finished*' were common but not creditworthy.

(f) This question asked for a suggested improvement to the apparatus given, not a wholesale replacement of it. The most popular correct responses involved adding a lid to or extra insulation around the polystyrene cup. Some candidates struggled with the distinction between apparatus and reagents, suggesting the use of powdered solids or acid of a different concentration.

(g) The experiment is designed so that the acid is in excess, thus a measuring cylinder might seem the obvious choice to measure the volume of the acid here. However, the experimental procedure states 'Transfer 50.00 cm^3 …' and the volume of the solution is used in the later calculation of q, so it is important to choose a measurement method capable of achieving this degree of precision and accuracy. Burette was the most popular acceptable response, followed by pipette. The acid being in excess appeared to lead many candidates into thinking a measuring cylinder, the most popular incorrect response, would suffice.

(h) The irritant nature of all three substances means that chemical resistant gloves are required. The explanation of this choice required reference to the hazard information given earlier in the question. A significant number of responses suggested the use of goggles, even though the question began 'Apart from wearing safety glasses…'.

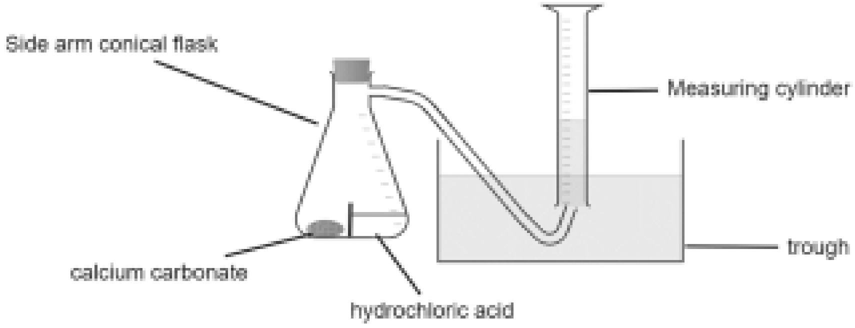
Question 2

(a) Diagrams

Candidates who have carried out experiments like the one described in the question are at a great advantage when drawing experimental diagrams. The diagrams were not graded in terms of their neatness and a degree of latitude was allowed in their construction. This said, neat and well-presented diagrams are to be encouraged.

Most candidates drew a reaction vessel connected to a gas collection device.

This set-up would have gained all three marks.



The most commonly missing element in the reaction vessel was a device keeping the two reagents (calcium carbonate and hydrochloric acid) apart prior to mixing and reaction, for example, by using a divided flask. The reactants had to be shown separate from each other in the flask

The addition of hydrochloric acid from a funnel with a tap was not awarded the mark as gas displaced from the reaction vessel by addition of the acid would be collected in the measuring cylinder introducing inaccuracy in measurement.

Several candidates included a gas syringe to collect the carbon dioxide even though the question requires collection by displacement of water.

(b) (i) The table of results was completed correct in most cases.

(ii) Selection of suitable scales for the axes caused few problems. There were two obvious scales for the *x*-axis; the first has one large square equal to 50 s and the other 30 s. The best scale for the *y*-axis has one large square equal to 10 cm^3.

The points plotted easily and were generally located accurately on the grid.

Drawing a curved line of best fit freehand in an exam requires a good deal of skill and some allowance is made for this. Overall, these lines were drawn well. There were, however, some poor examples and candidates would benefit from plenty of practice in this technique.

(iii) The most anomalous point was clear and well recognised. Very few failed to circle this point.

(iv) This proved to be an elusive mark for most candidates who had to recognise that the reason for the anomaly lay in reading volume of carbon dioxide before 240 s. Many candidates had the correct idea but lost the mark because they did not say exactly what was being measured. '*The recorded volume was too low*' was a common response without any reason being offered. Vague responses such as '*read too early*' were not credited. Candidates are expected to explain their answers fully and with precision at this level.

(v) Many candidates recognised which lines to construct, and some drew horizontal and vertical lines with great precision. Frequently, the lines were correctly drawn at 46.5 cm^3 and 23.25 cm^3.

A common error was to give the first half life correctly, e.g. 78 s, and then the second half life incorrectly as the sum of the first two, e.g. 160 s instead of 82 s. Calculation of the average was done well.

(vi) This calculation was successfully executed by most candidates. Credit was given, error carried forward, for the correct use of any calculated value from **(b)(v)**.

(c) Nearly all candidates stated correctly that *k* would increase, with the majority of these giving half-life decreasing as the correct explanation. Credit was given for explaining in terms of increased rate of reaction. Some candidates gave an extended answer, including unnecessary extra points which sometimes lost the mark. List answers are best avoided.

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