Principal examiner reports for teachers

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

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

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

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

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CHEMISTRY

Paper 9701/12
Multiple choice

Key messages

Candidates performed well on **Questions 1**, **2**, **3**, **4**, **6**, **7**, **8**, **9**, **10**, **11**, **12**, **13**, **16**, **17**, **18**, **19**, **20**, **22**, **23**, **24**, **26**, **27**, **28**, **29**, **30**, **31**, **32**, **34**, **35**, **36**, **37**, **38**, **39** and **40**.

Candidates performed less well on **Questions 5**, **14**, **15**, **21**, **25** and **33**.

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

Comments on specific questions

Question 5

- Option **A** was a common incorrect answer.
- Bond angle 1 is on an sp^3 hybridised carbon atom with no lone pairs. The bond angle will therefore be close to 109.5°. Bond angle 2 is on an sp^2 hybridised carbon atom with no lone pairs. The bond angle will therefore be close to 120°. Bond angle 3 is on an sp^3 hybridised oxygen atom with two lone pairs. The bond angle will therefore be close to 104.5°. The bond angles in ascending order (smallest first) is $3 \rightarrow 1 \rightarrow 2$. The correct option is **C**.

Question 14

- Option **A** was a common incorrect answer.
- Since the pressure of the mixture has been increased at constant temperature all of the molecules have become closer together without any change in the average molecular energy. This means that the frequency of all collisions between molecules will have increased. Since the frequency of effective collisions has increased, and the frequency of non-effective collisions has also increased, the correct option is **B**.

Question 15

- Option **D** was a common incorrect answer.
- The forward reaction has an activation energy of 50 $kJ\,mol^{-1}$. When this activation energy is halved, by the addition of a catalyst, the activation energy of the forward reaction decreases by 50 percent. The activation energy of the forward reaction therefore becomes 25 $kJ\,mol^{-1}$.

  When the catalyst is present:
  - The activation energy of the forward reaction is 25 $kJ\,mol^{-1}$
  - The enthalpy change of the forward reaction is +20 $kJ\,mol^{-1}$
  - The activation energy of the backward reaction is 5 $kJ\,mol^{-1}$.

  The correct option is **D**.

Question 21

- Options **C** and **D** were common incorrect answers.
- When concentrated sulfuric acid is added to sodium bromide, the colourless gas produced, which gives a cream precipitate with $AgNO_3(aq)$, is HBr. This can be deduced because the cream precipitate is

AgBr, so the colourless gas must give Br^- ions when it dissolves in water. HBr is produced by the reaction $H^+ + Br^- \rightarrow HBr$. This is an acid-base reaction so the correct option must be **A** or **B**.

The only brown-coloured product of the reaction between concentrated sulfuric acid and sodium bromide is bromine. Bromine is produced when Br^- ions lose electrons. This is a redox reaction, so the correct option is **B**.

Question 25

- Option **B** was a common incorrect answer.
- The structural isomers of C_4H_8 that are alkenes or cyclic alkanes are:
  - But-1-ene
  - But-2-ene
  - Methylpropene
  - Cyclobutane
  - Methylcyclopropane.

Since the question specifies **structural** isomers the two geometrical isomers of but-2-ene are considered as a single isomer. There are five structural isomers, so the correct option is **C**.

Question 33

- Option **C** was a common incorrect answer.
- The compound that reacts with hydrogen cyanide, forming 2-hydroxybutanenitrile, is propanal.

$$CH_3CH_2CHO + HCN \rightarrow CH_3CH_2CH(OH)CN$$

Therefore propanal is produced when compound Y undergoes mild oxidation. Compound Y must be propan-1-ol. The correct option is **C**.

CHEMISTRY

Paper 9701/22
AS Level Structured Questions

Key messages

What candidates did well

- Candidates laid out their answers clearly, in both extended written response and calculations, which allowed examiners to follow the flow of a response.
- Diagrams were drawn neatly with a black pencil, and of a sufficient size to be scrutinised.
- Chemical terminology was used precisely, which reduced the volume of explanatory text that candidates needed to write.

What candidates needed to improve

- Candidates are reminded to address 'explain' questions fully – not merely to state facts or rules of thumb, rather to show how these combine to give reasons for chemical phenomena. This often requires a secure understanding of bonding and structure within molecules, in particular for organic species, linking structural feature to mechanistic probabilities.
- Working in calculations should be shown, especially where a numerical answer might be obtained by different methods, correctly or incorrectly. Harsh or early rounding of numbers should be avoided, as it leads to sizeable inaccuracies later.

Comments on specific questions

Question 1

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

- Candidates gave the full electronic configuration, properly formatted. Some candidates included $3d^0$, though this was unnecessary.

Limited responses

- Candidates used shorthand notation, capital letters and/or subscript numbers.

(ii) **Comprehensive responses**

- Candidates included all factors, including correct reference to shielding.

Limited responses

- Candidates abbreviated their answers by referring to effective nuclear charge, or included inaccurate information about the different elements.

(iii) **Limited responses**

- Candidates did not include state symbols in their equations.

(iv) **Comprehensive responses**

- Candidates were able to refer to the change of shell and the removal of an electron from the inner shell.

Limited responses

- Candidates were not explicit about the relevant ionisation process occurring.

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

- Candidates wrote a correct equation, with state symbols, for the formation of the hydroxide.

Limited responses

- Candidates' use of state symbols was incorrect. The species formed included SrO or H_2.

(ii) **Comprehensive responses**

- Candidates gave a clear idea of the colour of the precipitate and the idea that no reaction was observed, as opposed to no observation having been made.

Limited responses

- Candidates assumed both reactions produced effervescence, or were unclear whether there was any reaction at all.

(c) (i) Candidates needed only to answer with a single word.

(ii) **Comprehensive responses**

- Candidates were able to give a full balanced equation.

Limited responses

- Candidates proposed incorrect species as the metal-containing product.

(d) (i) **Comprehensive responses**

- Candidates constructed an accurate, balanced ionic equation, omitting spectator ions.

Limited responses

- Full equations, or unbalanced ionic equations were proposed.

(ii) **Comprehensive responses**

- Candidates limited their answers to the effect on bacteria.

Limited responses

- Candidates gave a range of answers, including non-specific terms about the removal of microorganisms. Some answers referred to the environment.

Question 2

(a) (i) Candidates needed only to answer with a single word.

(ii) **Comprehensive responses**

- Candidates showed a completed single pi (π) orbital, with lobes above and below the plane of the bond.

Limited responses

- Candidates showed p orbitals, sometimes not overlapping at all. The atom centres were occasionally misaligned.

(b) **Comprehensive responses**

- Candidates showed clear working that used the data given in successive steps (stoichiometric ratio, use of the ideal gas equation, conversion to cm^3).

Limited responses

- Candidates missed out one of the steps above, or converted between moles and volume using V_m = 24 dm^3 or 22.4 dm^3.

(c) (i) Candidates needed only to answer with a single word.

(ii) **Limited responses**

- Candidates wrote about VOCs, which are the progenitors of PAN.

(iii) **Comprehensive responses**

- Candidates provided two equations showing the consumption and regeneration of NO in successive steps, thereby establishing it as a catalytic reagent.

Limited responses

- Candidates wrote equations in the reverse order, so not establishing NO as a catalyst, or presented alternative sources for NO.

(d) (i) **Comprehensive responses**

- Candidates drew a clean, well labelled diagram that identified all species and energy changes accurately.

Limited responses

- Candidates did not label their diagrams carefully: lines showing activation energy or enthalpy changes were imprecisely drawn and did not stretch completely from one level to another.

(ii) **Comprehensive responses**

- Candidates drew a single additional pathway showing lower activation energy; examiners accepted single- or multi-step pathways.

Question 3

(a) **Comprehensive responses**

- Candidates were able to identify that the C atom attached to the halogen was the secondary carbon.

Limited responses

- Candidates wrote about the halogen, rather than the C atom, as being multiply bonded.

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

- Candidates drew an unambiguous structure representing but-1-ene.

Limited responses

- Candidates chose to draw a different isomer of C_4H_8.

(ii) **Comprehensive responses**

- Candidates drew an unambiguous structure representing *trans*-but-2-ene.

Limited responses

- Candidates repeated the structure given as **A**, often as a displayed structure; names for this structure were varied.

(iii) **Comprehensive responses**

- Candidates wrote both about the restricted rotation about a pi (π) bond and the different constitution of substituents on each C of the C=C bond.

Limited responses

- Candidates were not specific that each C of C=C needed different substituents, or were imprecise in their wording about the lack of rotation, sometimes suggesting that the entire molecule is not able to rotate.

(c) (i) Limited responses

- Candidates could not identify the type of substitution that was shown in this reaction.

(ii) Comprehensive responses

- Candidates showed two unambiguous steps with radicals clearly marked with single electrons (•).

Limited responses

- Candidates' termination steps often showed the addition of different species, most commonly $2Cl\bullet \rightarrow Cl_2$, or occasionally $2C_4H_9\bullet \rightarrow C_8H_{18}$.

(d) Comprehensive responses

- Candidates wrote concisely about the variation in bond strength as the predominant factor.

Limited responses

- Candidates switched the order of hydrolysis and/or wrote about polarity of the H—X bond as the relevant factor.

(e) Comprehensive responses

- Candidates gave short, clear answers, identifying the state of the missing reagent, and clearly showing the type of bonding between O and Na in the sodium alkoxide.

Limited responses

- Candidates gave an ambiguous structure, or were not specific about the conditions and state of iodine. The colour change was often reversed in the reaction with acidified $K_2Cr_2O_7$.

Question 4

(a) (i) Comprehensive responses

- Candidates wrote clearly about the partial dissociation of the acid molecules, releasing H^+.

Limited responses

- Candidates' responses were not clearly worded, with some suggesting that the H^+ ions are themselves dissociating. Other responses used the word 'dissolve' instead.

(ii) Comprehensive responses

- Titration curves were shown clearly with distinct phases: a weak acid profile, a sharp change at 25 cm^3, and a final strong alkali profile.

Limited responses

- The change in pH around the equivalence point was not sharp enough, or was centred around the wrong titre value. In some cases, the profile after 25 cm^3 continued rising beyond pH 14, or did not tend to a final pH early enough.

(iii) Comprehensive responses

- Candidates were able to write a succinct answer using $H^+(aq)$ and $OH^-(aq)$. Some candidates assumed the carboxylic acid to be undissociated and wrote correct, though more complicated, answers.

Limited responses

- Candidates did not write ionic equations.

(iv) Comprehensive responses

- Candidates were able to show the product after alkaline hydrolysis of the nitrile group.

Limited responses

- Candidates focused on the acid–base reaction of the COOH group only.

(b) **Comprehensive responses**

- Hydrogen bonds were labelled clearly, or shown as quite distinct from the covalent bonds. A full set (⩾ 3) of partial charges were shown in the correct order.

Limited responses

- Candidates often neglected to show the lone pair on the electronegative atom, or formed an improbable hydrogen bond to one of the methylene hydrogens. When more than one H bond was shown, candidates did not complete each part of the diagram with enough detail.

(c) (i) **Comprehensive responses**

- Two curly arrows were shown clearly, originating from a lone pair on C of CN^-, and flowing to the δ+ C of C—C*l*.

Limited responses

- Curly arrows were misdirected or their destination was unambiguous. Some dipoles were missing.

(ii) **Limited responses**

- Candidates referred to a nitrile group rather than a cyanide ion.

(iii) **Limited responses**

- Candidates could not identify the type of substitution that was shown in this reaction.

(d) (i) Candidates needed only to answer with a single word.

(ii) Candidates needed only to answer with a single word.

(iii) **Limited responses**

- Candidates gave more structure to their answer than was required/correct.

(iv) **Comprehensive responses**

- Candidates showed the side groups clearly, with correct connectivity to the relevant C atoms. The repeat unit had extended bonds (stretching beyond parentheses if shown), to indicate that this was a partial structure only.

Limited responses

- There was little differentiation between the ‘extended’ bonds and other covalent bonds in the structure; the side groups were shown as condensed formulae (which gave no indication of structure), or the covalent bonds connecting to them were ambiguously placed.

(v) **Comprehensive responses**

- Candidates identified the peak clearly and went on to establish that this disappears as that functionality of the molecule is lost.

Limited responses

- Candidates identified the wrong peak, or were not specific enough in their writing to establish that monomers contain C=C whereas the polymer has lost this functionality.

CHEMISTRY

Paper 9701/33
Advanced Practical Skills

Key messages

Manipulation, measurement and observation

What candidates did well

- Many candidates successfully set up and used apparatus to collect accurate mass, temperature and volume data. They obtained temperature changes (in **Question 1**) and concordant titres (in **Question 2**) which were in close agreement with those of their supervisor.

What candidates needed to improve

- When carrying out qualitative tests, candidates should be aware of the range of observations which may be possible. For example, the appearance of a precipitate and its solubility or insolubility in excess reagent, the initial and final colour of a solid or solution, or the effervescence of a gas which may then be tested to identify it.

Presentation of data and observations

What candidates did well

- Most candidates presented numerical data clearly in a single table with clear headings and correctly displayed units.
- Candidates usually presented all readings to the correct precision for the measuring instrument used.
- Most candidates displayed their numerical working clearly when calculating a quantity.
- Many candidates displayed their answers to an appropriate number of significant figures.

What candidates needed to improve

- For qualitative analysis questions, candidates should concisely describe the appearance of the starting chemical as well as what happens during the experiment.
- Candidates should consider, where appropriate, the solubility and colour of a precipitate after the addition of excess reagent or on standing.
- Candidates should usually identify a gas is produced during an experiment by carrying out tests listed in the Qualitative analysis notes.

Analysis, conclusions and evaluation

What candidates did well

- Candidates were able to use their experimental data to calculate enthalpy changes for reactions. They were also able to use results from a titration experiment to determine information about the composition of a mixture of solids.
- Candidates were able to identify some unknown ions by using their results from qualitative chemical tests.

What candidates needed to improve

- Candidates should practice using the Qualitative analysis notes together with their own observations to identify ions following a series of chemical tests using a compound or its solution.
- Candidates should consider how a change in one part of an experiment, such as the specific chemical used, its concentration, or a piece of equipment, would affect the accuracy of the conclusion of the experiment.

Comments on specific questions

Question 1

(a) **Comprehensive responses**

- Most candidates recorded of readings of mass and temperature in **(a)** and **(c)** with clear headings and correctly displayed units.
- Many candidates consistently recorded mass to either 2 or 3 decimal places.

Limited responses

- Some candidates did not record temperatures to .0 or .5 °C.

(b) **Comprehensive responses**

- Many candidates applied the correct formula for each part of **(b)** and gave each answer to 2 – 4 significant figures.

Limited responses

- Some candidates used the wrong mass when calculating the energy change in **(i)**. Any use of the mass of **FA 1** is incorrect.
- Some candidates did not correctly round their answers for **(i)** or **(ii)**.
- Some candidates did not provide the correct sign for the enthalpy change, ΔH_1, to match the temperature change observed.

(c) (i) **Comprehensive responses**

- Most candidates correctly calculated the masses of **FA 1** and **FA 3** used and both temperature changes.
- Candidates often recorded a temperature change close to that of the Supervisor.

Limited responses

- A few candidates did not record one or both temperature changes for the reactions in Question 1.

(ii) **Comprehensive responses**

- Most candidates clearly displayed their working in each of the stage of the calculation of enthalpy change.

Limited responses

- Some candidates used incorrect data within their calculations. Errors included use of the moles of the reactant which was in excess (**FA 2**), adding 273 to the temperature change, adding the mass of **FA 3** to the mass of acid and incorrect conversion of J to kJ.
- Some candidates incorrectly wrote a positive sign for ΔH_2. The reaction between **FA 2** and **FA 3** is exothermic.

(d) **Comprehensive responses**

- Some candidates applied Hess's Law and used their values of ΔH_1 and ΔH_2 to calculate ΔH_3.

Limited responses

- Some candidates incorrectly applied Hess's Law.
- Some candidates did not attempt the question part.

(e) **Comprehensive responses**

- A few candidates provided both a statement as to whether the suggestion was correct or not together with a matching explanation. These candidates realised the change of acid would increase the concentration of H^+ ions, increasing the rate of reaction and heat loss. Alternatively, they suggested that changing acid would have no effect on temperature change because it was not the limiting reagent.

Limited responses

- Some candidates did not give enough explanation for their conclusion.
- Some candidates incorrectly stated that one acid was a stronger acid than the other.

Question 2

(a) **Comprehensive responses**

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

Limited responses

- A few candidates did not record burette readings for their rough titre, labelled their burette readings incorrectly, such as 'initial titre', and recorded burette readings to 1 decimal place only.
- A minority of candidates did not carry out titrations until they had 2 titres within 0.1 cm^3.

(b) **Comprehensive responses**

- Most candidates clearly selected two or more titres within a range of 0.2 cm^3 and correctly averaged them to 2 decimal places.

Limited responses

- A few candidates did not show, either by ticks next to the titres in their results table or in **(b)**, which titres they chose to average.
- A few candidates did not either correctly round their mean titre or display their answer to 2 decimal places.

(c) (i) **Comprehensive responses**

- Many candidates answered all parts of **(c)** and displayed each answer to 3 or 4 significant figures.

Limited responses

- Some candidates did not attempt at least 3 of **(b)(ii)**, **(iii)**, **(iv)** or **(v)**.
- Some candidates displayed 1 or more answers to fewer than 3 or more than 4 significant figures.

(ii) **Comprehensive responses**

- Most candidates correctly calculated the amount of hydrochloric acid.

Limited responses

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

(iii) **Comprehensive responses**

- Some candidates used both the ratio of reacting moles in the equation for the reaction and a scaling up factor to account for the volume of **FA 4** used in each titration.

Limited responses

- Whilst some candidates correctly calculated the amount of metal carbonate in 25.0 cm^3 of **FA 4**, they did not multiply by 40 to scale that value up to the amount in 1 dm^3.

(iv) **Comprehensive responses**

- Many candidates successfully answered this question. Some candidates who had not multiplied by 40 in the previous question did so here, therefore providing a correct answer for this question part.

Limited responses

- A few candidates either did not use the correct formula or did not attempt the question part.

(v) **Comprehensive responses**

- A small number of candidates assigned a symbol, for example, x, for the proportion of sodium carbonate in **X**. They were than able to construct and use a formula to find the percentage of sodium carbonate which included the proportion of potassium carbonate as either $(1 – x)$ or $(100 – x)$.

Limited responses
- Many candidates used an incorrect formula, usually making use of their answer for **Question 2(c)(iv)**, along with the formula masses of either potassium or sodium carbonate or both and sometimes 5.85.

Question 3

(a) (i) Comprehensive responses
- Some candidates made several appropriate observations which included the initial colour and state of **FA 7**, the appearance of condensation on heating, and the disappearance of solid **FA 7** as heating continued.
- Most candidates made the correct decision to test the gas given off during heating using (red) litmus paper.

Limited responses
- Some candidates did not make enough correct observations.
- Some candidates did not record the initial appearance of **FA 7**.

(ii) Comprehensive responses
- Many candidates recorded that mixing **FA 7** and hydrochloric acids produced effervescence and tested the gas produced with limewater.
- A few candidates noted that the effervescence was vigorous and that when the gas was reacted with limewater, it produced a white precipitate.

Limited responses
- Some candidates suggested that the gas produced turned limewater milky or cloudy. 'Milky' and 'cloudy' are not sufficiently detailed observations as neither precise colour nor indication of state are given.

(b) (i) Comprehensive responses
- Candidates often made enough correct observations, including correct gas tests for reactions of **FA 8** in Tests 1, 2 and 3.
- Candidates were able to describe solids formed when two solutions were mixed together as precipitates and to clearly state each precipitate's colour and whether the precipitate went on to dissolve when additional reagent or another solution was added.

Limited responses
- In Tests 1 and 2, some candidates did not state whether a precipitate produced was either insoluble or soluble in excess reagent or on standing. Only some candidates noted when a colourless solution was formed. When candidates reported effervescence, they did not then test the gas produced.
- In Test 4, when some candidates reported white precipitates being formed, they did not go on to say whether they were soluble or insoluble in excess reagent.
- In Test 5, some candidates correctly reported the result of testing **FA 9** with red litmus. They did not also test with blue litmus.

(ii) Comprehensive responses
- Most candidates identified NH_4^+ as the cation in **FA 8** from the observation of red litmus going blue in either **Question 3(a)(i)** or **Question 3(b)(i) Test 3**.
- Some candidates identified CO_3^{2-} as the anion in **FA 8** from the observations in **Question 3(a)(ii)** and **Question 3(b)(i) Tests 1** or **2**.
- A minority of candidates identified OH^- as the anion in **FA 9** from the results of **Tests 3** and **4** in **Question 3(b)(i)**.
- A small number of candidates concluded that the cation in **FA 9** was unknown as there was no evidence to positively identify any specific ion.

Limited responses

- A few candidates wrongly identified SO_4^{2-} or SO_3^{2-} as the anion in **FA 8**. This was usually because they had not correctly identified gas given off when acid was added in **Question 3(a)(ii)** or **Question 3(b)(i) Test 1** or **2**.
- Some candidates did not correctly identify either ion in **FA 9** because they either did not have the correct practical test results or were unable to use the Qualitative analysis notes together with their observations to draw a conclusion.
- Some candidates identified the cation in **FA 9** as sodium. There was no evidence from the experiment results to be able to justify this conclusion.

(iii) Comprehensive responses

- A minority of candidates wrote a correct, balanced equation including the correct state symbols.

Limited responses

- Some candidates did not correctly identify all the products. Others did not include state symbols or did not balance the equation.

CHEMISTRY

Paper 9701/42
A Level Structured Questions

Key messages

What candidates did well

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

What candidates needed to improve

- Working should be shown clearly when answering questions involving calculations. The numbers should be linked to some text, for example in **Question 2(a)**: initial moles of Fe^{2+} = 17.70 ÷ 277.9.
- Chemical equations, ionic equations, and half-equations should always be balanced for substances and charge.
- Three-dimensional structures should be drawn correctly. If this is not done correctly, geometrical, or optical isomers cannot be assessed.
- If a candidate wishes to change an answer, they must cross out their original answer completely and a new answer should be written. If there is insufficient space to write their replacement answer, blank pages on the question paper can be utilised. A comment noting this is helpful.
- Candidates are advised to take care when writing words that could be read in more than one way – for example, exothermic or endothermic. This also happens with numbers; 1 and 2 can be written in a similar way, as can 4 and 9. Responses must be unambiguous and written in a legible way.

Comments on specific questions

Question 1

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

- Most candidates defined transition element accurately.

Limited responses

- Some candidates did not include the word ‘stable’ when describing the ions that transition elements form.
- Other answers omitted **d** when referring to incomplete orbitals.

(ii) **Comprehensive responses**

- Many candidates correctly completed the electrons-in-boxes diagram. Each of the five d-orbital boxes and the 4s box should contain a single arrow.

Limited responses

- Nearly all candidates realised that they needed to draw six electrons in the boxes. Many candidates still put two electrons in the 4s box.

(iii) **Comprehensive responses**

- Most sketches of the $3dz^2$ orbital were clear and showed lobes pointing along the *z*-axis with a circular ‘collar’.

Limited responses

- The circular ‘collar’ should be drawn to represent a continuous structure. Sometimes the sketches showed two separate half circles, which is incorrect.

(iv) Comprehensive responses

- Most candidates identified that chromium compounds have more than one oxidation state.

Limited responses

- Some candidates did not explain that d-orbitals needed to be vacant.

(b) (i) Comprehensive responses

- Most candidates answered this question precisely linked to the SHE. The standard conditions were well known.

Limited responses

- Some candidates referred to the voltage of a cell connected to a hydrogen cell, instead of a half cell.
- The standard temperature is 298 K rather than 273 K.

(ii) Comprehensive responses

- Some candidates were able to explain this statement fully with reference to relevant data from Table 1.1.

Limited responses

- Many candidates thought that the Cr^{2+} was reduced to Cr.
- Reference to E° of relevant electrode reactions is required and this was often omitted.

(iii) Comprehensive responses

- This equation was well known.

Limited responses

- Many candidates did not give an ionic equation: $CrCl_3 + 3NaOH \rightarrow Cr(OH)_3 + 3NaCl$.

(iv) Comprehensive responses

- Some candidates were able to identify the correct species in the expected equation.

Limited responses

- Many candidates did not combine the two electrode reactions to construct the ionic equation.
- Some candidates used the incorrect electrode reaction for oxygen, E° +1.23.

(c) (i) Comprehensive responses

- Most candidates were able to identify that there are more **gas** molecules on the right-hand side.

Limited responses

- Some candidates only referred to more molecules being formed which was insufficient.

(ii) Comprehensive responses

- Most candidates were able to correctly calculate the standard entropy of water.

Limited responses

- Some candidates did not divide the entropy value by four.

(iii) Comprehensive responses

- The explanation for statement 1 was more successful than statement 2.

Limited responses

- Some candidates explain statement 1 fully by reference to ΔG, ΔH and ΔS.
- Many candidates incorrectly suggested statement 2 was due to the enthalpy change being exothermic.

(d) (i) Comprehensive responses

- Many candidates defined first electron affinity correctly.

Limited responses
- Some candidates thought that energy required for this process.
- Other candidates thought a mole of electrons was accepted by a mole of gaseous ions.

(ii) Comprehensive responses
- The lattice energy was usually correctly calculated.

Limited responses
- Some candidates did not use the multipliers resulting in an answer of –7709.

(iii) Comprehensive responses
- This question was well answered by some candidates in terms of ionic radius and the attraction between the oppositely charged ions.

Limited responses
- Some candidates omitted any reference to attraction between oppositely charged ions.
- Others stated the lattice energy of Al_2O_3 is greater, instead of more negative, than Cr_2O_3.

Question 2

(a) (i) Comprehensive responses
- Many candidates answered this question well and clearly set out their calculation.

Limited responses
- Common errors were:
  - to calculate step 1 and 2 correctly but then use $16.535 \times 100 / 17.70$ giving a value of 93.4%
  - to omit the $\times$ 10 in their calculation giving a value of 90.7%.

(ii) Comprehensive responses
- This question was well answered by candidates who suggested that $KMnO_4$ would act as an indicator or that the solution changes (from colourless) to pink/purple at the **end point.**

Limited responses
- Some candidates stated that $KMnO_4$ changed from colourless to purple.

(b) Comprehensive responses
- Most candidates gave the correct structure of benzoic acid.

Limited responses
- None seen.

(c) Comprehensive responses
- Some candidates gave the correct explanation in terms of oxidation numbers: Mn with oxidation numbers of +7 and +2 reacting to give Mn with only one oxidation number of +3.

Limited responses
- Many candidates did not use oxidation numbers in their explanation, instead using the formulas of the ions Mn^{7+} and Mn^{2+} forming Mn^{3+} which was not sufficient.

(d) (i) Comprehensive responses
- Many candidates gave the correct K_{sp} expression.

Limited responses
- Some candidates omitted charges on the ions in their K_{sp} expression.

(ii) Comprehensive responses
- This question was well answered. Most candidates were able to give the correct units for K_{sp}.

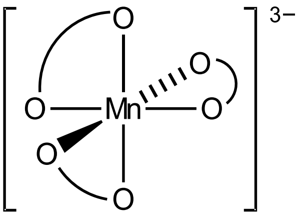
Limited responses
- Many candidates did not convert 3.20×10^{-3} g dm^{-3} to 3.60×10^{-5} mol dm^{-3}. They received M2 by error carried forward for 1.31×10^{-7}.

(e) (i) **Comprehensive responses**
- This was well answered and understood by candidates.

Limited responses
- Some candidates often referred to light being emitted**.**

(ii) **Comprehensive responses**
- Many fully correct answers were seen.

Limited responses
- Some candidates omitted the charge on the ligand or gave an incorrect charge.
- Common errors were seen in the three-dimensional structures. The expected orientation of bonds is shown.



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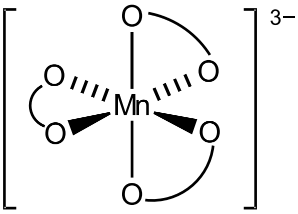


Question 3

(a) **Comprehensive responses**
- Many candidates gave the correct structure of **H**. Compound **G** was less commonly given the correct structure.

Limited responses
- Some candidates omitted continuation bonds or had an additional oxygen atom in **H**.
- Many did not identify **G** as an ester.

(b) **Comprehensive responses**
- Most candidates understand an acyl chloride is formed from the carboxylic acid.

Limited responses
- Many candidates realised that the hydroxy group would also be replaced by chlorine.

(c) (i) **Comprehensive responses**
- Most candidates were able to correctly calculate the pH of this solution.

Limited responses
- Some candidates incorrectly calculated the [H^+]. They received M2 by error carried forward.

(ii) **Comprehensive responses**
- Most candidates gave a correct definition for a buffer solution.

Limited responses
- None seen.

(iii) **Comprehensive responses**
- Most candidates gave a correct formula for the conjugate base.

Limited responses
- None seen.

(iv) Comprehensive responses

- Most candidates understood this was a buffer calculation and were able to work out the initial moles of $HO(CH_2)_3COOH$ and moles of NaOH.
- Some candidates used an alternative approach [Henderson-Hasselback equation] which was accepted.

Limited responses

- Common errors seen were:
  - 4.66 (reversed ratio used of $[HO(CH_2)_3COOH]$ and $[A^-]$).
  - 4.45 (initial moles used instead of $[HO(CH_2)_3COOH]_{eqm}$).

(d) Comprehensive responses

- Most candidates stated the correct oxidising agent.

Limited responses

- Some candidates omitted ‘heat’ or used alkaline conditions, instead of acidic.

(e) (i) Comprehensive responses

- Many candidates gave a correct definition for a partition coefficient.

Limited responses

- Some candidates omitted ‘at equilibrium’ or defined in terms of solubility instead of a ratio of concentrations of a solute.

(ii) Comprehensive responses

- Most candidates were able to calculate a value for K_{part} from their calculated concentrations.

Limited responses

- A common error was to divide the molar amounts by 0.025 instead of 0.010.

Question 4

(a) (i) Comprehensive responses

- Many candidates were able to quote two half-lives in the allowance range and state that this reaction has a constant half-life.

Limited responses

- Some candidates only stated one half-life.

(ii) Comprehensive responses

- Some candidates correctly drew a tangent at $t = 0$ and measured its gradient.

Limited responses

- Many did not draw a tangent at $t = 0$ or were unable to measure their gradient accurately.

(iii) Comprehensive responses

- Many candidates were able to give the correct rate equation. Correct units were frequently seen.

Limited responses

- Some candidates omitted k from their rate equation.
- Others attempted to calculate the rate rather than constructing a rate equation.

(b) (i) Comprehensive responses

- Only a few candidates referred to reaction 6 going to completion and reaction 7 being an equilibrium reaction.

Limited responses

- Most candidates gave an answer related to the relative reactivity or relative rate for these condensation reactions.

(ii) Comprehensive responses

- Some very good answers were seen. Many candidates were able to clearly draw curly arrows to show bond breaking and bond formation in this mechanism.

Limited responses

- A common error was omitting the dipole on the C=O. Sometimes a curly arrow incorrectly started from an atom instead of a bond, for example the breaking of the C=O or C–Cl bonds.

(c) Comprehensive responses

- Most candidates gave the correct relative rate of hydrolysis for these compounds. Many gave an explanation related to the different C–Cl bond strengths. The explanation for chlorobenzene was more well-known.

Limited responses

- Some candidates omitted some detail in their explanations, for example they did not relate the structure to the C–Cl bond strength.

Question 5

(a) (i) Comprehensive responses

- Many candidates were able to write an equation for the formation of NO_2^+.

Limited responses

- Some candidates gave an unbalanced equation.

(ii) Comprehensive responses

- This was well-known. Many candidates were able to draw a fully correct mechanism with clear annotations on their diagram.

Limited responses

- Common errors included:
  - The curly arrow from the delocalised ring going to the oxygen (instead of the nitrogen) of the NO_2^+
  - omission of the CH_3 group on the intermediate, and
  - the curly arrow starting from the hydrogen atom (instead of the C–H bond) into the ring.

(iii) Comprehensive responses

- Many candidates gave the correct equation.

Limited responses

- A common error was giving the equation: $CH_3C_6H_4NO_2 + 2[H] \rightarrow CH_3C_6H_4NH_2 + O_2$.

(iv) Comprehensive responses

- Many candidates were able to give the correct reagents and conditions.

Limited responses

- Some candidates omitted the conditions temperature $\leq 10\,°C$ for step 1 and warm for step 2.

(v) Comprehensive responses

- Most candidates were able to identify the correct reagents.

Limited responses

- Common errors included:
  - discussing the deactivation of the ring without any comment about the directing effect of the nitro group
  - giving an incorrect directing effect, such as 1, 3-directing or 2, 4-directing.

(b) (i) Comprehensive responses

- This was usually answered correctly.

Limited responses
- None seen.

(ii) Comprehensive responses
- Some candidates were able to correctly state a high boiling liquid or non-volatile liquid is used.

Limited responses
- Most candidates gave an incorrect answer. Common errors include:
  - a solid support such as silica
  - a shorter chain alkane and
  - chemicals from other analytical techniques such as TMS.

(iii) Comprehensive responses
- Some candidates were able to correctly suggest that 2-ethylphenol would be move attracted to the stationary phase.

Limited responses
- Many candidates explained in terms of relative M_r of the compounds.
- Some others referred to the solubility of 2-ethylphenol in the stationary phase.

(iv) Comprehensive responses
- Most candidates gave the correct answer.

Limited responses
- None seen.

(c) Comprehensive responses
- Most candidates gave the correct relative acidity of these compounds.
- Many related this to the acidity to the strength of the O–H bond or the stability of the conjugate base. Explanations were detailed.

Limited responses
- Some candidates did not describe the lone pair on oxygen delocalising into the benzene ring.

Question 6

(a) (i) Comprehensive responses
- Most candidates were able to draw clear structures of the amino acids.

Limited responses
- Some candidates omitted a carbon atom in the structure of the dicarboxylic acid structure, $HOOCCH_2CH(NH_2)COOH$.

(ii) Comprehensive responses
- Most candidates gave a precise definition of isoelectric point. Many described in terms of the pH where the amino acid exists as a Zwitterion.

Limited responses
- Some candidates omitted any reference to 'pH' in their answer.

(iii) Comprehensive responses
- Most candidates gave the correct structure of the Zwitterion of cysteine.

Limited responses
- A common error was giving the unionised structure of cysteine, $H_2NCH(CH_2SH)COOH$.

(b) Comprehensive responses
- Many candidates were able to correctly predict the positions of the amino acids, **X**, **Y** and **Z**.
- Some gave good explanations in terms of the direction of movement in terms of charge of the species and the distance moved in terms of relative size of the amino acid.

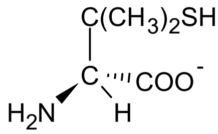
Limited responses
- Many candidates predicted that **Z** would go to the negative pole and **X** and **Y** to the positive pole.
- Some explained the distance moved in terms of 'mass' instead of relative size of the amino acid.

(c) (i) Comprehensive responses
- Most candidates were able to define a bidentate ligand.

Limited responses
- Some common errors were to omit any reference to lone pairs or the term 'metal' with atom/ion in their answer.

(ii) Comprehensive responses
- Some candidates displayed a good understanding drawing the three-dimensional diagrams for these isomers.

Limited responses
- Many candidates could not draw accurate three-dimensional diagrams for the enantiomers of Z^-. A common error is shown.



(iii) Comprehensive responses
- Many candidates were able to calculate a value for K_{part} from their calculated concentrations.

Limited responses
- Some candidates gave less specific answers and did not link to the other enantiomer and just stated 'less side effects'.

(iv) Comprehensive responses
- Some candidates correctly used Z^- as a bidentate ligand and were able to construct the equation.

Limited responses
- Many candidates used Z^- as a monodentate ligand and gave the incorrect equation shown.
  $Cu(H_2O)_6]^{2+} + 2Z^- \rightarrow [Cu(Z)_2(H_2O)_4] + 2H_2O$

CHEMISTRY

Paper 9701/52
Planning, Analysis and Evaluation

Key messages

What candidates did well
- Described how to prepare a standard solution.
- Knew which volumetric instrument to use.
- Plotted points and drew accurate lines of best fit on a graph.

What candidates needed to improve
- Candidates must read through and understand why various steps in an experiment are done in order to avoid giving responses that contradict the method given. For example, suggesting $NaNO_3$ would decompose at 320 °C in **1(g)** when $NaNO_3$ is not present in the precipitate formed.
- Avoid giving more than one response when one response is asked for. For example, in **1(d)(v)**, where often a second incorrect response such as '… and to remove impurities.' was seen.

Comments on specific questions

Question 1

(a) **Comprehensive responses**
- Nearly all candidates gave the correct answer to three decimal places to reflect the accuracy of the balance.

Limited responses
- A few candidates did not give their answer to three decimal places.

(b) (i) **Comprehensive responses**
- Many candidates showed full working and derived the correct answer.

Limited responses
- Some candidates showed incomplete working or calculated the percentage error in the mass of **X**.

(ii) **Comprehensive responses**
- Most candidates correctly stated that the mass of **X** should be increased.

Limited responses
- Some candidates suggested changing the apparatus.

(c) **Comprehensive responses**
- Most candidates gave full accurate descriptions.

Limited responses
- Some candidates transferred **X** to a second beaker without rinsing or used a pipette to transfer aqueous **X** into a volumetric flask or did not homogenise the final solution.

(d) (i) **Comprehensive responses**

- Nearly all candidates correctly stated chemically resistant gloves.

Limited responses

- Some candidates gave vague responses about the type of gloves.

(ii) **Comprehensive responses**

- Most candidates knew that a volumetric pipette should be used.

Limited responses

- Some candidates gave vague responses about the type of pipette.

(iii) **Comprehensive responses**

- Most candidates correctly stated that $NaB(C_6H_5)_4(aq)$ was in excess.

Limited responses

- A few candidates were too vague about which reagent was in excess.

(iv) **Comprehensive responses**

- Some candidates recognised that cold temperatures would result in a greater mass of precipitate.

Limited responses

- Most candidates made an incorrect assumption that the reaction was exothermic.

(v) **Comprehensive responses**

- Most candidates correctly stated that water would be driven from the crucible at 120 °C.

Limited responses

- Some candidates suggested that heating to 120 °C would drive away solid impurities.

(vi) **Comprehensive responses**

- Most candidates correctly calculated the answer.

Limited responses

- Some candidates did not appreciate that only 25.0 cm^3 of the original 250 cm^3 solution were used and gave answers that were out by a factor of 10.

(vii) **Comprehensive responses**

- Most candidates correctly multiplied their answer to **1(d)(vi)** by the relative formula mass of KCl.

Limited responses

- Some candidates calculated the relative formula mass of KCl incorrectly.

(e) (i) **Comprehensive responses**

- Most candidates calculated **Q** correctly although some answers were out by a factor of 10.

Limited responses

- Some candidates attempted to calculate *n*.

(ii) **Comprehensive responses**

- Some candidates successfully calculated *n* and multiplied this value by the correct relative formula mass of $NaCl$.

Limited responses

- Many candidates did not calculate *n* as shown in the equation given or used an incorrect relative formula mass of $NaCl$.

(iii) **Comprehensive responses**

- Most candidates correctly subtracted answers to **1(d)(vii)** and **1(e)(ii)** from the initial mass of **X**.

Limited responses

- Some candidates included extra subtractions.

(f) **Comprehensive responses**

- Some candidates gave two correct effects.

Limited responses

- Many candidates either knew the correct effect on the mass of KCl only or knew neither effect.

(g) **Comprehensive responses**

- Some candidates correctly suggested that at 320 °C thermal decomposition of the precipitate would result in a lower mass collected.

Limited responses

- Many candidates incorrectly suggested that melting or other physical changes such as sublimation would decrease the mass.

Question 2

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

- Most candidates completed Table 2.1 using correct values to two decimal places.

Limited responses

- Some candidates assumed the volume of distilled water was 50.00 cm^3 or did not give two decimal places.

(ii) **Comprehensive responses**

- Nearly all candidates identified a burette as the suitable piece of apparatus.

Limited responses

- A few candidates incorrectly suggested that non-volumetric apparatus such as a measuring cylinder should be used.

(iii) **Comprehensive responses**

- Nearly all candidates correctly identified relative light intensity.

Limited responses

- A few candidates suggested that $[K^+(aq)]$ was the dependent variable.

(iv) **Comprehensive responses**

- Most candidates plotted all 11 points correctly and drew two intersecting lines of best fit.

Limited responses

- Some candidates omitted the point at the origin, and some candidates drew inaccurate lines of best fit.

(v) **Comprehensive responses**

- Most candidates identified the line on the graph as being straight and passing through the origin.

Limited responses

- Some candidates assumed a straight line alone would show direct proportionality.

(vi) **Comprehensive responses**

- Most candidates realised that the anomaly was caused by over dilution of $KCl(aq)$ either by using too low a volume of $KCl(aq)$ or too high a volume of distilled water.

Limited responses
- Some candidate responses appreciated that [K^+(aq)] was incorrect and did not go on to explain how this discrepancy came about.

(b) (i) Comprehensive responses
- Most candidates correctly read the value of [K^+(aq)] from their graph

Limited responses
- Some candidates misread the scale of the *x*-axis, and some candidates assumed the *x*-axis had units of $g\,dm^{-3}$ instead of $10^{-3}\,g\,dm^{-3}$.

(ii) Comprehensive responses
- Some candidates applied the information given to determine that the [K^+(aq)] in undiluted blood was 100 times as high as that in the diluted sample of blood plasma and was therefore healthy.

Limited responses
- Most candidates did not apply the dilution factor of 100 and assumed the graph reading in **2(b)(i)** meant the plasma was unhealthy.

(iii) Comprehensive responses
- Most candidates realised other cations than K^+ were present in blood plasma.

Limited responses
- Some candidates gave vague statements such as other substances/materials/elements caused emission of different colours.

(c) Comprehensive responses
- Most candidates realised that the relative light intensity was constant above $8.00 \times 10^{-3}\,g\,dm^{-3}$ K^+(aq).

Limited responses
- Some did not link their calibration graph to the question.

(d) Comprehensive responses
- Nearly all candidates stated that the presence of an anomaly meant the data was unreliable.

Limited responses
- A few candidates incorrectly stated that a straight line of best fit meant data was reliable.