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June 2022

GCE Chemistry 9CH0 01

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June 2022

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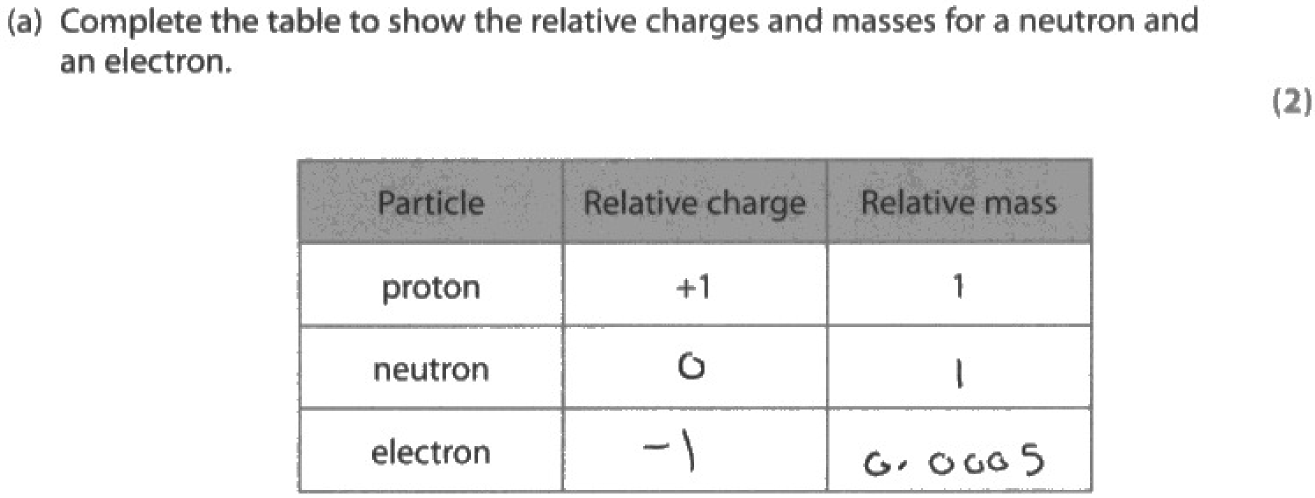
Introduction

This was the first Chemistry A-level paper that was sat by candidates in the June examination series since 2019 due to the impact of the coronavirus pandemic. The majority of candidates sitting this paper would not have experienced any public examinations as the summer exams did not run in their GCSE or AS years. This paper proved accessible to all candidates and there was no evidence that any were hindered by not having sufficient time to complete their answers. A number of the questions were found to be demanding, and on a few occasions a question required more than one statement to score a single mark. It was pleasing to note that many candidates rose to the challenge and demonstrated their knowledge and understanding of A Level chemistry. Nonetheless, there are some key lessons for centres and candidates to learn from the feedback illustrated in the following examples.

Question 1 (a)

This question was designed to assess the candidates' knowledge of sub-atomic particles. Many completely correct responses were seen. However, there was some confusion over the mass of an electron with this commonly being incorrectly given as '0'. Various options for the mass of an electron were allowed on the mark scheme including 'negligible' and '1/1840'.

This is an example of a completely correct response to this question.



(a) Complete the table to show the relative charges and masses for a neutron and an electron.

(2)

Particle	Relative charge	Relative mass
proton	+1	1
neutron	0	1
electron	−1	0.0005

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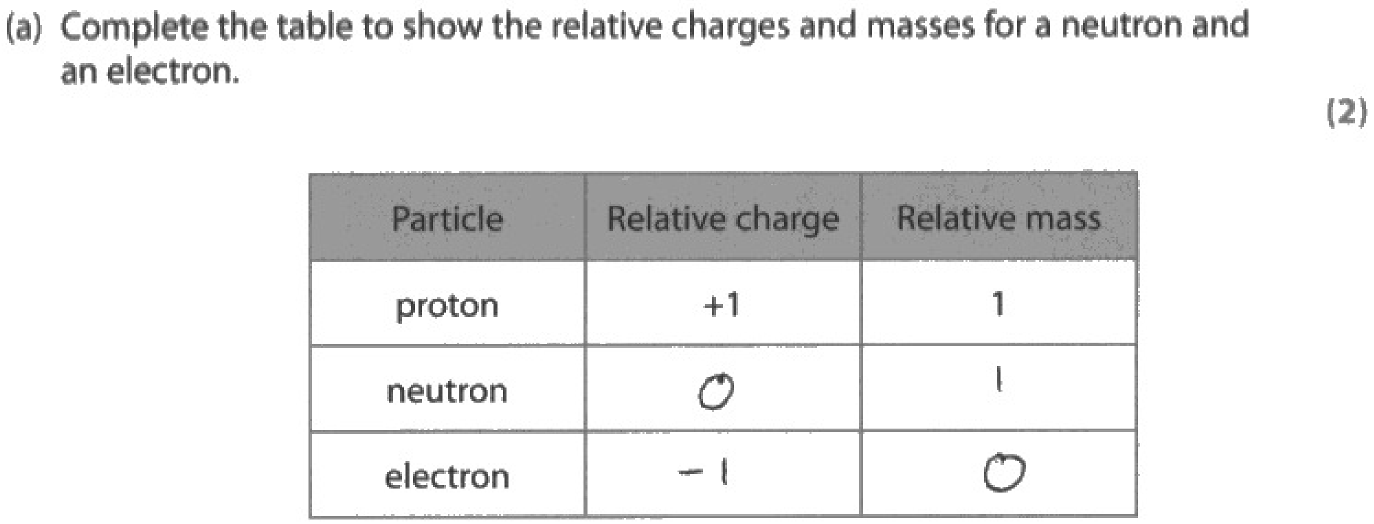
Examiner Comments

All of the properties of the sub-atomic particles were correctly given. The answer of 0.0005 for the mass of an electron was allowed.



(a) Complete the table to show the relative charges and masses for a neutron and an electron.

(2)

Particle	Relative charge	Relative mass
proton	+1	1
neutron	0	1
electron	−1	0

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Examiner Comments

This is an example of an answer that scored just one mark. The three boxes for the relative charge and mass of a neutron, and the relative charge of an electron are correct. However the mass of an electron is given incorrectly as '0'.

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Examiner Tip

Remember that the mass of an electron is very small, but is greater than zero and is generally given as a relative mass of 1/1840

Question 1 (c)

This question required candidates to draw the shape of a p orbital.

Many correct answers were seen, and we allowed for a set of three p-orbitals joined together to score.

Some candidates tried to draw over-lapping p-orbitals to show a pi bond which was not asked for in the question and so the mark was not awarded.

(c) Draw the shape of a p orbital.

(1)

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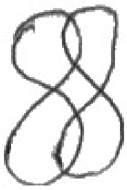
Examiner Comments

This is an example of a drawing that was awarded the mark.

(c) Draw the shape of a p orbital.

(1)



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Examiner Comments

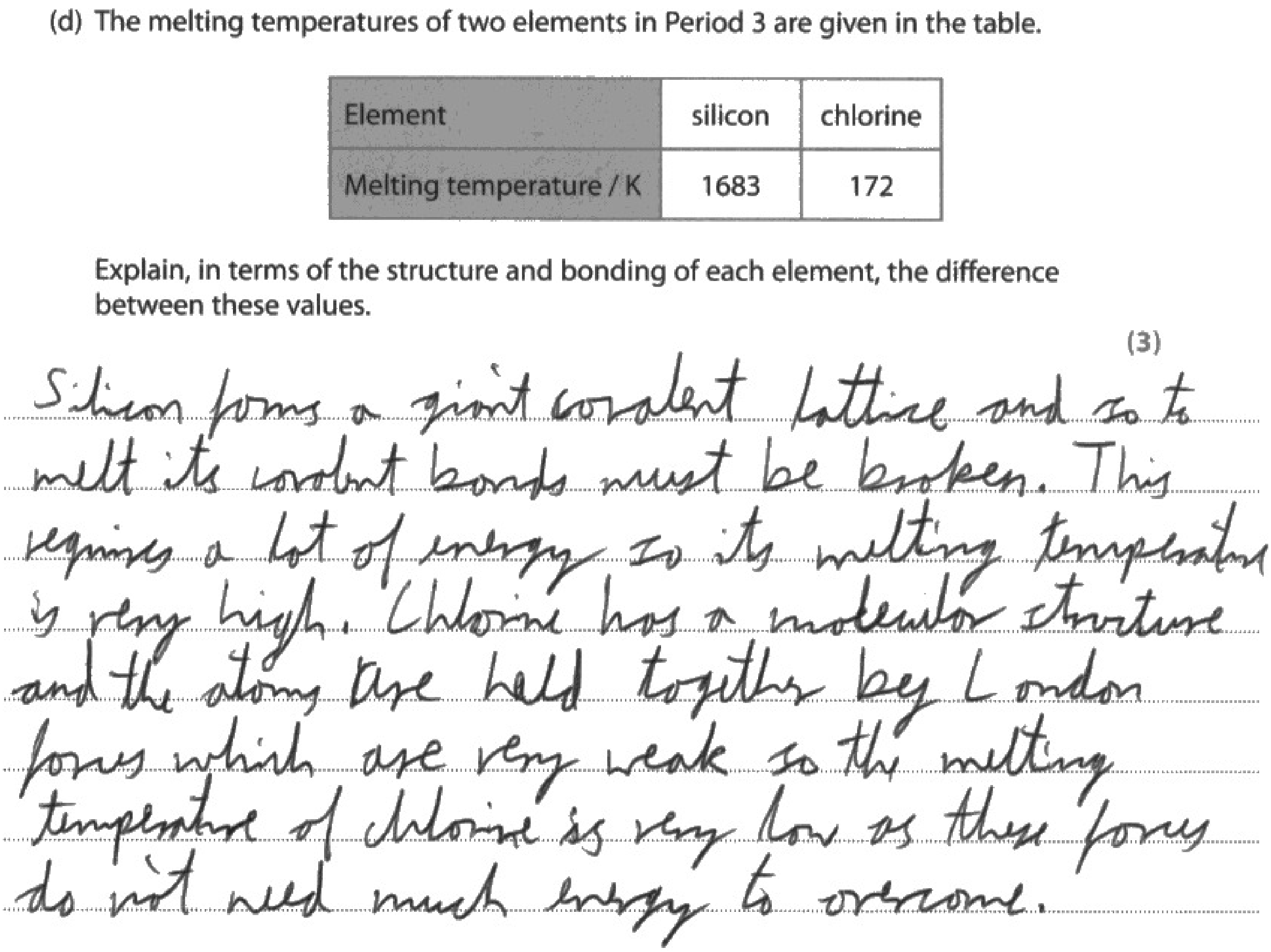
This candidate did not score the mark as there were two p-orbitals overlapping which might have been intended to show a pi bond.

Question 1 (d)

This three mark question proved more challenging.

The best answers showed a full understanding of the structure and bonding in silicon and chlorine. There was some confusion over the structure of silicon with metallic, ionic and molecular all being used as descriptors.

Some candidates suggested that the covalent bonds in chlorine were broken on melting. These answers generally did not include a reference to the London forces between chlorine molecules.



(d) The melting temperatures of two elements in Period 3 are given in the table.

Element	silicon	chlorine
Melting temperature / K	1683	172

Explain, in terms of the structure and bonding of each element, the difference between these values.

(3)

Silicon forms a giant covalent lattice and so to melt its covalent bonds must be broken. This requires a lot of energy so its melting temperature is very high. Chlorine has a molecular structure and the atoms are held together by London forces which are very weak so the melting temperature of chlorine is very low as these forces do not need much energy to overcome.

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Examiner Comments

This is an example of an excellent response to this question which covers the structure of both silicon and chlorine in detail and links the strengths of the covalent bonds in silicon and the London forces between chlorine molecules to the melting points of the elements.

(d) The melting temperatures of two elements in Period 3 are given in the table.

Element	silicon	chlorine
Melting temperature / K	1683	172

Explain, in terms of the structure and bonding of each element, the difference between these values.

(3)

Chlorine has a simple molecular structure so there are weak intermolecular forces of attractions between molecules but covalent bonds between atoms. These forces of attraction do not require a lot of energy from heat to break. Silicon has a giant covalent structure and is a lattice with each silicon atom covalently bonded to 4 other silicon atoms. Covalent bonds require much more energy from heat to break than weak intermolecular forces so silicon has a higher melting point as many strong, covalent bonds must be broken

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Examiner Comments

This is a well-structured answer and if that candidate had named the intermolecular forces between chlorine molecules as London forces three marks would have been scored.

Question 2 (a)

This is an example where careful reading of the information in the question would have helped the candidates to access both marks.

The first mark was awarded for noting that the Universal Indicator would change colour to blue/purple.

The second mark was scored for realising that the water in the test tube would drop as a gas would collect at the top of the tube.

Candidates were asked for observations, and should be made aware that 'solution goes alkaline' is not an observation, whereas the accompanying correct colour change of the Universal Indicator is.

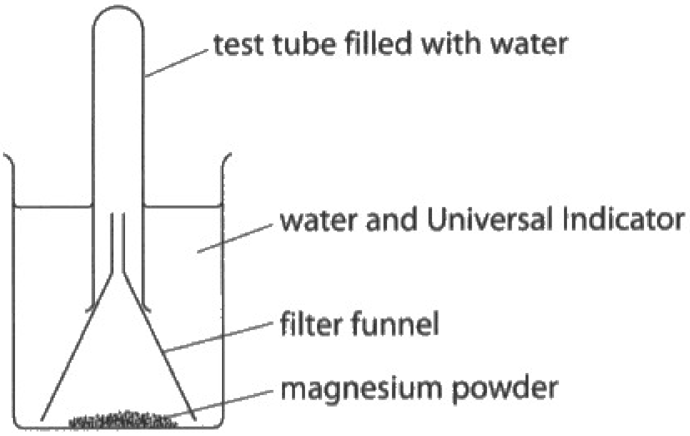
Some candidates named the gas produced. Again, the observation would not be that the gas was hydrogen, it would have been that a gas would collect at the top of the tube.

If the gas was correctly named as hydrogen then this was not penalised. However incorrect gases were penalised, as were incorrect colour changes of Universal Indicator, such as 'an alkaline solution produces a red colour'.

This answer scored 1 out of the possible 2 marks.

(a) Magnesium ~~powder~~ solid is added to a beaker of water containing a few drops of Universal Indicator.

The apparatus is set up as shown and allowed to stand for a few days.



State **two** changes that will be **seen** after a few days.

(2)

- colour change
- decrease in solid magnesium powder

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Examiner Comments

Here the candidate has noted that there would be a colour change but has not described the colour, so this first mark is not scored.

The second mark is scored for the decrease in the amount of the solid magnesium.

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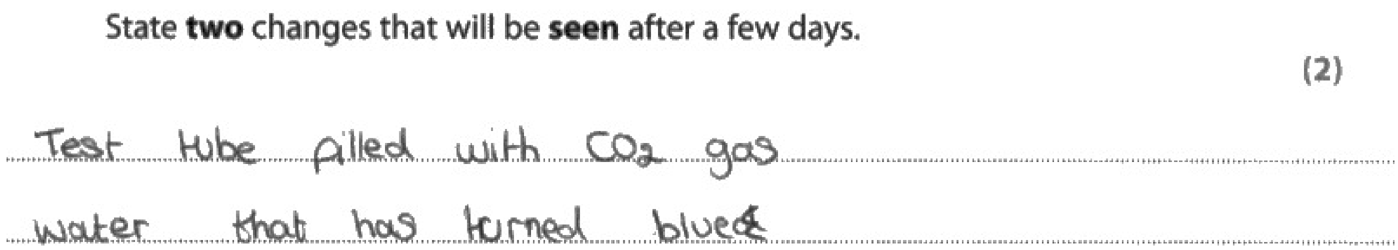
Examiner Tip

Read all of the information in the question and make use of it when thinking of your answer.


State **two** changes that will be **seen** after a few days.

(2)

Test tube filled with CO_2 gas

water that has turned blued

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Examiner Comments

This scored one mark out of the two for the colour of the water being blue.

The second mark was not awarded as although the candidate has noted that a gas would be produced, they have incorrectly identified it as carbon dioxide.

Question 2 (b)

This question required candidates to explain the trend in reactivity of the Group 2 elements with reference to their electronic configurations.

Full explanations included reference to the weaker attraction of the outer electron to the nucleus as the group is descended due to increased distance of the outer electron from the nucleus and the increased shielding from inner electron shells, meaning that less energy is required for the outer electron to be lost.

Common omissions included the shielding effect, reference to the electrons being in the outer shell and not explaining that reactivity is linked to the loss of an electron.

This shows an example of a fully correct answer covering all of the points required for full marks.

(b) Explain how the trend in the reactivity of the Group 2 elements is determined by their electronic configurations.

(3)

- Down group 2, the reactivity metals increases.
- This is because down the group, the metals' atomic radii increase and the outer electrons are further away from the nucleus.
- Also, the number of electron shells increases, so outer electrons experience more electron shielding.
- This outweighs the increased number of protons, overall resulting in outer electrons being less attracted to the nuclei of the atoms, and making outer electrons easier to lose.

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Examiner Comments

This is a clear explanation with each point made in a logical order.

ResultsPlus
Examiner Tip

This candidate has shown a good understanding of the factors affecting reactivity.

(b) Explain how the trend in the reactivity of the Group 2 elements is determined by their electronic configurations.

(3)

-As you move down the group reactivity increases

- this is because as you move down the group the elements atomic radius increases as the further down the group the more electron shielding they experience.

- this means there is a weaker electrostatic force of attraction between the nucleus and outer shell electrons so has a large radius as electrons are further away from the nucleus.

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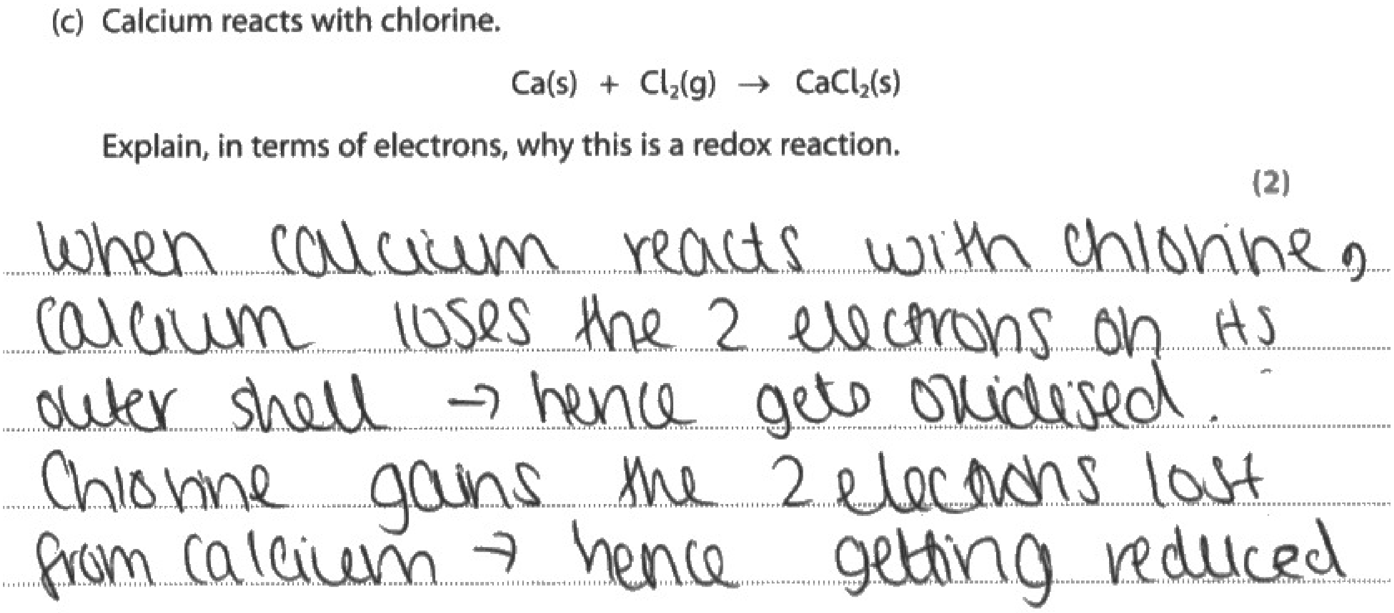
Examiner Comments

This response scored two. They had made the first two marking points (greater distance between the outer shell electron and the nucleus and greater shielding) but they did not complete their explanation by saying that the reason why reactivity increased was because the outer electrons would be lost more easily.

Question 2 (c)

Candidates were asked to explain, in terms of electrons, why the reaction between calcium and chlorine is a redox reaction. Candidates who gave good answers to this question made sure that they had included a description of the loss and gain of electrons. Others who did not score the full two marks answered in terms of oxidation number changes and did not include reference to the electrons.



(c) Calcium reacts with chlorine.

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s)$$

Explain, in terms of electrons, why this is a redox reaction.

(2)

When calcium reacts with chlorine, calcium loses the 2 electrons on its outer shell → hence gets oxidised. Chlorine gains the 2 electrons lost from calcium → hence getting reduced

ResultsPlus
Examiner Comments

This response scored both marks as they have correctly explained that the reaction is a redox reaction and have included information about the electrons.

(c) Calcium reacts with chlorine.

$$\overset{0}{Ca}(s) + \overset{0}{Cl_2}(g) \rightarrow \overset{+2\ -1}{CaCl_2}(s)$$

Explain, in terms of electrons, why this is a redox reaction.

(2)

because the oxidation number of at least one species changed. oxidation number of Ca changed from 0 to +2 which is oxidised. the oxidation number of chlorine changed from 0 to -1, which is reduced.

ResultsPlus
Examiner Comments

This is an example of a response that scored just one of the two marks available. Their statements are correct but they have not mentioned loss or gain of electrons as asked for in the question.

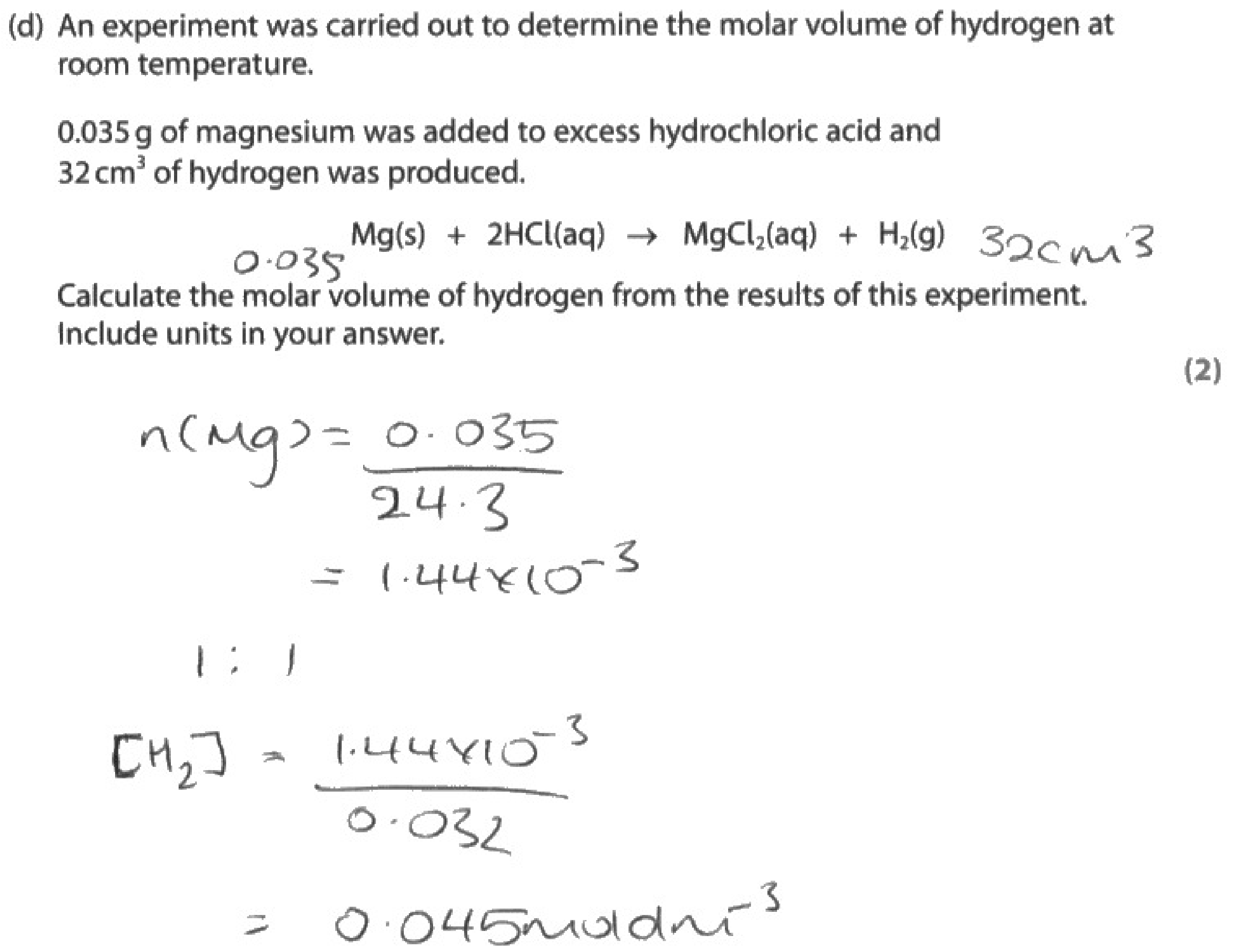
Question 2 (d)

This question required the candidates to calculate the moles of magnesium added to the acid and then to use this information to calculate the molar volume of hydrogen with appropriate units.

Many candidates accessed the first mark, and calculated the number of moles correctly (1.44 X 10^{-3}) and some went on to give the correct answer in cm^3 or dm^3 as appropriate.

However many candidates found it difficult to work out how to use this to answer the second part of the question, with many dividing 1.44 X 10^{-3} by $32cm^2$ instead of dividing 32 by 1.44 X 10^{-3} to give the correct answer of 22,200 cm^3 or 22.2 dm^3.

This response is typical of an answer that gained one mark only for the first step, to calculate the moles of hydrogen.



(d) An experiment was carried out to determine the molar volume of hydrogen at room temperature.

0.035 g of magnesium was added to excess hydrochloric acid and $32\,cm^3$ of hydrogen was produced.

$$\overset{0{\cdot}035}{Mg(s)} + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \quad 32cm^3$$

Calculate the molar volume of hydrogen from the results of this experiment. Include units in your answer.

(2)

$$n(Mg) = \frac{0{\cdot}035}{24{\cdot}3}$$

$$= 1{\cdot}44 \times 10^{-3}$$

1 : 1

$$[H_2] = \frac{1{\cdot}44 \times 10^{-3}}{0{\cdot}032}$$

$$= 0{\cdot}045 mol dm^{-3}$$

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Examiner Comments

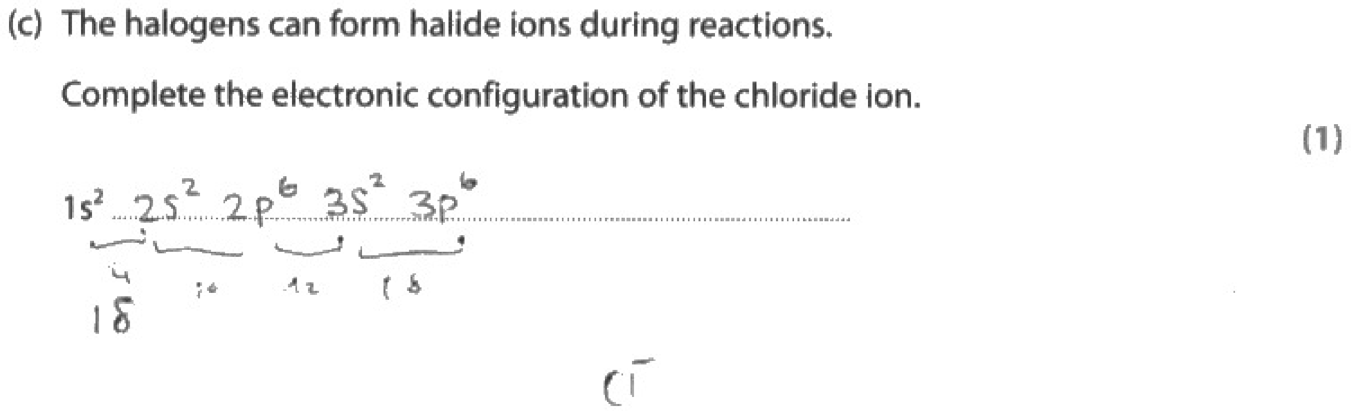
The candidate has correctly calculated the moles of hydrogen and has then incorrectly divided this number by the volume of gas given in the question.

Question 3 (c)

This question was about the electron configuration of a chloride ion. Many correct answers were seen.

The majority of incorrect answers gave the electronic configuration of a chlorine atom.

This is an example of a fully correct response. Although not necessary for the mark, the candidate's correct working out can be seen below their answer.



(c) The halogens can form halide ions during reactions.

Complete the electronic configuration of the chloride ion.

(1)

$1s^2\ \underbrace{2s^2}_{4}\ \underbrace{2p^6}_{10}\ \underbrace{3s^2}_{12}\ \underbrace{3p^6}_{18}$

18

Cl^-

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Examiner Comments

The correct electron configuration of the chloride ion has been given and the mark has been awarded.

This is an example of a common incorrect answer where the candidate has given the correct electron configuration of a chlorine atom rather than the chloride ion asked for in the question.

(c) The halogens can form halide ions during reactions.

Complete the electronic configuration of the chloride ion.

(1)

$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^5$

ResultsPlus
Examiner Comments

The candidate did not remember to add on the extra electron for the negative charge of the chloride ion.

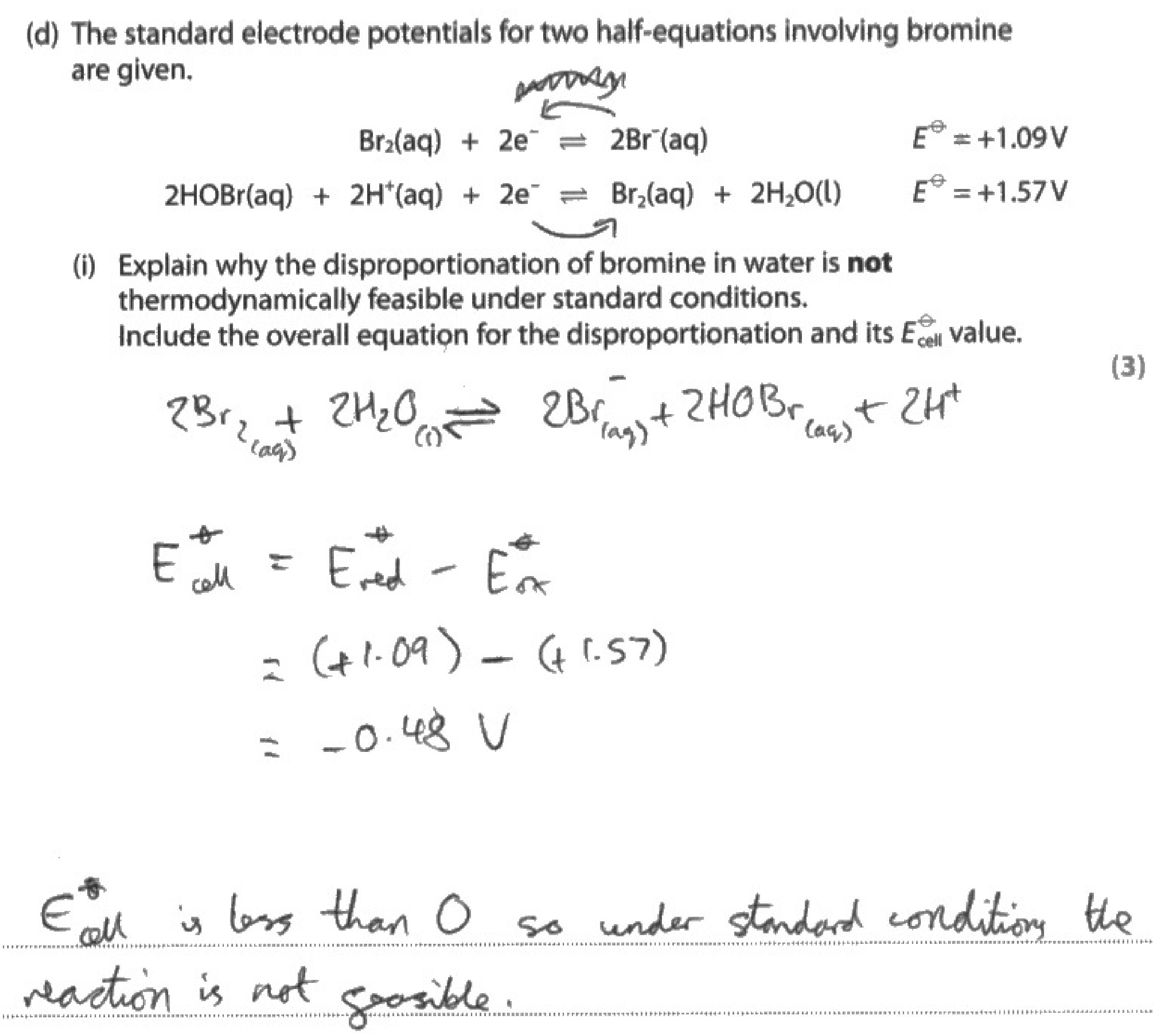
ResultsPlus
Examiner Tip

If the electron configuration of an ion is required, this will be different from that of the atom.

Question 3 (d)(i)

Many candidates were able to give a correct value for the first part of this answer, even if their equation was not quite correct. It was possible to score marks for correct statements about the equation for the reverse of disproportionation and some candidates made good arguments from a correct reverse equation. There was some confusion over the final part of the question, with some candidates saying that because the value was negative, the reaction would be feasible.

This answer is fully correct and scores all three marks. State symbols were ignored as they were not asked for in the question and so the absence of the (aq) on the H^+ ions did not matter.



(d) The standard electrode potentials for two half-equations involving bromine are given.

$$Br_2(aq) + 2e^- \rightleftharpoons 2Br^-(aq) \qquad E^\ominus = +1.09\,V$$

$$2HOBr(aq) + 2H^+(aq) + 2e^- \rightleftharpoons Br_2(aq) + 2H_2O(l) \qquad E^\ominus = +1.57\,V$$

(i) Explain why the disproportionation of bromine in water is **not** thermodynamically feasible under standard conditions.
Include the overall equation for the disproportionation and its $E^\ominus_{cell}$ value.

(3)

$$2Br_{2(aq)} + 2H_2O_{(l)} \rightleftharpoons 2Br^-_{(aq)} + 2HOBr_{(aq)} + 2H^+$$

$$E^\ominus_{cell} = E^\ominus_{red} - E^\ominus_{ox}$$

$$= (+1.09) - (+1.57)$$

$$= -0.48\ V$$

$E^\ominus_{cell}$ is less than 0 so under standard conditions the reaction is not feasible.

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Examiner Comments

The candidate has balanced the equation correctly and shown it in the forward direction with reversible arrows and so this scores the first mark.

For the second part, the candidate has correctly calculated the value for the electrochemical cell emf and so this is scored too.

The final statement is correct and so three marks scored overall.

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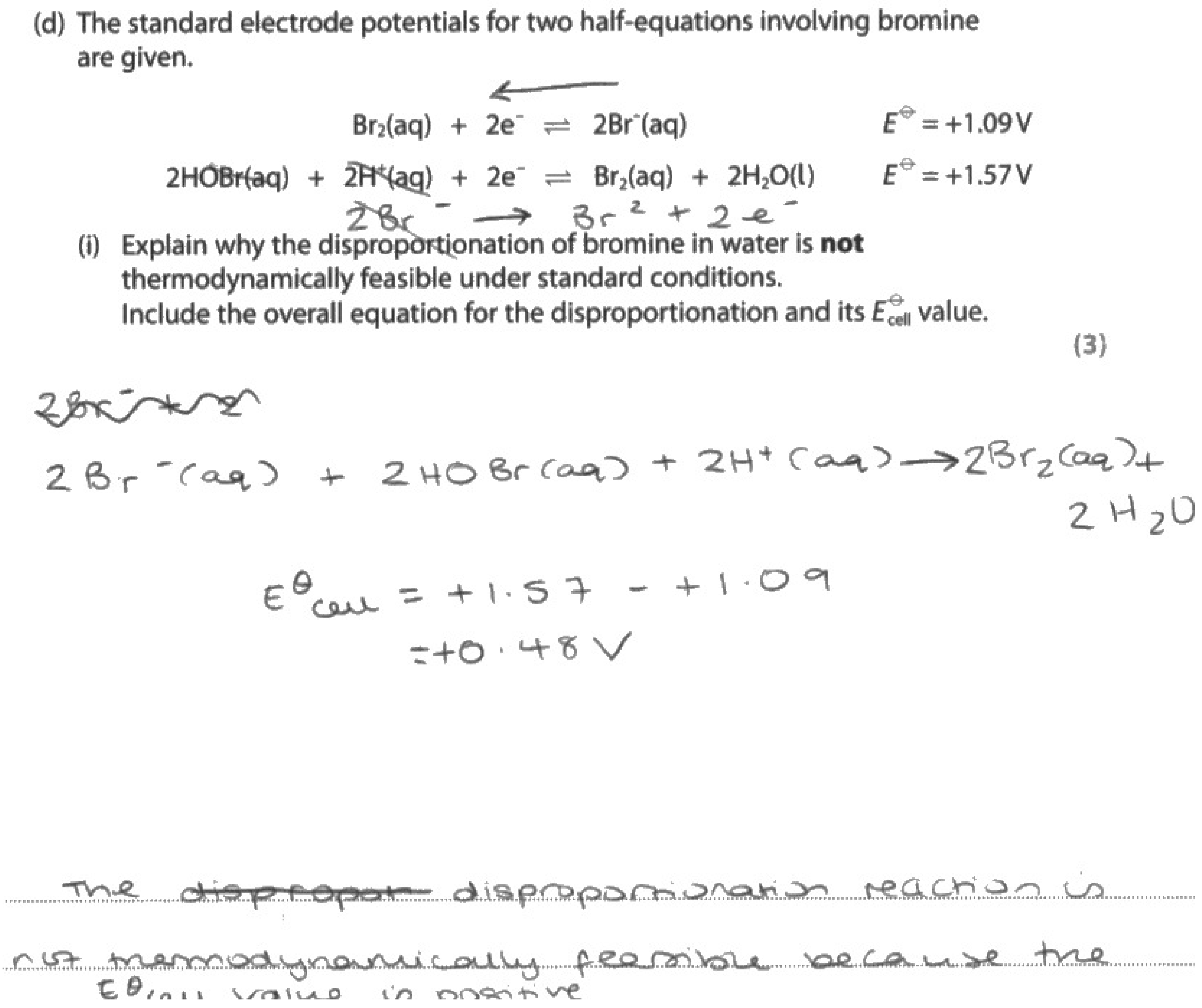
Examiner Tip

The candidate has shown their full working and so avoided making a mistake with their calculation.

This shows an example of where the candidate has written the reverse equation and gained two marks. Their final statement does not explain why the disproportionation reaction would not be thermodynamically feasible and so does not score.



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$$\mathrm{2HOBr(aq) + \cancel{2H^+(aq)} + 2e^- \rightleftharpoons Br_2(aq) + 2H_2O(l)} \qquad E^\ominus = +1.57\,\mathrm{V}$$

$$\mathrm{2Br^- \longrightarrow Br^2 + 2e^-}$$

(i) Explain why the disproportionation of bromine in water is **not** thermodynamically feasible under standard conditions.
Include the overall equation for the disproportionation and its $E^\ominus_{cell}$ value.

(3)

~~$\mathrm{2Br^- + 2e}$~~

$$\mathrm{2Br^-(aq) + 2HOBr(aq) + 2H^+(aq) \longrightarrow 2Br_2(aq) + 2H_2O}$$

$$E^\theta_{cell} = +1.57 - +1.09$$
$$= +0.48\,\mathrm{V}$$

The ~~dispropor~~ disproportionation reaction is not thermodynamically feasible because the E^θ_{cell} value is positive

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Examiner Comments

This candidate has scored two marks as they have written the reverse equation and calculated the electrochemical cell value correctly. However they have made the incorrect interpretation of their value and may not have realised that they had given the reverse equation and so did not score the final mark.

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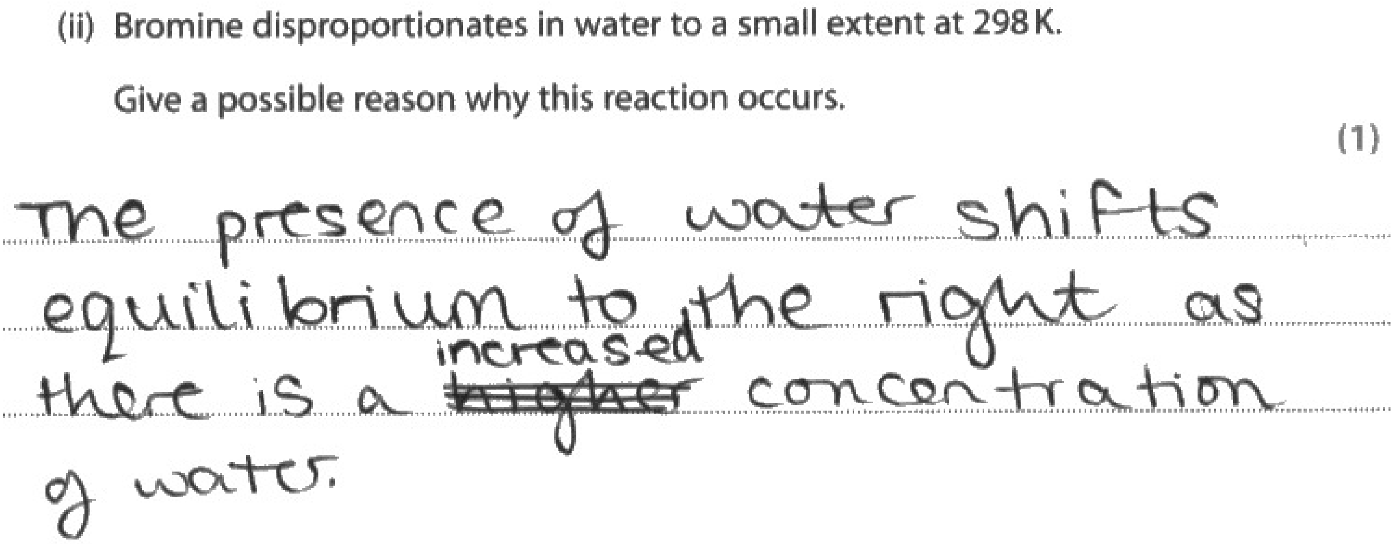
Examiner Tip

Check your work to ensure that your conculsion follows on from your calculations.

Question 3 (d)(ii)

Very few candidates appreciated that the system is an equilibrium and so there would be a presence of all of the species in the equation. Many answers referencing a high activation energy or non-standard conditions were seen. A few candidates realised that if water were in excess or bromine was at a higher concentration than 1 mol dm^{-3} then disproportionation could occur.



(ii) Bromine disproportionates in water to a small extent at 298 K.

Give a possible reason why this reaction occurs.

(1)

The presence of water shifts equilibrium to the right as there is a ~~higher~~ increased concentration of water.

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Examiner Comments

This response scored the mark for the reference to the equilibrium and to the excess water which would shift the position of equilibrium to the right hand side.

Question 4 (b)

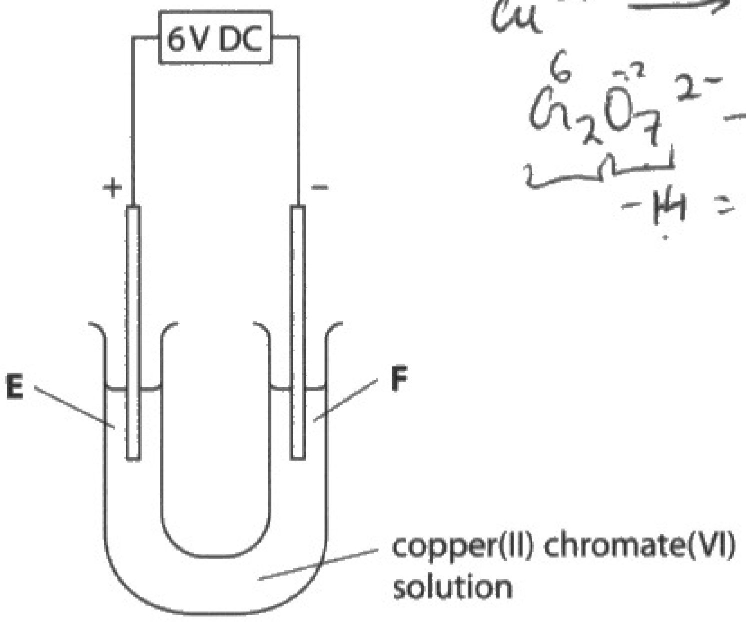
This question required candidates to know the colours of the transition metal ions in aqueous solutions and then to work out which ion migrated to each electrode. The Cu^{2+} ion would migrate to the negative electrode and give a blue colour, whereas the CrO_4^{2-} ion would migrate to the positive electrode and give a yellow colour. Many candidates knew that one of the colours that would be seen would be blue, although they did not always identify the correct electrode. Fewer candidates knew the correct colour of the chromate ion, with answers of green or orange seen relatively frequently.

(b) An aqueous solution of copper(II) chromate(VI) was electrolysed using the apparatus shown in the diagram.

$Cu^{2+} \longrightarrow F$

$\overset{6}{Cr_2}\overset{-2}{O_7}{}^{2-} \longrightarrow E$

$2 \quad -14 = -2$



Deduce the colours of the solutions in regions **E** and **F** after the electrolysis has occurred.

(2)

Colour in region **E** ~~Blue~~ Orange

Colour in region **F** ~~Orange~~ Blue

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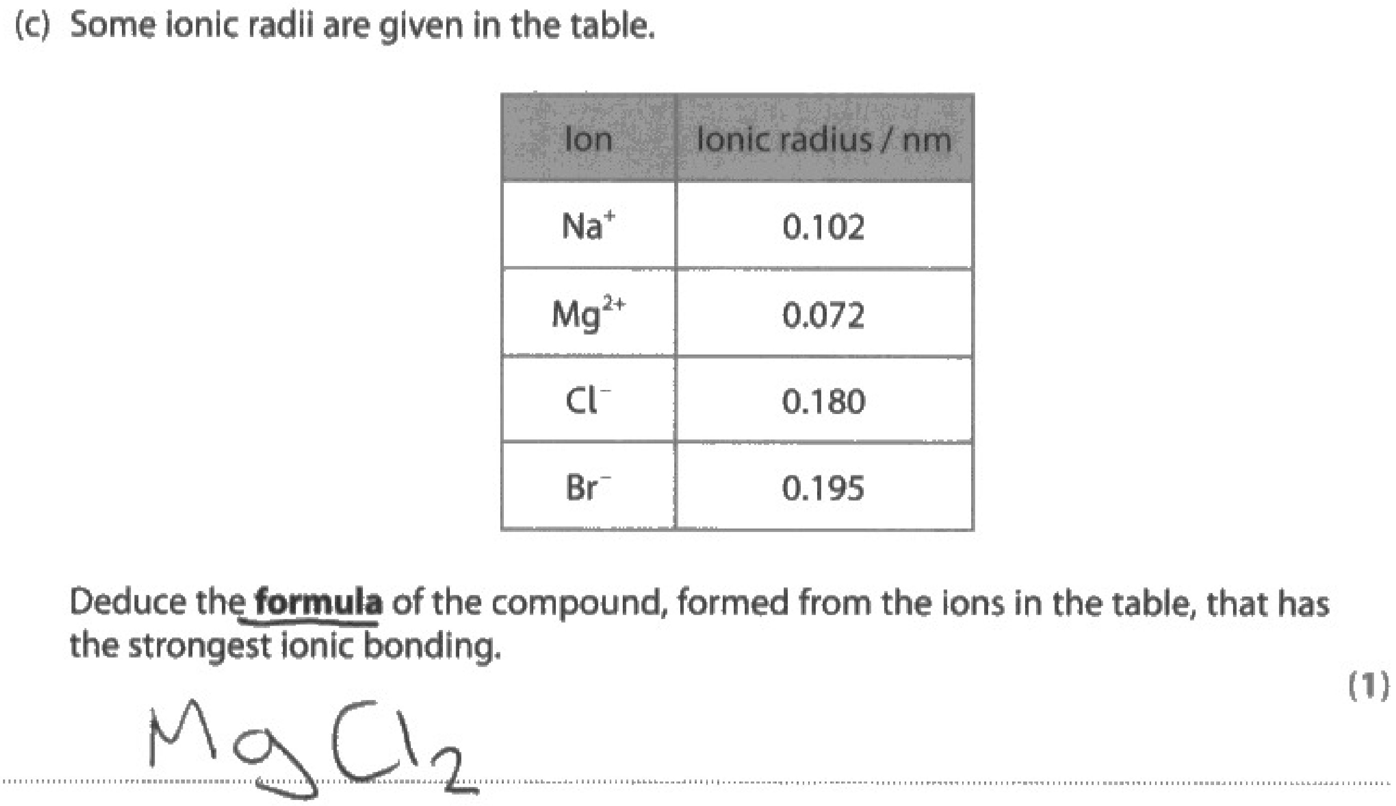
Examiner Comments

This candidate has given the incorrect colour of orange for the chromate (VI) ion, possibly confusing it with the orange of the dichromate (VI) ion. They have the correct colour for the copper (II) ion.

Question 4 (c)

The question required the candidates to apply their knowledge of factors that affect the strength of an ionic bond and to select appropriate ions from a table that would form a compound with the strongest ionic bonding. Candidates would be expected to know that the smaller the ion, the stronger the bond and the larger the charge, the stronger the bond and therefore to select Mg^{2+} and Cl^- from the table. They then had to combine these into the appropriate formula. Most candidates, if they correctly selected the ions then derived the correct formula of $MgCl_2$



(c) Some ionic radii are given in the table.

Ion	Ionic radius / nm
Na^+	0.102
Mg^{2+}	0.072
Cl^-	0.180
Br^-	0.195

Deduce the **formula** of the compound, formed from the ions in the table, that has the strongest ionic bonding.

(1)

$MgCl_2$

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Examiner Comments

This is an example of a correct response with the correct formula given.

ResultsPlus
Examiner Tip

Formula is in bold here so the name will not suffice.

Question 4 (e)

This question assessed the candidate's knowledge of factors that affect the properties of water compared to hydrogen sulfide. Many candidates recognised that there was hydrogen bonding present in water and most made an attempt at a diagram to show the hydrogen bonding present between two water molecules. To score the marks for the diagram it was necessary to show the dipoles, the lone pair on the oxygen that was joined to the second molecule by the hydrogen bond, and for the bond angle to be 180^{o}. The most common feature that was omitted was the lone pair on the oxygen. The next step in the answer was to consider the factors causing the difference in the melting temperature of the molecules. Most candidates noted that the hydrogen bonding in water would be stronger than the intermolecular forces between hydrogen sulfide molecules. Fewer picked up on the information about the number of electrons in each molecule and linked it to the fact that there would be stronger London forces between hydrogen sulfide molecules. The final step was to explain why ice had a lower density than water at $0^{o}C$. Many candidates scored just one of the two marks for commenting that in ice the water molecules were arranged in a hexagonal lattice with spaces in the structure with fewer noting that liquid water would be more dense as the molecules were closer together. Some candidates mixed up their comments for these two points, saying that ice would be more dense than water.

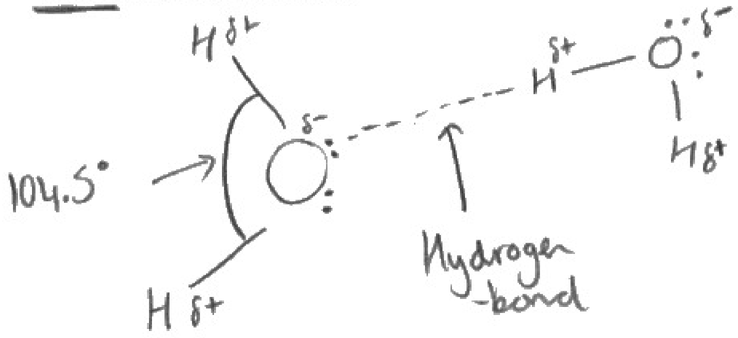
*(e) Water has two significant anomalous properties:

- it has a higher melting temperature than hydrogen sulfide, H_2S, even though it has fewer electrons in its molecules
- the density of ice at 0 °C is less than that of water at 0 °C.

Explain these properties.

You should include a labelled diagram to show the intermolecular forces between two molecules of water.

(6)



The bonding between 2 molecules of water is hydrogen bonding but between molecules of H_2S, there is pemanent dipole interactions – and London forces in both. The hydrogen bonding in water arises due to the greater difference in electronegativity between the oxygen and the hydrogen allowing the hydrogen to be greatly attracted towards the lone pair in oxygen more strongly. These hydrogen bonds are very much stronger and are the ~~highest~~ strongest types of intermolecular force so require more energy to break and overcome, thus water has a higher melting point. Water can also form 2 hydrogen bonds per molecule making it even more stronger. The difference in electronegativity between hydrogen and sulfur is not that large, hence there is no hydrogen bonding in H_2S.

In ice, water molecules arrange themselves in hexagonal ring structures to maximise the area and each water molecule is bonded to another by hydrogen bonds. But this arrangement leaves gaps in the structure making ~~water~~ ice less dense at 0°C. In water at 0°C, each water molecule fills the space by bonding with another so there are greater number of bonds between water molecules in less space so it has a higher density than ice.

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Examiner Comments

This shows a good example of the diagram of a hydrogen bond between two water molecules. The dipoles, the lone pair on the oxygen in the hydrogen bond and the correct bond angle are all evident. This scored the first two marks for the question.

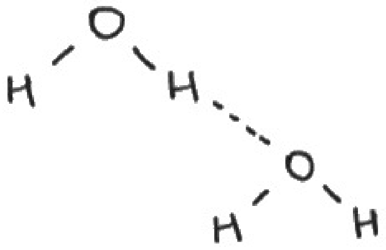
*(e) Water has two significant anomalous properties:

- it has a higher melting temperature than hydrogen sulfide, H_2S, even though it has fewer electrons in its molecules
- the density of ice at 0 °C is less than that of water at 0 °C.

Explain these properties.

You should include a labelled diagram to show the intermolecular forces between two molecules of water.

(6)



ResultsPlus
Examiner Comments

This is an example of an incomplete diagram of a hydrogen bond. The hydrogen bond itself is shown at the correct 180^{o} angle, but there are no dipoles and no lone pairs on the oxygen atoms.

ResultsPlus
Examiner Tip

If a labelled diagram is called for then check that you have added every detail that you could in your answer.

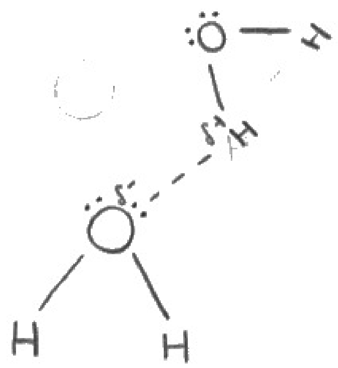
*(e) Water has two significant anomalous properties:

- it has a higher melting temperature than hydrogen sulfide, H_2S, even though it has fewer electrons in its molecules
- the density of ice at 0 °C is less than that of water at 0 °C.

Explain these properties.

You should include a labelled diagram to show the intermolecular forces between two molecules of water.

(6)



water has a higher melting temperature than H_2S because ~~H_2S~~ water does hydrogen bonding as well as having london forces so although H_2S has stronger london forces and perminant dipole - perminant dipole forces due to the net dipole across the molecule, water can hydrogen bond which is a much stronger intermolecular force requiring more energy to break these bonds in water than in H_2S therefore water has a much higher melting point. ~~Water is le~~ Ice is less dense than water because water has the opportunity to have 4 hydrogen bonds per molecule ~~a~~ because it has two lone pairs available and 2 hydrogens available this creates a rigid structure with gaps in between the molecules, the gaps mean ~~that more~~ more air spaces and therefore less dense. The liquid version does not form 4 hydrogen bonds as the molecules flow making it more dense than ice.

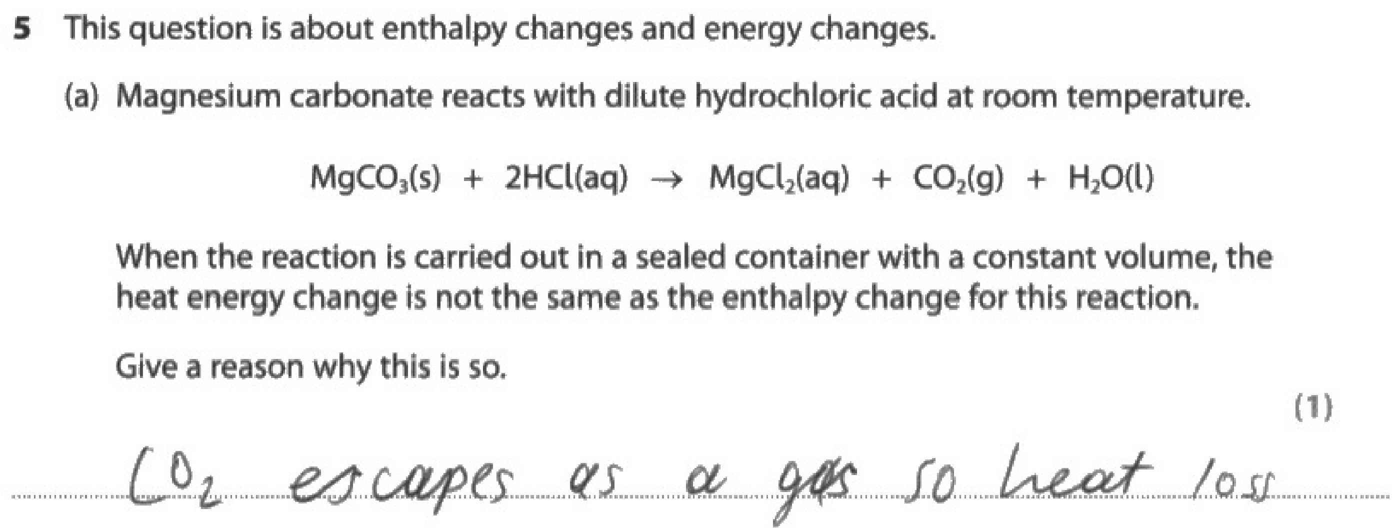
Water is able to hydrogen bond due to the oxygen being highly electronegative meaning electrons are pulled away from the hydrogen making it very electron deficient and able to form a hydrogen bond with the lone pair of electrons on the other water molecule.

ResultsPlus
Examiner Comments

This response scored four marks. M1 was scored for the lone pair on the oxygen in the hydrogen bond and for the correct dipole. However, the angle in the diagram is incorrect and so M2 was not awarded. M3 and M4 were both awarded for the comments about greater London forces in hydrogen sulfide and hydrogen bonding being a stronger intermolecular force than London forces. M5 was evident for the comment about there being gaps/air spaces between the molecules in ice. M6 was not awarded as there was no mention of the water molecules being closer together in ice. This gave four indicative points which translated to three marks plus one reasoning mark and therefore a total of four marks.

Question 5 (a)

Candidates found this question challenging with few linking the production of carbon dioxide to an increase in pressure. There were many responses linked to heat loss and to non-standard conditions, but not specifically to an increase in pressure.



5 This question is about enthalpy changes and energy changes.

(a) Magnesium carbonate reacts with dilute hydrochloric acid at room temperature.

$$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$$

When the reaction is carried out in a sealed container with a constant volume, the heat energy change is not the same as the enthalpy change for this reaction.

Give a reason why this is so.

(1)

CO_2 escapes as a gas so heat loss

ResultsPlus
Examiner Comments

This response did not score the mark, as although the candidate has mentioned the production of carbon dioxide they have written that it will escape. In the question it states that the container is sealed, so the carbon dioxide would not escape. The have then mentioned 'heat loss' which is not relevant to this answer.

5 This question is about enthalpy changes and energy changes.

(a) Magnesium carbonate reacts with dilute hydrochloric acid at room temperature.

$$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$$

When the reaction is carried out in a sealed container with a constant volume, the heat energy change is not the same as the enthalpy change for this reaction.

* Give a reason why this is so.

(1)

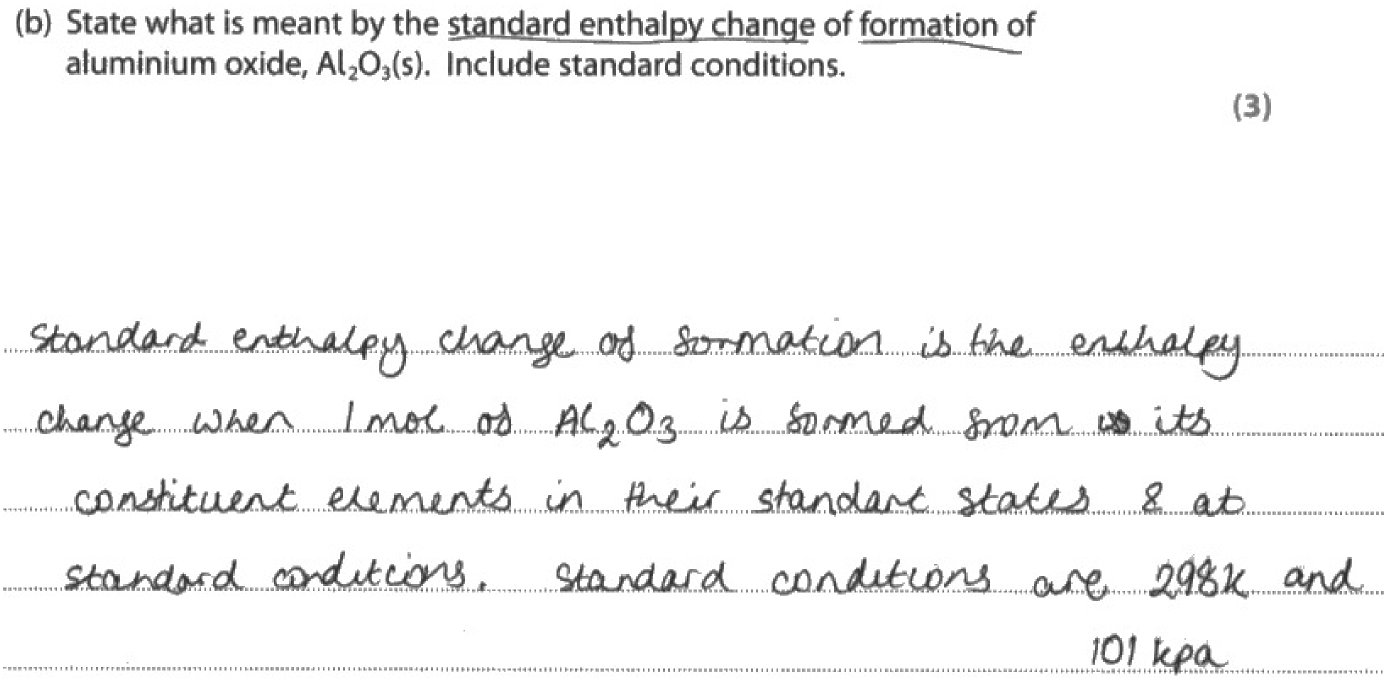
gas is evolved so pressure increases

ResultsPlus
Examiner Comments

This response scores the mark for the comment that the pressure increases as a gas is produced.

Question 5 (b)

This question asked for a description of the standard enthalpy of formation of alumiumium oxide. Many candidates were able to score the mark for describing standard conditions correctly. Some candidates opted to attempt equations for M1 and M2, but there were often contradictions between the equation and what they wrote as a description, particularly evident were references to ions in the gaseous state rather than elements in their standard states for M2.



(b) State what is meant by the standard enthalpy change of formation of aluminium oxide, $Al_2O_3(s)$. Include standard conditions.

(3)

Standard enthalpy change of formation is the enthalpy change when 1 mol of Al_2O_3 is formed from ~~us~~ its constituent elements in their standard states & at standard conditions. standard conditions are 298K and 101 kpa

ResultsPlus
Examiner Comments

This is an example of a fully correct response.

(b) State what is meant by the standard enthalpy change of formation of aluminium oxide, $Al_2O_3(s)$. Include standard conditions.

(3)

The energy change for 1 mol of ~~gaseous~~ Al_2O_3 to be formed from its elements (Al and O_2) under standard conditions – 100 kpa, 298 K

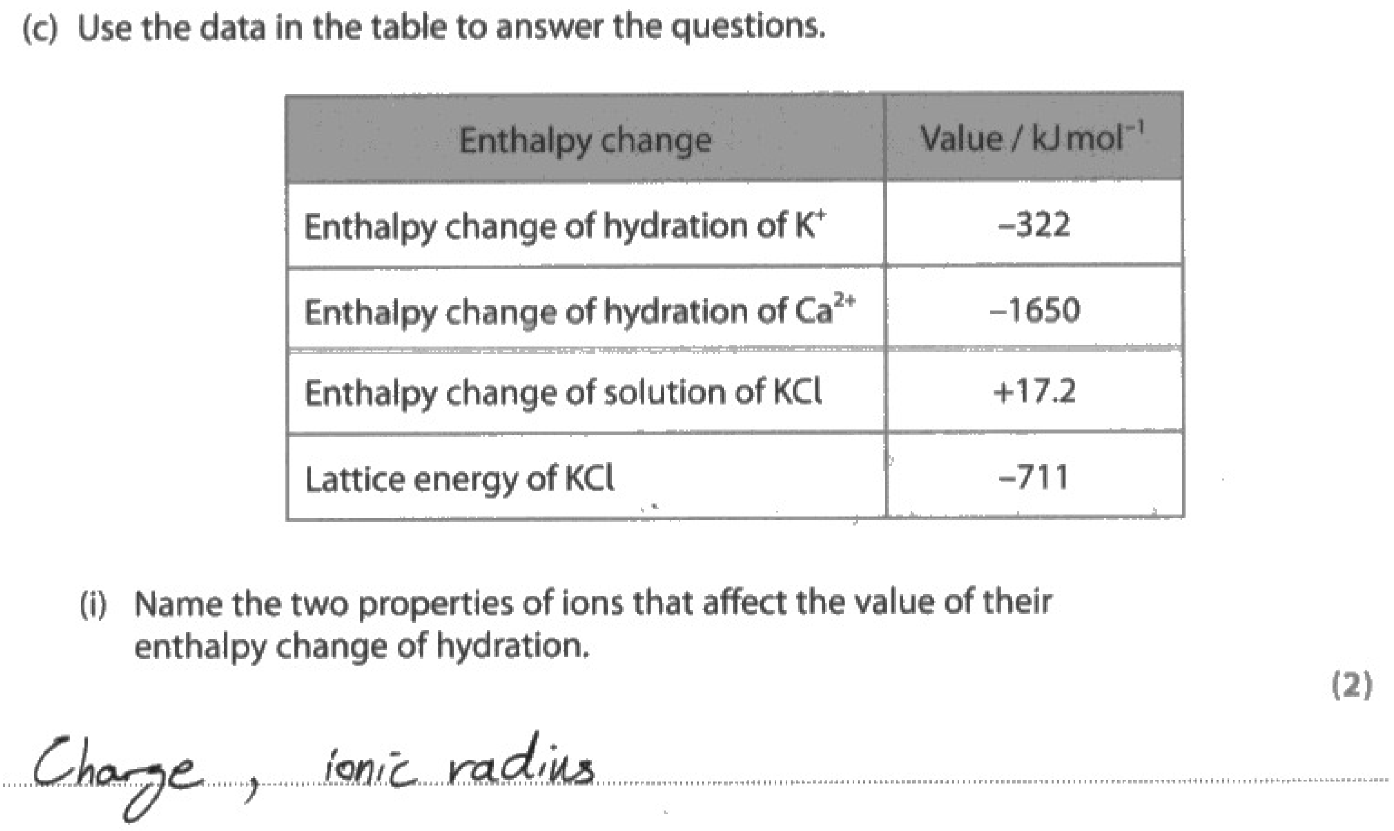
ResultsPlus
Examiner Comments

This response scored two marks as the candidate omitted to refer to the standard states of aluminium and oxygen.

Question 5 (c)(i)

This question was about the factors that affect the solubility of ionic compounds.

This is a completely correct response, scoring both marks.



(c) Use the data in the table to answer the questions.

Enthalpy change	Value / kJ mol^{-1}
Enthalpy change of hydration of K^+	−322
Enthalpy change of hydration of Ca^{2+}	−1650
Enthalpy change of solution of KCl	+17.2
Lattice energy of KCl	−711

(i) Name the two properties of ions that affect the value of their enthalpy change of hydration.

(2)

Charge, ionic radius

ResultsPlus
Examiner Comments

The candidate has identified the ionic charge and radius correctly.

This answer just scored one mark.

(i) Name the two properties of ions that affect the value of their enthalpy change of hydration.

(2)

The charge they have and their size / atomic radius.

ResultsPlus
Examiner Comments

The candidate has correctly identified the features of the charge and the size. However, they have referred to the 'atomic' radius and this question concerns ions and so they have only scored one of the two marks available.

ResultsPlus
Examiner Tip

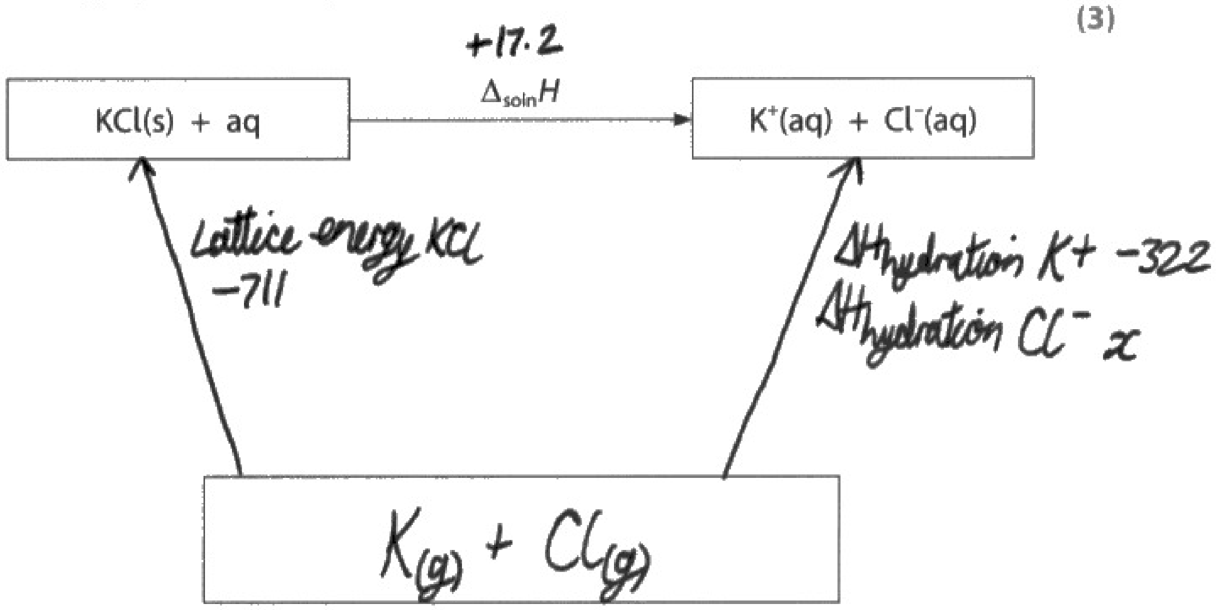
If the question is about ions be sure to check that your answer is in terms of ions and not atoms.

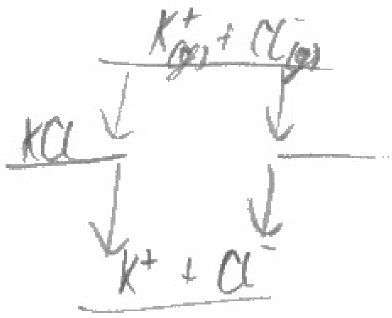
Question 5 (c)(ii)

This question required candidates to complete an energy cycle to calculate the enthalpy change of hydration for chloride ions. There were many correct answers seen, although it was also common to see arrows the wrong way round and incorrect states for the ions in the bottom box.

(ii) Calculate the enthalpy change of hydration for chloride ions by completing the energy cycle, including labels, and using the data in the table.

(3)





~~--711 + -322 + 1650~~

+17.2 = --711 + -322 + x

+17.2 = 389 + x

x = -371.8

-372

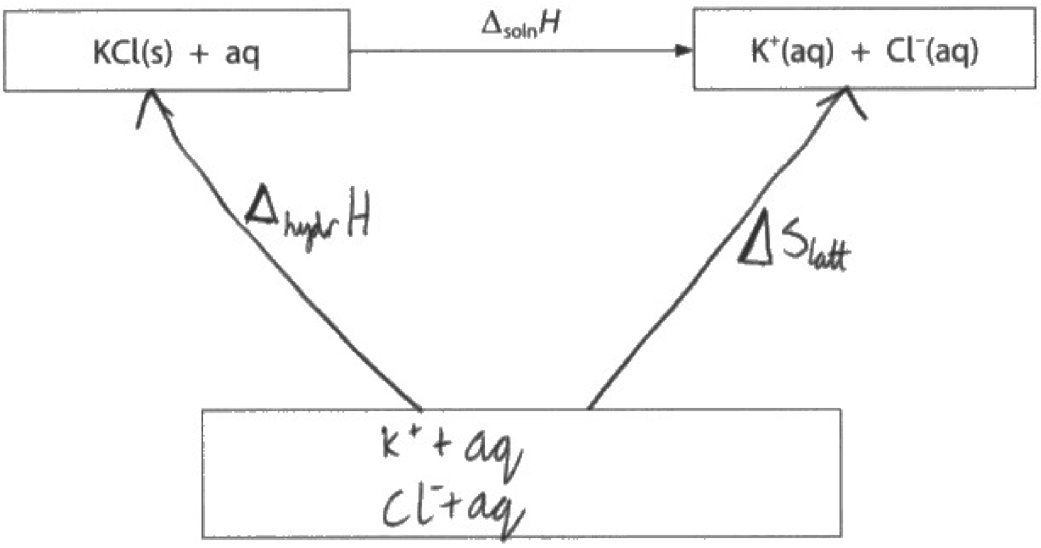
enthalpy change of hydration for Cl⁻ ions ~~-371.8~~ kJ mol⁻¹

ResultsPlus
Examiner Comments

This scored two marks. The arrows are fully labelled and in the right direction, and the final answer is correct. However the candidate has omitted the charges on the ions in the bottom box.

(ii) Calculate the enthalpy change of hydration for chloride ions by completing the energy cycle, including labels, and using the data in the table.

(3)



$-322 + 17.2 + x = -711$

$x = -406.2$

enthalpy change of hydration for Cl^- ions -406.2 kJ mol^{-1}

ResultsPlus
Examiner Comments

This response did not score. The arrows, although labelled are pointing in the wrong direction, the ions in the box are given as (aq) instead of (g) and the final answer is not correct.

Question 6 (a)

This was a straightforward question and scored well. A few candidates wrote that a base was a proton donor, confusing the definition with that of an acid. Others commented incorrectly that a base would react with an alkali.

6 This question is about acids and bases.

(a) State what is meant by a Brønsted-Lowry base.

(1)

proton acceptor

ResultsPlus
Examiner Comments

This correct answer scored the mark.

(a) State what is meant by a Brønsted-Lowry base.

(1)

proton donor

ResultsPlus
Examiner Comments

This was a common incorrect answer which describes an acid instead of a base.

Question 6 (b)

This question required the candidates to write an ionic equation for the reaction between magnesium oxide and an acid. Many candidates worked a balanced symbol equation for this reaction with hydrochloric acid being the most popular example, and then either did not convert this to an ionic question or used the wrong state symbols. It was common to see (aq) as the state symbol for the solid magnesium oxide and/or (aq) for water.

(b) Write the ionic equation for the reaction between magnesium oxide and an acid. State symbols **are** required.

(2)

$MgO_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_2{}_{(s)} + H_2O_{(l)}$

ResultsPlus
Examiner Comments

This response scored no marks. The candidate has written a balanced chemical equation rather than the ionic equation and the state symbol for the magnesium is incorrect.

(b) Write the ionic equation for the reaction between magnesium oxide and an acid. State symbols **are** required. $MgO\,(s) + 2HCl \rightarrow MgCl_2 + H_2O$

(2)

$MgO\,(s) + 2H^+\,(aq) \rightarrow Mg^{2+}\,(aq) + H_2O\,(l)$

ResultsPlus
Examiner Comments

This is an example of a fully correct ionic equation with the correct state symbols and scored both marks.

Question 6 (c)

Many correct answers for the concentration of the hydrogen ions were seen. A few candidates did not score the mark because they incorrectly rounded their answer to 3.17×10^{-10}

(c) Calculate the concentration of hydrogen ions, in mol dm^{-3}, in a solution with a pH of 9.43

(1)

$$10^{-9.43} = 3.7153 \times 10^{-10}$$

$$[H^+] = 3.72 \times 10^{-10} \text{ mol dm}^{-3}$$

ResultsPlus
Examiner Comments

This candidate scored the mark for a correct answer.

(c) Calculate the concentration of hydrogen ions, in mol dm^{-3}, in a solution with a pH of 9.43

(1)

$$pH = -\log[H]$$

$$[H^+] = \log_{10}[9.43] = 0.9745$$

$$= 0.975 \text{ mol dm}^{-3}$$

ResultsPlus
Examiner Comments

This candidate did not score as although their expression for the concentration of the hydrogen ions was correct, they omitted the '-' sign from their calculation and so their answer was not correct.

Question 6 (e)(i)

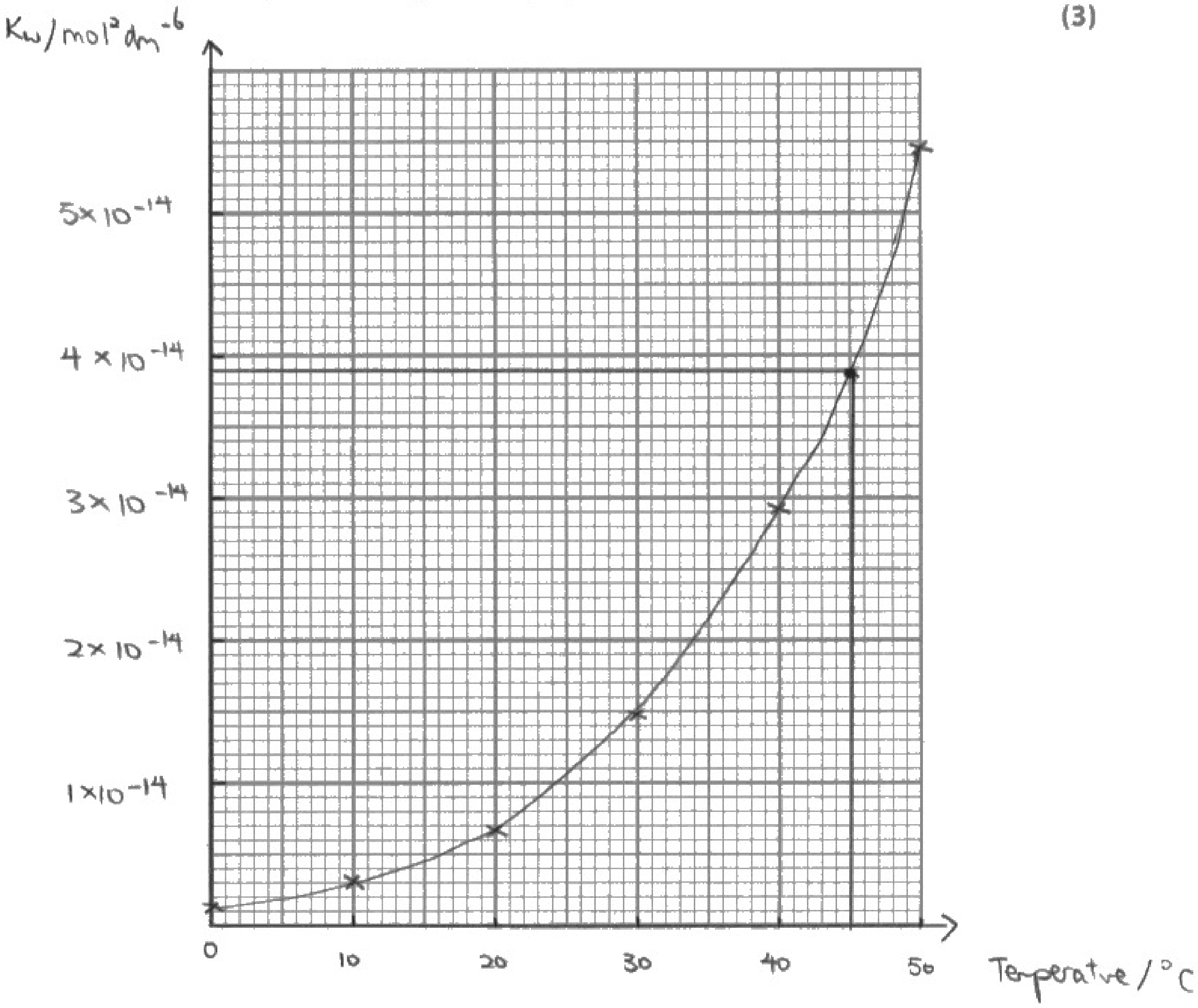
Candidates were asked to plot a graph and to use this graph to determine a value for *Kw* at 45^{o}c. Many candidates produced graphs that covered more than half of the paper with suitable labelled axes and were able to use this to determine the value for *Kw*. Some candidates omitted the labels on the axes and a few plotted the axes the wrong way round. It was possible to score the marks by converting *Kw* to p*Kw* and candidates that adopted this approach were often able to draw the graph but sometimes forgot to convert their final answer back to a *Kw* value.

(e) The ionic product of water, K_w, varies with temperature as shown.

Temperature / °C	K_w / mol^2 dm^{-6}
0	0.11×10^{-14}
10	0.29×10^{-14}
20	0.68×10^{-14}
30	1.47×10^{-14}
40	2.92×10^{-14}
50	5.48×10^{-14}

(i) Determine the value of K_w at 45 °C by plotting a suitable graph.
You must show your working on the graph.

(3)



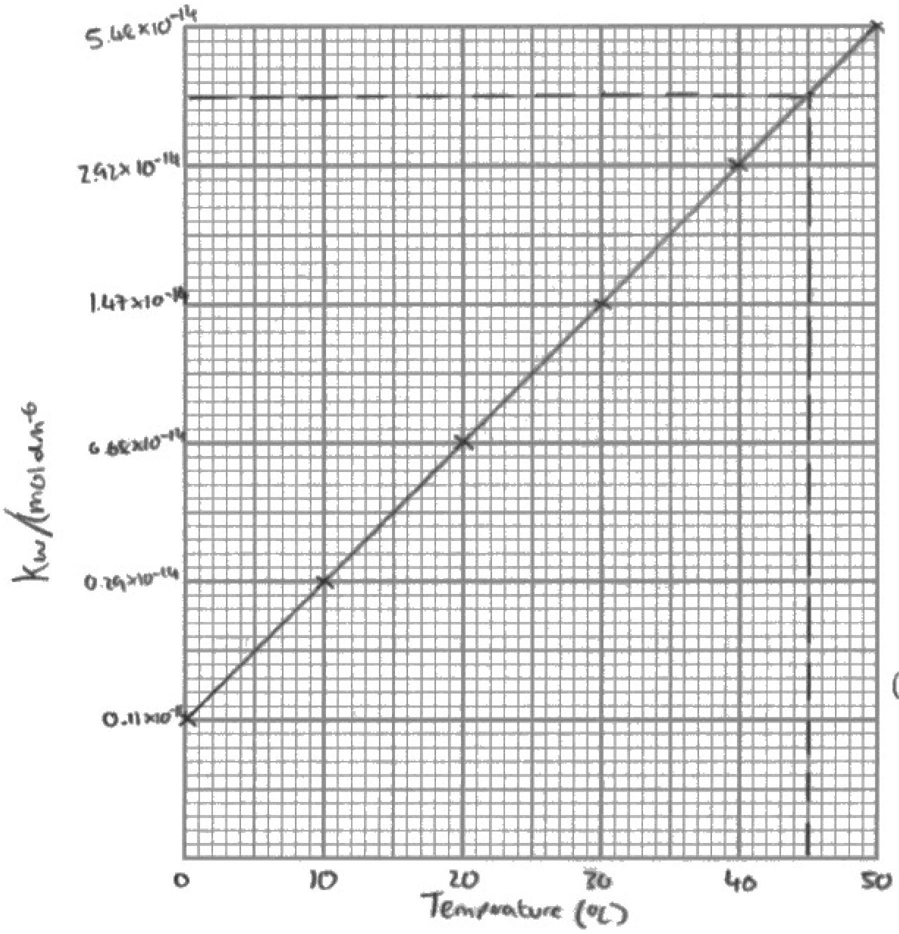
K_w at 45 °C = 3.9 × 10^{-14}

ResultsPlus
Examiner Comments

This is a fully correct response scoring all three marks. The axes are fully labelled, the scale is appropriate and the final answer is correct.

(i) Determine the value of K_w at 45 °C by plotting a suitable graph.
You must show your working on the graph.

(3)



$$\frac{(5.46\times10^{-14})+(2.92\times10^{-14})}{2}$$

$= 4.2\times10^{-14}$

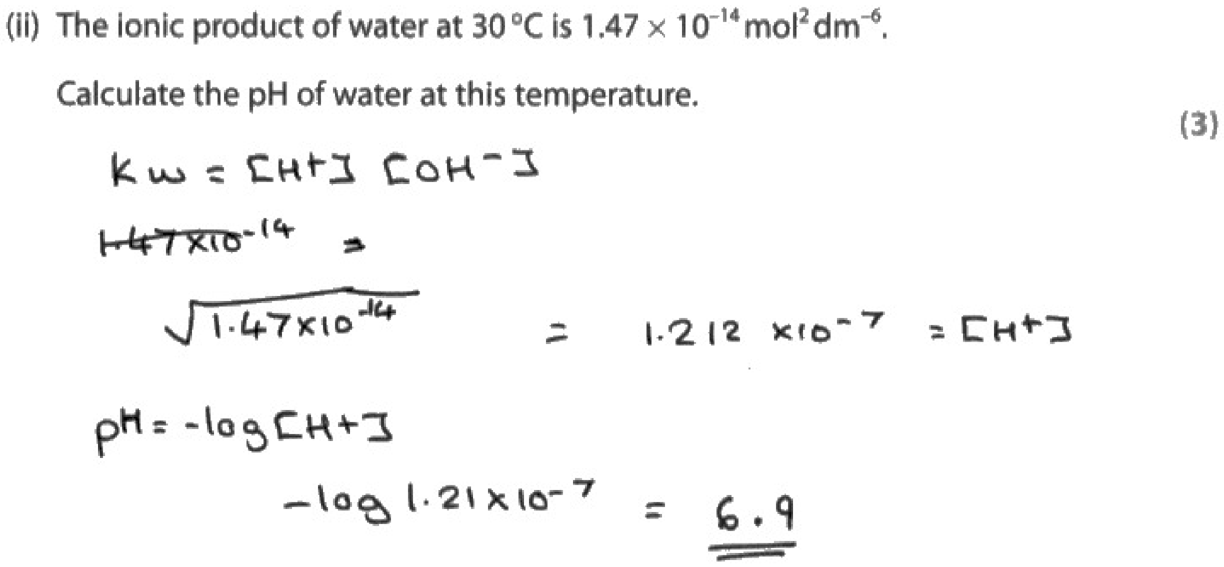
K_w at 45 °C = 4.2×10^{-14}

ResultsPlus
Examiner Comments

The scale on the y-axis is not even and so that candidate did not score the first mark. However their points are plotted correctly and the line they have drawn is appropriate for their points. The final answer is within the tolerance of the mark scheme and so this candidate scored two of the three marks available.

Question 6 (e)(ii)

Candidates were asked to calculate the pH of water at 30^{o} given the ionic product. Many correct answers were seen, with a few rounding their final answer incorrectly and so losing the third mark. Some candidates divided the *Kw* by two rather than using the square root.



(ii) The ionic product of water at 30 °C is 1.47×10^{-14} mol^2 dm^{-6}.

Calculate the pH of water at this temperature.

(3)

$K_w = [H^+][OH^-]$

~~1.47×10^{-14}~~ =

$\sqrt{1.47\times10^{-14}} = 1.212\times10^{-7} = [H^+]$

$pH = -\log[H^+]$

$-\log 1.21\times10^{-7} = \underline{\underline{6.9}}$

ResultsPlus
Examiner Comments

This fully correct answer scored all three marks. The answer was correctly rounded to 2SF.

(ii) The ionic product of water at 30 °C is $1.47 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$.

Calculate the pH of water at this temperature.

(3)

Ionic product of water = $1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$

$$\text{pH} = \log(1.47 \times 10^{-14}) = -13.83$$

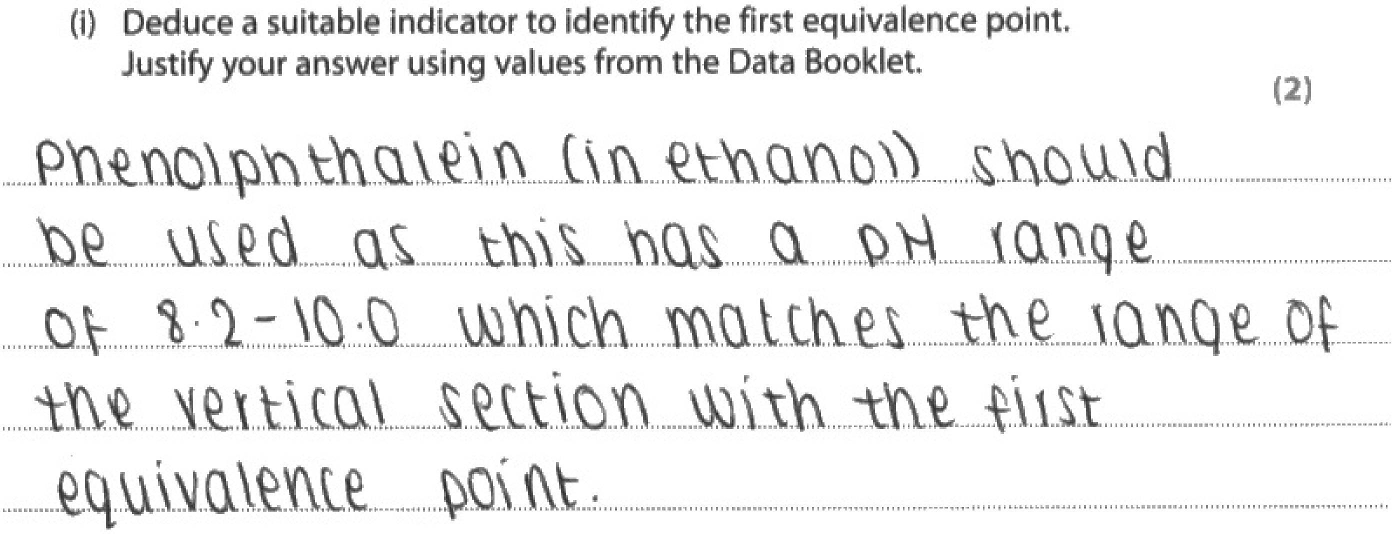
ResultsPlus

Examiner Comments

This response failed to score any of the marks. They have quoted the ionic product of water at 298K which is not relevant to this question. They could have scored a transferred error (TE) mark for their calculation of the pH from their hydrogen ion concentration but the expression is incorrect as they have omitted the minus sign before the log.

Question 6 (f)(i)

Candidates generally showed a good understanding of how to choose an appropriate indicator with phenolphthalein being selected in the majority of cases. The reason was generally linked to the equivalence point and/or the first vertical jump in the graph. A few candidates stated the colour change would be from colourless to red which negated the second mark as the correct colour change would be from red to colourless.



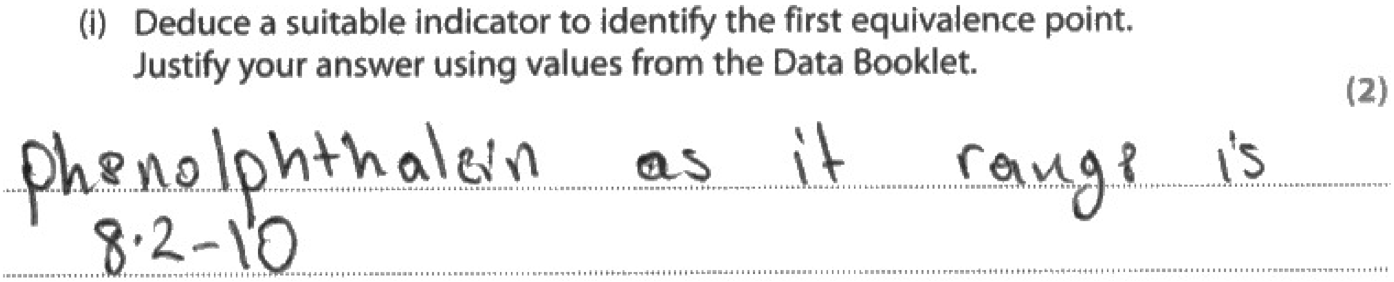
(i) Deduce a suitable indicator to identify the first equivalence point.
Justify your answer using values from the Data Booklet.

(2)

Phenolphthalein (in ethanol) should be used as this has a pH range of 8·2-10·0 which matches the range of the vertical section with the first equivalence point.

ResultsPlus
Examiner Comments

This response scores both marks for the correct choice of indicator and for the link to the vertical region of the graph.



(i) Deduce a suitable indicator to identify the first equivalence point.
Justify your answer using values from the Data Booklet.

(2)

Phenolphthalein as it range is 8·2-10

ResultsPlus
Examiner Comments

This response scored the first mark for identification of the indicator. However there was no justification linked to the graph given for this choice and so the second mark was not scored.

(i) Deduce a suitable indicator to identify the first equivalence point.
Justify your answer using values from the Data Booklet.

(2)

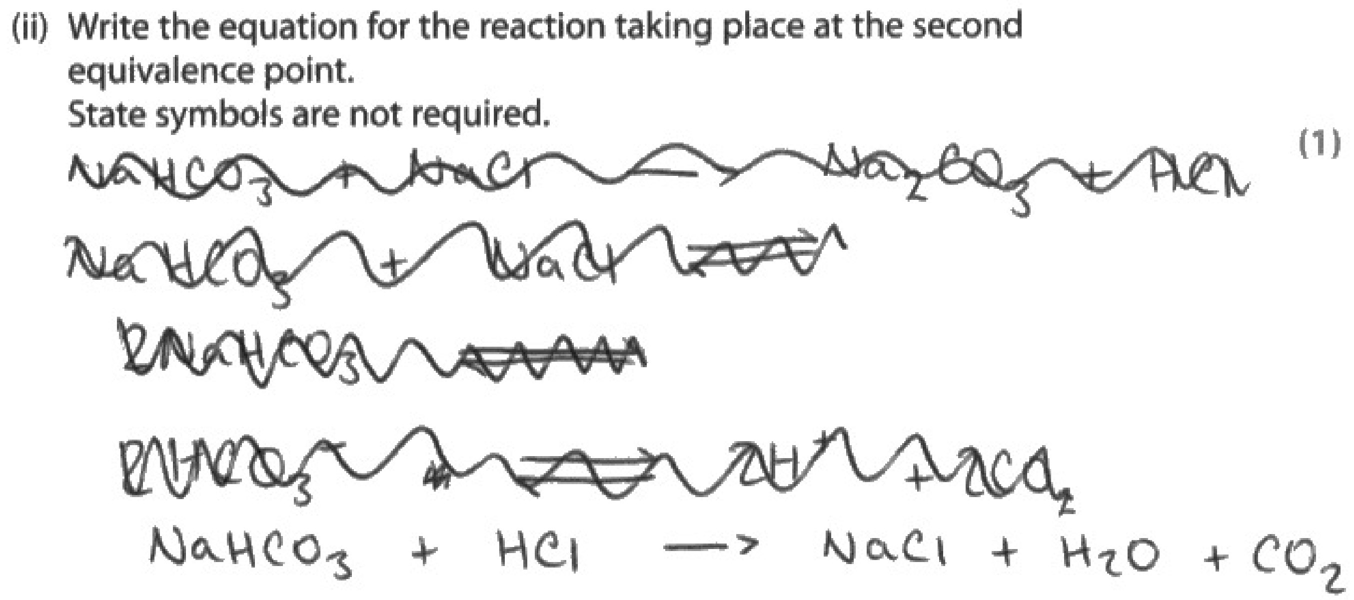
phenol phthalein in methanol, between 8.2 – 10.0 = PH range, and we need between 8.5 and 9.5 ∴ most suitable. we expect colour change from red to colourless.

ResultsPlus
Examiner Comments

This response also scored both marks for the correct choice of indicator and the link to the required pH range for it to cover. The given colour change is correct.

Question 6 (f)(ii)

Candidates were required to identify the reaction occurring at the second equivalence point and to write an equation. Candidates found this more challenging that some of the other questions with many writing equations that showed the sodium hydrogen carbonate reacting with sodium chloride instead of hydrochloric acid.



(ii) Write the equation for the reaction taking place at the second equivalence point.
State symbols are not required.
(1)

~~$NaHCO_3 + NaCl \rightarrow Na_2CO_3 + HCl$~~

~~$NaHCO_3 + NaCl \rightarrow$~~

~~$2NaHCO_3 \rightarrow$~~

~~$2NaHCO_3 \rightarrow 2H^+ + 2CO_2$~~

$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$

ResultsPlus
Examiner Comments

This is a fully correct answer as in the mark scheme. State symbols were not required as stated in the question.

(ii) Write the equation for the reaction taking place at the second equivalence point.
State symbols are not required.

(1)

$NaHCO_3 + NaCl \longrightarrow H_2CO_3 + NaCl$.

ResultsPlus
Examiner Comments

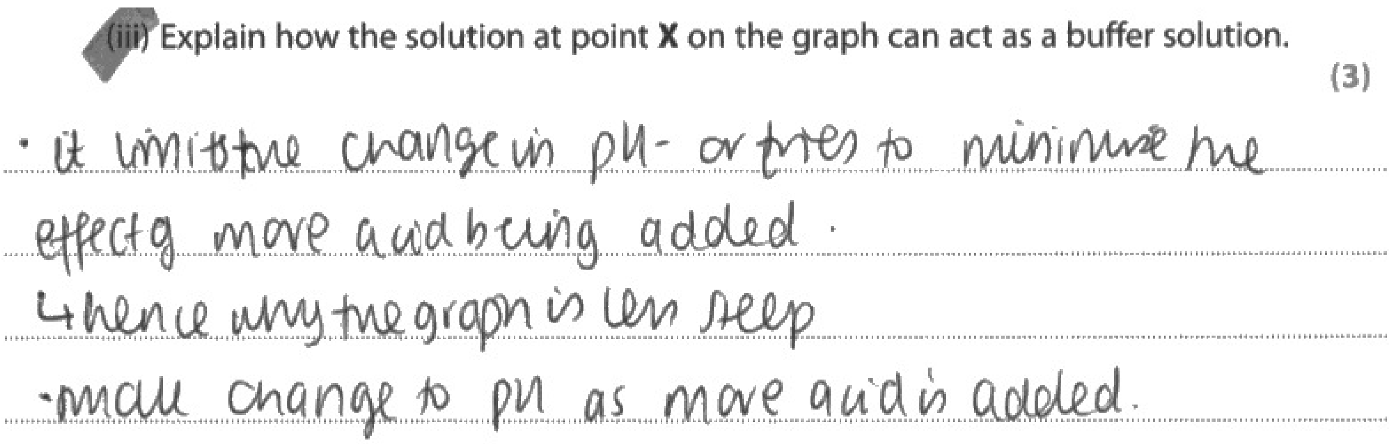
This response did not score as the candidate has reacted the sodium hydrogen carbonate with sodium chloride and so has been unable to produce a correct balanced equation.

ResultsPlus
Examiner Tip

If an equation cannot be balanced correctly then check again as there must be an error with the products and/or the reactants.

Question 6 (f)(iii)

This question proved challenging with candidates having difficulty explaining the actions of the specific buffer. There were many general answers referring to buffers as resisting changes to pH when small amounts of H^+ or OH^- ions were added which did not score any marks. The most commonly awarded mark was for the reaction with carbonate ions with H^+ ions. Candidates who mentioned the carbonate and the sodium hydrogen carbonate rarely mentioned that there was a large reservoir of these substances.



(iii) Explain how the solution at point **X** on the graph can act as a buffer solution.

(3)

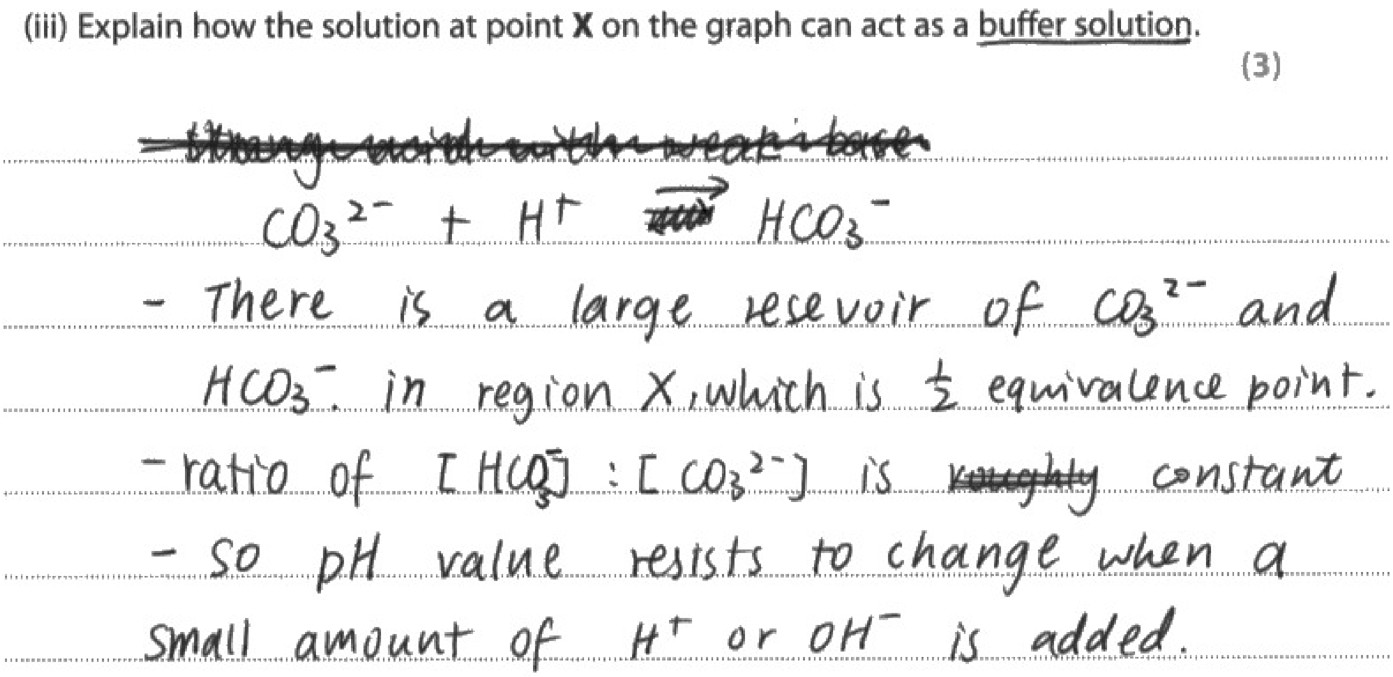
• it limits the change in pH - or tries to minimise the effect of more acid being added.

↳ hence why the graph is less steep

- small change to pH as more acid is added.

ResultsPlus
Examiner Comments

This response did not score. There was an attempt at explaining buffer action, but nothing creditworthy in terms of the buffer in the question.



(iii) Explain how the solution at point **X** on the graph can act as a buffer solution.

(3)

~~strong acid with the weak base~~

$CO_3^{2-} + H^+ \xrightarrow{} HCO_3^-$

- There is a large reservoir of CO_3^{2-} and HCO_3^-. in region X, which is ½ equivalence point.
- ratio of $[HCO_3^-] : [CO_3^{2-}]$ is ~~roughly~~ constant
- so pH value resists to change when a small amount of H^+ or OH^- is added.

ResultsPlus
Examiner Comments

This response scored two out of the three marks. They have mentioned a large reservoir of the carbonate and the hydrogen carbonate and also given the equation for the reaction of H^+ ions with carbonate ions. However, they have not given an explanation of how the buffer would work when OH^- ions were added.

Question 7 (a)

The question required candidates to explain in terms of ionisation energies why chromium can show variable oxidation numbers. Many answers that were not creditworthy were seen, including that all of the ionisation energies were low, or giving answers in terms of electron configuration.

7 This question is about chromium and some of its compounds.

(a) The common oxidation numbers of chromium are +2, +3 and +6.

Give a reason, in terms of ionisation energies, why chromium can show variable oxidation numbers.

(1)

It can lose variable number of electrons, because the 3d and 4s energy levels are very close together. This means there is not too big an ~~jum~~ increase in ionisation energies.

ResultsPlus
Examiner Comments

This response scored the mark for the comment that there is no big jump in the ionisation energies.

Give a reason, in terms of ionisation energies, why chromium can show variable oxidation numbers.

(1)

The second, third and sixth ionisation energies of chromium are low i.e. exothermic. Chromium's electronic configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$ ~~[illegible]~~ $3d^4$.

ResultsPlus
Examiner Comments

This answer did not score. There is no reference to ionisation energies as asked for in the question.

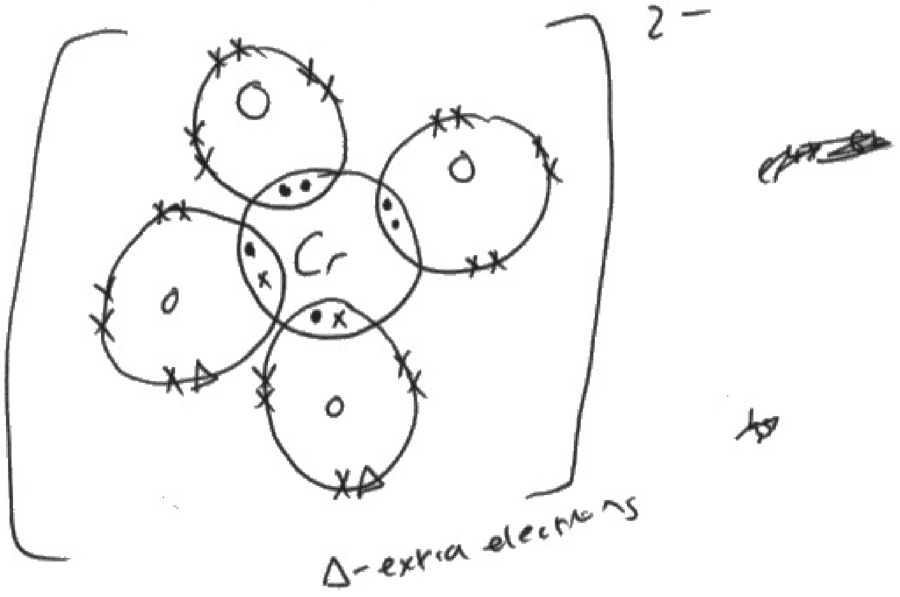
Question 7 (b)

The question required candidates to draw a dot-and-cross diagram to show the bonding in chromate (VI) ions. Many fully correct answers were seen, some with symbols to depict the origin of the electrons, although this was not required. Errors included missing electrons on the oxygens and additional electrons on the chromium.

(b) The bonding in chromate(VI) ions, CrO_4^{2-}, is similar to that in sulfate(VI) ions, SO_4^{2-}.

Draw a possible dot-and-cross diagram for a chromate(VI) ion.

(2)



ResultsPlus
Examiner Comments

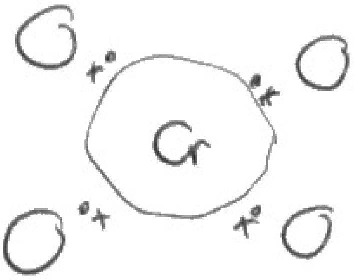
This answer scored both of the marks. The candidate has shown four single bonds between the chromium and oxygen and added the correct number of electrons to each oxygen atom. Although not required in the question, they have indicated the extra electrons in the ion.

(b) The bonding in chromate(VI) ions, CrO_4^{2-}, is similar to that in sulfate(VI) ions, SO_4^{2-}.

Draw a possible dot-and-cross diagram for a chromate(VI) ion.

(2)

Cr



ResultsPlus
Examiner Comments

This response scored one mark of the two available. Four electron pairs were shown around the central chromium. However the diagram was incomplete as the electrons around the oxygen atoms were not drawn.

Question 7 (c)(i-iii)

This question concerned the reaction of zinc with acidified potassium dichromate (VI). Many candidates derived the equation correctly, although some careless omission of charges occasionally resulted in loss of marks. The electrochemical cell potential was also well answered. The third part of the question scored the best when +0.35 had been calculated as those who tried to explain it in terms of more positive/less negative electrode potentials sometimes got them the wrong way round.

(c) A student added some pieces of zinc to an acidified solution of potassium dichromate(VI).

Some standard electrode potentials are given in the table.

Right-hand electrode system	$E^\ominus$ / V	
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76	(oxidation)
$2Cr^{3+}(aq) + 2e^- \rightleftharpoons 2Cr^{2+}(aq)$	−0.41	
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33	(reduction)

(i) Write the overall equation for the reduction of dichromate(VI) ions to chromium(III) ions by zinc in acid conditions.
State symbols are not required.

(2)

$3Zn^{2+} + 6e^- \rightleftharpoons 3Zn$.

$Cr_2O_7^{2-} + 14H^+ + 3Zn \longrightarrow 2Cr^{3+} + 7H_2O + 3Zn^{2+}$

(ii) Calculate $E^\ominus_{cell}$ for the reaction in (c)(i).

(1)

$E^\ominus_{cell} = 1 \cdot 33 + 0 \cdot 76 = +2 \cdot 09\ V$

(iii) Predict whether or not a further reduction of chromium(III) ions to chromium(II) ions will occur. Justify your answer.

(1)

$2Cr^{3+} + Zn \longrightarrow 2Cr^{2+} + Zn^{2+}$

$E^\ominus_{cell} = -0 \cdot 41 + 0 \cdot 76 = +0 \cdot 35\ V \longrightarrow$ feasible.

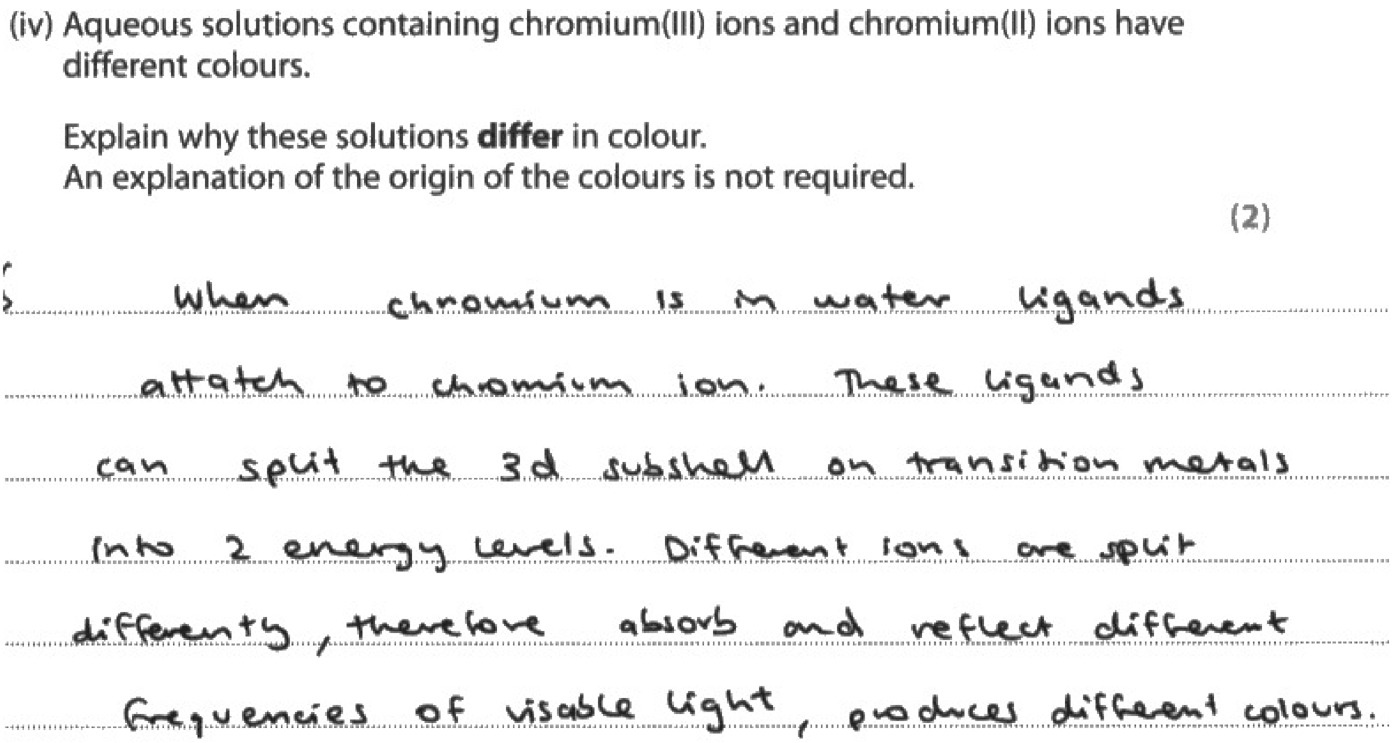
A further reduction reaction will occur because the $Cr^{2+}|Cr^{3+}$ electrode system has a less negative $E^\ominus$ relative to the $Zn|Zn^{2+}$ electrode system.

ResultsPlus
Examiner Comments

This is an example of a fully correct response where the candidate has derived the correct equation, calculated the correct value for the electrochemical cell emf and given a good explanation (including the correct value) for the reason why the further reduction reaction is feasible.

Question 7 (c)(iv)

This question proved challenging for many candidates although some good explanations for the differences in colour between the solutions were seen. The marks were awarded for an explanation of the reason for a different energy gap (the d-subshell being split differently by the ligand) and for the origin of the different colours (a different amount of energy is absorbed). Candidates were often unsure of what to include in the explanation and incorrect answers included references to 'the oxidation numbers/electron configurations are different'. A significant number of candidates mentioned splitting of a single d-orbital rather than the d-subshell. For the second part of the answer a significant number of the candidates referenced electrons being promoted up to a higher energy level and emitting light as they drop back to the ground state. This relates to the visualisation of colour in a flame test and not to transition metal ions in solution and so no marks were scored if this was given as an explanation.



(iv) Aqueous solutions containing chromium(III) ions and chromium(II) ions have different colours.

Explain why these solutions **differ** in colour.
An explanation of the origin of the colours is not required.

(2)

When chromium is in water ligands attatch to chromium ion. These ligands can split the 3d subshell on transition metals into 2 energy levels. Different ions are split differenty, therefore absorb and reflect different frequencies of visable light, produces different colours.

ResultsPlus
Examiner Comments

This is an example of fully correct response scoring both marks. The candidate has explained that the d subshell splits differently into two different energy levels and there is a clear explanation of the origin of the colours.

Question 7 (d)

This question required the candidates to use experimental results from a titration to calculate the percentage of iron in a nail and hence identify the brand of nail. Many candidates were able to follow through the required steps to obtain the correct answer.

(d) An iron nail was analysed using the following outline procedure.

- An iron nail was placed in a beaker and excess dilute sulfuric acid was added.
- After all the iron had reacted to form iron(II) ions, the solution was made up to 1.00 dm^3 in a volumetric flask.
- 25.0 cm^3 portions of the solution were acidified and titrated with potassium dichromate(VI) solution of concentration 0.0167 mol dm^{-3}.

Results

mass of iron nail = 3.54 g

mean titre = 15.50 cm^3

The table shows the percentage by mass of iron in four different brands of nail.

Brand of nail	Percentage by mass of iron
A	92
B	94
C	96
D	98

Potassium dichromate(VI) in acid solution oxidises iron(II) ions as shown in the equation

$$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$$

Determine, using the experimental data, the brand of nail that was analysed.

(5)

mol $K_2Cr_2O_7 = 0.0167 \times \frac{15.5}{1000} = 2.589 \times 10^{-4}$

mol $Fe^{2+} = 2.589 \times 10^{-4} \times 6 = 1.553 \times 10^{-3}$

mol Fe^{2+} $(1dm^3) = \frac{1.553 \times 10^{-3}}{25} \times 1000 = 0.0621$ mol

mass = mol × mr

$= 0.062124 \times 55.8$

$= 3.4665192$

% Fe = $\frac{3.4665}{} \times 100 = 97.9\%$ ∴ Brand D

ResultsPlus
Examiner Comments

This is an example of a completely correct response.

The candidate has laid out their work so that the steps in their calculation can be clearly identified.

Potassium dichromate(VI) in acid solution oxidises iron(II) ions as shown in the equation

volumetric = 250cm^3
25cm^3

$$Cr_2O_7^{2-} + \underbrace{14H^+ + 6Fe^{2+}} \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$$

Determine, using the experimental data, the brand of nail that was analysed.

(5)

$Cr_2O_7^{-2}$ mean titre = 0.0155 dm^3

0.0167 mol dm^{-3}

mol = 2.5885×10^{-4} mol

ratio $Cr_2O_7^{-2}$: Fe^{2+}

1 : 6

Fe^{2+} mol = 1.5531×10^{-3} mol in 25 cm^3

$\times 10$ = 0.015531 mol in 250cm^3

mr (Fe) = 55.8

mass (Fe) = 55.8 × 0.015531 = 0.8666g

$$\frac{0.8666}{3.54} \times 100 = 24.48\%$$

ResultsPlus
Examiner Comments

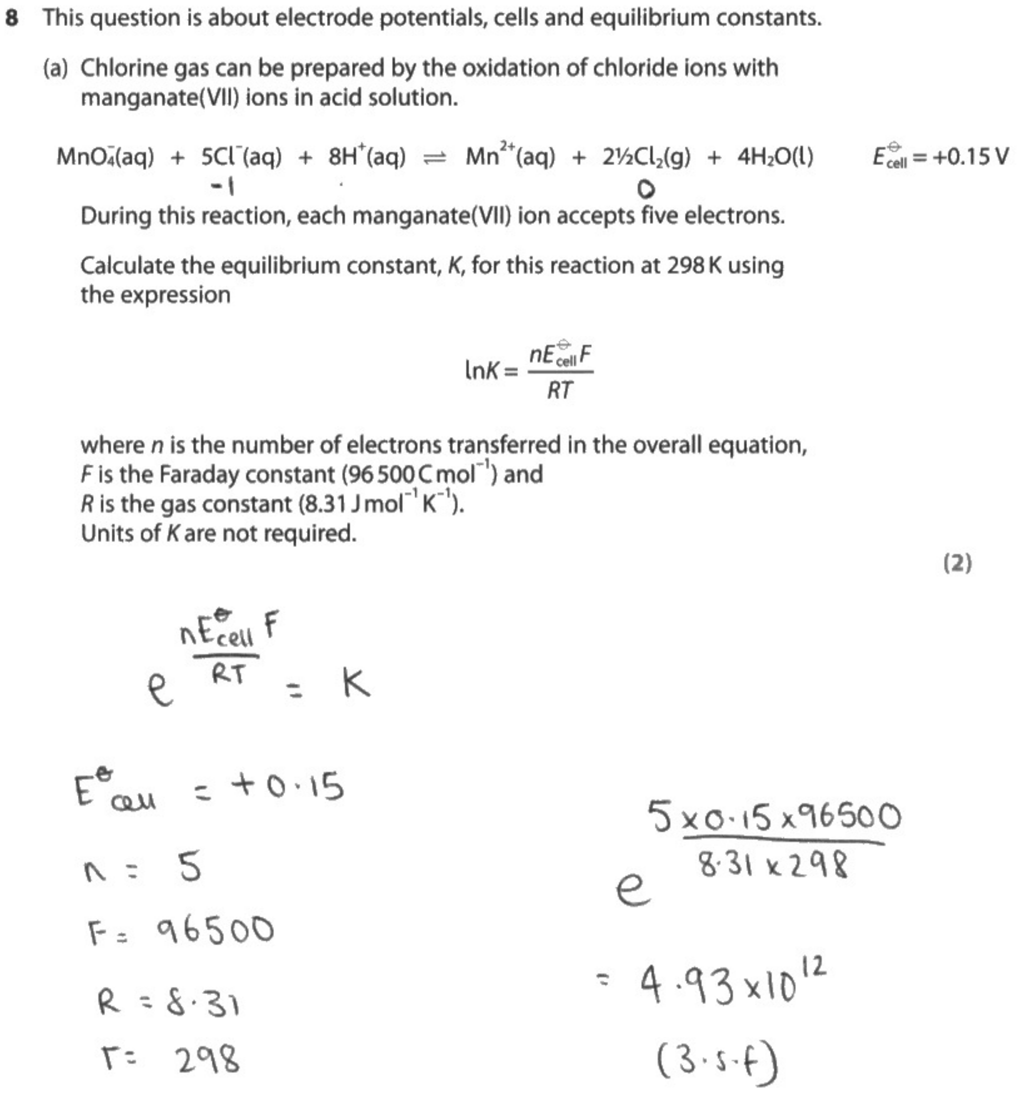
This candidate carried out all of the required steps. However they calculated the concentration of the Fe2+ incorrectly, using a volume of 250cm3 instead of 1.00dm3 and so their final answer was incorrect and did not match any of the nail brands.

ResultsPlus
Examiner Tip

If your final answer does not match any of the possibilities given then go back and check your calculations again.

Question 8 (a)

The question required candidates to substitute values into an equation to calculate the equilibrium constant '*K*' for a redox reaction. Many candidates read the question properly and were able to gain full marks. A few substituted the incorrect value of the number of electrons transferred (the number '5' was in the question), and some used the logarithm to base 10 instead of the natural logarithm to calculate their final answer. It was possible to score the second mark as a TE on the wrong equation and a number of candidates were awarded one mark by this means.



8 This question is about electrode potentials, cells and equilibrium constants.

(a) Chlorine gas can be prepared by the oxidation of chloride ions with manganate(VII) ions in acid solution.

$$MnO_4^-(aq) + 5Cl^-(aq) + 8H^+(aq) \rightleftharpoons Mn^{2+}(aq) + 2\tfrac{1}{2}Cl_2(g) + 4H_2O(l) \qquad E^\ominus_{cell} = +0.15\,V$$

−1 0

During this reaction, each manganate(VII) ion accepts five electrons.

Calculate the equilibrium constant, *K*, for this reaction at 298 K using the expression

$$\ln K = \frac{nE^\ominus_{cell}F}{RT}$$

where *n* is the number of electrons transferred in the overall equation,
F is the Faraday constant (96 500 C mol^{-1}) and
R is the gas constant (8.31 J mol^{-1} K^{-1}).
Units of *K* are not required.

(2)

$$e^{\frac{nE^\ominus_{cell}F}{RT}} = K$$

$E^\ominus_{cell} = +0.15$

$n = 5$

$F = 96500$

$R = 8.31$

$T = 298$

$$e^{\frac{5\times0.15\times96500}{8.31\times298}}$$

$= 4.93\times10^{12}$

(3.s.f)

ResultsPlus
Examiner Comments

This is an example of a fully correct response to the question with the correct final answer and scored both marks.

$2Cl^- + 2e^- \rightarrow Cl_2$

$5Cl^- + 5e^- \rightarrow 2.5Cl_2$

8 This question is about electrode potentials, cells and equilibrium constants.

(a) Chlorine gas can be prepared by the oxidation of chloride ions with manganate(VII) ions in acid solution.

$MnO_4^-(aq) + 5Cl^-(aq) + 8H^+(aq) \rightleftharpoons Mn^{2+}(aq) + 2\tfrac{1}{2}Cl_2(g) + 4H_2O(l) \qquad E^\ominus_{cell} = +0.15\,V$

acc $5e^-$ donates $5e^-$

During this reading, each manganate(VII) ion accepts five electrons. $MnO_4^- + 5e^-$

Calculate the equilibrium constant, K, for this reaction at 298 K using the expression

$$\ln K = \frac{nE^\ominus_{cell}F}{RT}$$

where n is the number of electrons transferred in the overall equation,
F is the Faraday constant ($96\,500\,C\,mol^{-1}$) and
R is the gas constant ($8.31\,J\,mol^{-1}\,K^{-1}$).
Units of K are not required.

(2)

$$\ln K = \frac{n \times 0.15 \times 96500}{8.31 \times 298}$$

✗

$n = 5$

$$\ln K = \frac{5 \times 0.15 \times 96500}{8.31 \times 298}$$

$\ln K = 29.226$

$K = e^{29.226}$

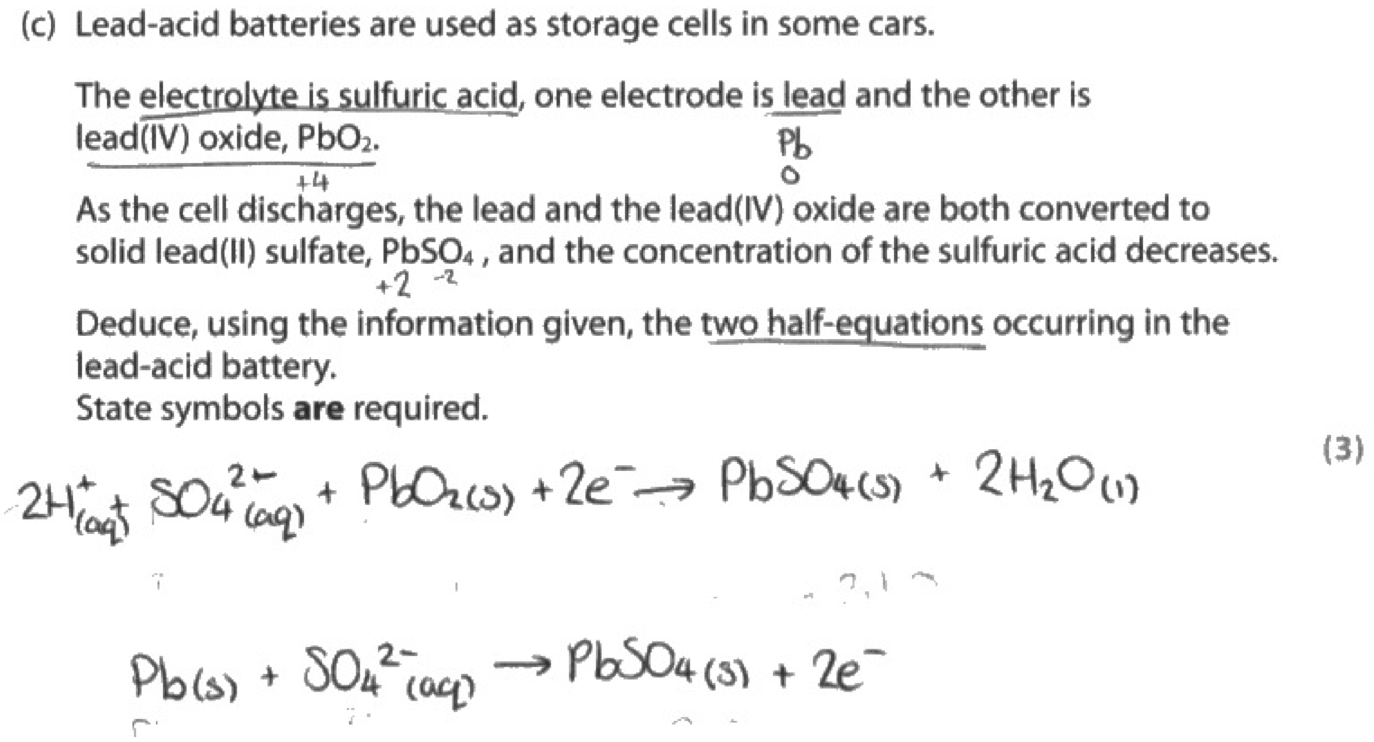
$K = 4.93$ (3sf)

ResultsPlus
Examiner Comments

This response scored one of the two marks available. The candidate has carried all of the steps out correctly, but omitted the x10^{12} in their final answer. Careful checking of their calculator would have been beneficial here.

Question 8 (c)

The greater demand of the paper toward the end was evident in this question as many candidates struggled to work out the equations correctly. The information in the question stem clearly stated the substances involved and where necessary their states, but these were often missed by candidates. It was also not uncommon to see the equations written without electrons, despite the requirement for half-equations given in the question.



(c) Lead-acid batteries are used as storage cells in some cars.

The electrolyte is sulfuric acid, one electrode is lead and the other is lead(IV) oxide, PbO_2.

Pb
0

+4

As the cell discharges, the lead and the lead(IV) oxide are both converted to solid lead(II) sulfate, $PbSO_4$, and the concentration of the sulfuric acid decreases.

+2 -2

Deduce, using the information given, the two half-equations occurring in the lead-acid battery.
State symbols **are** required.

(3)

$2H^+_{(aq)} + SO_4{}^{2-}{}_{(aq)} + PbO_{2(s)} + 2e^- \rightarrow PbSO_{4(s)} + 2H_2O_{(l)}$

$Pb_{(s)} + SO_4{}^{2-}{}_{(aq)} \rightarrow PbSO_{4(s)} + 2e^-$

ResultsPlus
Examiner Comments

This response scored two of the three marks. The state symbols in the first equation given are correct but the equation is not balanced for hydrogens and should have 4H+ on the left hand side instead of 2. Equations could be given in either order and single headed arrows in the forward direction were allowed.

ResultsPlus
Examiner Tip

Check equations are balanced before you move on to the next question.

(c) Lead-acid batteries are used as storage cells in some cars.

The electrolyte is sulfuric acid, one electrode is lead and the other is lead(IV) oxide, PbO_2.

As the cell discharges, the lead and the lead(IV) oxide are both converted to solid lead(II) sulfate, $PbSO_4$, and the concentration of the sulfuric acid decreases.

Deduce, using the information given, the two half-equations occurring in the lead-acid battery.
State symbols **are** required.

(3)

$$Pb_{(s)} + SO_4{}^{2-}{}_{(aq)} \rightarrow PbSO_{4(s)} + 2e^-$$

$$4H^+{}_{(aq)} + PbO_{2(s)} + SO_4{}^{2-}{}_{(aq)} + 2e^- \rightarrow PbSO_{4(s)} + 2H_2O_{(l)}$$

ResultsPlus
Examiner Comments

This response is fully correct and so scored all three marks. The equations were all balanced and the state symbols correct.

Question 8 (d)

This question was the last on the paper and was a relatively complex multi-step calculation. Candidates who were able to devise a logical progression through the calculation scored highly. Common errors included confusion over which moles should be subtracted and which volume should be used to determine the concentrations. The *Kc* expression was given in the question and so many correct units were seen, although some candidates derived their own expression and so did not score the units mark.

(d) When solid lead(II) sulfate is added to aqueous sodium iodide, an equilibrium is established.

$$PbSO_4(s) + 2I^-(aq) \rightleftharpoons PbI_2(s) + SO_4^{2-}(aq)$$

The expression for the equilibrium constant, K_c, for this reaction is

$$K_c = \frac{[SO_4^{2-}(aq)]}{[I^-(aq)]^2}$$

In an experiment, K_c may be determined by adding excess lead(II) sulfate to 25.0 cm^3 of 0.100 mol dm^{-3} sodium iodide.
The volume remains constant at 25.0 cm^3.
The mixture is left to reach equilibrium at room temperature.

Ice-cold water is added to freeze the position of equilibrium and the mixture is then titrated with standard silver nitrate solution.

The whole mixture requires 12.20 cm^3 of 0.0500 mol dm^{-3} silver nitrate solution to react with the aqueous iodide ions at equilibrium.

$$Ag^+(aq) + I^-(aq) \rightarrow AgI(s)$$

Calculate the equilibrium concentrations of the sulfate ions and the iodide ions, and hence the value of K_c at room temperature.
Give your answer to an appropriate number of significant figures and include units for K_c, if any.

↳ 3

(7)

$n\,Ag^+ = 0.05 \times 0.0122$
$= 6.1 \times 10^{-4}$

$n\,I^- = 6.1 \times 10^{-4}$

initial I_2

$0.025 \times 0.1 = 2.5 \times 10^{-3}$

	$PbSO_4$ +	$2I^-_{(aq)} \rightarrow$	PbI_2 +	$SO_4^{2-}{(aq)}$
Initial n		2.5×10^{-3}		0
change		-1.89×10^{-3}		$+9.45\times10^{-4}$
Final n		6.1×10^{-4}		9.45×10^{-4}
		$\div 0.025$		$\div 0.025$
conc		0.0244		0.0378

$$Kc = \frac{[0.0378]}{[0.0244]^2} = 63.5\ mol^{-1}\,dm^3$$

$$Kc = \frac{mol\ \cancel{dm^{-3}}}{mol\ \cancel{dm^{-3}} \times mol\,dm^{-3}}$$

ResultsPlus
Examiner Comments

This candidate has followed a logical pathway throughout and has scored all seven marks. Their final answer is given to three significant figures and the units are correct.

ResultsPlus
Examiner Tip

Set out your work in multi-step calculations so that you keep track of where you are.

Calculate the equilibrium concentrations of the sulfate ions and the iodide ions, and hence the value of K_c at room temperature.
Give your answer to an appropriate number of significant figures and include units for K_c, if any.

(7)

$$n(Ag^+) = \frac{12.2}{1000}\,dm^3 \times 0.05\,mol\,dm^{-3}$$

$$n(Ag^+) = 6.1 \times 10^{-4}\,mol$$

$$n(Ag^+) = n(I^-) \qquad \underset{\substack{\downarrow \\ \text{at equilibrium}}}{n(I^-)} = 6.1 \times 10^{-4}\,mol$$

$$\underset{\text{reacted}}{n(I^-)} = \underset{\text{initial}}{n(I^-)} - \underset{\text{equilibrium}}{n(I^-)} = \frac{25}{1000}\,dm^3 \times 0.1\,mol\,dm^{-3} - 6.1 \times 10^{-4}\,mol$$

$$= 2.5 \times 10^{-3} - 6.1 \times 10^{-4}$$

$$= 1.89 \times 10^{-3}$$

$$\underset{\text{reacted}}{n(I^-)} : n(SO_4^{2-}) = 2 : 1$$

$$n(SO_4^{2-}) = \frac{1.89 \times 10^{-3}}{2} = 9.45 \times 10^{-4}\,mol$$

At equilibrium:

$$[I^-] = \frac{6.1 \times 10^{-4}\,mol}{\frac{25}{1000}\,dm^3} = \cancel{0.0244\,mol\,dm^{-3}}\ 0.0244\,mol\,dm^{-3}$$

$$[SO_4^{2-}] = \frac{9.45 \times 10^{-4}\,mol}{\frac{25}{1000}\,dm^3} = 0.0378\,mol\,dm^{-3}$$

$$K_c = \frac{0.0378}{0.0244} = 1.55 \text{ no units}$$

ResultsPlus
Examiner Comments

This response scored five out of the seven marks. The candidate has followed all of the steps through to the end, but has not used the Kc expression given in the question and so has not scored either M6 for the value of *Kc* or M7 for the correct units.

ResultsPlus
Examiner Tip

Read the question very carefully and make sure you use all of the information.

Paper Summary

Based on the performance of this paper candidates should:

- Read the question thoroughly and use all of the available information given
- Set out multi-step calculations clearly indicating the steps they have taken
- Check all calculations, especially for correct rounding and exponentials
- Ensure that ionic equations are fully balanced and that state symbols, when required, are correct
- Be familiar with the colours of the transition metal ions in the specification
- Be able to explain how specific buffer solutions work
- Ensure they know when to use natural logarithms and when to use $\log_{10}$.

Grade boundaries

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