Example Candidate Responses

Cambridge International AS & A Level

Cambridge International AS & A Level Chemistry

9701

Paper 2 – AS Level Structured Questions

Cambridge Advanced

CAMBRIDGE International Examinations

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Contents

Introduction

The main aim of this booklet is to exemplify standards for those teaching Cambridge International AS and A Level Chemistry (9701), and to show how different levels of candidates' performance (high, middle and low) relate to the subject's curriculum and assessment objectives.

In this booklet candidate responses have been chosen to exemplify a range of answers. Each response is accompanied by a brief commentary explaining the strengths and weaknesses of the answers.

For each question, each response is annotated with a clear explanation of where and why marks were awarded or omitted. This, in turn, is followed by examiner comments on how the answer could have been improved. In this way it is possible for you to understand what candidates have done to gain their marks and what they will have to do to improve their answers. At the end there is a list of common mistakes candidates made in their answers for each question.

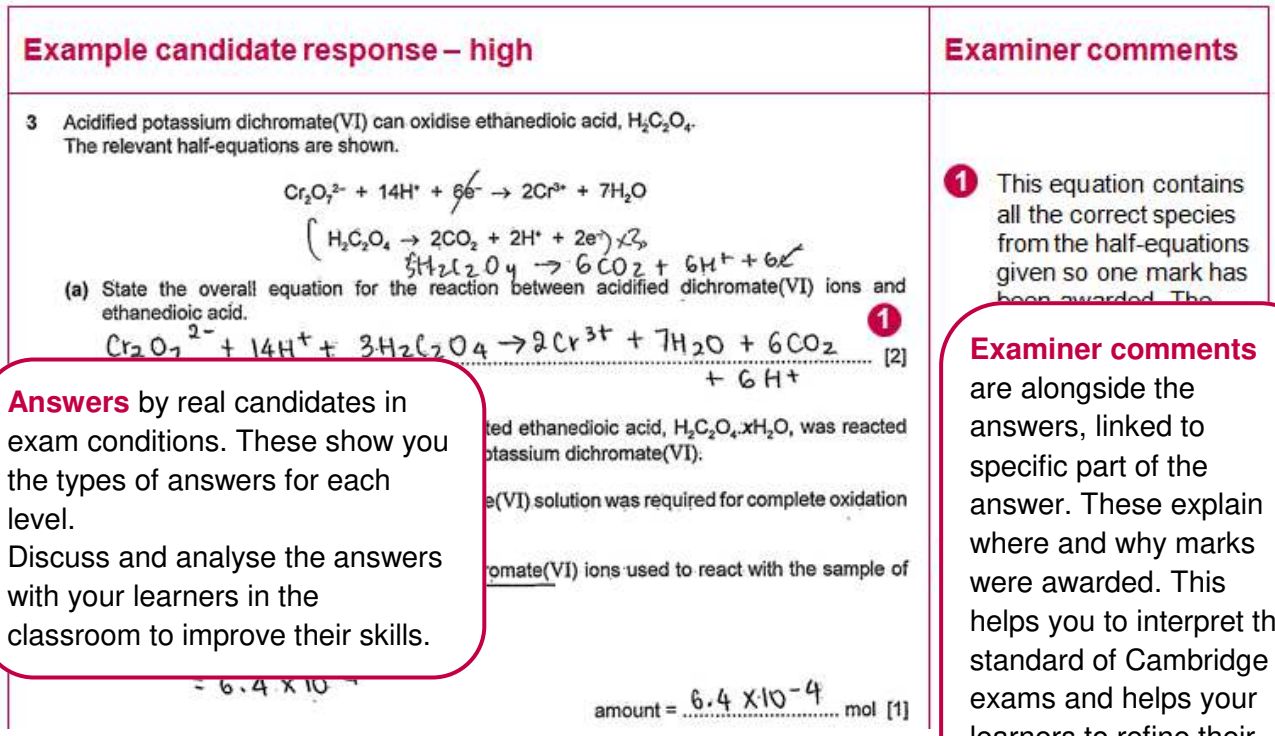
This document provides illustrative examples of candidate work. These help teachers to assess the standard required to achieve marks, beyond the guidance of the mark scheme. Some question types where the answer is clear from the mark scheme, such as short answers and multiple choice, have therefore been omitted.

The questions, mark schemes and pre-release material used here are available to download as a zip file from Teacher Support as the Example Candidate Responses Files. These files are:

Question Paper 22, June 2016	
Question paper	9701_s16_qp_22.pdf
Mark scheme	9701_s16_ms_22.pdf
Question Paper 33, June 2016	
Question paper	9701_s16_qp_33.pdf
Mark scheme	9701_s16_ms_33.pdf
Question Paper 42, June 2016	
Question paper	9701_s16_qp_42.pdf
Mark scheme	9701_s16_ms_42.pdf
Question Paper 52, June 2016	
Question paper	9701_s16_qp_52.pdf
Mark scheme	9701_s16_ms_52.pdf

Past papers, Examiner Reports and other teacher support materials are available on Teacher Support at **https://teachers.cie.org.uk**

How to use this booklet



Example candidate response – high

3 Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

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

$(H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-) \times 3$

$3H_2C_2O_4 \rightarrow 6CO_2 + 6H^+ + 6e^-$

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

$Cr_2O_7^{2-} + 14H^+ + 3H_2C_2O_4 \rightarrow 2Cr^{3+} + 7H_2O + 6CO_2 + 6H^+$ [2]

ted ethanedioic acid, $H_2C_2O_4.xH_2O$, was reacted
otassium dichromate(VI).

e(VI) solution was required for complete oxidation

romate(VI) ions used to react with the sample of

$= 6.4 \times 10^{-4}$

amount = 6.4×10^{-4} mol [1]

Examiner comments

1 This equation contains all the correct species from the half-equations given so one mark has

Answers by real candidates in exam conditions. These show you the types of answers for each level.
Discuss and analyse the answers with your learners in the classroom to improve their skills.

Examiner comments are alongside the answers, linked to specific part of the answer. These explain where and why marks were awarded. This helps you to interpret the standard of Cambridge exams and helps your learners to refine their exam technique.

How the candidate could have improved their answer

In **(a)** the candidate needed to remember that the key
loss in one half-equation must balance the electron ga

In **(b)(iii)** the candidate used the correct method but n
number of significant figures in the answer must corre
provided.

This explains how the candidate could have improved their answer and helps you to interpret the standard of Cambridge exams and helps your learners to refine exam technique.

Common mistakes candidates made in this question

(a) The skills needed to combine two half-equations and
tricky for many candidates. Good candidates often got c
them out, while weaker candidates failed to recognise th

(b) The first two parts of the calculation were generally c
the *M*r calculation depended on the previous answer tog

This lists the common mistakes candidates made in answering each question. This will help your learners to avoid these mistakes at the exam and give them the best chance of achieving a high mark.

Assessment at a glance

Candidates for Advanced Subsidiary (AS) certification take Papers 1, 2 and 3 (either Advanced Practical Skills 1 or Advanced Practical Skills 2) in a single examination series.

Candidates who, having received AS certification, wish to continue their studies to the full Advanced Level qualification may carry their AS marks forward and take Papers 4 and 5 in the examination series in which they require certification.

Candidates taking the full Advanced Level qualification at the end of the course take all five papers in a single examination series.

Candidates may only enter for the papers in the combinations indicated above.

Candidates may not enter for single papers either on the first occasion or for resit purposes.

All components are externally assessed.

Component	Weighting	
	AS Level	A Level
Paper 1 Multiple Choice **1 hour** This paper consists of 40 multiple choice questions, 30 of the direct choice type and 10 of the multiple completion type, all with four options. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on an answer sheet. [40 marks]	31%	15.5%
Paper 2 AS Level Structured Questions **1 hour 15 minutes** This paper consists of a variable number of questions of variable mark value. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on the question paper. [60 marks]	46%	23%
Paper 3 Advanced Practical Skills **2 hours** This paper requires candidates to carry out practical work in timed conditions. Candidates will be expected to collect, record and analyse data so that they can answer questions related to the activity. The paper will consist of two or three experiments drawn from different areas of chemistry. Candidates will answer all questions. Candidates will answer on the question paper. [40 marks]	23%	11.5%
Paper 4 A Level Structured Questions **2 hours** This paper consists of a variable number of free response style questions of variable mark value. All questions will be based on the A Level syllabus but may require knowledge of material first encountered in the AS Level syllabus. Candidates will answer all questions. Candidates will answer on the question paper. [100 marks]	–	38.5%
Paper 5 Planning, Analysis and Evaluation **1 hour 15 minutes** This paper consists of a variable number of questions of variable mark value based on the practical skills of planning, analysis and evaluation. The context of the questions may be outside the syllabus content, but candidates will be assessed on their practical skills of planning, analysis and evaluation rather than their knowledge of theory. Candidates will answer all questions. Candidates will answer on the question paper. [30 marks]	–	11.5%

Teachers are reminded that the latest syllabus is available on our public website at **www.cie.org.uk** and Teacher Support at **https://teachers.cie.org.uk**

Paper 2 – AS Level Structured Questions

Question 1

Example candidate response – high

1 (a) Complete the table to show the composition and identity of some atoms and ions. 1

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
boron	10	5	5	5	5	0
nitrogen	15	7	7	8	10	-3
lead	208	82	82	126	80	+2
lithium	6	3	3	3	2	+1

[4]

(b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	7012	8496	27107	31671
Y	6542	9362	11018	33606
Z	7238	8781	11996	13842

(i) State and explain the group number of element **Y**.

group number 7

2 explanation There is a large difference between the seventh and eighth ionization energy as compared to others. [1]

(ii) State and explain the general trend in **first** ionisation energies across the third period.

3 Ionization energy increases along the period because the nuclear charge increases whereas the shielding effect remains same. So, attraction between nucleus and outer electrons increases. [2]

(iii) Complete the electronic configuration of element **X**.

1s^2 2s^2, 2p^6, 3s^2, 3p^6 [1]

4

Examiner comments

1 All correct.

Mark for (a) = 4/4

2 This is correct.

Mark for (b) (i) = 1/1

3 Both parts of this answer are clearly and correctly explained.

Mark for (b) (ii) = 2/2

4 It appears that the candidate has correctly identified X as being in Group 6 and therefore decided that it will have six electrons in the outer shell, but has then mistakenly shown six electrons in the outer subshell instead of showing a total of six in shell three as 3s^2 3p^4.

Mark for (b) (iii) = 0 /1

Example candidate response – high, continued	Examiner comments
(c) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table. mass number: 16, 17 abundance: 99.76%, 0.04% 0.2. (i) Calculate the abundance of the third isotope. 100 − (99.76 + 0.04) = 0.2 % 5 abundance = ...0.2.... % [1] (ii) The relative atomic mass of this sample of oxygen is 16.0044. Calculate the mass number of the third isotope. You **must** show your working. $\frac{(16 \times 99.76) + (17 \times 0.04) + (0.2x)}{100} = 16.0044$ 6 1596.84 + 0.2x = 1600.44 0.2x = 3.6 $x = \frac{3.6}{0.2} = 18$ mass number = ...18.... [2] [Total: 11]	5 This is correct. Mark for (c) (i) = 1/1 6 This clear indication of the first stage in the calculation means that one mark would have been awarded even if there had been a calculator error leading to an incorrect answer later. Mark for (c) (ii) = 2/2 **Total marks awarded = 10 out of 11**

How the candidate could have improved their answer

Apart from the factual mistake in **(b) (iii),** there was very little that could have been improved upon here. The explanations were clear and the working was shown clearly in the calculations.

(b) (ii) This could have been expressed more succinctly by simply saying 'it increases because . . .' in the first sentence, as the rest is already in the question.

Mark awarded = **(a) 4/4**
Mark awarded = **(b) (i) 1/1, (ii) 2/2, (iii) 0 /1**
Mark awarded = **(c) (i) 1/1, (ii) 2/2**

Total marks awarded = 10 out of 11

Example candidate response – middle

1 (a) Complete the table to show the composition and identity of some atoms and ions.

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
boron	10	5	5	5	5	0
nitrogen	14 ①	7	7	8	10	-3
lead	208	82	82	126	80	+2
lithium	6	3	3	3	2	+1

[4]

(b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	7012	8496	27107	31671
Y	6542	9362	11018	33606
Z	7238	8781	11996	13842

(i) State and explain the group number of element **Y**.

group number 3 VII

explanation The fifth, sixth, seventh ionisation energies increase steady but the eigth has big energy gap. ②

[1]

(ii) State and explain the general trend in **first** ionisation energies across the third period.

There is a general increase in ionisation energies. This is ③ because nuclear charge increases, number of protons increase ④ so force of attraction increases making it hard to remove electron. [2]

(iii) Complete the electronic configuration of element **X**.

1s^2 2s^2 2p^4 ⑤ [1]

Examiner comments

① The candidate has possibly got confused between the idea of the relative atomic mass given on the Periodic Table and the nucleon number, which is simply the total number of protons and neutrons. This should be 15.

Mark for (a) = 3/4

② This is correct.

Mark for (b) (i) = 1/1

③ As well as stating that the nuclear charge increases, the candidate also needs to state that the shielding remains approximately the same (across the period) or that the electrons are being added to the same shell.

④ Although not explicitly stated, it is clear from the general context that the candidate is referring to the attraction between the nucleus and the outer electron so this mark is awarded.

Mark for (b) (ii) = 1/2

⑤ The candidate has the correct number of outer shell electrons but has overlooked the statement in the question that X is in the third period, so the outer electrons will be in shell three.

Mark for (b) (iii) = 0 /1

Example candidate response – middle, continued

(c) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table.

mass number	16	17
abundance	99.76%	0.04%

(i) Calculate the abundance of the third isotope.

$100 - (99.76 + 0.04)$

abundance = 0.28 6 % [1]

(ii) The relative atomic mass of this sample of oxygen is 16.0044.

Calculate the mass number of the third isotope. You **must** show your working.

$\frac{(16 \times 99.76) + (17 \times 0.04) + (0.28x)}{100} = 16.0044$ 7

$\frac{(16 \times 99.76) + (17 \times 0.04) + (0.28x)}{100} = 16.0044$

$1596.84 + 0.28x = 1600.44$

$0.28x = 3.6$

$x = 12.86$

mass number = 12.86 8 g [2]

[Total: 11]

Examiner comments

6 Although the working has been shown correctly, no marks have been awarded as it is only a one mark question and the candidate has made a calculator error. It appears as though the sum has been entered as '100 – 99.76 + 0.04' without the brackets that are shown in the working, and this has changed the outcome. A careful check of the sense of a calculation should allow this sort of error to be spotted, as 99.76 + 0.04 is clearly 99.8.

Mark for (c) (i) = 0/1

7 The inclusion of 0.28 in this calculation is clearly incorrect, but it has been allowed as an 'error carried forward' from the previous answer because the information has been used correctly at this stage. Both marks for this calculation could potentially have been awarded.

8 As the question asks for a mass number, the answer must be an integer, so although the first mark has been awarded (which was possible as the working is clearly shown) the second mark would only have been awarded if the answer had been rounded to 13.

Mark for (c) (ii) = 1/2

Total marks awarded = 6 out of 11

How the candidate could have improved their answer

The explanation in **(b) (ii)** needed more detail to ensure that the shielding effect was referred to as well as the nuclear charge. The candidate could also have made it clearer that the attraction being referred to was between the nucleus and the outer electron, although the context was sufficient for the mark to be awarded on this occasion.

The use of a highlighter pen or underlining to draw attention to key pieces of information in the stem of a question is recommended; this might have helped the candidate to spot that X is in the third period and so avoid the error in **(b) (iii)**.

Mark awarded = **(a) 3/4**
Mark awarded = **(b) (i) 1/1, (ii) 1/2, (iii) 0 /1**
Mark awarded = **(c) (i) 0/1, (ii) 1/2**

Total marks awarded = 6 out of 11

Example candidate response – low

1 (a) Complete the table to show the composition and identity of some atoms and ions.

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
boron	10	5	5	5	5	0
nitrogen	14	7	7	8	10	-3
lead	208	82	82	126	80	+2
lithium	7 ❶	3	3	3	2	+1

[4]

(b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	7012	8496	27107	31671
Y	6542	9362	11018	33606
Z	7238	8781	11996	13842

(i) State and explain the group number of element Y.

group number 6th or sixth ❷

explanation There is huge change in ionisation energy which tell us that there are six valence electron.

[1]

Examiner comments

❶ With both nitrogen and lithium it appears that the candidate has got confused about the difference between the idea of relative atomic mass (as quoted on the Periodic Table) and nucleon number (which is specific to a particular isotope of an element and equals the total number of protons and neutrons in the nucleus). These totals should therefore be 15 for this isotope of N and 6 for the isotope of Li. The candidate seems to have used rounded-off values from the Periodic Table instead.

Mark for (a) = 2/4

❷ The most likely explanation for this error is that the candidate has misread the question and/or the table of data and is giving the group number and explanation for X instead of for Y.

Mark for (b) (i) = 0/1

Example candidate response – low, continued	Examiner comments
(ii) State and explain the general trend in **first** ionisation energies across the third period. Across the third period the ionisation energy increases because of same atomic radius ③ and the nuclear charges increase ④ due to more number of proton [2] (iii) Complete the electronic configuration of element **X**. $1s^2$ $2s^2\ 2p^6\ 3s^1\ 3p^6\ 4d^5\ 4s^1$ ⑤ [1]	③ Although not needed to answer this question, this reference to atomic radius is incorrect as atomic radius decreases across a period. ④ Ionisation energy is a measure of the strength of attraction between the nucleus and the outer electron so this should have been mentioned here. Next, the explanation needed to mention both the increasing nuclear charge and the fact that the electrons are being added to the same shell across the period. Mark for (b) (ii) = 0/2 ⑤ The reasoning behind this incorrect answer is not clear and suggests a lack of familiarity with the rules for the sequence in which shells and subshells are filled. Mark for (b) (iii) = 0 /1

Example candidate response – low, continued	Examiner comments

(c) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table.

mass number	16	17
abundance	99.76%	0.04%

(i) Calculate the abundance of the third isotope.

Total = 100 %

So, = 100 − 99.76 − 0.04

= 0.20

abundance = 0.20 % [1]

6

(ii) The relative atomic mass of this sample of oxygen is 16.0044.

Calculate the mass number of the third isotope. You **must** show your working.

$16.0044 = \frac{16 \times 99.76 + 0.04 \times 17 + 0.20 \times n}{100}$

$1600.44 = 1596.84 + 0.20n$

$3.6 = 0.2n$

$\frac{3.6}{0.2} = n$

mass number = 18.0 [2]

7

[Total: 11]

6 This is correct.

Mark for (c) (i) = 1/1

7 Everything is correct here, except that the final answer includes a decimal point, which means the candidate has not shown their appreciation that a mass number must be an integer, as it refers to the total number of protons and neutrons in the nucleus. However, because the working has been shown clearly one mark can be awarded.

Mark for (c) (ii) = 1/2

Total marks awarded = 4 out of 11

How the candidate could have improved their answer

The nature of the errors in this candidate's responses suggests that the problem lay mainly in the level of attention to detail in learning. Things such as the distinction between nucleon/mass number and relative atomic mass and the rules for working out electronic configurations will only become secure with thorough rote learning.

The use of a highlighter pen or underlining when reading a question is recommended so that key pieces of information – such as the period number in part **(b)** – do not get overlooked.

Mark awarded = **(a) 2/4**
Mark awarded = **(b) (i) 0/1, (ii) 0/2, (iii) 0 /1**
Mark awarded = **(c) (i) 1/1, (ii) 1/2**

Total marks awarded = 4 out of 11

Common mistakes candidates made in this question

In **(a)**, confusion between nucleon number and relative atomic mass was common.

In **(b)**, errors most often came in part **(i)** either as a result of misreading the question or because of a lack of clarity in the explanation. For example, the phrase 'a large increase in the 7th and 8th ionisation energies' could not be credited as it implied that both the values show a large increase; the key word needed here is 'between'. A significant number of candidates did not earn any marks in part **(iii)** and this was most commonly due to overlooking the fact that X is in the third period so the outer electrons will be in the third shell.

In **(c)**, mistakes were usually due to mathematical slips and calculator errors.

Question 2

Example candidate response – high

2 The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol^{-1}	standard enthalpy change of atomisation, $\Delta H^{\ominus}_{at}$ /kJ mol^{-1}	boiling point of element /K	boiling point of **hydrogen halide** /K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

(a) (i) Explain the meaning of the term *standard enthalpy change of atomisation*.

The enthalpy change when one mole of gaseous atoms is formed from its elements under standard conditions. The element should be in its standard state. [3]

(ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

Fluorine and chlorine are in gaseous form at room temperature. Bromine and iodine is a liquid and a solid ~~gas~~ respectively. Energy is needed to change their states. [1]

(iii) The standard enthalpy of formation of iodine monochloride, ICl, is –24.0 kJ mol^{-1}.

Use this information and the bond energies of iodine and chlorine to calculate the I–Cl bond energy.

$\frac{1}{2}I_2 + \frac{1}{2}Cl_2 \rightarrow ICl$

$\frac{1}{2}I\text{-}I + \frac{1}{2}Cl\text{-}Cl \rightarrow I\text{-}Cl$

Bonds broken

$E(\frac{1}{2}I\text{-}I) = \frac{151}{2} = 75.5$

$E(\frac{1}{2}Cl\text{-}Cl) = \frac{242}{2} = 121$

Bonds formed

$E(I\text{-}Cl) = x$

So, $+75.5 + 121 - x = -24$

$196.5 - x = -24$

$x = 196.5 + 24$

$x = 220.5$

I–Cl bond energy = 220.5 kJ mol^{-1} [2]

Examiner comments

1 The reference to the element being in its standard state seems to be a bit of an afterthought, but all three marking points are correctly stated.

Mark for (a) (i) = 3/3

2 This is correct.

Mark for (a) (ii) = 1/1

3 Although the candidate has not fully drawn out the cycle or an equation, their working clearly follows the pattern that would be derived from a cycle or equation. They have also remembered that the definition of bond energy is per mole of bonds broken and not per mole of atoms formed, so correctly divide the bond energy values by 2.

Mark for (a) (iii) = 2/2

Example candidate response – high, continued

(b) (i) Explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.

Number of electrons increases from HCl < HBr < HI.
So, strength of van der waals increases from
HCl to HI. Greater energy is needed to overcome the forces. [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl, HBr and HI.

Fluorine is more electronegative than hydrogen. So, HF has hydrogen bonds between the molecules. Hydrogen bonds are stronger than van der waals and greater energy is needed to overcome. [2]

(c) In an experiment, two of the halogens are represented as P_2 and Q_2.

P_2 combines with hydrogen on heating to form HP, which can be easily broken down into its elements. A solution of HP in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

Q_2 combines explosively with hydrogen in sunlight to form HQ, which is stable to heat. A solution of HQ in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

(i) Identify the halogens P_2 and Q_2.

P_2 = Iodine / I_2 Q_2 = Chlorine / Cl_2 [1]

(ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.

H-P bond length is ~~greater~~ greater than bond length of H-Q. So, H-P has bond energy of 299 $kJmol^{-1}$ which is less than bond energy of H-Q (431 $kJmol^{-1}$) [2]

(iii) Write an equation for the thermal decomposition of HP.

$2HI \rightleftharpoons H_2 + I_2$ [1]

Examiner comments

4 This is correct and avoids the common mistake of confusing intermolecular forces with bonds.

Mark for (b) (i) = 2/2

5 This is correct.

Mark for (b) (ii) = 2/2

6 Both halogens are correctly identified here.

Mark for (c) (i) = 1/1

7 The relative magnitudes of the bond energies are correctly identified and explained with correct reference to their relative lengths.

Mark for (c) (ii) = 2/2

8 This is the correct equation.

Mark for (c) (iii) = 1/1

Example candidate response – high, continued

(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous HQ,

$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$ 9

2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

$Ag^+(aq) + 2NH_3(aq) \rightarrow [Ag(NH_3)_2]^+_{(aq)}$ 10

[2]

(d) Chlorine reacts directly with many elements to form chlorides. Three such compounds are $MgCl_2$, $AlCl_3$ and $SiCl_4$.

(i) State and explain the pattern shown by the formulae of these three chlorides.

Number of Chlorine atoms in an ~~i~~ ionic compound increases from $MgCl_2$ to $SiCl_4$. The oxidation state increases from Mg to Si. So, more chlorine atoms are needed to gain the electrons. 11

[2]

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

$MgCl_2$ ~~$MgCl_2$~~ + ~~H_2O~~ $\rightarrow MgCl_2 + aq \rightarrow Mg^{2+} + 2Cl^-$

$AlCl_3$ $[Al(H_2O)_6]^{+3} \rightarrow [Al(H_2O_5)OH]^{+2} + H^+$ 12

$SiCl_4$ $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$

[3]

[Total: 21]

Examiner comments

9 This equation is correct and includes state symbols, as requested in the question.

10 Strictly speaking, this equation does not actually show the dissolving of the ppt as, to do so, it should start with AgCl(s). However, this alternative answer is accepted as the solid will actually be in equilibrium with a low concentration of Ag+(aq) ions and, when these ions complex with ammonia, more solid will dissolve, in accordance with Le Chatelier's Principle.

Mark for (c) (iv) = 2/2

11 This answer is very close to 2 marks but it just needed a specific reference to the fact that the number of chlorines increases by one each time.

Mark for (d) (i) = 1/2

12 The first and third equations are correct but the second equation does not show the reaction of $AlCl_3$ with water but instead shows the hydrolysis of the hexaaquaaluminium ion that would be produced by this reaction.

Mark for (d) (ii) = 2/3

Total marks awarded = 19 out of 21

How the candidate could have improved their answer

The definition in **(a) (i)** was almost word perfect, although the second sentence could have been omitted if the phrase 'in its standard state' had been included after the word 'elements' (which, though it should really have been 'element' in the singular, was not penalised).

The key to the second mark in **(d) (i)** was to remember the general advice that, if specific information is given, then the answer based on that information should be as specific, and quantitative, as possible. For example, candidates should not just say 'increase' if it can be seen that 'increase by one' is more appropriate.

Mark awarded = **(a) (i) 3/3, (ii) 1/1, (iii) 2/2**
Mark awarded = **(b) (i) 2/2, (ii) 2/2**
Mark awarded = **(c) (i) 1/1, (ii) 2/2, (iii) 1/1, (iv) 2/2**
Mark awarded = **(d) (i) 1/2, (ii) 2/3**

Total marks awarded = 19 out of 21

Example candidate response – middle

2 The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol^{-1}	standard enthalpy change of atomisation, $\Delta H^{\ominus}_{at}$ /kJ mol^{-1}	boiling point of element /K	boiling point of **hydrogen halide** /K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

(a) (i) Explain the meaning of the term *standard enthalpy change of atomisation*.

The enthalpy change when one mole of gaseous atom is formed from its element under standard state conditions. 1 [3]

(ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

Down the group, number of electrons increases, V.W.F's increases. So more energy is required for atomisation. 2 [1]

(iii) The standard enthalpy of formation of iodine monochloride, ICl, is –24.0 kJ mol^{-1}.

Use this information and the bond energies of iodine and chlorine to calculate the I–Cl bond energy.

$I_2 + Cl_2 \xrightarrow{-24} 2ICl$

$151 + 242 \rightarrow I\text{-}Cl + (-24)$

$393 + 24 \rightarrow I\text{-}Cl$

$I\text{-}Cl \rightarrow 417$

$I_2 + Cl_2 \rightarrow 2ICl$

$151 + 242 \rightarrow I\text{-}Cl(-24)$

$I\text{-}Cl \rightarrow 417$

3

I–Cl bond energy = 417 kJ mol^{-1} [2]

Examiner comments

1 The phrase 'standard state conditions' is not a standard phrase but is taken to be a reference to 'standard conditions'. One mark is not awarded for omitting to state clearly that the element is in its standard state.

Mark for (a) (i) = 2/3

2 The answer could be made clearer by referring to the change of state required for bromine and iodine.

Mark for (a) (ii) = 1/1

3 The candidate has chosen to write the equation to show the formation of 2 moles of ICl – which means that the enthalpy of formation value of -24 should have been doubled to give 441 as the answer for the formation of 2 × I-Cl bonds. This should then be halved to give the true answer of 220.5. It could be argued that there are therefore two mistakes here and the mark should be 0/2. However, the answer 417 was often seen as a result of simply failing to halve the bond energies in an equation showing the formation of one mole of ICl so, to ensure consistency, this answer was uniformly awarded one mark.

Mark for (a) (iii) = 1/2

Example candidate response – middle, continued

(b) (i) Explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.

Boiling point increases from HCl to HI, as the number of electrons increases. Hence Vander Waal's forces increases and more energy is required to overcome these forces. [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl, HBr and HI.

H-F has a greater electronegativity difference between H and F, as compared to other hydrogen halides. [2]

(c) In an experiment, two of the halogens are represented as P_2 and Q_2.

P_2 combines with hydrogen on heating to form HP, which can be easily broken down into its elements. A solution of HP in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

Q_2 combines explosively with hydrogen in sunlight to form HQ, which is stable to heat. A solution of HQ in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

(i) Identify the halogens P_2 and Q_2.

P_2 = Iodine Q_2 = chlorine [1]

(ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.

HP is H-I which has the bond energy 299 $kJ\,mol^{-1}$ which is lower than bond energy of HCl (HCL) that is 431 $kJ\,mol^{-1}$. So, HP decomposes easily as less heat required. H-I has longer bond lengths than H-Cl. [2]

(iii) Write an equation for the thermal decomposition of HP.

$2HI \longrightarrow H_2 + I_2$ [1]

Examiner comments

4 This is correct.

Mark for (b) (i) = 2/2

5 The candidate should have noticed that this question has 2 marks, which indicates that more than a single statement is required. Here, a comparison of the relative strengths of intermolecular forces is required. Although hydrogen bonds have not specifically been mentioned, this reference to the electronegativity difference is accepted as an alternative to the ideal answer.

Mark for (b) (ii) = 1/2

6 This is correct.

Mark for (c) (i) = 1/1

7 The middle sentence here is unnecessary as it simply repeats the question. The second mark is earned with the explanation of why the bond is weaker in the final sentence.

Mark for (c) (ii) = 2/2

8 This equation is correct.

Mark for (c) (iii) = 1/1

Example candidate response – middle, continued

(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous HQ,

$Cl^-_{(aq)} + Ag^+_{(aq)} \rightarrow AgCl_{(s)}$ 9

2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

$AgCl_{(s)} \rightarrow Ag^+_{(aq)} + Cl^-_{(aq)}$ 10 [2]

(d) Chlorine reacts directly with many elements to form chlorides. Three such compounds are $MgCl_2$, $AlCl_3$ and $SiCl_4$.

(i) State and explain the pattern shown by the formulae of these three chlorides.

11 The number of chlorine atoms attached to the elements increases from Mg to Si because the charge ~~of~~ number increases from Mg(+2) to Al(+3) and Si(+4). [2]

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

12 $MgCl_2$ $MgCl_2 + 2H_2O \rightarrow Mg(OH)_2 + 2HCl$

$AlCl_3$ $2AlCl_3 + 3H_2O \rightarrow Al_2O_3 + 6HCl$

$SiCl_4$ $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$

[3]

[Total: 21]

Examiner comments

9 This equation is correct and includes state symbols.

10 This equation shows the dissolving of AgCl, but not as a result of a reaction with ammonia, as asked for in the question.

Mark for (c) (iv) = 1/2

11 The reference to an increasing number of chlorines is not specific enough; it needed to say 'by one each time'. The reference to 'charge' is incorrect, as silicon does not form a cation; the phrase 'valency' or 'oxidation number/state' was needed instead.

Mark for (d) (i) = 0/2

12 Only the third equation is correct here. The first two equations seem to have been written as if the chlorides are fully covalent whereas $MgCl_2$ is ionic (so simply dissolves) and $AlCl_3$ is covalent but with intermediate character so partially hydrolyses.

Mark for (d) (ii) = 1/3

Total marks awarded = 13 out of 21

How the candidate could have improved their answer

Apart from gaps in knowledge about chlorides for the final part of the question, most of the answers were close to being completely correct, although a little lacking in precision and detail. As a result, single marks could not be awarded consistently throughout the various parts of the question.

Part **(a) (i)** showed the importance of word perfect learning of definitions (especially enthalpy terms, A_r, M_r, isomerism). This was also evident in **(a) (iii)** where an appreciation of the definition of enthalpy of formation would have allowed the candidate to recognise that the value given needed doubling to match their equation.

The mark that wasn't awarded on **(b) (ii)** was a good example of poor exam technique, as the candidate clearly knew what they were writing about, they simply did not provide enough for a 2 mark question.

Mark awarded = **(a) (i) 2/3, (ii) 1/1, (iii) 1/2**
Mark awarded = **(b) (i) 2/2, (ii) 1/2**
Mark awarded = **(c) (i) 1/1, (ii) 2/2, (iii) 1/1, (iv) 1/2**
Mark awarded = **(d) (i) 0/2, (ii) 1/3**

Total marks awarded = 13 out of 21

Example candidate response – low

2 The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol^{-1}	standard enthalpy change of atomisation, $\Delta H^{\ominus}_{at}$ /kJ mol^{-1}	boiling point of element /K	boiling point of **hydrogen halide** /K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

(a) (i) Explain the meaning of the term *standard enthalpy change of atomisation*.

The enthalpy change needed when 1 mole of an atom is converted to its gaseous state under standard conditions [3]

(ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

Fluorine and Chlorine have low boiling points so similar energy is needed for atomization. They are reactive and have weak vander wall forces between them [1]

(iii) The standard enthalpy of formation of iodine monochloride, ICl, is –24.0 kJ mol^{-1}.

Use this information and the bond energies of iodine and chlorine to calculate the I–Cl bond energy.

$Cl_2 + I_2 \longrightarrow 2ICl$

$(242 + 151)$

$\Delta H_1 - \Delta H_2 = -24$

$393 + 24 = 2x$

$x = 208.5$

I–Cl bond energy = 208.5 kJ mol^{-1} [2]

Examiner comments

1 The only mark awarded here is for a statement about 'standard conditions'. The rest of the definition has not been learned properly. Candidates should avoid referring to energy 'needed' in any enthalpy definition as it implies that the change is always endothermic. This is not a problem here as atomisation is always endothermic, but it is not good practice generally. The safe phrase to use for all such definitions is 'The enthalpy change when . . .'

Mark for (a) (i) = 1/3

2 This is close to earning the mark but the reference to fluorine and chlorine being more reactive is irrelevant and suggests that the candidate does not know the answer. They also needed to use a comparative here, referring to the VdW forces being weaker to describe the comparison with bromine and iodine.

Mark for (a) (ii) = 0/1

3 The candidate has shown working that is correct in style, although it would have been better if they had identified what ΔH1 and ΔH2 referred to. The mistake here is the failure to double the value of enthalpy of formation in line with the formation of 2ICl in the equation.

Mark for (a) (iii) = 1/2

Example candidate response – low, continued

(b) (i) Explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.

Boiling points generally ~~decrease~~ Increase . ~~HI > HBr > HCl~~

Boiling points decrease . HCl > HBr > HI . This is due to more energy to break bonds 4 [2]

(ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl, HBr and HI.

HF is polar and has strong electronegitivity so more energy is needed to break the bond . 5

[2]

Examiner comments

4 Technique and content errors here mean no marks can be awarded. The candidate only makes a single statement for a two-mark question so a maximum of one mark only can be awarded. However, an unqualified reference to 'bonds' is always interpreted as meaning covalent (or ionic or metallic) bonds. This is a very common source of confusion in discussions of melting and boiling point trends. For molecular substances such as these, the discussion should always clearly be about the relative strengths of intermolecular forces.

Mark for (b) (i) = 0/2

5 The initial statement about HF being polar is on the right track, but the candidate then mistakenly refers to HF having 'strong electronegativity', which is incorrect as electronegativity is a feature of an atom, not a whole compound. There is another reference to breaking a 'bond' when intermolecular forces need to be discussed.

Mark for (b) (ii) = 0/2

Example candidate response – low, continued	Examiner comments

(c) In an experiment, two of the halogens are represented as P_2 and Q_2.

P_2 combines with hydrogen on heating to form HP, which can be easily broken down into its elements. A solution of HP in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

Q_2 combines explosively with hydrogen in sunlight to form HQ, which is stable to heat. A solution of HQ in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

(i) Identify the halogens P_2 and Q_2. 6

P_2 = Iodine (I_2) Q_2 = ~~Cl~~ Chlorine (Cl_2) [1]

(ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.

More energy is needed to break the H–Q bond. Less is needed for H–P so it easily breaks into its elements. 7 [2]

(iii) Write an equation for the thermal decomposition of HP.

$2HP \xrightarrow{Heat} H_2 + I_2$ $2HI \xrightarrow{heat} H_2 + I_2$ 8 [1]

6 This is correct.

Mark for (c) (i) = 1/1

7 This is a correct statement, but the fact that there are two marks available should have served as a clue that more was needed, such as an explanation of *why* this is the case.

Mark for (c) (ii) = 1/2

8 This is correct.

Mark for (c) (iii) = 1/1

Example candidate response – low, continued

(iv) Write ionic equations, including state symbols, for $Ag^+_{(aq)} + Cl^-_{(aq)} \longrightarrow AgCl_{(s)}$

$NH_3 + AgCl + H^+ \rightarrow$

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous HQ,

$Ag^+_{(aq)} + Cl^-_{(aq)} \longrightarrow AgCl_{(s)}$

2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

$NH_4^+_{(aq)} + Cl_{(s)} \longrightarrow NH_4Cl_{(aq)}$

[2]

9

(d) Chlorine reacts directly with many elements to form chlorides. Three such compounds are $MgCl_2$, $AlCl_3$ and $SiCl_4$.

(i) State and explain the pattern shown by the formulae of these three chlorides.

$MgCl_2$ is ionic bond, Mg transfered 1 electron to each Cl atom

$AlCl_3$ is bonded by sharing of electron to each electron.

$SiCl_4$ is giant covalent structure. Each Cl is covalently bonded [2]

10

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

$MgCl_2$ $MgCl_2 + 2H_2O \longrightarrow Mg(OH)_2 + 2HCl$

$AlCl_3$ $AlCl_3 + 3H_2O \longrightarrow Al(OH)_3 + 3HCl$

$SiCl_4$ $SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$

[3]

$AlCl_3 + 3H_2O \longrightarrow Al(OH)_3 + 3HCl$

$SiCl_4 + 4H_2O \longrightarrow Si(OH)_4 + 4HCl$

11

[Total: 21]

Examiner comments

9 The first equation is correct and includes state symbols, but the second equation does not correspond to the question asked.

Mark for (c) (iv) = 1/2

10 The candidate seems to have confused the idea of 'formulae' with 'structure', as they write about the structure and bonding rather than the formulae.

Mark for (d) (i) = 0/2

11 The candidate has treated all three chlorides as though they are simple covalent, molecular chlorides ($SiCl_4$ is simple molecular, so this equation is correct). However, the point of the question is to illustrate the differing behaviours of different types of chloride when added to water.

Mark for (d) (ii) = 1/3

Total marks awarded = 7 out of 21

How the candidate could have improved their answer

(a) (i) This definition should have been learned and remembered. The rote learning of definitions is a key part of revision, not only for questions such as this, where they need writing out, but also, as illustrated in **(a) (iii)**, so that data relating to defined terms can be interpreted and used correctly.

This candidate also demonstrated another common confusion in part **(b)** where the answers referred to (covalent) bonds. Discussions of the melting/boiling points of molecular substances should always be in terms of the intermolecular forces acting between the molecules, such as hydrogen bonds, permanent dipole-permanent-dipole forces or instantaneous dipole-induced dipole forces, where pd-pd and id-id forces are collectively known as van der Waal's forces.

Part **(d)** indicated the importance of understanding key subject terminology, so that questions can be interpreted correctly. The candidate also demonstrated another common weakness amongst candidates, which is that the chemistry of chlorides is not as well recognised as the chemistry of oxides.

Mark awarded = **(a) (i) 1/3, (ii) 0/1, (iii) 1/2**
Mark awarded = **(b) (i) 0/2, (ii) 0/2**
Mark awarded = **(c) (i) 1/1, (ii) 1/2, (iii) 1/1, (iv) 1/2**
Mark awarded = **(d) (i) 0/2, (ii) 1/3**

Total marks awarded = 7 out of 21

Common mistakes candidates made in this question

In **(a) (i)**, many candidates were not able to give the specific wording of this definition.

In **(a) (iii)**, either the bond energies were not halved if the candidate used the version of the equation forming one mole of IC*l*, or the enthalpy of formation was not doubled if using the equation forming 2IC*l*. These errors also illustrate the importance of careful learning of the precise meaning of enthalpy change definitions.

In part **(b)**, many candidates showed confusion between 'bonds' and 'intermolecular forces'.

In **(c) (iv)**, state symbols were often left out despite being asked for in the question, and very few candidates could construct a suitable answer for the second equation.

In **(d) (i)**, most candidates were awarded one mark for the idea of increasing valency / outer shell electrons but, in some cases, the answer was not specific enough for the second mark, for which a clear reference to actual numbers was needed.

Question 3

Example candidate response – high

3 Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

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

$$(H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-) \times 3$$

$3H_2C_2O_4 \rightarrow 6CO_2 + 6H^+ + 6e$

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

$Cr_2O_7^{2-} + 14H^+ + 3H_2C_2O_4 \rightarrow 2Cr^{3+} + 7H_2O + 6CO_2 + 6H^+$ [2]

(b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $H_2C_2O_4.xH_2O$, was reacted with a 0.0200 mol dm^{-3} solution of acidified potassium dichromate(VI).

32.0 cm^3 of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

(i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

$n = c \times v$
$= 0.02 \times 32 \times 10^{-3}$
$= 6.4 \times 10^{-4}$

amount = 6.4×10^{-4} mol [1]

(ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

$n = 6.4 \times 10^{-4} \times 3$
$n = 1.92 \times 10^{-3}$

amount = 1.92×10^{-3} mol [1]

(iii) Calculate the relative molecular mass, M_r, of the hydrated ethanedioic acid.

$M_r = \frac{m}{n} = \frac{0.242}{1.92 \times 10^{-3}} = 126$

M_r = 126 [1]

(iv) Calculate the value of x in $H_2C_2O_4.xH_2O$.

M_r of $H_2C_2O_4 = (2 \times 1) + (12 \times 2) + (16 \times 4)$
$= 90$

$x = \frac{126 - 90}{18}$ M_r of $H_2O = 18$ x = 2 [1]

[Total: 6]

$X = 2$

Examiner comments

1 This equation contains all the correct species from the half-equations given, so one mark has been awarded. The second mark requires that the H^+ ions on the right of the equation are cancelled out to leave $8H^+$ on the left.

Mark for (a) = 1/2

2 All four stages in the calculation are correct, with clear working shown.

Mark for (b) = 4/4

Total marks awarded = 5 out of 6

How the candidate could have improved their answer

The candidate's only improvement would have been to cancel the hydrogen ions as well as the electrons when combining the half-equations in **(a)**.

Mark awarded = **(a) 1/2**
Mark awarded = **(b) (i) 1/1, (ii) 1/1, (iii) 1/1, (iv) 1/1**

Total marks awarded = 5 out of 6

Example candidate response – middle

3 Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

$Cr_2O_7^{2-} + H_2C_2O_4 + 12H^+ + 4e^- \rightarrow$

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

$H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-$

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

$Cr_2O_7^{2-} + 3H_2C_2O_4 + 2H^+ \rightarrow 2Cr^{3+} + 7H_2O + 6CO_2$ [2] 1

(b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $H_2C_2O_4.xH_2O$, was reacted with a 0.0200 mol dm^{-3} solution of acidified potassium dichromate(VI).

32.0 cm^3 of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

(i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

$0.0200 \times \frac{32}{1000} = 6.4 \times 10^{-4}$ 2

amount = 6.4×10^{-4} mol [1]

(ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

$Cr_2O_7^{2-}$: $H_2C_2O_4$
1 : 1

6.4×10^{-4} 3

amount = 6.4×10^{-4} mol [1]

Examiner comments

1 The candidate makes an attempt at cancelling when combining the two half-equations but forgets the initial step of multiplying the second equation by 3 so that the electron loss matches the electron gain. However, one mark is awarded, as the species on each side of the final equation are correct. Candidates should remember the final checks needed: counting the numbers of each type of atom on each side of an equation and checking that the overall charges are the same. In this case the left has an overall charge of 10+ while the right is 6+ so something must be wrong.

Mark for (a) = 1/2

2 This is correct.

Mark for (b) (i) = 1/1

3 This is an example of an 'error carried forward' as, although this answer does not correspond to the mark scheme, it follows correctly from the incorrect 1:1 ratio in the candidate's equation.

Mark for (b) (ii) = 1/1

Example candidate response – middle, continued	Examiner comments
(iii) Calculate the relative molecular mass, M_r, of the hydrated ethanedioic acid. Mr = Mass / moles Mr = 0.242 / 6.48×10^{-4} = 378.125 M_r = 378.125 [1] (iv) Calculate the value of x in $H_2C_2O_4.xH_2O$. H_2O = 18 378.125 − 80 = 298.125 x H = 298.125 / 18 x = 16.5625 [1] [Total: 6]	4 The working shows that the correct method has been used, but the answer is given to six significant figures when only three of four significant figures can be justified on the basis of the supplied data (all of which is to three significant figures). Mark for (b) (iii) = 0/1 5 Again, the working is correct but the candidate has failed to appreciate that an answer of this type must be an integer, as only whole numbers are used to indicate ratios in equations. Mark for (b) (iv) = 0/1 **Total marks awarded = 3 out of 6**

How the candidate could have improved their answer

In **(a)** the candidate needed to remember that the key idea when combining half-equations is that the electron loss in one half-equation must balance the electron gain in the other.

In **(b) (iii)** the candidate used the correct method but needed to remember the syllabus guidance that the number of significant figures in the answer must correspond to the number of significant figures in the data provided.

Mark awarded = **(a) 1/2**
Mark awarded = **(b) (i) 1/1, (ii) 1/1, (iii) 0/1, (iv) 0/1**

Total marks awarded = 3 out of 6

Example candidate response – low

3 Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

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

$$H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-$$

(a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

$6H^+ + 2Cr_2O_7 + 2H_2C_2O_4 \rightarrow 4CO_2 + 14H_2O + H_2 + 2Cr_2$ [2]

1

(b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $H_2C_2O_4.xH_2O$, was reacted with a 0.0200 mol dm^{-3} solution of acidified potassium dichromate(VI).

32.0 cm^3 of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

(i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

$n = cv = 32 \times 10^{-3} \times 0.02 = 6.4 \times 10^{-4}$

amount = 6.4×10^{-4} mol [1]

2

(ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

$n(C_2H_2O_4) = \frac{m}{M} = \frac{0.242}{90} = 2.69 \times 10^{-3}$

amount = 2.69×10^{-3} mol [1]

3

Examiner comments

1 It is not clear how the candidate has arrived at this suggested answer, but, although they have attempted to balance the various atoms in the formula, they have not made any attempt to balance the charges / electron transfer, which is a key skill with redox equations. No mark is possible for the species present either, as the candidate has simply transposed the '$2Cr_2$' from the left (where Cr is part of a complex anion) to the right, where it implies that the chromium exists as a diatomic molecule rather than the Cr^{3+} ions shown in the first half-equation.

Mark for (a) = 0/2

2 This is correct.

Mark for (b) (i) = 1/1

3 The candidate has failed to appreciate the significance of the sequence in this structures calculation and, instead of using their previous answer and the ratio in the equation, they have attempted to calculate an amount using the M_r of the ethanedioic acid, even though this cannot be known without knowing the value of *x*.

Mark for (b) (ii) = 0/1

Example candidate response – low, continued	Examiner comments
(iii) Calculate the relative molecular mass, M_r, of the hydrated ethanedioic acid. $M = \frac{m}{n} = 378$ $n(K_2Cr_2O_7) = n(H_2C_2O_4 \times H_2O) = 6.4 \times 10^{-3}$ M_r = 378 [4] [1] **(iv)** Calculate the value of x in $H_2C_2O_4.xH_2O$. $378 - 90 = 288$ $288 \div 18 = 16$ x = 16 [5] [1] [Total: 6]	**4** An 'error carried forward' would have been possible here if the answer to (ii) had been used, but, instead, the candidate has used the amount of dichromate from (i) to try and calculate the M_r of the acid. Data must always be consistent in calculations so, to calculate M_r of the acid, the amount and mass of the acid must be used. Mark for (b) (iii) = 0/1 **5** This is correct as an 'error carried forward' from the answer to (iii). Mark for (b) (iv) = 1/1 **Total marks awarded = 2 out of 6**

How the candidate could have improved their answer

In **(a)** the candidate needed to remember that the key idea when combining half-equations is that the electron loss in one half-equation must balance the electron gain in the other.

In **(b)** the candidate lost their way after the first part of the four-step calculation and failed to keep track of the context or the reason why the question was structured in this way. An M_r cannot be used if part of the formula of a compound is unknown.

Mark awarded = **(a) 0/2**
Mark awarded = **(b) (i) 1/1, (ii) 0/1, (iii) 0/1, (iv) 1/1**

Total marks awarded = 2 out of 6

Common mistakes candidates made in this question

(a) The skills needed to combine two half-equations and produce an overall balanced redox equation proved tricky for many candidates. Good candidates often got close but failed to balance the H^+ ions by cancelling them out, while weaker candidates failed to recognise the need to balance the electron transfer first.

(b) The first two parts of the calculation were generally done well but some candidates failed to realise that the M_r calculation depended on the previous answer together with the ratio in the equation.

Question 4

Example candidate response – high	Examiner comments

4 This question is about molecules with molecular formula $C_4H_8O_2$.

(a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.

$CH_3CH_2CH_2CO_2H$

$CH_3CH(CH_3)CO_2H$

1

[2]

(b) (i) Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.

$CH_3CO_2CH_2CH_3$

$HCO_2CH_2CH_2CH_3$

2

[2]

(ii) Give the reagents and conditions needed to produce one of your esters in (i).

~~One~~ of Alcohol and carboxylic acid. Heat both of them under reflux with concentrated sulfuric acid. 3

[2]

1 These two structures are both unambiguous representations so are credited even though the second one is not strictly a structural formula and should be written as $(CH_3)_2CHCOOH$.

Mark for (a) = 2/2

2 These structures are correct, although a better convention when writing the formulae of acids and esters is to use the form 'COO' rather than 'CO_2'.

Mark for (b) (i) = 2/2

3 The conditions are correct here, but, when a question asks for reagents, the names (or formulae) of specific compounds must be given whereas this candidate only gives the classes of compound needed.

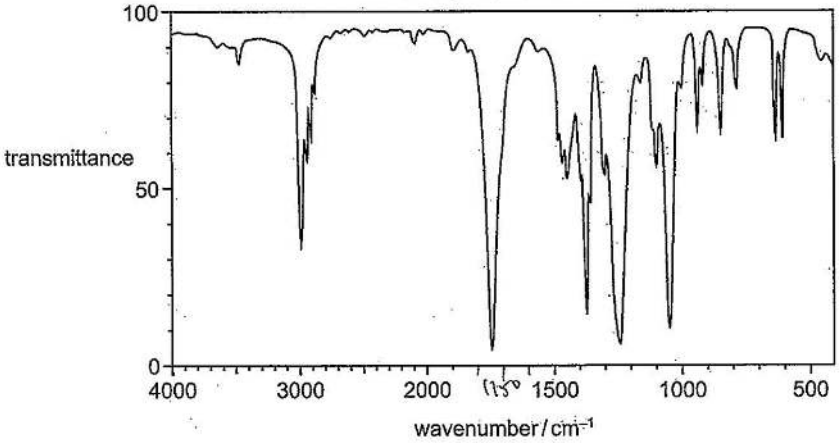
Mark for (b) (ii) = 1/2

Example candidate response – high, continued

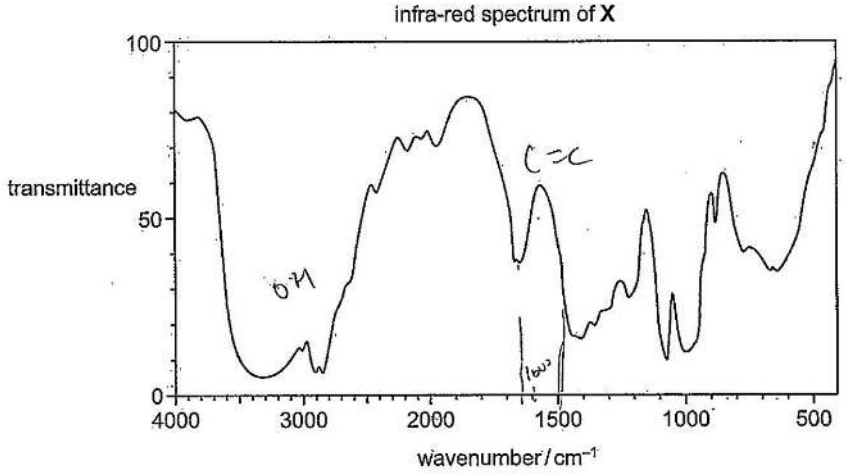
(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown.

X decolourises bromine water and is not an ester or an acid.

infra-red spectrum of the ester



infra-red spectrum of **X**



Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm⁻¹. 4

In ester's spectrum, there is one sharp and strong peak at 1750 cm⁻¹. It means there is - C=O group. In X's spectrum, there is one weak peak at approximately at 1650 cm⁻¹ and one broad peak between 3200 - 3600 cm⁻¹. [3]
That means there is C=C and O-H group in X.

[Total: 9]

Examiner comments

4 This is an excellent answer. Each of the wavenumbers quoted is correctly referenced and also linked to the specific bond responsible for the absorption. The dash before the C=O is possibly ambiguous as it may be indicating another bond to the carbon atom, but it was ignored here. It is also evidence of good exam technique to see the rough working that has been done on the diagrams to allow the candidate to organise their thinking before writing the actual answer.

Mark for (c) = 3/3

Total marks awarded = 8 out of 9

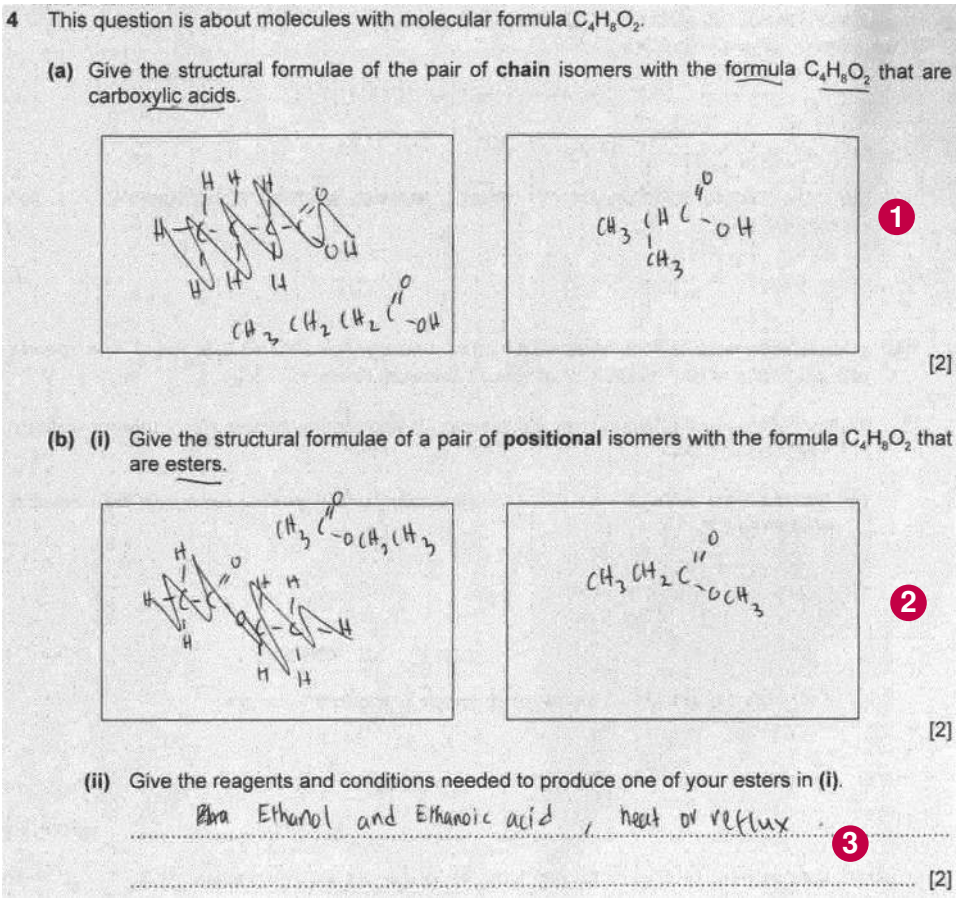
How the candidate could have improved their answer

Only one mark was not awarded here, illustrating the importance of being as specific as possible when answering and giving specific compound names when asked for 'reagents'.

Mark awarded = **(a) 2/2**
Mark awarded = **(b) (i) 2/2, (ii) 1/2**
Mark awarded = **(c) 3/3**

Total marks awarded = 8 out of 9

Example candidate response – middle



4 This question is about molecules with molecular formula $C_4H_8O_2$.

(a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.

[2]

(b) (i) Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.

[2]

(ii) Give the reagents and conditions needed to produce one of your esters in **(i)**.

Eg Ethanol and Ethanoic acid, heat or reflux

[2]

Examiner comments

1 Although, strictly speaking, these structures are not structural formulae, as asked for in the question, they are unambiguous representations of the correct compounds and therefore accepted.

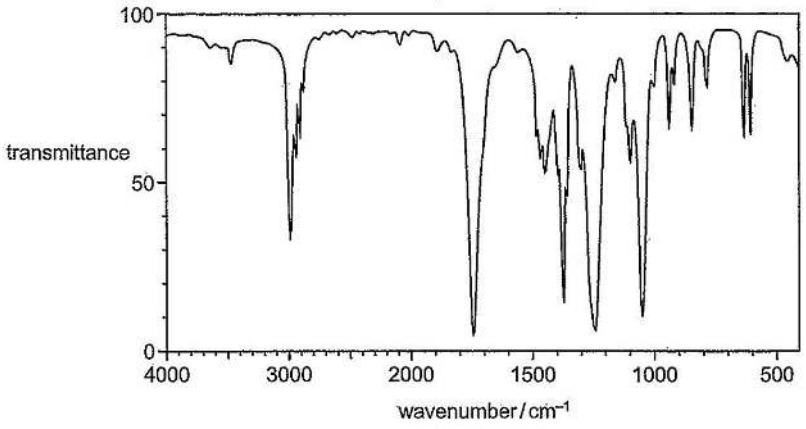
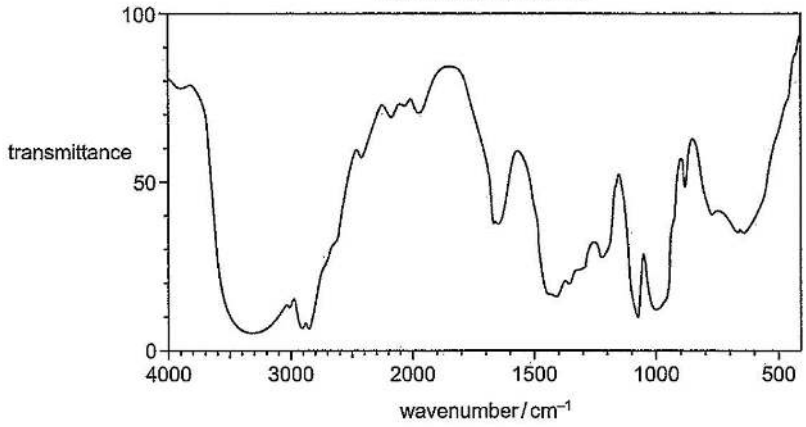
Mark for (a) = 2/2

2 Again, these are not structural formulae as asked for in the question but they are unambiguous representations of the correct compounds and therefore accepted.

Mark for (b) (i) = 2/2

3 The correct acid and alcohol have been chosen for the first ester given in (b) (i), but the need for concentrated sulfuric acid has been left out of the conditions.

Mark for (b) (ii) = 1/2

Example candidate response – middle, continued	Examiner comments
(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown. **X** decolourises bromine water and is not an ester or an acid. infra-red spectrum of the ester  infra-red spectrum of **X**  Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm⁻¹. **4** The shape of peak on infra red spectrum of ester is weak while the shape of peak on infra-red spectrum of X is strong and broad between wavenumbers 3200 – 3600 cm⁻¹. The shape of peak on infra red spectrum of ester is weak ~~while shape of peak on infra-red spectrum of~~ which shows X contain on ~~the~~ alkene. [3] [Total: 9]	**4** No marks could be awarded here as the references are too vague and there is no clear linkage between wavenumbers and specific bonds. The reference to the peak at 3200–3600 is correct, although it is even better to quote a single wavenumber when referring to an absorption on a spectrum. However, this needed linking to the presence of O–H in the compound. The reference to 3000–3100 suggests that the candidate is not referring to an absorption but to a point between two absorptions. Mark for (c) = 0/3 **Total marks awarded = 5 out of 9**

How the candidate could have improved their answer

Although the structures in **(a)** and **(b) (i)** were awarded the marks, it would have been better if the candidate had followed the instruction to give structural formulae in the form $(CH_3)_2COOH$, rather than showing a sort of 'semi-displayed' structure. However, the marking allowed for this, as the skill being tested was to identify the compounds referred to without insisting on a specific type of representation for the formula.

No marks were awarded in **(c)**; the key to success in IR questions is to make clear, specific references to wavenumbers and to link each one to a specific bond in the structure of the compound responsible for the spectrum.

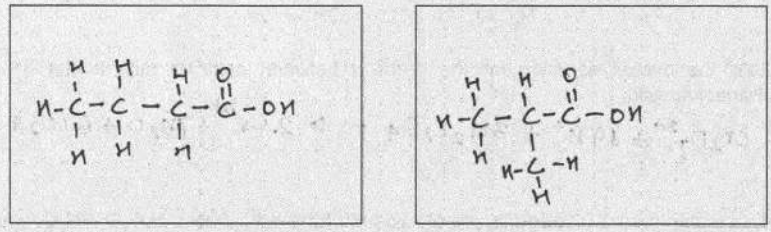
Mark awarded = **(a) 2/2**
Mark awarded = **(b) (i) 2/2, (ii) 1/2**
Mark awarded = **(c) 0/3**

Total marks awarded = 5 out of 9

Example candidate response – low

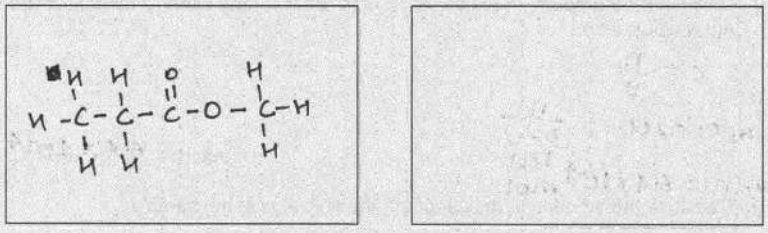
4 This question is about molecules with molecular formula $C_4H_8O_2$.

(a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.



[2]

(b) (i) Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.



[2]

(ii) Give the reagents and conditions needed to produce one of your esters in **(i)**.

when carboxylic acid is added to ethanol in warm condition it gives ~~a~~ ester.

condition: 70°c /warm

Reagent: Alcohol

[2]

Examiner comments

1 These are displayed formulae (or almost, as there is no bond shown between O and H), rather than structural formulae. However, they are allowed.

Mark for (a) = 2/2

2 The first structure is correct and clearly drawn, so it is odd that the candidate does not attempt a second structure with the ester link between different carbon atoms.

Mark for (b) (i) = 1/2

3 Ethanol is not the correct alcohol needed to make the ester drawn by the candidate, and the acid is not identified by name. The mark here would have required both propanoic acid and methanol to be named. The need for concentrated acid has been left out of the conditions.

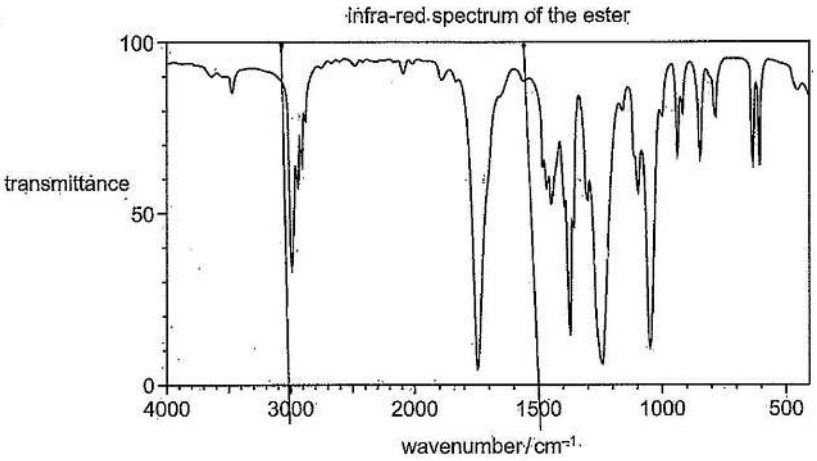
Mark for (b) (ii) = 0/2

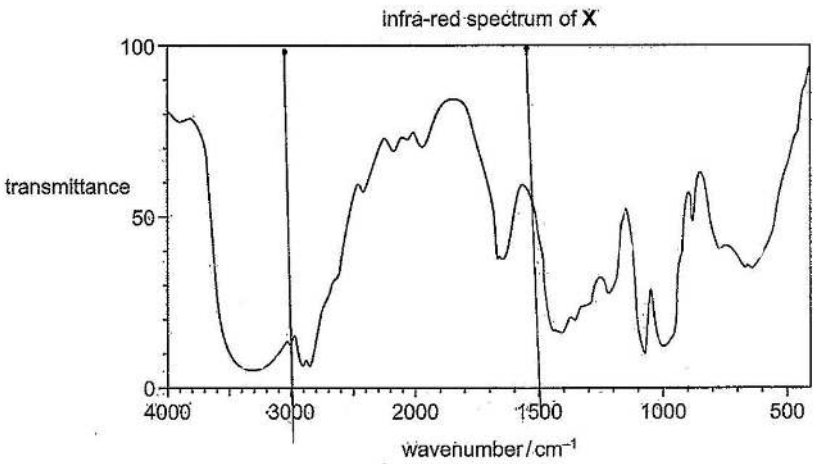
Example candidate response – low, continued

Examiner comments

(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown.

X decolourises bromine water and is not an ester or an acid.





Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1}.

There is a peak at around 1720, ~~whi~~ which is strong shows that there is ester group similarly a weak peak at the X shows that that is an aromatic compound or alkene. there is a double bond in second figure. Both the compounds contain alkanes group.

[3]

[Total: 9]

4 The reference to a peak at 1720 for the first spectrum is correct, but indicating that it is due to an ester group is not specific enough as this absorption is due to a C=O bond (in an ester group). There is then a reference to an alkene group (which is enough to refer to C=C) but it is not linked to a stated wavenumber. The absorption at 3300 cm^{-1} in the spectrum of X seems to have been ignored.

Mark for (c) = 0/3

Total marks awarded = 3 out of 9

How the candidate could have improved their answer

(b) (i) This answer illustrates the importance of always making an attempt at an answer – a blank space definitely gets no marks but an attempt may pay off.

No marks were awarded in **(c)**. Here the candidate needed to realise that the key to success in IR questions is to make clear, specific references to wavenumbers and to link each one to a specific bond in the structure of the compound responsible for the spectrum. In this case, there were two valid references, one to an absorption and one to a bond, but neither of these was linked to the other part of the answer.

Mark awarded = **(a) 2/2**
Mark awarded = **(b) (i) 1/2, (ii) 0/2**
Mark awarded = **(c) 0/3**

Total marks awarded = 3 out of 9

Common mistakes candidates made in this question

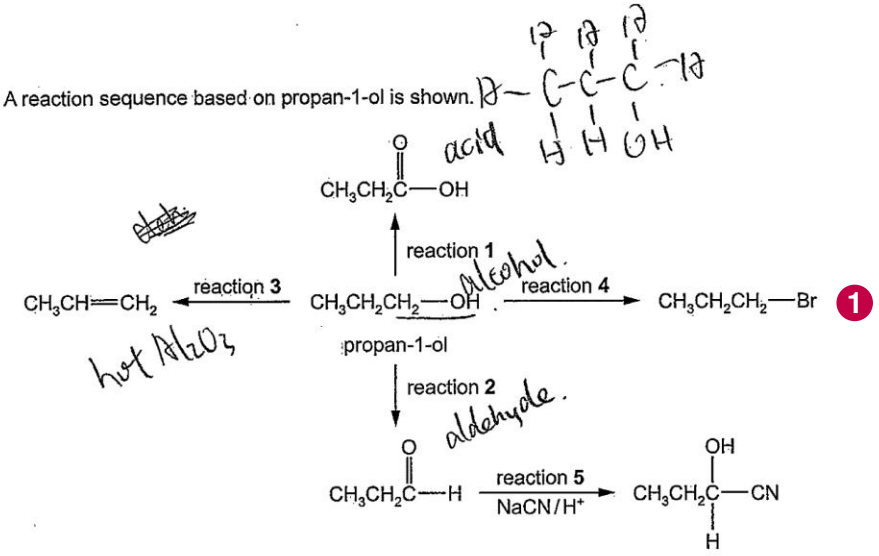
Structures were commonly drawn without giving the structural formulae, as required by the questions.

The most common mistakes were in part **(c)** where candidates did not identify the absorptions clearly enough and also failed to make a clear link between an absorption and a specific bond.

Question 5

Example candidate response – high

5 A reaction sequence based on propan-1-ol is shown.



(a) Reactions **1** and **2** can both be carried out using the same reagents.

(i) Identify suitable reagents for reactions **1** and **2**.

acidified potassium dichromate solution [1]

(ii) State and explain how the reaction should be carried out to ensure that reaction **2** rather than reaction **1** occurs.

The mixture of reaction reactants are heated gently. And aldehyde is distilled off as it forms. Because further oxidation of aldehyde to carboxylic acid will occur if it is not distilled off immediately. [2]

(b) Identify the necessary reagents and conditions for each of reactions **3** and **4**.

reaction 3 reagents: vapour propan-1-ol

conditions: hot Al_2O_3 powders, heated under reflux

reaction 4 reagents: NaBr and conc. H_2SO_4

conditions: heated under reflux [2]

Examiner comments

1 The candidate clearly organises their thoughts before writing their answers, as shown by the rough working on the flow diagram. This is good exam technique.

2 This is correct.

Mark for (a) (i) = 1/1

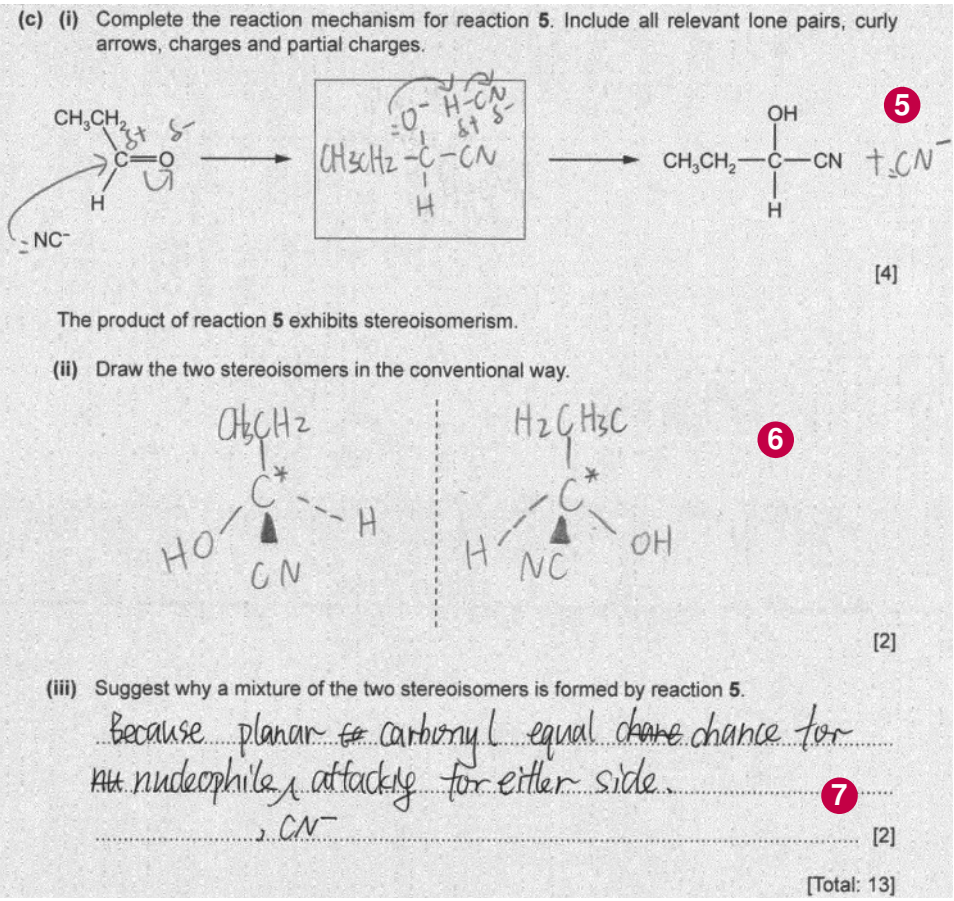
3 A correct, clearly explained answer, addressing both required points.

Mark for (a) (ii) = 2/2

4 The reagents and conditions for both reactions are correctly described and clearly presented.

Mark for (b) = 2/2

Example candidate response – high, continued



(c) (i) Complete the reaction mechanism for reaction **5**. Include all relevant lone pairs, curly arrows, charges and partial charges.

[4]

The product of reaction **5** exhibits stereoisomerism.

(ii) Draw the two stereoisomers in the conventional way.

[2]

(iii) Suggest why a mixture of the two stereoisomers is formed by reaction **5**.

Because planar ~~to~~ carbonyl equal ~~chance~~ chance for ~~the~~ nucleophile, attacking for either side. , CN^-

[2]

[Total: 13]

Examiner comments

5 This mechanism is almost completely correct, and, importantly, the curly arrows are shown clearly coming from either bonds or from lone pairs. The error is the positioning of the lone pair on CN^- ; this should be on the C so that the new bond formed is between C–C. If the mechanism was as shown here with the first curly arrow, the intermediate would have a C–NC bond in it, instead of the C–CN bond shown.

Mark for (c) (i) = 3/4

6 The 3D structures of the two enantiomers have been drawn clearly in the conventional style suggested in the syllabus and all 'connectivity' is correct.

Mark for (c) (ii) = 2/2

7 This is a more advanced explanation than required, but it is clearly correct so earns full marks.

Mark for (c) (iii) = 2/2

Total marks awarded = 12 out of 13

How the candidate could have improved their answer

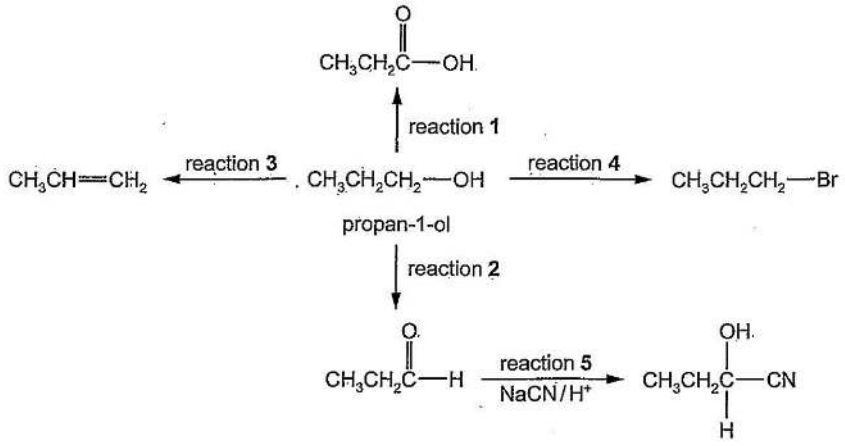
This near-perfect answer only required an adjustment to the positioning of the lone pair (and curly arrow from it) on CN^- (from the N to the C) to be worth full marks.

Mark awarded = **(a) (i) 1/1, (ii) 2/2**
Mark awarded = **(b) 2/2**
Mark awarded = **(c) (i) 3/4, (ii) 2/2, (iii) 2/2**

Total marks awarded = 12 out of 13

Example candidate response – middle

5 A reaction sequence based on propan-1-ol is shown.



(a) Reactions **1** and **2** can both be carried out using the same reagents.

(i) Identify suitable reagents for reactions **1** and **2**.

1

Acidified potassium dichromate.

[1]

(ii) State and explain how the reaction should be carried out to ensure that reaction **2** rather than reaction **1** occurs.

2

The reactants should be placed in a round bottom flask.

The reactants are heated and distilled so as to prevent complete oxidation of propan-1-ol.

[2]

(b) Identify the necessary reagents and conditions for each of reactions **3** and **4**.

3

reaction 3 conc H_2SO_4 200°C

reaction 4 Aqueous HBr Heat

[2]

Examiner comments

1 This is correct.

Mark for (a) (i) = 1/1

2 Both parts of the answer are clearly described and correct.

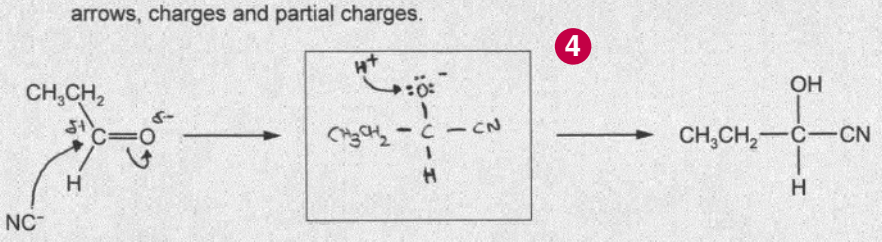
Mark for (a) (ii) = 2/2

3 The reagents and conditions for reaction 3 are correct, but the reference to 'aqueous' makes the conditions for reaction 4 incorrect. If this had been qualified as 'concentrated', this would have been acceptable because concentrated HBr is about a 50:50 mixture, but otherwise 'aqueous' is understood to imply dilute.

Mark for (b) = 1/2

Example candidate response – middle, continued

(c) (i) Complete the reaction mechanism for reaction **5**. Include all relevant lone pairs, curly arrows, charges and partial charges.



4

[4]

The product of reaction **5** exhibits stereoisomerism.

(ii) Draw the two stereoisomers in the conventional way.

5

[2]

(iii) Suggest why a mixture of the two stereoisomers is formed by reaction **5**.

The CN⁻ can do both backside or forward attack, thus forming a product with retension configuration and another one with inversion configuration (S_N2 mechanism) 6 [2]

[Total: 13]

Examiner comments

4 The missing lone pair on the C of CN^- means that M1 in the mark scheme cannot be awarded. M2 and M3 are awarded but not M4 as the curly arrow is shown from the H^+. However, the H^+ has no electrons and it is not possible for a curly arrow to start there because curly arrows are used to show the movement of a pair of electrons. The curly arrow should start at the lone pair of the O^- of the intermediate.

Mark for (c) (i) = 2/4

5 The 3D structures of the two stereoisomers have been drawn correctly.

Mark for (c) (ii) = 2/2

6 The candidate attempts to answer this question using a more advanced idea than required. The phrase 'both backside or forward attack' is credited as a reference to the nucleophile being able to attack from above or below the plane of the molecule. However, the candidate does not state that this is possible due to the planar nature of the carbonyl group.

Mark for (c) (iii) = 1/2

Total marks awarded = 9 out of 13

How the candidate could have improved their answer

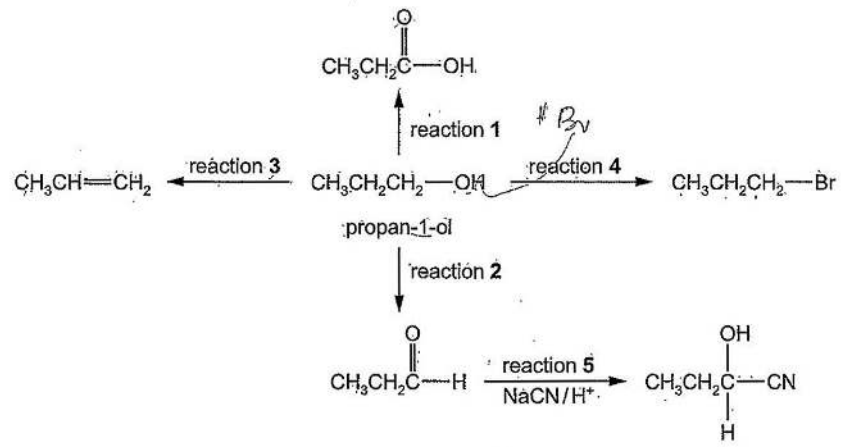
The candidate needed a better understanding of the reaction mechanism and to appreciate that curly arrows should only ever be shown as coming from a lone pair (or from a bond between two atoms).

Mark awarded = **(a) (i) 1/1, (ii) 2/2**
Mark awarded = **(b) 1/2**
Mark awarded = **(c) (i) 2/4, (ii) 2/2, (iii) 1/2**

Total marks awarded = 9 out of 13

Example candidate response – low

5 A reaction sequence based on propan-1-ol is shown.



(a) Reactions **1** and **2** can both be carried out using the same reagents

(i) Identify suitable reagents for reactions **1** and **2**.

~~fore for reaction 1 KMnO4 in H2SO4 or K~~
~~cold kmno4~~ $K_2Cr_2O_7$ in H_2SO_4 [1]

(ii) State and explain how the reaction should be carried out to ensure that reaction **2** rather than reaction **1** occurs.

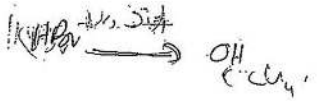
It can be carried out by using K_2CrO_7 at r.t.p
with H_2SO_4 ~~with gas~~ but with reaction ~~are~~ 1
the reaction should be ~~as~~ carried out with heat
with reflux in reaction 2 [2]

(b) Identify the necessary reagents and conditions for each of reactions **3** and **4**.

reaction 3 H_2SO_4 170°c temp

reaction 4 HBr at room temprate ~~as~~ in solvent
~~NaOH~~ NaOH / ethanol

[2]



Examiner comments

1 This is correct, as formulae are an acceptable way to identify reagents.

Mark for (a) (i) = 1/1

2 No mark here, as there is no reference to distillation or why it is needed.

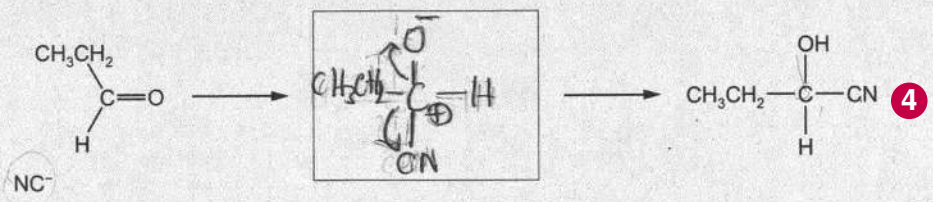
Mark for (a) (ii) = 0/2

3 The reagent and conditions for reaction 3 are correct but 'room temperature' is incorrect for reaction 4 as heat is required.

Mark for (b) = 1/2

Example candidate response – low, continued

(c) (i) Complete the reaction mechanism for reaction **5**. Include all relevant lone pairs, curly arrows, charges and partial charges.

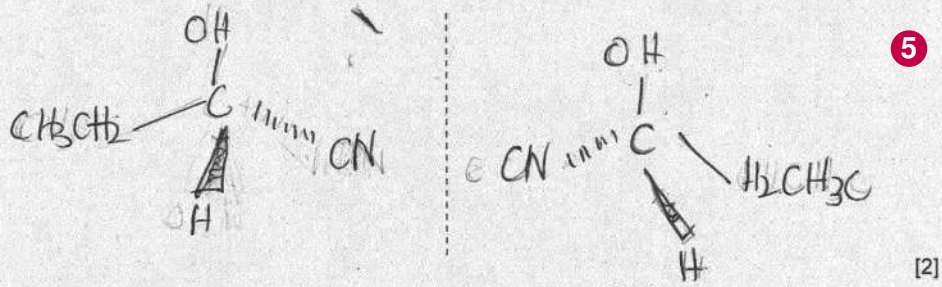


4

[4]

The product of reaction **5** exhibits stereoisomerism.

(ii) Draw the two stereoisomers in the conventional way.



5

[2]

(iii) Suggest why a mixture of the two stereoisomers is formed by reaction **5**.

It is because of the ~~keto~~ carbo cation formed and the double bond has enough electrons so ~~a~~ nucleophilic addition takes place

6

[2]

[Total: 13]

Examiner comments

4 The candidate ignores the need to start the mechanism by adding annotations to the structures drawn in the first stage to show the formation of the intermediate. The structure of the intermediate is almost correct but the mark cannot be awarded because of the incorrect '+' on the central carbon atom. The curly arrows in the box are meaningless.

Mark for (c) (i) = 0/4

5 These are good attempts at showing 3D structures in the conventional manner and they also indicate the mirror-image relationship between the stereoisomers. However, the bonds have been connected incorrectly, so one mark is not awarded (it is not penalised twice). In both structures the bond to OH goes to the H instead of O and, in the right-hand structure the bond to CN from the central C goes to the N instead of the C.

Mark for (c) (ii) = 1/2

6 This is incorrect: there is no carbocation involved in this reaction.

Mark for (c) (iii) = 0/2

Total marks awarded = 3 out of 13

How the candidate could have improved their answer

The candidate needed to have learned more about the oxidation of alcohols.

The candidate needed to follow the conventions involved in drawing mechanisms: curly arrows only ever originate from a bond (to show bond breaking) or from a lone pair on an atom/ion (to show bond forming).

Although the correct convention was used for drawing a 3D structure, connectivity rules should also have been correctly applied so that bonds were shown between the correct atoms.

Mark awarded = **(a) (i) 1/1, (ii) 0/2**
Mark awarded = **(b) 1/2**
Mark awarded = **(c) (i) 0/4, (ii) 1/2, (iii) 0/2**

Total marks awarded = 3 out of 13

Common mistakes candidates made in this question

Common mistakes here were mostly made when drawing the reaction mechanism and not placing the curly arrows carefully enough to represent the process correctly. Lone pairs were often also left out or placed on the wrong atom (in the CN^-).

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