OCR

A2 Chemistry

Questions and Answers

PHILIP ALLAN UPDATES

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Introduction

This online resource contains questions similar in style to those you can expect to see in your A2 examinations. It covers **Unit 4 (F324): Rings, polymers and analysis** and **Unit 5 (F325): Equilibria, energetics and elements**.

The Unit 4 examination lasts 60 minutes and there are 60 marks available. The Unit 5 examination is a longer paper worth 100 marks lasting 1 hour 45 minutes. Time is tight in examinations, so it is important that you practise answering questions under timed conditions. Each question on this online resource identifies the topic, the total marks and a suggested time that should be spent writing out the answer.

The A2 papers are significantly different from the AS papers. They contain stretch-and-challenge questions to extend your knowledge and understanding. We urge you to make use of the sections at the end of each chapter in the textbook by reading carefully the 'additional reading' and then attempting the stretch-and-challenge questions.

The limited number of questions means that it is impossible to cover all the topics and all question styles, but they should give you a flavour of what to expect. The responses given by Candidate A are, on average, A/B-grade standard; those of Candidate B are B/C-grade.

There are several ways of using this online resource. You could print out the questions and:

- 'hide' the answers to each question and try the question yourself. It needn't be a memory test — use your notes to see if you can make all the necessary points.
- check your answers against the candidates' responses and make an estimate of the likely standard of your response to each question
- take on the role of the examiner and mark each of the candidate's response and check to see if you agree with the marks awarded by the examiner
- check your answers against the examiner's comments to see whether you can appreciate where you might have lost marks

In all the questions it is important to analyse where each candidate went wrong and to identify what needs to be done to pick up the extra marks.

Examiner's comments

All candidate responses are followed by the examiner's comments, indicated by the icon *e*, which highlight where credit is due. In the weaker answers, they also point out areas for improvement, specific problems and common errors such as lack of clarity, irrelevance, misinterpretation of the question and mistaken meanings of terms.

Question 1
Polymers

Time allocation: 7–8 minutes

Propene is an important industrial chemical essential in the production of a range of polymers, plastics and fibres. By far the greatest use of propene is as the monomer for polymerisation to poly(propene).

a (i) Draw the monomer propene. (1 mark)

(ii) Draw a section of poly(propene) to show *two* repeat units. (2 marks)

b There are difficulties caused by waste polymers such as poly(propene). Not only are they non-biodegradable, but also when burnt they produce toxic fumes, including acrolein, CH_2=CHCHO, which has a choking odour and is the major cause of death by suffocation in house fires.

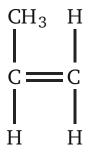
Identify the *two* functional groups present in acrolein and describe how you could test to show the presence of each group. Describe what you would see with each test. (6 marks)

Total: 9 marks

Candidates' answers to Question 1

Candidate A

a (i)



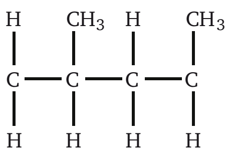
Candidate B

a (i) $CH_3CH{=}CH_2$

Both candidates score 1 mark.

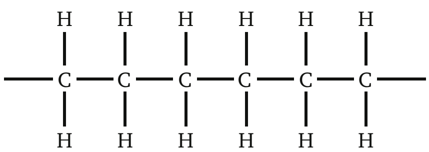
Candidate A

a (ii)



Candidate B

a (ii)



Candidate A scores 1 mark, but carelessly loses 1 mark by not showing the 'end' bonds on the terminal carbon atoms. These are essential because they indicate that the polymer continues on each side. It is worth remembering that a carbon atom must always be drawn with four bonds. Candidate B fails to score because the polymer drawn is three repeat units of poly(ethene), not poly(propene). This is a common error and one to avoid.

Candidate A

b Alkene and aldehyde groups. Alkenes decolourise bromine water. Aldehydes give a silver mirror with Tollens' reagent

Candidate B

b Acrolein contains a carbonyl, which will react with 2,4-dinitrophenylhydrazine to produce a red precipitate. It also contains a C=C, which turns bromine clear.

e Candidate A scores 4 out of the 6 marks. Candidate B scores 3 marks. Both candidates have identified the functional groups and have stated suitable reagents but neither has stated how the tests would be carried out — for example, the test using bromine only works if it is added dropwise to avoid being in excess. Candidate B loses a further mark by using the word 'clear' in the test for the alkene. Bromine is a clear solution; it just happens to be a clear brown solution — since it is already clear, it cannot 'turn clear'.

e **Candidate A scores 6 out of 9 marks while Candidate B scores 4. Candidate B's overall response to this question is equivalent to a grade D. With a little care, the score could have increased by 1 or 2 marks to the B/C borderline.**

Question 2
Nitration of arenes

Time allocation: 11–12 minutes

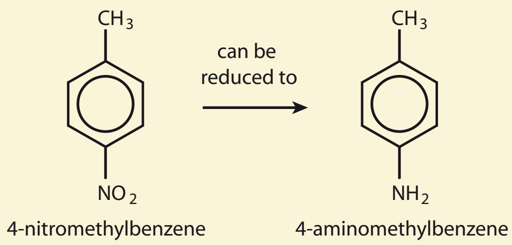
Methylbenzene is an important industrial chemical. It is used in the production of polyurethane plastic foams or fibres such as Lycra®. The production of such foams and fibres involves the nitration of methylbenzene.

a Methylbenzene undergoes electrophilic substitution with the nitronium ion, NO_2^+, to form 4-nitromethylbenzene, $CH_3C_6H_4NO_2$.

(i) With the aid of curly arrows, show the mechanism for the formation of 4-nitromethylbenzene. (3 marks)

(ii) In a laboratory preparation, 9.20 g of methylbenzene was used and 5.48 g of pure 4-nitromethylbenzene was isolated. Calculate the percentage yield and the atom economy of the reaction. (5 marks)

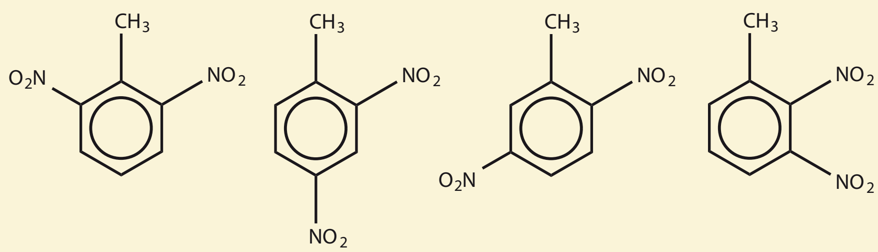
b



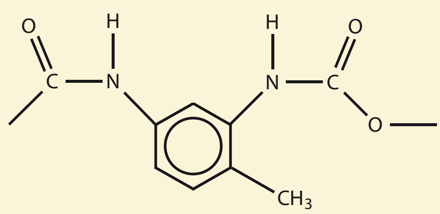
(i) Suggest a suitable reducing agent or a suitable reducing mixture for this reaction. (1 mark)

(ii) Construct a balanced equation for this reduction. Use [H] to represent the reducing agent. (2 marks)

c There are six structural isomers of dinitromethylbenzene, $CH_3C_6H_3(NO_2)_2$. Four are drawn for you, draw the structure of the other *two* isomers. (2 marks)



d The manufacture of Lycra® involves one of these six isomers. A small section of Lycra® is shown below.



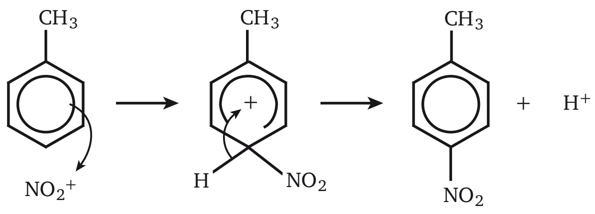
Draw the structure of the isomer of dinitromethylbenzene used in the manufacture of Lycra®. (1 mark)

Total: 14 marks

Candidates' answers to Question 2

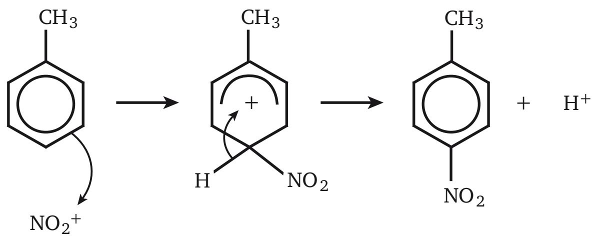
Candidate A

a (i)



Candidate B

a (i)



e Candidate A scores all 3 marks but Candidate B only scores 1. The first marking point is the curly arrow from the π-delocalised ring to the NO_2^+ ion. Candidate B's curly arrow doesn't start at the π delocalised ring. The second marking point is the intermediate, which must show clearly the net positive charge and the breaking of the π-delocalised ring at the carbon being attacked. Candidate B has carelessly drawn the broken π-delocalised ring over three carbon atoms. The final marking point is for the curly arrow showing the reforming of the π-delocalised ring. Both candidates score the final mark.

Candidate A

a (ii) moles of reagent = 9.20/93.0 = 0.099

moles of product = 5.48/139.0 = 0.039

% yield = (0.039/0.099) × 100 = 39.4%

atom economy = (mass of products/mass of reactants) × 100 = (139.0/93.0) × 100 = 149.5%

Candidate B

a (ii) % yield = 40%

atom economy = 67%

e Candidate A scores 1 out of 3 marks for the percentage yield calculation. The relative molecular masses of both methylbenzene and 4-nitromethylbenzene are incorrect and therefore Candidate A loses 2 marks. However, full credit is given for the rest of the calculation. The equation used for atom economy is incorrect and a percentage exceeding 100% should have alerted Candidate A that an error had been made. However, Candidate A displays good examination technique by showing all the working. This enables the examiner to see where mistakes were made and to award marks for the correct processing of the numbers. Candidate B scores all 3 marks for the correct percentage yield. However, Candidate B shows poor examination technique by not showing the working. Neither candidate scores any marks for the atom economy calculation. It is worth remembering that all A2 papers are synoptic and may test knowledge and understanding from the AS specification.

atom economy = (mass of desired product/mass of all products) × 100

The products are $CH_3C_6H_4NO_2$ and H_2O. Therefore:

atom economy = (137.0/155.0) × 100 = 88.4%

Candidate A

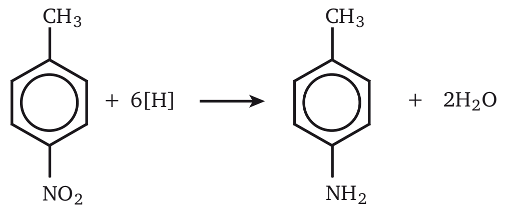
b (i) Sn and conc HCl

Candidate B

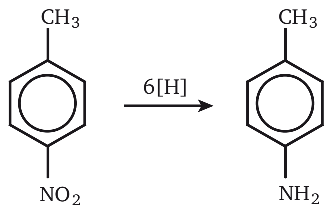
b (i) $LiAlH_4$

e Both candidates gain the mark. Candidate A has quoted the reducing agent mentioned in the specification, but $LiAlH_4$ would also work and so earns the mark for Candidate B.

Candidate A



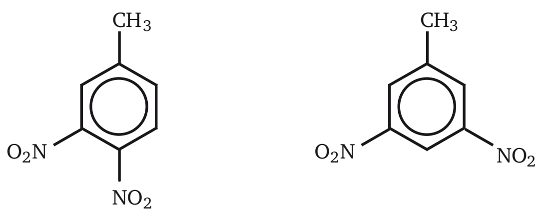
Candidate B



e Candidate A scores both marks. Candidate B loses 1 mark by forgetting to include water in the equation, which is, therefore, not balanced.

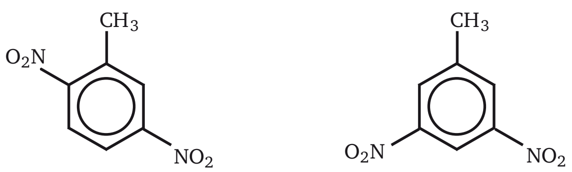
Candidate A

c



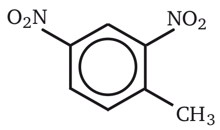
Candidate B

c



e Candidate A scores both marks. Candidate B scores 1 mark only. The first structure drawn by Candidate B is the same as the third structure given in the question.

Candidate A

d 

Candidate B

d 2, 4-dinitromethylbenzene

e Candidate A shows better examination technique by sensibly copying the structure given in the question and replacing the amide groups with NO_2 groups. Candidate B is smart and works out the correct compound, but loses the mark by naming the compound, rather than drawing it.

e **Candidate B seems to be a bright candidate who is perhaps trying to be too clever by cutting corners. This is evident in (a) (ii) when no working is shown. Candidate B scores all 3 marks for the percentage yield calculation but could have easily lost all 3. In the final part, Candidate B does more than is necessary by naming the product. This means that the candidate must have deduced the structure in order to be able to name it, and it appears that he/she did all of this mentally. (Again, there was no evidence of working.) Candidate A shows understanding and carefully uses all the information in the question. The net result is that Candidate A scores 10 out of 14 marks, a grade B answer, while Candidate B scores 7, which is borderline D/C standard.**

Question 3
Carbonyl compounds and carboxylic acids

Time allocation: 9–10 minutes

Propan-1-ol can be oxidised to both propanal and to propanoic acid.

a **(i)** State a suitable oxidising mixture. (2 marks)

(ii) State what you would see during the oxidations. (1 mark)

(iii) Using [O] to represent the oxidising mixture, write a balanced equation to show to show the oxidation of propan-1-ol to propanal. (1 mark)

(iv) Similarly, write a balanced equation to show the conversion of propanal to propanoic acid. (1 mark)

b Describe a simple chemical test that would distinguish between propanal and propanoic acid. State what you would see. (2 marks)

c Compound **X** contains C, H and O only. The relative molecular mass of compound **X** is 102.0. When 5.1 g of compound **X** is burnt in excess oxygen, 6.0 dm^3 CO_2 is produced. Compound **X** can be hydrolysed to form propan-1-ol and one other organic compound.

Use *all* of the information in the question to deduce the molecular formula of compound **X**. Draw the structure of compound **X**. Show all your working. (5 marks)

Total: 12 marks

Candidates' answers to Question 3

Candidate A

a **(i)** Acidified potassium dicromate

Candidate B

a **(i)** $H^+/Cr_2O_7^-$

e Candidate A scores both marks, 1 for the acid and 1 for the dichromate, even though 'dichromate' isn't spelt correctly. Candidate B scores the mark for the acid (H^+) but loses the mark for the dichromate because the charge on the ion should be 2–, not 1–. Spelling is only penalised when marks are allocated for quality of written communication; incorrect formulae are always penalised.

Candidate A

a **(ii)** Orange to green

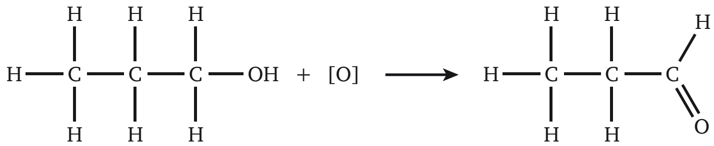
Candidate B

a **(ii)** Turns green

e Candidate A scores the mark. Candidate B, however, has only stated half of what would be observed, so no mark is awarded.

Candidate A

a (iii)



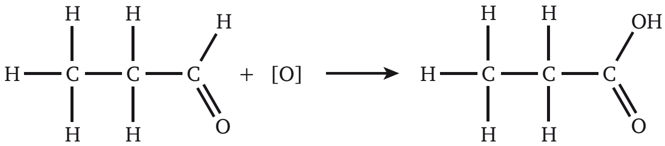
Candidate B

a (iii) $CH_3CH_2CH_2OH \xrightarrow{[O]} CH_3CH_2CHO$

Neither candidate scores the mark because neither has balanced the equation. This is a common error. Both have identified the organic product correctly but the balanced equation also has water as a product.

Candidate A

a (iv)



Candidate B

a (iv) $CH_3CH_2CHO \xrightarrow{[O]} CH_3CH_2COOH$

Both candidates score the mark because the equation is correctly balanced.

Candidate A

b Add a solution of sodium hydrogencarbonate to both. The propanoic acid will react and you will see bubbles of CO_2. The propanal will not react.

Candidate B

b The pH of the acid is lower than the pH of propanal.

Candidate A scores both marks by describing a suitable chemical test and appropriate observations. Candidate B has described how pH could be used to distinguish between the two chemicals. pH is most easily measured using a pH meter, which is not be a *chemical* test. Candidate B would probably be awarded 1 of the 2 marks but may fail to score.

Candidate A

c moles of X = 5.1/102.0 = 0.05

moles of CO_2 = 6.0/24 = 0.25

1 mol of X produces 5 mol of CO_2, therefore X must contain five carbons.

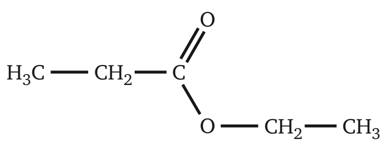
102.0 – 60.0 = 42.0

Hence X contains two oxygens and 10 hydrogens.

Molecular formula of X is $C_5H_{10}O_2$.

X is hydrolysed to form an alcohol. Hence X is an ester.

X is



Candidate B

c Compound X is propyl ethanoate because it hydrolyses to form propan-1-ol and ethanoic acid.

$CH_3COOCH_2CH_2CH_3 + H_2O \rightarrow CH_3COOH + CH_3CH_2CH_2OH$

e The marking points are:

- correct number of moles of X and CO_2 ✓
- ratio of moles of X and CO_2 as 1:5 ✓
- correct molecular formula, $C_5H_{10}O_2$ ✓
- deducing that X is an ester ✓
- identifying propyl ethanoate ✓

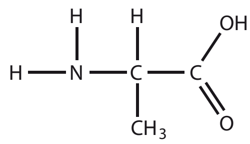
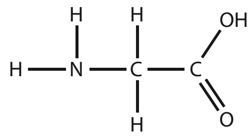
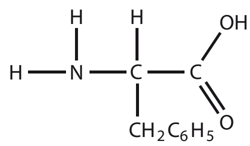
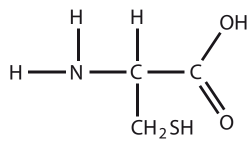
Candidate A has been methodical and followed the guidelines given in the question. Candidate A scores 4 marks for the first four marking points but then carelessly draws ethyl propanoate rather than propyl ethanoate. Candidate B is clearly able but has not followed the instructions in the question. The marks that can be awarded are those for the final three marking points, so Candidate B scores 3. He/she has not used the information given about the mass of X used and the volume of CO_2 produced. Examiners never give information unless it is relevant to the question.

e **As an examiner it is possible to feel a great deal of sympathy for Candidate B. Clearly, the candidate has a good understanding of the topic. However, poor examination technique results in consistent underachievement. This is particularly evident in part (c) where Candidate B quickly sees the answer and correctly deduces the identity of compound X, but doesn't follow the instructions in the question to use *all* of the information given. Consequently, Candidate B only scores 6 out of a possible 12 marks, which equates to a grade D. By contrast, Candidate A is much more methodical and scores 10 marks, which is equivalent to grade A.**

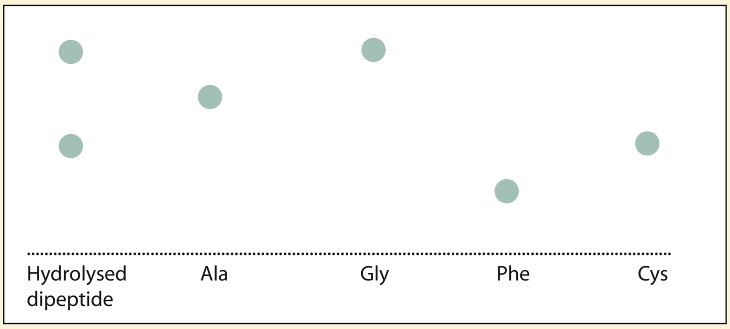
Question 4
Amino acids

Time allocation: 6–7 minutes

This question is about the amino acids in the table below.

Key	Name	Structure
Ala	Alanine	
Gly	Glycine	
Phe	Phenylalanine	
Cys	Cysteine	

a A dipeptide is hydrolysed into its amino acids and the amino acids are identified by chromatography. The results are shown on the chromatogram below.



(i) Identify the amino acids present in the dipeptide. (1 mark)

(ii) Suggest *two* possible structures of the dipeptide. (2 marks)

b The pHs at which the zwitterions of the following amino acids exist are

- glycine, 6.0
- alanine, 6.0
- phenylalanine, 5.5

(i) Draw the ions formed by glycine at pH = 6.0, alanine at pH = 10.0 and phenylalanine at pH = 2.0 (3 marks)

(ii) Suggest why a solution of glycine does *not* conduct electricity at pH = 6.0. (1 mark)

(iii) Suggest why a solution of alanine conducts electricity at pH = 10. (1 mark)

Total: 8 marks

Candidates' answers to Question 4

Candidate A

a (i) Glycine and cysteine

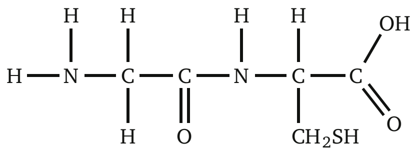
Candidate B

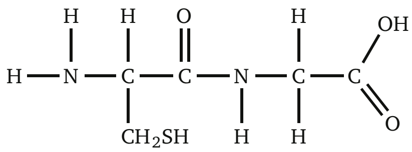
a (i) Gly and cys

e Both candidates gain the mark.

Candidate A

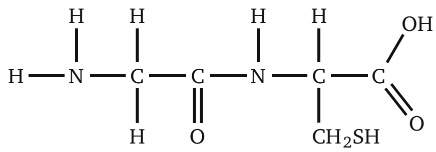
a (ii)





Candidate B

a (ii)

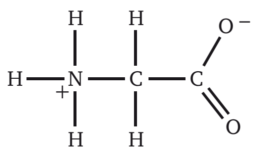


e Candidate A scores both marks. Candidate B has drawn only one of the dipeptides for 1 mark. Candidate B has not read the question carefully — there are 2 marks available, which is a clear indication that two responses are required.

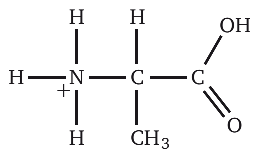
Candidate A

b (i)

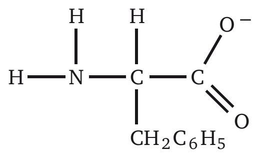
pH = 6.0



pH = 10.0



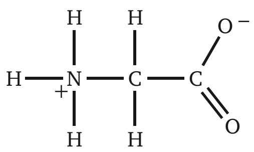
pH = 2.0



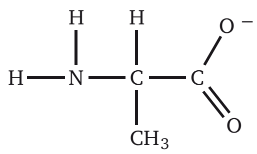
Candidate B

b (i)

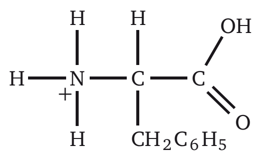
pH = 6.0



pH = 10.0



pH = 2.0



e Candidate A scores 1 mark for the zwitterion at pH = 6.0. However, the charges on the other two ions are incorrect. Candidate B scores all 3 marks.

Candidate A

b (ii) The zwitterion has no net charge.

Candidate B

b (ii) It is a poor conductor.

e Candidate A gains the mark. Candidate B has simply restated the question and no mark is awarded.

Candidate A

b **(iii)** The ion is positive and therefore moves to the cathode.

Candidate B

b **(iii)** It is a good conductor.

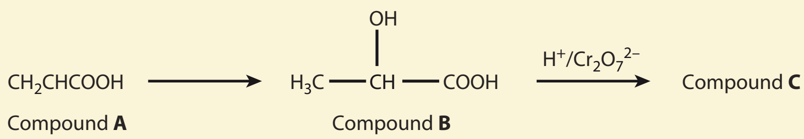
e Candidate A gains the mark. Candidate B has made the same mistake as in part (b) (ii) and fails to score.

e **The most difficult part of this question is (b) (i). Overall, Candidate A scores 6 marks out of 8 and Candidate B scores 5.**

Question 5
Organic synthesis

Time allocation: 7–8 minutes

Consider the reaction scheme shown below.



a **(i)** Name compound **A**. (1 mark)

(ii) Write a balanced equation for the conversion of compound **A** into compound **B**. (1 mark)

b Compound **B**, lactic acid, is found in cheese. It has two stereoisomeric forms.

(i) Draw the two stereoisomers of compound **B.** (2 marks)

(ii) Explain whether or not compound **B**, prepared by the reaction scheme shown, would be a mixture of both stereoisomers. (1 mark)

c **(i)** Draw the structure of compound **C**. (1 mark)

(ii) Compound **C** can be reduced to propane-1,2-diol. Using [H] to represent the reducing agent, construct a balanced equation for this reduction. (3 marks)

Total: 9 marks

Candidates' answers to Question 5

Candidate A

a **(i)** Propenoic acid

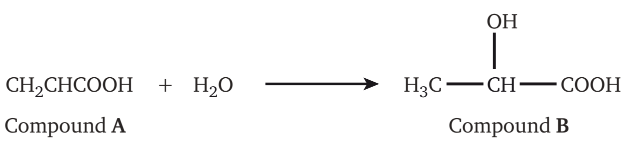
Candidate B

a **(i)** Propanoic acid

e At first glance this part-question looks easy, but it is not. The correct systematic name is prop-2-enoic acid. Candidate B does not notice that there has to be a double bond between the CH_2 and the CH in $CH_2CHCOOH$. Candidates A's attempt is better and would score the mark. Carboxylic acids always end in …oic acid and the carboxylic acid group is always at carbon atom 1. This means that the C=C double bond must be between the second and third carbon atoms. However, in this case, the name propenoic acid is unambiguous and scores the mark.

Candidate A

a **(ii)**



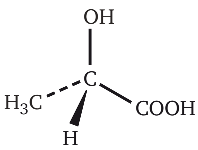
Candidate B

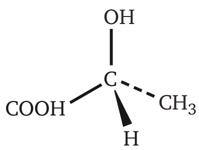
a **(ii)** $C_3H_4O_2 + H_2O \rightarrow C_3H_6O_3$

e Both candidates score the mark. Candidate A has shown good examination technique and copied the information in the question. Candidate B has made life hard by using molecular formulae, which are not required. Many candidates do this and often make mistakes. Use the information in the question and whenever possible avoid mistakes by copying the formulae/structures from the question.

Candidate A

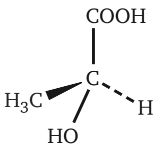
b (i)

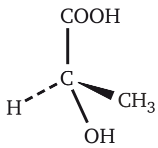




Candidate B

b (i)





e Both candidates score 1 mark, for different reasons. Candidate A has drawn a correct 3D structure but loses a mark for the structure on the right because the carboxylic acid group appears to be bonded to the central carbon via the hydrogen — in examiner jargon this is known as 'incorrect bond linkage'. Candidate B has the four groups bonded correctly and the two isomers are mirror images, but the 3D arrangement is incorrect.

In a 3D diagram the bonds are represented as either a solid line, a wedge or a dotted line:

— indicates a bond in the plane of the paper
◄ indicates a bond in front of the plane of the paper
--- indicates a bond behind the plane of the paper

If two bonds are drawn as — then they are adjacent to each other. This is difficult to visualise but easy to see if you build models of the two stereoisomers.

Candidate A

b (ii) It forms a mixture of both because addition across the double bond could be from either side, it is not stereo-specific. You only get one isomer if enzymes are used.

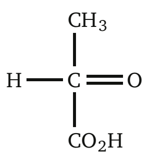
Candidate B

b (ii) An equal amount of each isomer would be formed and therefore they would cancel each other out.

e This is a difficult concept and Candidate A gives a good answer, for 1 mark. Candidate B shows good understanding but does not score the mark because there is no *explanation* given of why a mixture is obtained, merely a statement that a 50:50 mixture would be formed.

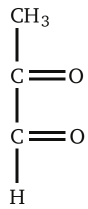
Candidate A

c (i)

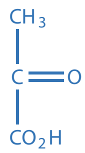


Candidate B

c (i)

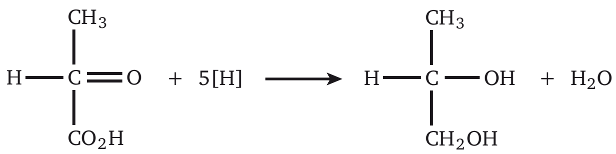


e Neither candidate scores the mark. It is important to recognise that the functional group attached to the middle carbon atom is a secondary alcohol and will therefore be oxidised to a ketone. The other functional group is a carboxylic acid, which is not oxidised. Both candidates recognise that the alcohol will be oxidised. However, Candidate A loses the mark because the central carbon atom has five bonds. Candidate B loses the mark because the carboxylic acid has been reduced back to an aldehyde. The correct structure is:



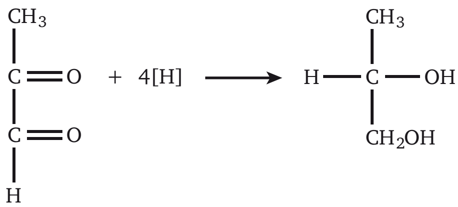
Candidate A

c (ii)



Candidate B

c (ii)



e The three marking points for this part are:

- correct formula for propane-1,2-diol ✓
- H_2O as a product ✓
- equation balanced correctly ✓

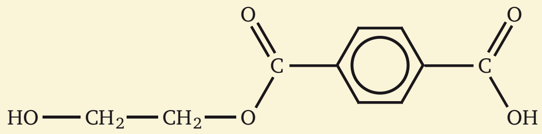
Applying this mark scheme, Candidate A scores 2 marks and Candidate B scores 1.

e **This is a difficult question. Candidate A scores 6 out of 9 marks and Candidate B scores 3. Questions like this are often asked. Examiners are able to use unfamiliar molecules to test routine functional group chemistry. The key to answering this type of question successfully is to identify the essential functional groups and, in each case, to concentrate on the chemistry of the group, ignoring the rest of the molecule.**

Question 6
Carboxylic acids, esters and aldehydes

Time allocation: 9–10 minutes

Compound A has the structure shown below.



Compound A

a Deduce the empirical formula and molecular formula of compound **A**. (2 marks)

b Suggest three different reagents that will react with compound **A.** Identify the organic product(s) of each reaction and name the type of reaction involved. (9 marks)

Total: 11 marks

Candidates' answers to Question 6

Candidate A

a The molecular formula is $C_{10}H_{10}O_5$ and the empirical formula is C_2H_2O.

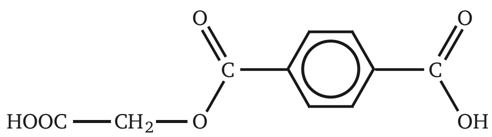
Candidate B

a Empirical formula = C_2H_2O; molecular formula = $HOCH_2CH_2OOCC_6H_4COOH$

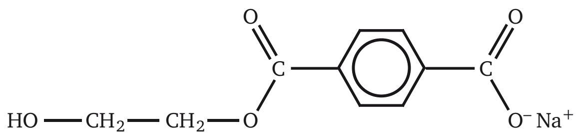
e Candidate A scores both marks but Candidate B scores only 1. Molecular formulae should always be written in the form $C_xH_yO_z$, with the elements that make up the compound grouped together.

Candidate A

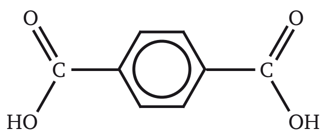
b It is oxidised with $H^+(aq)/Cr_2O_7^{2-}(aq)$ to give:



It is neutralised by NaOH(aq) to give:

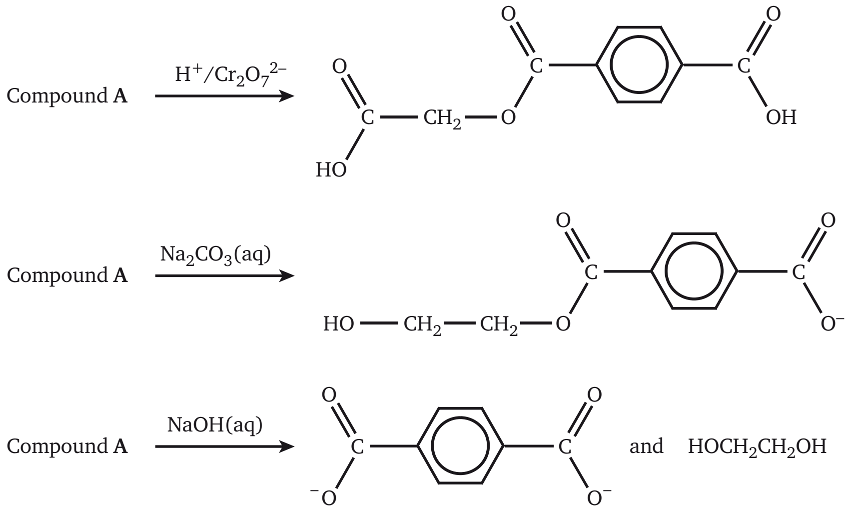


It is hydrolysed by $H_2SO_4(aq)$ to give:



Candidate B

b



Candidate A scores 7 out of 9 marks and Candidate B scores 6. However, Candidate B appears to be the better chemist. The two candidates have adopted different approaches. Candidate A carefully follows the instructions in the question and for each of the three reactions gives reagent, organic product and type of reaction. In the first reaction, all three are correct, for 3 marks. In the second reaction, NaOH neutralises the carboxylic acid but, as it will also hydrolyse the ester, 1 mark is lost. Candidate A drops 1 mark in the final reaction by showing only one of the organic products. Candidate B shows excellent chemistry but loses a mark in each reaction by not stating the type of reaction. Failure to read the question carefully has cost Candidate B a third of the marks.

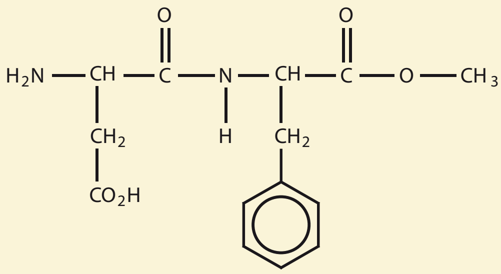
This is a difficult question making use of functional group chemistry in an unfamiliar situation. Candidate A does very well, scoring an A-grade mark of 9 out of 11. Candidate B scores 7 marks. However, the responses to part (b) show clearly that Candidate B is the better chemist. With more care, Candidate B could have scored all 11 marks. Every mark is important! Candidate B scores just over 60%, which is equivalent to grade C.

Question 7
Amides, esters and chirality

Time allocation: 11–12 minutes

Print out this question, so that you can make the required additions to the diagram.

Aspartame, shown below, can be used as an artificial sweetener:



a **(i)** Aspartame contains five functional groups including the benzene ring. Name the other four functional groups (4 marks)

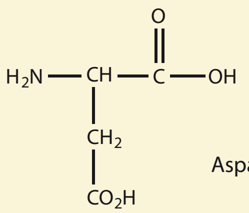
(ii) *Two* of the four functional groups can be hydrolysed. Circle these groups on the diagram. (2 marks)

(iii) Show the structures of the organic products formed by the acid hydrolysis of aspartame. (3 marks)

b **(i)** Aspartame has two chiral carbon atoms. Identify each with an asterisk (*) on the diagram. (2 marks)

(ii) Explain what is meant by the term *chiral* and deduce the number of possible stereoisomers. (2 marks)

c Aspartame can be made from aspartic acid.



Aspartic acid

Suggest the structure of a compound that could react with aspartic acid to make aspartame. (1 mark)

Total: 14 marks

Candidate A

a **(i)** Amide, carboxylic acid, ester, peptide

Candidate B

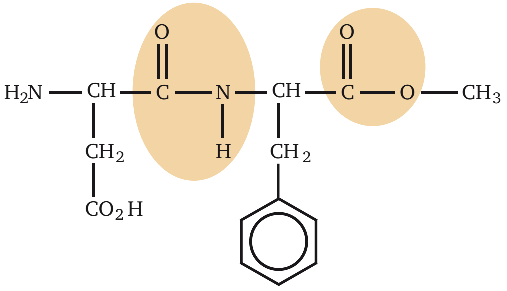
a **(i)** Amine, amide, ketone, carboxylic acid, ester.

e Candidate A scores 3 of the 4 marks. 1 mark is lost because amide and peptide are the same. The missing functional group is amine. Many candidates adopt the technique used by Candidate B. The question asks for *four* functional groups, so candidates think that they are hedging their bets by listing *five* functional groups. There are *only four* functional groups.

By writing five, Candidate B automatically loses 1 mark. The wrong answer is marked first — the examiner will not select the correct answers from a list of alternatives.

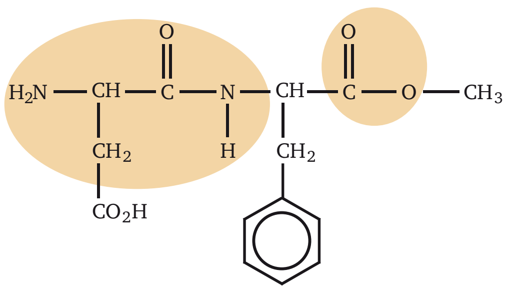
Candidate A

a (ii)



Candidate B

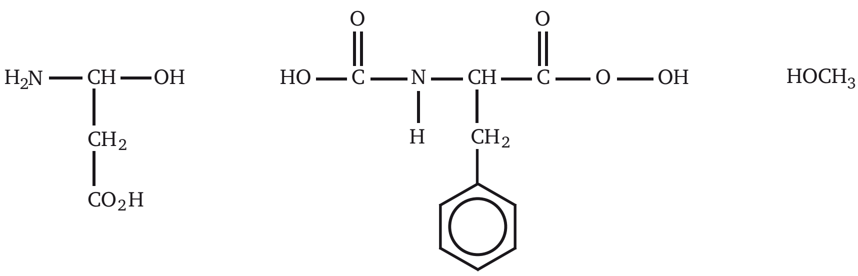
a (ii)



e Candidate A scores both marks. Candidate B loses a mark by extending the circle to include both the amide and the amine groups.

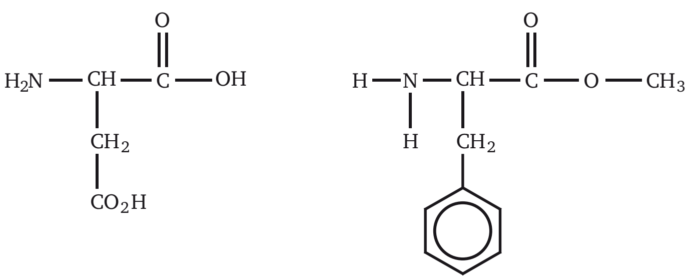
Candidate A

a (iii)

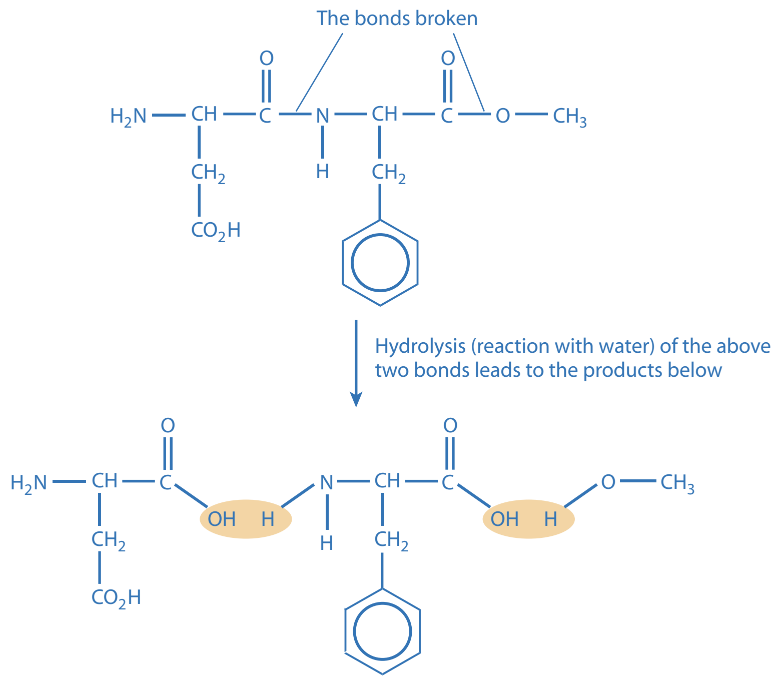


Candidate B

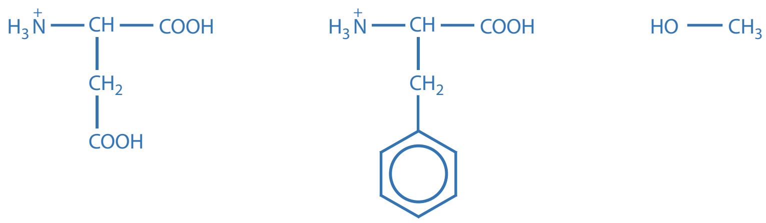
a (iii)



e There are 3 marks allocated here, indicating that there are three products. Candidate A has used this information but Candidate B displays poor examination technique by only drawing two products. Hydrolysis is a difficult concept. Both the amide and the ester undergo hydrolysis. The bonds that break and the correct products are shown in the diagram below. However, the acid used as a catalyst will then react with NH_2 groups to form $^{+}NH_3$ salts. Use the answer below to work out where each candidate went wrong.



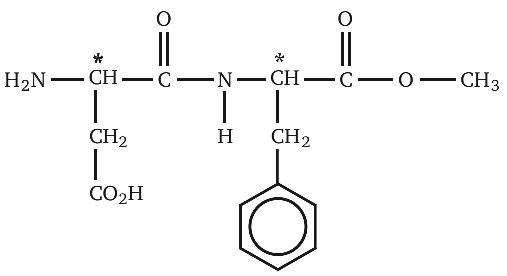
The final products using acid hydrolysis are:



Candidate A scores just 1 mark and Candidate B fails to score.

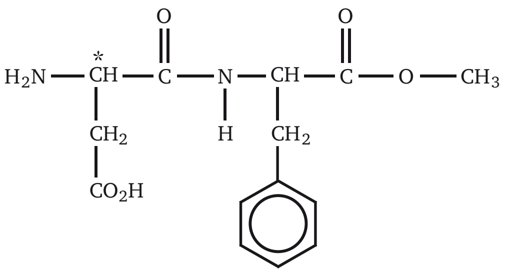
Candidate A

b (i)



Candidate B

b (i)



e Candidate A scores both marks. Candidate B has ignored the instructions in the question and only identified one of the chiral carbons, for 1 mark.

Candidate A

b **(ii)** The carbon is bonded to four different atoms or groups. There will be four (2^2) stereoisomers.

Candidate B

b **(ii)** Carbon is bonded to four atoms or groups and there will be four isomers.

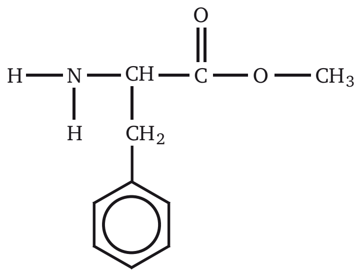
e Candidate A scores both marks. Candidate B scores 1 mark for the correct number of stereoisomers but carelessly loses 1 mark. Almost all carbon atoms are bonded to four atoms or groups. The key word missed by Candidate B is that the four atoms/groups must all be *different*.

Candidate A

c [This was left blank]

Candidate B

c



e Candidate A has made no attempt at this part whereas Candidate B has used the information given in the question and deduced the structure of the compound correctly, for 1 mark. Writing nothing will definitely earn no marks, so always have a try.

e **Candidate B's response to the final section demonstrates considerable understanding and yet the outcome for the whole question is that Candidate B scores 7 out of 14 marks and Candidate A scores 10. Look back at B's responses and identify where careless errors have been made.**

Question 8
Azo dyes

Time allocation: 8–9 minutes

a Nitrobenzene can be converted into benzenediazonium chloride, $C_6H_5N_2Cl$. For each step, state the reagents and conditions, and write an equation. Show the structure of the organic products. (6 marks)

b Benzenediazonium chloride reacts with a chlorinated phenol to form an azo dye with a relative molecular mass of 267.0 and the following composition by mass: C, 53.9%; H, 3.0%; N,10.5%; Cl 26.6%; O, 6.0%. Use this information to deduce the structure of the azo dye. (4 marks)

Total: 10 marks

Candidates' answers to Question 8

Candidate A

a Step 1:

Reagents: concentrated HCl and Sn

Conditions: reflux

Equation: $C_6H_5NO_2 + 6[H] \rightarrow C_6H_5NH_2 + 2H_2O$

Step 2:

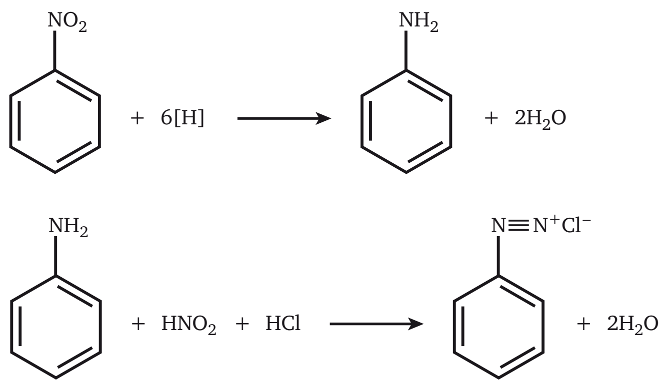
Reagents: sodium nitrite and hydrochloric acid

Conditions: excess HCl(aq), temperature below 10°C

Equation: $C_6H_5NH_2 + HNO_2 + HCl \rightarrow C_6H_5N_2Cl + 2H_2O$

Candidate B

a



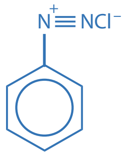
Both candidates clearly know the chemistry, but both lose marks due to poor examination technique. Before attempting this type of question, read the question carefully and work out where the marks are likely to be allocated. Here, there are 6 marks for two steps, i.e. 3 marks for each step. The marking points are:

- reagents and conditions ✓
- an equation ✓
- the structure of the organic products ✓

Candidate A displays good examination technique but only scores 2 marks for each step because he/she fails to show the structures of phenylamine and benzenediazonium chloride.

Candidate B scores 3 marks. In the first step, the equation is correct and the structure of phenylamine is correct, for 2 marks. 1 mark is lost because the reagents and conditions are not given. The second equation is also correct, but the charge is on the wrong nitrogen in the diazonium compound. There is also no reference to the temperature required, so just 1 mark is awarded.

The correct structure for benzenediazonium chloride is:



Candidate A

b

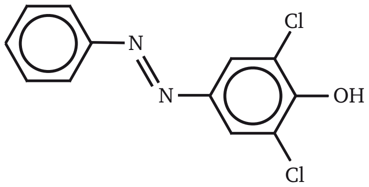
	C	H	N	Cl	O
Moles	53.9/12.0 = 4.5	3.0/1.0 = 3.0	10.5/14.0 = 0.75	26.6/35.5 = 0.75	6.0/16.0 = 0.375
Ratio (divide by smallest)	12	8	2	2	1
Mass of element in compound	144.0	8.0	28.0	71.0	16.0

Mass of compound = 144.0 + 8.0 + 28.0 + 71.0 + 16.0 = 267.0

Therefore, empirical and molecular formulae are both $C_{12}H_8N_2Cl_2O$.

Candidate B

b $C_{12}H_8N_2Cl_2O$



Both candidates score 3 marks. Candidate B successfully deduces the structure of the azo dye (the most difficult part of the question) while Candidate A makes no attempt to do so. Candidate A demonstrates good examination technique, showing all working. Candidate B calculates the empirical formula but does not use the relative molecular mass (267.0) to show that the molecular formula is the same as the empirical formula.

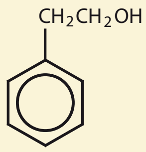
Candidate A score 7 out of 10 marks and Candidate B scores 6. This might not seem to be much of a difference, but if this were repeated throughout the paper Candidate A would achieve a grade B and Candidate B would get a grade C. Once again, poor examination technique has cost marks.

Question 9
Spectroscopy

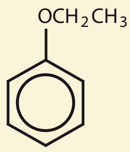
Time allocation: 11–12 minutes

Compounds **A** and **B** are structural isomers.

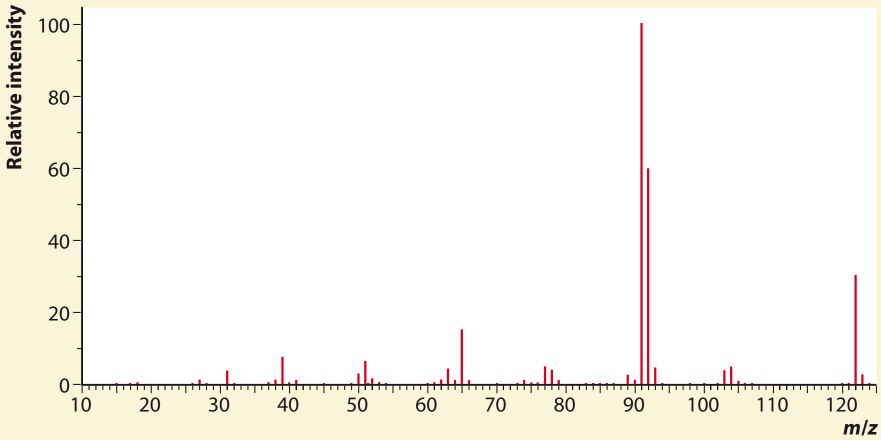
A



B

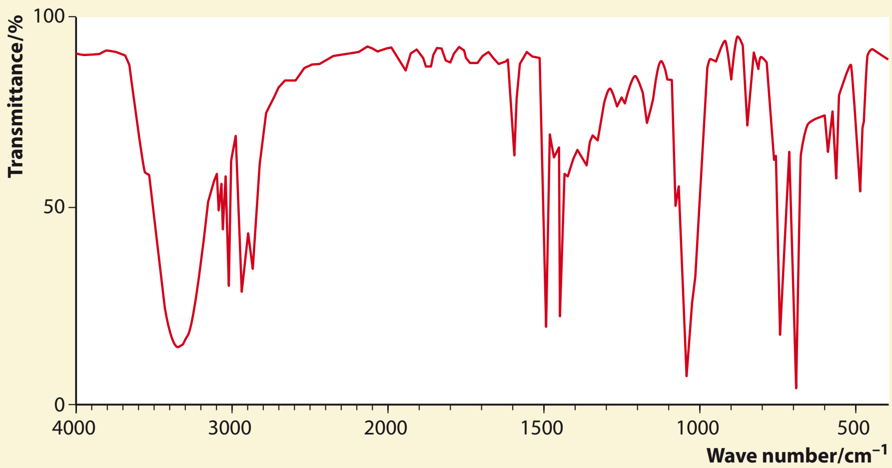


a **(i)** The mass spectrum of one of the compounds is shown below. Explain how the fragmentation pattern allows you to deduce that it is *not* compound **B**. (2 marks)



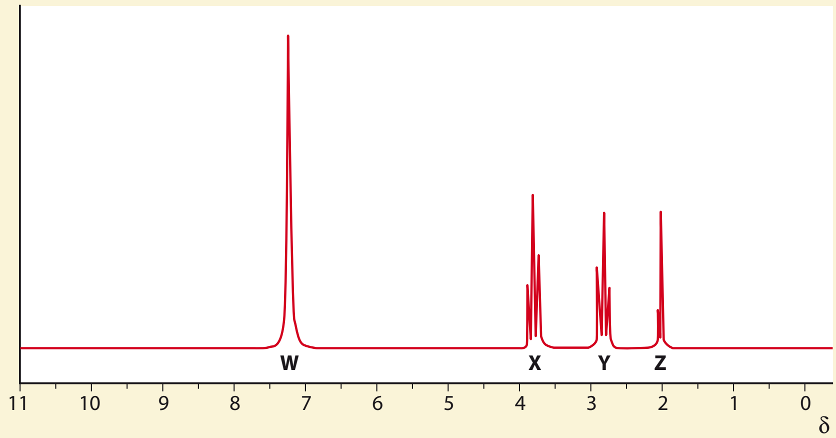
(ii) Write an equation to show the formation of the molecular ion for compound **A**. (1 mark)

b One of the compounds **A** or **B** gives the infrared spectrum below.



Using the *Data Sheet*, identify which of the two compounds **A** or **B** has this spectrum. Explain your reasoning carefully. (2 marks)

c One of the compounds **A** and **B** gives the ^1H NMR spectrum below.



When a second spectrum was run with D_2O added, the peak **Z** at $\delta = 2.0$ disappeared. Using the *Data Sheet*, suggest the identity of the protons responsible for the groups of peaks **W, X, Y** and **Z**. For each group of peaks, explain your reasoning carefully. Use *all* of the information given. (9 marks)

1 mark is available for the quality of written communication.

Total: 15 marks

Candidates' answers to Question 9

Candidate A

a (i) Parts of the side chains break off. Compound A will form an ion due to CH_2OH at $m/z = 31$; compound B will form an ion at 29 due to CH_2CH_3. This peak is not present in the spectrum.

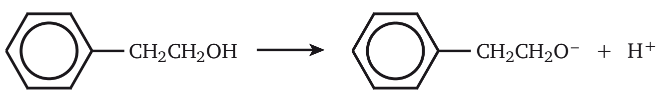
Candidate B

a (i) B would form an ion at 29 and this peak is not present.

Candidate A gives a textbook answer and scores both marks. Candidate B understands fragmentation but does not explain what would be responsible for a peak at 29 and only scores 1 out of 2 marks.

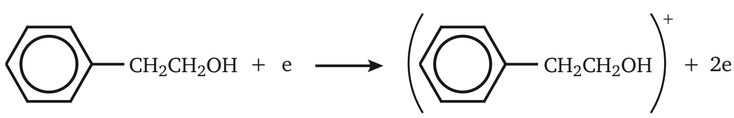
Candidate A

a (ii)



Candidate B

a (ii)



Candidate B scores the mark. Candidate A has misunderstood the process of forming the molecular ion and fails to score.

Candidate A

b The peak between 3230 cm^{-1} and 3550 cm^{-1} is due to the hydrogen bonding in alcohols and therefore the spectrum is for compound A.

Candidate B

b It is the alcohol.

e Candidate A gives the perfect answer making use of the instructions in the question and quoting directly from the *Data Sheet*. Candidate B is awarded 1 mark for identifying that the spectrum shown is that of an alcohol, but loses the other mark for not giving a reason and not identifying the alcohol as either compound A or B.

Candidate A

c When the spectrum is re-run using D_2O, peak Z disappears, showing that peak Z is due to a labile proton, which is found in groups such as the –OH group. Peaks X and Y are both split into triplets, showing that the adjacent carbons must be attached to two hydrogens — the $(n + 1)$ rule. Peak W is due to the five hydrogens on the benzene ring.

Candidate B

c It has to be compound A because the alcohol (OH) peak disappears when run in D_2O. Compound B does not have an OH.

e The marking points are:

- Peak **W**:
  - benzene ring ✓
  - chemical shift = 7.1– 7.7 ppm or relative number of H's = 5 ✓
- Peaks **X** and **Y**:
  - both are CH_2 ✓
  - both are split into triplets ✓
  - adjacent carbons attached to two hydrogens ✓
- Peak **X**: CH_2 attached to the benzene ring 2.3 – 2.7 ppm ✓
- Peak **Y**: CH_2 attached to O 3.3 – 4.3 ppm ✓
- Peak **Z**:
  - OH ✓
  - when re-run in D_2O it disappears ✓

e The quality of written communication mark is awarded for the correct use of at least two terms from labile, chemical shift or splitting.

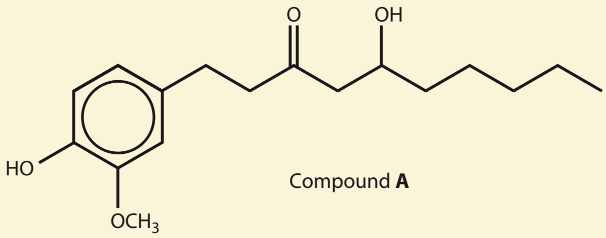
Candidate A follows the guidelines given in the question and scores 6 marks. Try marking Candidate A's answer and see if you can identify which 3 marks have been lost. Candidate B clearly understands NMR and can use it to identify the correct compound, but ignores most of the question. This poses a dilemma for the examiner. The marker has to stick to the agreed mark scheme and it is just about possible to award 2 marks to Candidate B. However, the candidate has not followed the instructions and has not identified which group is responsible for any of the four peaks and scores only 1 mark.

e **The outcomes for the candidates are very different. Candidate A scores 10 out of 15 marks while Candidate B scores only 4. Once again, Candidate A demonstrates better examination technique. This is most apparent in the open-ended final part of the question, which allows a free response. Candidates have to use the information given in the question together with the mark allocation and plan how best to obtain those marks. It is worth remembering that 1 mark is usually given for each correct point, so an allocation of 9 marks indicates that nine separate points are required.**

Question 10
Analysis

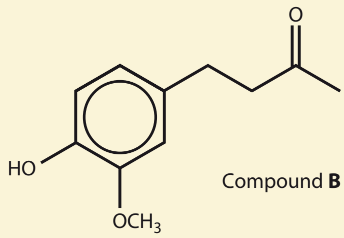
Time allocation: 6–7 minutes

a A sample of torn clothing was found at the scene of a crime. The clothing had a yellow stain, which was thought to be one of the two compounds shown below:



Compound **A**

or



Compound **B**

Explain how a forensic scientist could determine which, if either, of compound **A** or compound **B** is responsible for the yellow stain. (5 marks)

b Suggest a chemical test that could be used to distinguish between compounds **A** and **B**. State the reagent and conditions and explain what you would expect to see. Identify the organic product. (3 marks)

Total: 8 marks

Candidates' answers to Question 10

Candidate A

a The forensic scientist should use spectroscopy. A mass spectrum of each compound could be used to determine the molar mass. Compound A would have a higher mass than compound B. The ^{13}C NMR spectrum of compound A would have more peaks than that of compound B. The infrared spectrum of compound A would have a broad peak around 3200–3500 cm^{-1} due to the alcohol, –OH. This peak would not be present in the infrared spectrum of compound B.

Candidate B

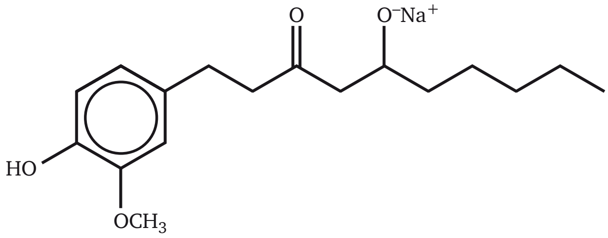
a The ^{1}H NMR spectra of both compounds would have some peaks in common and it would be difficult to distinguish between them. If D_2O were used, two peaks would disappear from the spectrum of compound A and only one peak would disappear from the spectrum of compound B. Compound A would react with a carboxylic acid to make an ester and compound B would not react.

e This is a difficult question because it is open-ended and there are a number of possible approaches. However, both candidates have missed the point of the question. They have explained how compounds **A** and **B** differ, but have not explained how each one could be identified unambiguously. Both candidates have made some correct statements. Candidate A has recognised that the mass spectra of compounds A and B would have different molecular ion peaks and that their ^{13}C NMR spectra would have a different number of peaks. Candidate A would probably score 2 out of 5 marks. Candidate B would probably score 1 mark for recognising that ^{1}H NMR could be used to distinguish between the two compounds.

Unambiguous identification can be achieved only by comparing the spectra with spectra from a database. The fingerprint region of the infrared spectrum is helpful, but may not be conclusive. If infrared spectroscopy is used in conjunction with GC–MS it should, by also using the fragmentation pattern of the mass spectrum, lead to an unambiguous identification.

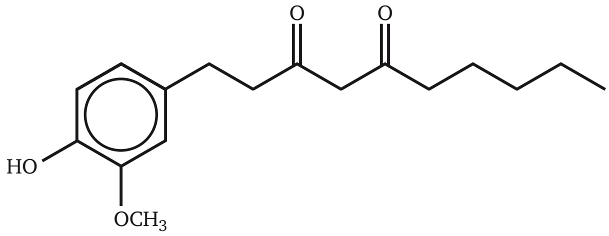
Candidate A

b Compound A contains an alcohol, so it will react with sodium and give off bubbles of hydrogen. The organic product is:

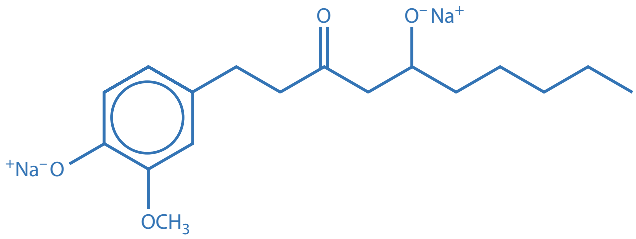


Candidate B

b Compound A can be oxidised by $H^+/Cr_2O_7^-$. It will turn from orange to green. The product is:



e Both candidates would probably score 2 of the 3 marks. Candidate A loses a mark for suggesting that sodium could be used. Sodium does react with the alcohol group, but it also reacts with the phenolic OH. Compounds A and B are both phenols. Candidate A scores 1 mark for the observation and might score a mark for the product. However, the correct product is:



Candidate B carelessly loses a mark by writing the dichromate ion as $Cr_2O_7^-$ when it should be $Cr_2O_7^{2-}$.

e **The is not a good question for either candidate. Candidate A scores 4 (possibly only 3) out of 8 marks and Candidate B scores 3.**

Marks scored by the candidates on Unit 4 questions

The total number of marks available for Unit 4 questions is 110.

- **Candidate A scores 78 marks, which is 71%.**
- **Candidate B scores 52 marks, which is 47%.**

Candidate A's total equates to a grade B. However, another 10 marks would be an A-grade. This sounds a lot, but across ten questions Candidate A only needs to improve by 1 mark per question to achieve this. Candidate B achieves a disappointing grade E. An improvement of just 3 marks per question would give Candidate B a comfortable grade B. If you look carefully at Candidate B's responses, you will see a mixture of poor examination technique and insufficient knowledge. Candidate B is better than a grade E. Examiners often feel that a candidate has underperformed, but marking schemes are rigid and marks are awarded only when the question has been answered fully.

Question 11
Rate equation

Time allocation: 12–13 minutes

The reaction between hydrogen and nitrogen monoxide is a redox reaction, which results in the formation of nitrogen and water.

a **(i)** Write a balanced equation for the reaction. (1 mark)

(ii) Identify the oxidising agent in the reaction. Justify your answer. (2 marks)

The rate equation for the reaction is:

rate = $k[H_2(g)][NO(g)]^2$

b Using 1.2×10^{-2} mol dm^{-3} $H_2(g)$ and 6.0×10^{-3} mol dm^{-3} NO(g), the initial rate of this reaction was 3.6×10^{-2} mol dm^{-3} s^{-1}. Calculate the rate constant, *k*, for this reaction. Quote your answer to two significant figures. State the units of the rate constant, *k*. (4 marks)

c Calculate the initial rate of reaction when each of the following changes is made. Show your working.

(i) The concentration of the H_2 is tripled. (1 mark)

(ii) The concentration of the NO is halved. (1 mark)

(iii) The concentrations of both are doubled. (1 mark)

d Dinitrogen pentoxide decomposes according to the equation:

$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$

The decomposition is a first-order reaction with respect to $N_2O_5(g)$.This decomposition proceeds by a two-step mechanism with the rate-determining step taking place first.

(i) Write a rate equation for this reaction. (1 mark)

(ii) Explain the term *rate-determining step*. (1mark)

(iii) Suggest the two steps for this reaction and write their equations below. Show clearly that the two steps equate to the balanced equation given above. (3 marks)

Total: 15 marks

Candidates' answers to Question 11

Candidate A

a **(i)** $2H_2 + 2NO \rightarrow N_2 + 2H_2O$

Candidate B

a **(i)** $H_2 + NO \rightarrow \frac{1}{2}N_2 + H_2O$

e Both candidates score the mark. The equation must be balanced and it is acceptable to use fractions.

Candidate A

a **(ii)** The H_2 has been oxidised because its oxidation number increases. Therefore, the NO is the oxidising agent.

Candidate B

a (ii) NO

e There are only two possible answers, the oxidising agent must be either H_2 or NO, so there is a 50:50 chance of guessing the answer. When questions like this are asked, there are usually no marks just for the correct answer. The marks are awarded for the explanation. Both candidates have given the correct answer but Candidate B has given no explanation and so fails to score. The explanation given by Candidate A scores both marks, although the answer is not ideal. It would be better to include relevant oxidation numbers to support the answer. The oxidation number of nitrogen in NO is +2; the oxidation number of nitrogen in N_2 is 0. This reduction in the oxidation number as a result of the reaction identifies NO as the oxidising agent.

A good exam tip is to write the oxidation numbers above each element in the equation:

0 +2–2 0 +1–2

$2H_2 + 2NO \rightarrow N_2 + 2H_2O$

The changes can then be seen easily.

Candidate A

b rate = $k[H_2(g)][NO(g)]^2$

$3.6 \times 10^{-2} = k\ (1.2 \times 10^{-2})(6.0 \times 10^{-3})^2$

$3.6 \times 10^{-2} = k\ (1.2 \times 10^{-2})(3.6 \times 10^{-5})$

$3.6 \times 10^{-2} = k\ (4.32 \times 10^{-7})$

$k = 3.6 \times 10^{-2}/(4.32 \times 10^{-7}) = 83333.3 \quad = 8.3 \times 10^4$ (2 s.f.)

Candidate B

b $3.6 \times 10^{-2} = k\ (1.2 \times 10^{-2})(6.0 \times 10^{-3})^2$

$3.6 \times 10^{-2} = k\ (1.2 \times 10^{-2})(36 \times 10^{-6})$

$3.6 \times 10^{-2} = k\ (43.2 \times 10^{-8})$

$k = 3.6 \times 10^{-2}/(43.2 \times 10^{-8}) = 83333.3$

e Both candidates have calculated the correct numerical value but neither has quoted the units for k and both, therefore, lose a mark. Units for the rate constant involve some thought and will always carry 1 mark. The question also asks for the answer to two significant figures. Candidate B has ignored this and loses another mark. In the examination, there is usually a question that tests understanding of significant figures. It is easy to forget this by the time you arrive at the end of a calculation.

At A2, it is also possible that a mark might be awarded for the correct use of significant figures, without a specific warning being given in the question. If this is the case, there is usually some leeway. However, it is good practice always to consider the appropriate number of significant figures that should be included in your answer. This is not difficult. All that is required is that the number of significant figures in your answer should be the same as that of the information given in the question. In this question part, all the data in the question is given to two significant figures.

Candidate A

c (i) The rate triples.

Candidate B

c (i) The rate triples.

e Both candidates are correct, for 1 mark

Candidate A

c (ii) The rate is twice as slow.

Candidate B

c (ii) The rate is half as fast.

e Neither candidate is correct. If the concentration of NO is halved, then the rate will change by a factor of $(\frac{1}{2})^2 = \frac{1}{4}$.

Candidate A

c (iii) The rate is four times as fast.

Candidate A

c (iii) The rate is eight times as fast.

e Candidate B scores the mark. Overall, the reaction is third order and if both concentrations are doubled, the rate will change by a factor of $2^3 = 8$. Candidate A does not score.

Candidate A

d (i) rate = $k[N_2O_5]$

Candidate B

d (i) rate = $[N_2O_5]$

e Candidate A gains the mark. Candidate B has forgotten to include the rate constant, *k*, and loses the mark.

Candidate A

d (ii) The slowest step in the mechanism.

Candidate B

d (ii) The slowest step

e Both candidates score the mark.

Candidate A

d (iii) Slow rate-determining step: $1N_2O_5 \rightarrow 2NO_2 + O$

Fast step $O + 1N_2O_5 \rightarrow 2NO_2 + O_2$

Balanced equation $2N_2O_5 \rightarrow 4NO_2 + O_2$

Candidate B

d (iii) $1N_2O_5 \rightarrow N_2O_3 + O_2$

$N_2O_3 + 1N_2O_5 \rightarrow 4NO_2$

$2N_2O_5 \rightarrow 4NO_2 + O_2$

e Candidates find devising mechanisms difficult. However, both candidates have given good answers, scoring full marks. Where a question says 'Suggest', it means that the examiner is not expecting a particular answer but is trying to find out whether candidates can provide an idea that could be true. The exact mechanism is not relevant, but both candidates have used the information in the question to suggest valid alternatives.

e **Overall, Candidate A scores 12 out of 15 marks which is grade-A standard. Candidate B scores 9, which equates to grade C. With a little more care and better examination technique, this could easily have become grade-A standard.**

Question 12 Equilibrium

Time allocation: 14–15 minutes

Hydrogen and iodine react according to the equation:

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = +53.0\,kJ\,mol^{-1}$

a State Le Chatelier's principle. (1 mark)

b Use Le Chatelier's principle to predict what happens to the position of the equilibrium when:

(i) the temperature is increased

(ii) the pressure is increased

(iii) a catalyst is used

Justify each of your predictions. (6 marks)

c Write an expression for K_c for the equilibrium. State the units, if any. (2 marks)

d **(i)** When 0.18 mol of I_2 and 0.50 mol H_2 were placed in a 500 cm^3 sealed container and allowed to reach equilibrium, the equilibrium mixture was found to contain 0.01 mol of I_2. Calculate K_c. (5 marks)

(ii) Explain what would happen to the value of K_c if the experiment were repeated using a container with a volume of 1.00 dm^3. (2 marks)

Total: 16 marks

Candidates' answers to Question 12

Candidate A

a When a system at equilibrium is subjected to a change, the system will move to try to minimise the effect of the change.

Candidate B

a When a system at equilibrium is subjected to a change in external conditions, the system will move to cancel the effect of the change.

e Candidate A scores the mark but Candidate B doesn't. Le Chatelier's principle states that the system responds to change by trying to *minimise* the effect of that change. It *cannot* cancel out the change.

Candidate A

b **(i)** The equilibrium moves to the right because it favours the endothermic forward reaction.

Candidate B

b **(i)** More HI will be produced because heat is absorbed when the forward reaction takes place

e Both candidates are correct, for 2 marks.

Candidate A

b (ii) No effect, because there is an equal number of molecules of gas on both sides.

Candidate B

b (ii) It speeds up the reaction because it increases the chances of collision.

e Candidate A is correct, for 2 marks. Candidate B fails to score because the response relates to the rate of the reaction, *not* the position of equilibrium.

Candidate A

b (iii) A catalyst lowers the activation energy. The H_2 and I_2 react more readily so that more HI is made. Therefore, the equilibrium moves to the right.

Candidate B

b (iii) It speeds up the reaction by lowering the activation energy.

e What Candidate A has written is partly correct, but the candidate has failed to realise that the catalyst also affects the reverse reaction, so the position of the equilibrium remains unchanged. Therefore, Candidate A loses the marks. Candidate B fails to score because the response relates to the rate of the reaction and not to the position of equilibrium.

Candidate A

c

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

There are no units.

Candidate B

c

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

There are no units.

e Both candidates score 2 marks.

Candidate A

d (i) $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

Initial moles: H_2, 0.50; I_2, 0.18; HI, 0

Final moles: 0.01 mol of I_2 remain.

Therefore, it follows that 0.17 mol of I_2 and 0.17 mol of H_2 also reacted.

Hence the moles of H_2 left = 0.50 – 0.17 = 0.33 mol.

For each mole of I_2 and H_2 that react, 2 mol of HI are formed. Therefore, the equilibrium amount of HI = 2×0.17 = 0.34 mol. K_c is measured in terms of concentration and so each of the equilibrium amounts must be converted to mol dm^{-3}.

$I_2 = 0.01/0.50 = 0.02\ \text{mol dm}^{-3}$

$H_2 = 0.33/0.50 = 0.66\ \text{mol dm}^{-3}$

$HI = 0.34/0.5 = 0.68\ \text{mol dm}^{-3}$

$$K_c = \frac{(0.68)^2}{(0.02)(0.66)} = 35$$

Candidate B

d (i)

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

$[I_2] = 0.01$ mol; $[H_2] = 0.5 - 0.17 = 0.33$; $[HI] = 0.34$

$K_c = 0.34/(0.01 \times 0.33) = 103$

e Candidate A has worked through the calculation systematically and obtained the correct answer, scoring 5 marks. Candidate B has made progress but carelessness once again means that marks are lost. First the correct use of '[ ]' indicates a concentration. However, here the candidate is referring to an amount in moles; statements such as $[I_2] = 0.01$ mol are incorrect and must not be used. Candidate A wisely converts the amount in moles into a concentration before calculating the equilibrium constant. Candidate B does not do this and also writes 0.34, rather than $(0.34)^2$. In this case, the total number of particles does not change as a result of the reaction, so the volume of the container is immaterial and the correct answer would be obtained using the amount in moles. However, it is not clear that Candidate B understands this. The result is that he/she scores 3 marks.

Candidate A

d (ii) If the volume of the container is increased to 1.00 dm^3, the equilibrium constant must be calculated as follows:

$I_2 = 0.01/1 = 0.01 \text{ mol dm}^{-3}$

$H_2 = 0.33/1 = 0.33 \text{ mol dm}^{-3}$

$HI = 0.34/1 = 0.34 \text{ mol dm}^{-3}$

$$K_c = \frac{(0.34)^2}{(0.01)(0.33)} = 35$$

This seems to be the same as in part d (i)

Candidate B

d (ii) K_c will be half what it was — $103/2 = 51.5$

e Candidate A seems rather surprised by the result and perhaps does not fully understand why this is the case. Nevertheless, the response is correct, for 2 marks. Candidate B seems confused — the answer may be just a guess. No marks can be awarded.

e **Overall, Candidate A scores 14 out of 16 marks, which is an extremely good mark. Candidate B has not revised this topic carefully enough and scores only 7 marks, which is on the D/E borderline.**

Question 13
pH

Time allocation: 17–18 minutes

a **(i)** A weak organic acid, HA, has the following percentage composition by mass: C, 40.0%; H, 6.7%; O, 53.3%. Calculate the empirical formula of HA. (2 marks)

(ii) The relative molecular mass of HA is 60.0, What is its molecular formula? (1 mark)

b 1.20 g of HA was dissolved in 250.0 cm^3 water. Calculate the pH of the resulting solution. Show all your working. (K_a of HA = 1.7×10^{-5} mol dm^{-3}) (5 marks)

c A 0.04 mol dm^{-3} solution of HA was titrated with a 0.05 mol dm^{-3} sodium hydroxide solution.

(i) Calculate the pH of the NaOH(aq). ($K_w = 1.0 \times 10^{-14}$ $mol^2\,dm^{-6}$) (2 marks)

(ii) Calculate the volume of NaOH(aq) required to neutralise 25.0 cm^3 of HA solution. (3 marks)

(iii) Sketch a graph to show the change in pH during the titration. (4 marks)

d Indicators can be used to determine the end point of a titration. Which of the following would be most suitable for this titration? Justify your answer and suggest what you would see at the end point. (2 marks)

Indicator	Acid colour	pH range	Alkaline colour
Thymol blue (acid)	Red	1.2–2.8	Yellow
Bromocresol purple	Yellow	5.2–6.8	Purple
Thymol blue (base)	Yellow	8.0–9.6	Blue

Total: 19 marks

Candidates' answers to Question 13

Candidate A

a **(i)**

	Carbon	Hydrogen	Oxygen
% composition	40.0	6.7	53.3
Divide by A_r	40.0/12.0 = 3.33	6.7/6.7 = 1	53.3/16.0 = 3.33
Divide by smallest	1	2	1
Empirical formula = CH_2O			

Candidate B

a **(i)** molecular mass = 60.0

C is 40% = 24 = 2 carbons

H is 6.7% = 4.02 = 4 hydrogens

O is 53.3% = 31.98 = 2 oxygens

So, the formula is $C_2H_4O_2$, which means the empirical formula is CH_2O.

e Candidate A scores 2 marks. Candidate B, however, has not answered the question in the order presented. The relative molecular mass is given in part (ii) but has been used by the candidate to answer part (i). This is not the correct way of handling this question. It is possible (but unlikely) that the examiner might allow both marks for part (i), but tackling the question in this way is not a good strategy. Candidate B is likely to score just 1 mark.

Candidate A

a (ii) mass of $CH_2O = 12.0 + 2.0 + 16.0 = 30.0$

empirical mass $\times$ 2 = molecular mass

molecular formula = $C_2H_4O_2$

Candidate B

a (ii) Molecular formula is $C_2H_4O_2$.

e Candidate A scores 1 mark. Candidate B might be awarded the mark for part (ii), but this is by no means certain and it should be assumed that Candidate B fails to score.

Candidate A

b $K_a = \dfrac{[H^+][A^-]}{[HA]} = \dfrac{[H^+]^2}{[HA]}$

Therefore, $[H^+]^2 = K_a \times [HA]$

$K_a = 1.7 \times 10^{-5}$

$[HA] = 1.2/60.0 = 0.02$

Therefore, $[H^+]^2 = 1.7 \times 10^{-5} \times 0.02 = 3.4 \times 10^{-7}$

$[H^+] = \sqrt{3.4 \times 10^{-7}} = 5.8 \times 10^{-4}$

$pH = -\log_{10}[H^+] = -\log_{10} 5.8 \times 10^{-4} = 3.23$

Candidate B

b $pH = -\log_{10}(\sqrt{K_a \times [HA]})$

$pH = 4.69$

e Questions of this type are difficult to mark because there are a number of equally valid ways of carrying out the calculation. The instructions ask the candidates to show *all* of their working. Neither candidate has the correct answer of pH = 2.93. However, Candidate A scores 4 out of 5 marks while Candidate B only scores 1 mark. Candidate A has shown all of the working so it is possible to see where mistakes have been made. The only error made by Candidate A is in working out the [HA] concentration. By using the value 1.2/60.0 = 0.02, Candidate A has worked out the number of moles of HA rather than the concentration. The correct concentration is 0.08 mol dm^{-3}. It is impossible to deduce where Candidate B has gone wrong and so the only mark that can be awarded is for quoting the equation $pH = -\log_{10}(\sqrt{K_a \times [HA]})$, which could be used to obtain the correct answer. Try the calculation: remember, $K_a = 1.7 \times 10^{-5}$ and [HA] = 0.08.

Candidate A

c (i) $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$

$[H^+][0.05] = 1.0 \times 10^{-14}$

Therefore, $[H^+] = 1.0 \times 10^{-14}/0.05 = 2.0 \times 10^{-13}$

$pH = -\log_{10}[H^+] = -\log_{10}(2.0 \times 10^{-13}) = 12.7$

Candidate B

c (i) $pOH = -\log_{10}[OH^-] = -\log_{10}(0.05) = 1.30$

$pH = 14 - pOH = 14 - 1.30 = 12.7$

e Both candidates score 2 marks. The methods adopted are very different but both are valid and lead to the correct answer.

Candidate A

c (ii) $HA + NaOH \rightarrow NaA + H_2O$

1 mole 1 mole

moles of HA = moles of NaOH

$n = cV = 0.04 \times 25/1000 = 0.001$

volume of NaOH $= V = n/c = 0.001/0.05 = 0.02\ dm^3 = 20\ cm^3$

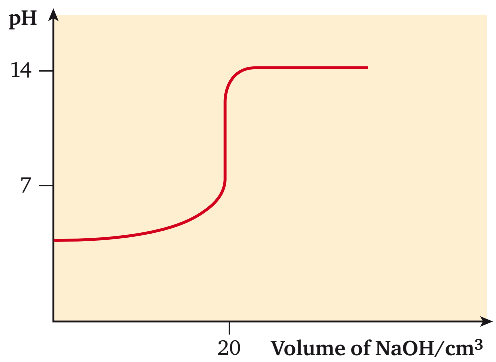
Candidate B

c (ii) $K_c = \dfrac{0.04 \times 25}{0.05} = 20\ cm^3$

e Both candidates score all 3 marks. However, Candidate B is living dangerously by not providing any explanation. It is vital to show your working in any calculation.

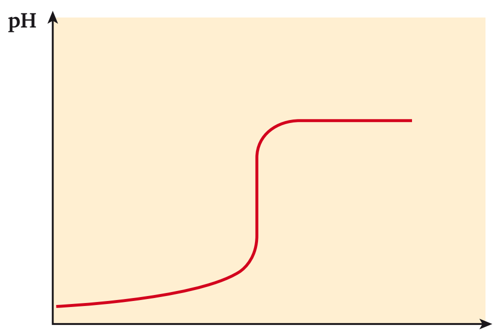
Candidate A

c (iii)



Candidate B

c (iii)



e The marking points for the sketch are:

- correct labels, including units ✓
- initial and final pH approximately correct ✓
- correct shape ✓
- rapid change in pH from about 7–12 after the addition of 20 cm^3 of NaOH ✓

Candidate A is methodical and gains all 4 marks. Candidate B also understands the chemistry but only scores 2 marks. Use the mark scheme above to see if you can identify where Candidate B has lost 2 marks.

Candidate A

d Thymol blue (base) would be the best indicator because it changes colour in the pH region 8.0–9.6, which matches the rapid change in pH for this reaction.

Candidate B

d Thymol blue (base) would be the best indicator because it changes colour in the pH region 8.0–9.6. The end point would be green.

e Both candidates have selected the correct indicator. Candidate A gives a very good explanation of the choice of thymol blue (base) but has forgotten to give the colour of the end point. Candidate B has not really explained the choice of indicator and has simply copied the pH range from the question. The end point should occur when there is an equal amount acid and the alkaline forms of the indicator, i.e. an equal amount of yellow and blue. Hence the end point would be green. Both candidates score 1 mark.

e **Both candidates seem to understand the chemistry but Candidate B demonstrates poor examination technique throughout the question. Candidate A scores 17 out of 19 marks, but Candidate B only scores 10. The net result of this poor technique is that Candidate B is underachieving by two to three grades. Look back at Candidate B's responses and identify marks that should have been gained.**

Question 14
Acids and bases

Time allocation: 9–10 minutes

A patient suffering from a duodenal ulcer has gastric juices with increased acidity. The exact acidity of the patient's gastric juice is monitored by measuring the pH.

a (i) Define pH (1 mark)

(ii) On a particular day, the patient's gastric juice was found to have a hydrochloric acid concentration of 8.0×10^{-2} mol dm^{-3}. Calculate the pH of the gastric juice. (1 mark)

b One of the most common medications designed for the relief of excess stomach acidity contains aluminium hydroxide, $Al(OH)_3$.

(i) Write an equation for the reaction between HCl and $Al(OH)_3$. (1 mark)

(ii) On another day, the patient's gastric juice was found to have a pH of 1.3. The patient produces 2 dm^3 of gastric juice in a day. The patient is prescribed tablets containing $Al(OH)_3$. Calculate the mass of aluminium hydroxide required to raise the pH of 2 dm^3 of gastric juice from 1.3 to 2.0. (5 marks)

c The control of blood pH is important. This is achieved by HCO_3^- ions in blood plasma. Using appropriate equations, explain how HCO_3^- ions can act as a buffer solution. (3 marks)

Total: 11 marks

Candidates' answers to Question 14

Candidate A

a (i) pH is minus the logarithm to base 10 of the hydrogen ion concentration in a solution.

Candidate B

a (i) $pH = -\log[H^+]$

e Both candidates gain the mark. Candidate A makes it more difficult to answer the question by defining pH in words. Some candidates seem to think that definitions should always be given in words. This is not the case. Candidate B has the better approach.

Candidate A

a (ii) $pH = -\log_{10}(8.0 \times 10^{-2}) = 1.1$

Candidate B

a (ii) $pH = 1.097$

e Both candidates score the mark, although Candidate B quotes the answer to too many significant figures. If the mark allocation for this part question had been 2 marks, then it is likely that Candidate B would have scored only 1.

Candidate A

b (i) $3HCl + Al(OH)_3 \rightarrow AlCl_3 + 3H_2O$

Candidate B

b (i) $3HCl + Al(OH)_3 \rightarrow AlCl_3 + 3H_2O$

e Both candidates gain the mark.

Candidate A

b (ii) pH 2 means $[H^+] = 10^{-2}$ or 0.01 mol dm^{-3}

pH 1.3 means $[H^+] = 10^{-1.3} = 0.05$ mol dm^{-3}

The pH has to be raised by 0.04 mol

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

Therefore 0.04/3 mol of $Al(OH)_3$ are needed = 0.0133 mol

1 mol of $Al(OH)_3$ = 78.0 g

So $Al(OH)_3$ needed is $0.0133 \times 78.0 = 1.04$ g

Candidate B

b (ii) pH 2 is 0.01 mol dm^{-3}

pH 1.3 is 0.02 mol dm^{-3}

So 2 dm^3 of gastric juice has 0.04 mol and must become 0.02 by adding $Al(OH)_3$

Using the equation gives mol of $Al(OH)_3$ of 0.02/3

$Al(OH)_3$ = 78.0 g

So $Al(OH)_3$ needed is $78.0 \times 0.02/3 = 0.52$ g

e This is quite a difficult question intended to 'stretch-and-challenge' the most able students. Neither candidate obtains the correct answer, but both do well, scoring 4 out of 5 marks. The marking points are as follows:

- correct conversion of the pH values to concentrations of H^+ ✓
- the amount in moles of H^+ that would need to be neutralised ✓
- correct use of the equation ✓
- the moles of aluminium hydroxide required to neutralise the acid ✓
- converting the moles of aluminium hydroxide into grams ✓

Candidate A forgets that the volume being treated is 2 dm^3 and concludes that 0.04 mol of HCl are neutralised by the $Al(OH)_3$, whereas the figure should be 0.08 mol. So the third mark is lost. Subsequently, the calculation is correct, so only 1 mark is dropped overall. The examiner always awards marks for correct parts of a response that follow an earlier error. Candidate A makes a poorly worded statement. It is incorrect to write 'The pH has to be raised by 0.04 mol'; the candidate should have written 'To raise the pH from 1.3 to 2.0 requires the amount in moles of H^+ to be changed from 0.05 to 0.01'. However, in a calculation the examiner is unlikely to be too hard on poor wording. Be careful though always to provide correct units for quantities because these might carry marks.

Candidate B fails to convert the pH of 1.3 to the correct concentration of hydrogen ions. This is a common type of error that occurs because students do not know how to use their calculators correctly. You should make sure that this does not happen to you. Although the response is poorly worded, Candidate B remembers that 2 dm^3 is being used and from this stage the calculation is correct. Candidate B scores 4 marks.

Candidate A

c The addition of H^+ causes the HCO_3^- ion to convert to CO_2:

$HCO_3^- + H^+ \rightleftharpoons CO_2 + H_2O$

This allows any excess acid to be partly controlled.

The addition of alkali converts the HCO_3^- to CO_3^{2-}:

$HCO_3^- + OH^- \rightleftharpoons CO_3^{2-} + H_2O$

This is not very likely to happen in the blood.

Candidate B

c The buffer works like:

$HCO_3^- + H^+ \rightleftharpoons CO_2 + H_2O$

$HCO_3^- + OH^- \rightleftharpoons CO_3^- + H_2O$

e Candidate A provides a satisfactory answer and does well to mention that buffers only partly control pH. A common error is to say that buffer solutions stop the pH from changing. This always loses a mark because, although buffer solutions stabilise pH they cannot totally prevent change. Candidate A scores 3 marks. Candidate B does not give any explanation and so loses 1 mark. The first equation is correct but the second has the carbonate ion as CO_3^-. This is a bad error at A2 and means a second mark is lost. Candidate B scores 1 mark only.

e **Overall, Candidate A scores 10 out of 11 marks. Candidate B scores 8, falling just short of A-grade standard, through unnecessary errors.**

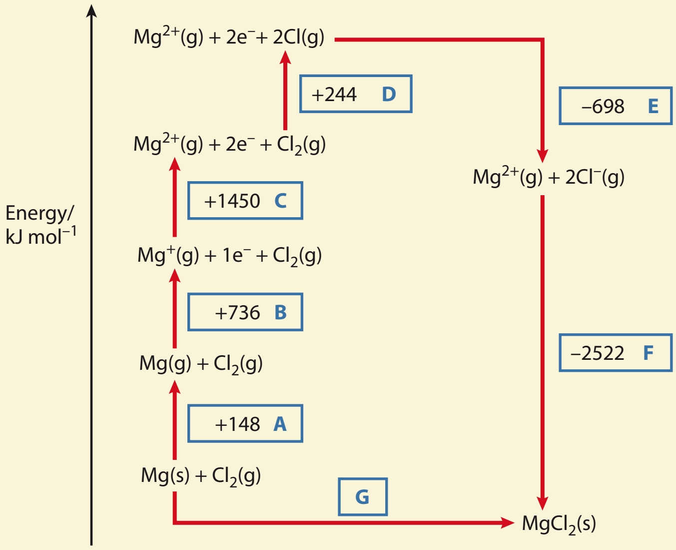
Question 15
Born–Haber cycle

Time allocation: 20–21 minutes

a **(i)** Explain what is meant by the term *lattice enthalpy*. (2 marks)

(ii) Write an equation to show what is meant by the lattice enthalpy of magnesium chloride. (2 marks)

b Use the Born–Haber cycle below to answer the questions that follow.



(i) Identify which step represents the second ionisation energy of magnesium. (1 mark)

(ii) Write an equation that illustrates the second ionisation of magnesium. (1 mark)

(iii) Explain why the enthalpy value for the second ionisation of magnesium is about twice the value of the first ionisation of magnesium. (2 marks)

(iv) Write an equation that illustrates the first electron affinity of chlorine. (1 mark)

(v) State the energy, in $kJ\,mol^{-1}$, for the first electron affinity of chlorine. (1 mark)

(vi) Calculate the enthalpy of formation of magnesium chloride. (2 marks)

c The lattice enthalpy for magnesium bromide is $-2440\,kJ\,mol^{-1}$. Explain the difference in the values of the lattice enthalpies of magnesium bromide and magnesium chloride. (1 mark)

d Magnesium bromide is soluble in water. The enthalpy of hydration of magnesium ions is $-1921\,kJ\,mol^{-1}$ and the enthalpy of hydration of the bromide ion is $-336\,kJ\,mol^{-1}$. Calculate the enthalpy of solution of magnesium bromide. (2 marks)

e Using enthalpies of solution is not always a reliable way of predicting whether a substance will be soluble in water.

(i) What other energy-related change should be considered when making a prediction of solubility? (1 mark)

(ii) Explain whether this other energy change is likely to suggest that a substance will be more or less soluble in water. (2 marks)

f Describe how you could distinguish between aqueous solutions of magnesium bromide and magnesium chloride. State the observations you would make. (3 marks)

Total: 21 marks

Candidates' answers to Question 15

Candidate A

a (i) The lattice enthalpy is the enthalpy change when 1 mole of ionic solid is formed from its ions in the gas state.

Candidate B

a (i) It is the enthalpy released when the constituent gaseous ions form 1 mole of ionic solid.

e Both candidates score 2 marks. It is essential to learn straightforward definitions. The marks in this definition are for: forming 1 mole of ionic solid ✓ from the gaseous ions ✓.

Candidate A

a (ii) $Mg^{2+}(g) + 2Cl^-(g) \rightarrow MgCl_2(s)$

Candidate B

a (ii) $Mg^{2+} + Cl_2^-(g) \rightarrow MgCl_2(s)$

e Candidate A scores 2 marks. Candidate B fails to score because the state symbol, (g), after Mg^{2+} is omitted. In cases such as this, where there is a change of state, state symbols are essential. Many candidates forget to include them — don't be caught out by this. Candidate B makes another common error — $Cl_2^-(g)$ is not the same as $2Cl^-(g)$. Writing $Cl_2^-(g)$ implies that two chlorine atoms are joined together to make a Cl_2 molecule that has then received an electron. This is incorrect; each chlorine atom has received an electron, so the equation must include $2Cl^-$.

Candidate A

b (i) C

Candidate B

b (i) C

e Both candidates score the mark.

Candidate A

b (ii) $Mg^+(g) \rightarrow Mg^{2+}(g) + 1e^-$

Candidate B

b (ii) $Mg(s) \rightarrow Mg^{2+}(g) + 2e^-$

e Candidate A makes good use of the information in the question and scores the mark. Candidate B fails to score. The equation given by Candidate B is incorrect. First, the equation shows the combined first and second ionisations. Second, Candidate B makes another common error. The candidate thinks of magnesium as a solid and has automatically attached (s) as the state symbol, forgetting that, to determine the ionisation enthalpy, magnesium is atomised and is therefore a gas.

Candidate A

b (iii) Mg^+ is smaller than the Mg atom and therefore it is more difficult to remove the second electron.

Candidate B

b (iii) The second ionisation energy removes two electrons but the first ionisation energy removes only one electron: therefore it is twice as much.

e This is a difficult concept. The ease with which an electron can be removed depends on the attraction between the protons in the nucleus and the outer electrons. The three main factors that influence this are:

- distance from the nucleus
- shielding by inner shells
- proton-to-electron ratio

Candidates must remember to consider all three factors to identify which is/are relevant to the question. The shielding remains constant for the first and second ionisation energies of magnesium, but the distance from the nucleus and the proton:electron ratio both change. Candidate A scores 1 mark for explaining the variation in size/distance from the nucleus. Candidate B does not score. He/she has misinterpreted the question and jumped to the wrong conclusion.

Candidate A

b (iv) $Cl(g) + 1e^- \rightarrow Cl^-(g)$

Candidate B

b (iv) $Cl(g) + e^- \rightarrow Cl^-(g)$

e Both candidates score the mark.

Candidate A

b (v) $-698\ kJ\ mol^{-1}$

Candidate B

b (v) 349

e Neither candidate gains the mark. Candidate A has used the information in the question but failed to spot that the enthalpy change given is for twice the first electron affinity of chlorine. Candidate B has spotted this and has halved the numerical value. However, Candidate B fails to score because both the negative sign and the units are missing.

Candidate A

b (vi) $\Delta H_f = 148 + 736 + 1450 - 698 - 2522 = -642\ kJ\ mol^{-1}$

Candidate B

b (vi) $-642\ kJ\ mol^{-1}$

e Both candidates score 2 marks, but Candidate A shows better examination technique by showing the working. Although candidates should use calculators to avoid making an arithmetical error, it is wise to write down the working. If this is done and an error is made, the examiner will look to see if a mark can still be awarded. It is surprising how often how this turns out to be the case. Although a correct answer normally scores full marks, no marks will be awarded if there is an error and no working is shown. If a question specifies that working *must* be shown, this means that there are marks allocated for specific steps in the calculation.

Candidate A

c The lattice enthalpy depends on the ionic radius and the size of the charge. The charge for Cl^- and Br^- is the same but Cl^- is smaller than Br^- and therefore the attraction between the Mg^{2+} and the Cl^- is greater.

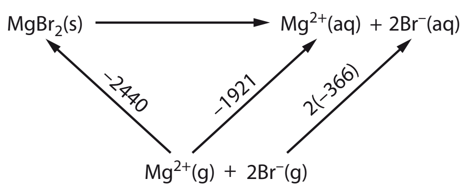
Candidate B

c The charge density of $Cl^- > Br^-$. Therefore, the lattice enthalpy of $MgCl_2$ is bigger than that of $MgBr_2$.

e Candidate A scores the mark and it is probable that Candidate B would also do so. However, Candidate B's answer is not clear. The difficulty lies in the use of the word 'bigger'. This is problematic because we are dealing with negative numbers. It is true that the numerical value of the lattice energy for magnesium chloride is greater than that for magnesium bromide, but is –2522 bigger or smaller than –2440? In answering questions of this type, which involve negative numbers, it is better to avoid saying that the lattice energy is bigger, greater, more, less or smaller and say instead that the *numerical value* of the lattice energy is greater or smaller, or that it is more negative.

Candidate A

d



$\Delta H = 2440 - 1921 - (2 \times 336) = -153\,\text{kJ mol}^{-1}$

Candidate B

d enthalpy of solution $= -2440 + 1921 + 772 = 153\,\text{kJ mol}^{-1}$

e Candidate A scores both marks. Candidate B makes an error in the sign of the answer and scores 1 mark only. In questions that involve enthalpy change it is always a good idea to provide a diagram indicating the direction of the enthalpy changes involved. This helps to avoid unnecessary errors.

Candidate A

e (i) The entropy change

Candidate B

e (i) Entropy

e Both candidates score the mark.

Candidate A

e (ii) Entropy increases when a substance dissolves in water because the particles move more readily. This means that substances will be predicted to be more soluble than when just enthalpy is used.

Candidate B

e (ii) More soluble.

e Candidate A gains the 2 marks. Candidate B fails to score because no explanation is given. If the answer to a question is a straightforward 50:50 choice (in this case 'more' or 'less') the mark is only awarded if a correct explanation is provided.

Candidate A

f Add silver nitrate to each and observe the colour of the precipitate. $MgCl_2$ would give a white solid and $MgBr_2$ would give a yellow solid.

Candidate B

f Both solutions would conduct electricity. If electricity is passed through the $MgCl_2$, a green gas will be evolved at the anode. With $MgBr_2$ an orange–brown liquid will be produced.

e This part of the question is synoptic — you have to recall information and knowledge from others areas of the specification. Candidate A has selected $AgNO_3$ as the reagent. This relates to AS Unit 1: Atoms, Bonds and Groups, where $AgNO_3$ is used to distinguish between the halides in the section on group 7. The observation for the chloride is correct but the colour for the bromide is incorrect. The iodide gives a yellow precipitate with $AgNO_3$ and the bromide gives a cream precipitate. Candidate A scores 2 marks but is lucky not to have lost a mark for not specifying that the silver nitrate should be aqueous. When describing chemical tests you should include state(s) of the reagents as they may be included on the marking scheme. Candidate B has given an unexpected answer, but it is good chemistry and would probably work. Candidate B might gain all 3 marks, even though it would be difficult to detect the chlorine by colour .

e **Candidate A shows a good grasp of this topic, makes good use of the information in the question and is systematic in supplying the answers. The score of 18 out of 21 marks is a comfortable grade-A standard. Candidate B scores 12 marks, which is equivalent to a C grade. The marks lost in (b)(iii) could reflect a lack of understanding, but those missed in (a)(ii), (b)(ii), (b)(v), (d) and (e)(ii) are due largely to carelessness.**

Question 16
Enthalpy, entropy and free energy

Time allocation: 8–9 minutes

a Use the data below to calculate the standard enthalpy change for the reaction:

$C(s) + CO_2(g) \rightarrow 2CO(g)$

$\Delta H_f^{\ominus}(CO_2) = -393.7\ \text{kJ mol}^{-1}$; $\Delta H_f^{\ominus}(CO) = -110.5\ \text{kJ mol}^{-1}$ (2 marks)

b Use the data below to calculate the standard entropy change for the reaction:

$C(s) + CO_2(g) \rightarrow 2CO(g)$

$S^{\ominus}(CO_2) = 213.8\ \text{J mol}^{-1}\ \text{K}^{-1}$; $S^{\ominus}(C) = 5.7\ \text{J mol}^{-1}\ \text{K}^{-1}$; $S^{\ominus}(CO) = 197.9\ \text{J mol}^{-1}\ \text{K}^{-1}$ (2 marks)

c (i) State the relationship between ΔG, ΔH and ΔS (1 mark)

(ii) Use your answers to (a) and (b) to determine the value of $\Delta G^{\ominus}$ for the reaction of carbon dioxide and carbon under standard conditions of 298 K and 101 kPa. (2 marks)

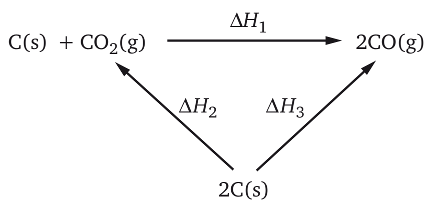
d Calculate the minimum temperature in °C required for the reaction between carbon dioxide and carbon to become feasible. (3 marks)

Total: 10 marks

Candidates' answers to Question 16

Candidate A

a



$\Delta H_1 = -\Delta H_2 + \Delta H_3 = 393.7 - (2 \times 110.5) = 172.7\ \text{kJ mol}^{-1}$

Candidate B

a enthalpy change $= -(2 \times 110.5) - (-393.7) = -172.7\ \text{kJ mol}^{-1}$

Candidate A scores 2 marks. It is not a requirement to provide an enthalpy diagram, but it may help to avoid errors. Candidate B sees the enthalpy change as the (enthalpy of the products) – (enthalpy of the reactants). This is fine, but the candidate becomes muddled in the calculation and gives the wrong sign in the answer. Only 1 mark is scored. It is easy to make such a mistake and all calculations should be checked carefully. It is worthwhile looking at the reaction and considering whether you expect the reaction to be exothermic or endothermic.

Enthalpy cycles were studied in the AS Unit 2. They are relevant to the study of free energy here, in Unit 5. Therefore, you must be ready to complete calculations of this type.

Candidate A

b entropy change $= 2S^{\ominus}(CO) - S^{\ominus}(CO_2) - S^{\ominus}(C) = 2 \times 197.9 - 213.8 - 5.7 = 176.3\ \text{kJ mol}^{-1}$

Candidate B

b change $= 2 \times 197.9 - 213.8 - 5.7 = 176.3\ \text{J mol}^{-1}\ \text{K}^{-1}$

e Both candidates have the correct arithmetic. However, Candidate A has rather thoughtlessly written the units as $kJ\,mol^{-1}$. Therefore, Candidate A scores only 1 mark while Candidate B scores 2.

Candidate A

c (i) $\Delta G = \Delta H - T\Delta S$

Candidate B

c (i) $\Delta G = \Delta H - T\Delta S$

e Both candidates score the mark.

Candidate A

c (ii) $\Delta G^{\ominus} = 172.7 - 298 \times 0.1763 = 120.2\ kJ\,mol^{-1}$

Candidate B

c (ii) $\Delta G^{\ominus} = -224.5\ kJ\,mol^{-1}$

e Candidate A remembers to convert the entropy value from joules into kilojoules and completes the calculation correctly, for 2 marks. Candidate B uses the incorrect answer obtained in part (a) and subsequently completes the calculation correctly. The examiner will award marks for calculations based on an error that has already been penalised. If Candidate B had shown the working of the calculation, 2 marks would have been awarded. If the examiner cannot see how the answer has been obtained, these marks will be lost. The importance of showing your working is obvious.

Candidate A

d For a reaction to be feasible, $\Delta G = 0$, so $\Delta H = T\Delta S$

$172.7 = T(0.1763)$

$T = 980°C$

Candidate B

d At equilibrium, $\Delta H = T\Delta S$

$-172.7 = 0.1763T$

$T = -980\ K$ or $-980 - 273 = -1253°C$

e Candidate A scores 2 out of 3 marks because the answer given is in K, not °C. The correct answer is 980 – 273 = 707°C. Candidate B is still suffering from the error made in part (a). However, this time the working is shown and, as this is all correct, Candidate B scores 3 marks, even though the answer is wrong. It is a pity that the candidate, having obtained an answer that is clearly wrong, did not check the arithmetic. Of course, this may not be possible if time is short. Sometimes candidates, on recognising that the answer obtained cannot be correct, cross out parts of answers. This is a mistake because it could still be possible to gain some credit.

e **Candidate A scores 8 out of 10 marks. Although this is grade-A standard, with just a little more care, the candidate could have scored full marks. Candidate B scores 7 marks at least. It is possible that the score might be higher if the examiner recognises what has happened in part (c)(ii). However, this cannot be guaranteed.**

Question 17
Redox equations and electrode potentials

Time allocation: 12–13 minutes

a Draw a diagram to show how the standard electrode potential of the half-cell $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ would be measured. State the conditions necessary. (6 marks)

b Use the electrode potentials below to predict whether, under standard conditions, $Fe^{3+}(aq)$ will be able to react with:

(i) $I^-(aq)$ (3 marks)

(ii) $Br^-(aq)$ (2 marks)

If a reaction is possible, state what you would observe as the reaction takes place.

$I_2(aq) + 2e^- \rightleftharpoons 2I^-(aq)$ $E^\ominus = +0.54\,V$

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $E^\ominus = +0.77\,V$

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

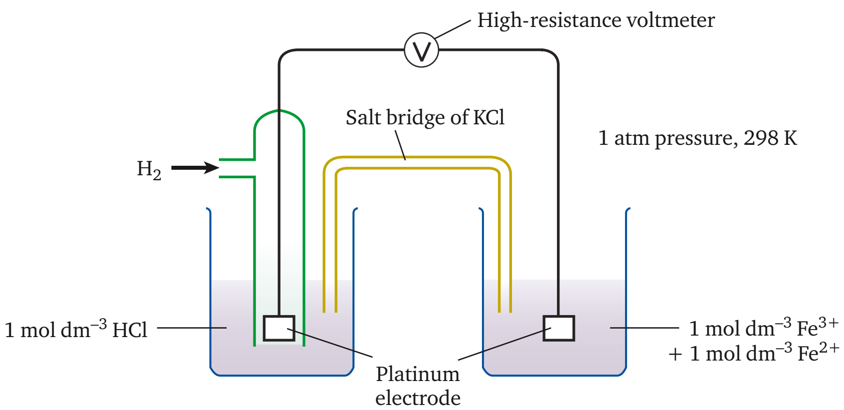
c $I^-(aq)$ reacts with acidified $KMnO_4$ to form $Mn^{2+}(aq)$ ions and $I_2(aq)$. Write half-equations for each of these reagents and then use the half-equations to construct a balanced ionic equation for the reaction. (3 marks)

Total: 14 marks

Candidates' answers to Question 17

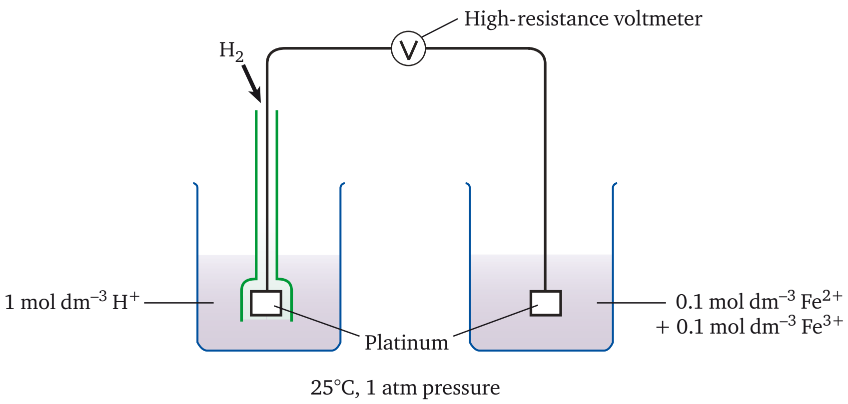
Candidate A

a



Candidate B

a



e Candidate A knows this topic well and scores all 6 marks. Candidate B knows the work quite well but fails to include a salt bridge in the diagram, which loses 1 mark. The diagram is not well drawn, but as long as it is clear this will not lose marks. A good point about Candidate B's response is that the concentrations chosen for Fe^{2+}(aq) and Fe^{3+}(aq) are more realistic than those chosen by Candidate A. The value of the electrode potential measured will be the same for redox pairs such as Fe^{2+}(aq) and Fe^{3+}(aq) provided that their concentrations in mol dm^{-3} are the same. The use of concentrations of 1 mol dm^{-3} would be difficult if the compounds are not very soluble in water. However, no mark should be lost if the higher concentrations are suggested.

Candidate A

b (i) $I_2(aq) + 2e^- \rightleftharpoons 2I^-(aq)$ $E^\ominus = +0.54\,V$

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $E^\ominus = +0.77\,V$

So the overall reaction would be:

$2Fe^{3+}(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2Fe^{2+}(aq)$

$E^\ominus$ for this is $0.77 - 0.54 = 0.23\,V$, so the reaction is possible.

In the reaction, you would see iodine formed.

Candidate B

b (i) Possible equation is $2Fe^{3+}(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2Fe^{2+}(aq)$

Overall $E^\ominus = 2 \times 0.77 - 0.54 = 1.00\,V$.

So the reaction can take place. You will see the brown colour of iodine in solution and the yellow Fe^{3+} will go green.

e Candidate A uses the electrode potential data correctly, for 1 mark, and gains the second mark for the correct prediction of the outcome of the reaction. However, the statement that iodine is produced is not a description of what is observed, so the candidate loses the third mark. Candidate B takes the trouble to give the balanced overall equations. However, this leads to an error in interpreting the electrode potential data. It is incorrect to double the value of the electrode potential. They are to be used as given; balancing numbers to match the equation is incorrect. The prediction is however correct , for 1 mark. The description of the reaction between Fe^{3+}(aq) and $2I^-$(aq) is also correct, so Candidate B scores 2 marks for this part-question.

Candidate A

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

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $E^\ominus = +0.77\,V$

So the overall reaction would be:

$2Fe^{3+}(aq) + 2Br^-(aq) \rightarrow Br_2(aq) + 2Fe^{2+}(aq)$

$E^\ominus$ for this is $0.77 - 1.09 = -0.32\,V$, so the reaction is not possible.

Candidate B

b (ii) Possible equation is $2Fe^{3+}(aq) + 2Br^-(aq) \rightarrow Br_2(aq) + 2Fe^{2+}(aq)$

Overall $E^\ominus = 2 \times 0.77 - 1.09 = +0.45\,V$

So the reaction can take place. You will see brown bromine in solution and the yellow Fe^{3+} will go green.

e Candidate A gains both marks. Candidate B loses 1 mark for incorrectly interpreting the electrode potential data. However, based on the candidate's calculation, the prediction is correct. Therefore, 1 mark is awarded on the basis of 'error carried forward'.

Candidate A

c $2I^-(aq) \rightarrow I_2(aq) + 2e^-$ $(\times 5)$

$5e^- + MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l)$ $(\times 2)$

Overall equation is:

$10e^- + 2MnO_4^-(aq) + 16H^+(aq) + 10I^-(aq) \rightarrow 2Mn^{2+}(aq) + 5I_2(aq) + 4H_2O(l) + 10e^-$

Candidate B

c $2I^-(aq) \rightarrow I_2(aq) + 2e^-$

$5e^- + MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l)$

The overall equation is:

$2MnO_4^-(aq) + 16H^+(aq) + 10I^-(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 5I_2(aq)$

e Candidate B does better than Candidate A, scoring all 3 marks. Candidate A scores 2 marks — but only just. The multiplication factors for both half-equations are correctly identified but there are two errors in the overall equation. The $10e^-$ should not be included and, although the examiner might be prepared to accept that, the candidate has written $4H_2O(l)$ on the right-hand side of the equation, rather than $8H_2O(l)$. This means that 1 mark is lost. When combining half-equations, it is easy to forget to multiply all the components by the necessary factor. In answering questions of this type, you should take a good look at what you have written down and try to avoid such an error.

e **Overall, Candidate A scores 12 out of 14 marks and Candidate B scores 11.**

Question 18
Fuel cells

Time allocation: 10–11 minutes

a Explain the changes that take place at each electrode in a hydrogen–oxygen fuel cell. Give the overall reaction that takes place in the cell. (4 marks)

b Under standard conditions, a fuel cell can produce a voltage of 1.23 V. If the cell is used in a vehicle, the voltage is less than 1.23 V. Suggest *two* reasons why the voltage is less. (2 marks)

c State *three* advantages that fuel cells might have over petrol as the source of energy in vehicles. (3 marks)

d Suggest *two* ways in which hydrogen might be stored in a vehicle powered by a fuel cell. (2 marks)

Total: 11 marks

Candidates' answers to Question 18

Candidate A

a Hydrogen and oxygen are supplied to the fuel cell. At the cathode, hydrogen gas is converted to hydrogen ions:

$H_2(g) \rightarrow 2H^+(aq) + 2e^-$

At the anode, oxygen is converted to water by reaction with the hydrogen ions:

$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$

Overall, the equation is:

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$

Candidate B

a $H_2(g) \rightarrow 2H^+(aq) + 2e^-$

$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

e Both candidates know the chemistry involved. Candidate A scores all 4 marks, but Candidate B scores only 3. To gain the final mark, Candidate B should have mentioned that the gases are supplied to the cell externally. Having seen that this part-question carries 4 marks, it would make sense to pause and try to think of a further point. Usually, the marks available give an idea of the number of points required by the examiner.

Candidate A

b The pressure of the gas may mean that the concentration of the gases is reduced.

The vehicle operates at a high temperature.

Candidate B

b The vehicle is not at standard conditions because the temperature is not standard.

The rate of the reaction will vary depending how fast the vehicle is travelling.

e Candidate A picks up 2 fairly straightforward marks. Candidate B gains 1 mark for the first statement. However, the second statement, while true, would not lead to a change in the voltage. This is a common confusion that occurs in a number of ways on examination scripts The energy change of a reaction is not affected by the rate at which it occurs. When using electrode potentials, it is tempting to associate the size of the voltage with the rate at which the process occurs. A large electrode potential does *not* indicate a fast reaction and a reaction may occur readily even when the electrode potential is low.

Candidate A

c Fossil fuels will eventually run out whereas sources of hydrogen will not.

Hydrogen is more efficient as a fuel.

Hydrogen produces less pollution and no CO_2.

Candidate B

c Hydrogen is much lighter to carry.

Hydrogen is cheap to produce.

Hydrogen produces no pollution.

e Candidate A has clearly learned this topic and provides three good advantages, for 3 marks. Candidate B is guessing. Hydrogen cannot simply be said to be lighter — it depends on how it is stored in the vehicle. Hydrogen is unlikely to be a cheaper alternative because energy is needed to produce it. It is unwise to suggest that hydrogen will produce no pollution. The source of oxygen is the air and the nitrogen contained in air might still produce some polluting oxides. In addition, the manufacture of the hydrogen required by fuel cells might produce some pollution. Candidate B fails to score.

In questions of this type there is no substitute for learning the content of the specification and being ready to give the answers indicated there. It is possible that Candidate B might get some credit because the ideas are not completely incorrect. However, it is silly to risk being caught out by quite rigid mark schemes.

Candidate A

d Adsorbed onto the surface of a solid

As a liquid under pressure

Candidate B

d Absorbed into a solid carrier

Liquefied

e Both candidates have learned this topic and both score 2 marks.

e **Overall, Candidate A scores all 11 marks while Candidate B scores 6, which is only grade-D standard. It is essential not to shirk the hard graft of learning the facts when preparing for an exam. It is also important to realise that an exam paper is almost certain to contain some part-questions focused on chemistry in everyday situations or where it is of international concern.**

Question 19 Transition metal chemistry and redox titrations

Time allocation: 10–11 minutes

a (i) What is meant by the term *transition element*? (2 marks)]

(ii) Complete the electronic configuration of the iron atom: $1s^2\ 2s^2\ 2p^6$… (1 mark)

(iii) Write the electron configuration of Fe^{2+} and Fe^{3+} ions. (2 marks)

b (i) Aqueous Fe^{2+} ions react with aqueous hydroxide ions. Write an ionic equation for this reaction and state what you would see. (2 marks)

(ii) The product formed when aqueous Fe^{2+} ions react with aqueous hydroxide ions, slowly darkens and eventually turns 'rusty'. What happens to cause this colour change? (1 mark)

c The dichromate(VI) ion, $Cr_2O_7^{2-}$, is an oxidising agent used in laboratory analysis. It reacts with acidified Fe^{2+} ions to form Cr^{3+} and Fe^{3+} ions.

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

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$

(i) Construct the full ionic equation for this reaction. (1 mark)

(ii) Calculate the volume of 0.0100 mol dm^{-3} potassium dichromate(VI) required to react with 20.0 cm^3 of 0.0500 mol dm^{-3} acidified iron(II) sulphate. (3 marks)

Total: 12 marks

Candidates' answers to Question 19

Candidate A

a (i) An element that forms one or more stable ions that have partly-filled *d*-orbitals.

Candidate B

a (i) An element that has partly-filled *d*-orbitals.

e Candidate A scores both marks but Candidate B only scores 1 mark. There are two key marking points:

- partly-filled *d*-orbitals ✓
- the element forms one or more *ions* that have partly-filled *d*-orbitals ✓

Candidate A

a (ii) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$

Candidate B

a (ii) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$

e Both candidates gain the mark. The order of 3*d* and 4*s* is acceptable as either 3*d* followed by 4*s* or 4*s* followed by 3*d*. However, if written as $4s^2\ 3d^6$, mistakes might be made when writing the electron configurations of any resulting ions.

Candidate A

a (iii) Fe^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

Fe^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

Candidate B

a (iii) Fe^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^4$

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$

e Candidate A gains both marks but Candidate B fails to score. The way in which Candidate B wrote the Fe atom configuration in (a)(ii) reflects that the 4*s*-subshell fills before the 3*d*-subshell. However, the danger of writing it this way is that when ions are formed, the tendency is to remove electrons from the 3*d*-orbitals first when in fact the first electrons to be lost are always the outer electrons — in this case, the electrons in the 4*s*-orbital.

Candidate A

b (i) $Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$

Green precipitate

Candidate B

b (i) $Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$

$Fe(OH)_2$ is a blue–green gelatinous precipitate.

e Both candidates score 2 marks.

Candidate A

b (ii) Fe^{3+} is more stable than Fe^{2+} and therefore iron(II) compounds are readily oxidised. The rust colour is due to $Fe(OH)_3$ being formed.

Candidate B

b (ii) $Fe(OH)_3$ is a rust–brown gelatinous precipitate and therefore $Fe(OH)_2$ must have been converted to $Fe(OH)_3$.

e Both candidates gain the mark.

Candidate A

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

Candidate B

c (i) $Cr_2O_7^{2-} + 14H^+ + 5e^- + Fe^{2+} \rightarrow Fe^{3+} + 2Cr^{3+} + 7H_2O$

e Candidate A gains the mark but Candidate B fails to score. The full ionic equation does not contain electrons. It is essential to scale the two ionic half-equations so that the electrons cancel out.

Candidate A

c (ii) moles of $Fe^{2+} = 0.0500 \times 20.0/1000 = 0.001$ mol

moles of $Cr_2O_7^{2-} = 6 \times$ moles of $Fe^{2+} = 0.001 \times 6 = 0.006$ mol

1 dm^3 contains 0.01 mol of $Cr_2O_7^{2-}$

so, volume of $Cr_2O_7^{2-} = 0.006/0.01 = 0.600\ dm^3 = 600\ cm^3$

Candidate B

c (ii) moles of Fe^{2+} = moles of $Cr_2O_7^{2-} = 0.0500 \times 20.0/1000 = 0.001$ mol

$n = cV$

so, $V = n/c = 0.001/0.01 = 0.100\ dm^3 = 100\ cm^3$

e Both candidates score 2 marks, for different reasons. Candidate A has calculated the moles of Fe^{2+} correctly but has multiplied this value by 6 instead of *dividing* it by 6. Candidate B has also calculated the moles of Fe^{2+} correctly, but has ignored the 1:6 molar ratio. This might be considered a consequence of the error in the equation in (c)(i) and therefore be awarded a mark but since this has made the calculation easier, it is unlikely to be accepted. Both candidates have gone on to calculate the volume of $Cr_2O_7^{2-}$ required. Both display good examination technique by showing their working. Titration calculations are usually designed so that the volume added from the burette is around 25 cm^3. In such calculations, the volume required rarely, if ever, exceeds 50 cm^3. The answers obtained by both candidates should have prompted them to check their calculations for errors. The correct value is 16.7 cm^3.

e **Overall, Candidate A scores 11 out of 12 marks and Candidate B scores 7.**

Question 20
Transition metal chemistry

Time allocation: 13–14 minutes

a Explain the meaning of the terms *ligand* and *coordinate bond*. (2 marks)

b Stereoisomerism is sometimes shown by complexes and complex ions of transition metals. Using a suitable named example in each case, show how a complex ion of a transition metal can exist as

(i) *cis–trans* isomers (4 marks)

(ii) optical isomers (4 marks)

c Ligand exchange can occur when transition metal complex ions react. This takes place if a new complex ion of greater stability can be formed. An example of a ligand exchange reaction is the formation of $[CoCl_4]^{2-}$ from $[Co(H_2O)_6]^{2+}$.

(i) The stability of a complex ion is expressed by its stability constant. Give the expression for the stability constant of $[CoCl_4]^{2-}$. (2 marks)

(ii) Describe how you would convert $[Co(H_2O)_6]^{2+}$ into $[CoCl_4]^{2-}$ and state what you would see as the reaction takes place. (3 marks)

Total: 15 marks

Candidates' answers to Question 20

Candidate A

a A ligand is a lone pair donor.

A coordinate bond is the same as a dative bond.

Candidate B

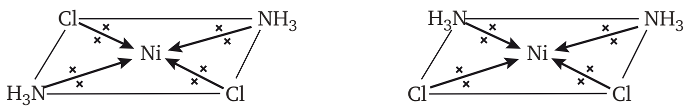
a A ligand is a lone pair donor.

A coordinate bond is formed between the ligand and the vacant *d*-orbitals of the ion. The ligand supplies both electrons for the bond.

e Candidate A scores 1 mark — the definition of a coordinate bond is insufficient. Candidate B scores both marks because of the detail in the explanation of coordinate bond.

Candidate A

b (i) *cis–trans* isomerism occurs when a complex has two different ligands. In one isomer, the ligands of one type are alongside each other while in the other isomer they are opposite. An example is the diamminedichloronickel(II) complex shown below:



trans (*E*) *cis* (*Z*)

Candidate B

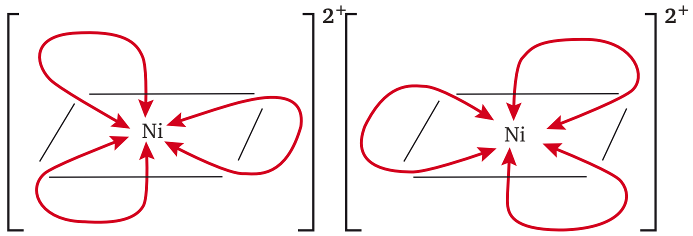
b (i) Nickel(II) can form a complex containing ammonia and chloride. In one version of the complex, the ammonia molecules are next to each other and so are the chloride ions. This is the *cis*-isomer. The ions could also be opposite to each other across the complex, which is the *trans*-isomer.

e The marking points are:
- named example ✓
- shape ✓
- explanation of difference between *cis* and *trans* ✓
- correct identification of *cis* and *trans* isomers ✓

Candidate A scores all 4 marks. For *cis–trans* isomerism, all of the marks could be obtained from a clearly labelled diagram. Candidate B may know the answer but tries to answer the question without a diagram. This is almost impossible. Candidate B scores the third and fourth marks for the *cis–trans* explanation.

Candidate A

b (ii) Optical isomerism occurs when one stereoisomer is a reflection of the other. The ligands must be multidentate. An example is with nickel(II). In my diagram, the ligand is shown as a double-headed arrow:



As you can see, the right-hand isomer is a reflection of the left-hand isomer. They are non-superimposable.

Candidate B

b (ii) Optical isomers occur when ligands attach at two points on the metal ion. Nickel(II) complexes can also be optical isomers. If there are three ligands attached, there are two versions that are mirror images of each other.

e The marking points are:
- named example ✓
- explanation that a multidentate ligand is required ✓
- explanation that the isomers are reflections of each other ✓
- indication of how the ligands are attached ✓

e Candidate A scores 3 out of 4 marks by drawing a clearly labelled diagram. A mark is lost because an example of a complex ion showing optical isomerism is not named. Candidate B scores 2 marks by including the second and third marking points in the response.

An exam question may tell you to draw diagrams to illustrate your answer. However, even if the question does not say so (as in **(b) (i)** and **(b) (ii),** you should use a diagram if you find it hard to write what you want to say in words.

Candidate A

c (i) $$K = \frac{[[CoCl_4]^{2-}]}{[Co^{2+}][Cl^-]^4}$$

Candidate B

c (i) $$K_{stab} = \frac{[Co^{2+}][Cl^-]^4}{[[CoCl_4]^{2-}]}$$

Candidate A scores 2 marks. Candidate B has written the expression upside-down and scores only 1 mark.

Candidate A

c (i) The addition of chloride ions converts $[Co(H_2O)_6]^{2+}$ into $[CoCl_4]^{2-}$. You would see the pink solution of $[Co(H_2O)_6]^{2+}$ change to a blue colour, showing that $[CoCl_4]^{2-}$ has been formed.

Candidate B

c (ii) Concentrated hydrochloric acid must be added to the aquo complex ion. When it is added, the colour change that occurs is from pink to blue.

Candidate B obtains all 3 marks while Candidate A only scores 2. To make the conversion, *excess* chloride ions are necessary and Candidate A does not provide this detail.

Once again, Candidate A does well, scoring 12 out of 15 marks. Candidate B scores 10.

Question 21 Synoptic

Time allocation: 9–10 minutes

Most questions on this paper are based on the specification content so you can expect questions on:

- organic reactions
- analysis of spectra
- redox reactions
- rates
- equilibria
- enthalpy, entropy and free energy
- acids and bases
- transition elements

All these questions could test some areas from the AS chemistry units. There is also usually at least one question or part-question that does not relate directly to Unit 5. You are likely to be given data and asked to use those data to answer the question. It might involve extended writing or a more lengthy calculation. The question that follows is along these lines.

Copper reacts with nitric acid, HNO_3. The products depend on the concentration of the acid.

Copper + dilute nitric acid:

$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

$4H^+(aq) + NO_3^-(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$

Copper + concentrated nitric acid:

$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

$2H^+(aq) + NO_3^-(aq) + e^- \rightarrow NO_2(g) + H_2O(l)$

a Write an overall balanced equation for each of the above reactions. (5 marks)

b In an experiment, nitric acid reacts with 1.27 g of copper and 320 cm^3 of gas is produced. Deduce whether the acid is dilute or concentrated. Show all your working. (4 marks)

Total: 9 marks

Candidates' answers to Question 21

Candidate A

a The electrons have to balance.

Dilute acid:

Multiply $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ by 3 to give:

$3Cu(s) \rightarrow 3Cu^{2+}(aq) + 6e^-$

Multiply $4H^+(aq) + NO_3^-(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$ by 2 to give:

$8H^+(aq) + 2NO_3^-(aq) + 6e^- \rightarrow 2NO(g) + 4H_2O(l)$

balanced equation: $8H^+(aq) + 2NO_3^-(aq) + 3Cu(s) \rightarrow 3Cu^{2+}(aq) + 2NO(g) + 4H_2O(l)$

Concentrated acid:

Multiply $2H^+(aq) + NO_3^-(aq) + 1e^- \rightarrow NO_2(g) + H_2O(l)$ by 2 to give:

$4H^+(aq) + 2NO_3^-(aq) + 2e^- \rightarrow NO_2(g) + H_2O(l)$

Add to $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

Balanced equation: $4H^+(aq) + 2NO_3^-(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + NO_2(g) + H_2O(l)$

Candidate B

a Dilute nitric: $8H^+(aq) + 2NO_3^-(aq) + 3Cu(s) \rightarrow 3Cu^{2+}(aq) + 2NO(g) + 4H_2O(l)$

Concentrated nitric: $4H^+(aq) + 2NO_3^-(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$

e The marking points are:

- dilute acid:
  - multiply copper half-equation by 3 ✓
  - multiply acid half-equation by 2 ✓
  - the correct balanced equation ✓
- concentrated acid
  - multiply acid half-equation by 2 ✓
  - the correct balanced equation ✓

e Candidate A scores 3 marks for the dilute acid equations. However, the candidate loses 2 marks for the concentrated acid equations by failing to multiply the product side of the acid half-equation by 2, which resulted in an incorrect final equation. Candidate B poses a dilemma for the examiner. Clearly he/she is very able and has deduced the balanced equations for both reactions correctly. However, there is no working. Candidate B would probably gain 4 of the 5 marks.

Candidate A

b With dilute nitric acid: 3 mol of Cu produce 2 mol of NO(g)

With concentrated nitric acid: 1 mol of Cu produces 1 mol of $NO_2(g)$

Amount (in moles) of copper reacted is $1.27/63.5 = 0.0200$

Amount (in moles) of gas produced is $320/24\,000 = 0.0133$

	Copper	**Gas**
Molar ratio	0.0200	0.0133
Divide by smallest	1.5	1
Whole numbers	3	2

Three moles of copper produce two moles of gas. Therefore the acid must be dilute.

Candidate B

b Moles of Cu used = 0.02

Moles of gas = 320/24 = 13.3

e The marking points are:

- moles of copper used ✓
- moles of gas produced ✓
- molar ratio of copper:gas ✓
- relating the molar ratio to the correct equation ✓

Candidate A scores 4 marks by deducing correctly that dilute acid was used. Candidate B scores 1 mark for the moles of copper used, but fails to score the remaining marks. In the final part of the calculation, the candidate divides 320 cm^3 by 24 dm^3, which gives a value that does not relate to either equation. Candidate B is, therefore, unable to continue with the calculation.

e **Overall, Candidate A scores 7 out of 9 marks even though one of the equations is wrong. Candidate B deduced both equations correctly, but scores only 5 marks.**

Marks scored by the candidates on Unit 5 questions

The total number of marks available for Unit 5 questions is 153.

- **Candidate A scored 132 marks, which is 86%.**
- **Candidate B scored 92 marks, which is 60%.**

Candidate A's total is equivalent to a comfortable grade A; Candidate B just scrapes into the grade C category. If this was because the candidate did not have sufficient knowledge about the unit, this would be fair enough. However, with better examination technique and greater attention to detail, Candidate B could have achieved at least a grade B. Examiners often feel that a candidate has underperformed, but marking schemes are rigid and marks are awarded only when the question has been answered fully.