

CANDIDATE
NAME

CENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

9701/41

May/June 2021

2 hours

You must answer on the question paper.

You will need: Data booklet

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Answer **all** the questions in the spaces provided.

- 1 (a) The carbonates and hydroxides of Group 2 elements show similar trends in thermal stability.
Suggest and explain the variation in the trend in the thermal stability of the Group 2 hydroxides.

.....

.....

.....

.....

..... [3]

- (b) Calcium hydroxide is slightly soluble in water.

- (i) Write an equation to show the dissociation of calcium hydroxide, $\text{Ca(OH)}_2(\text{s})$, in aqueous solution. Include state symbols.

..... $\rightleftharpoons$ [1]

- (ii) Calculate the solubility, in mol dm^{-3} , of Ca(OH)_2 .
[K_{sp} : Ca(OH)_2 , $5.02 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9}$]

solubility = ... mol dm^{-3} [2]

- (iii) Suggest how the solubility of Ca(OH)_2 in aqueous NaOH compares to its solubility in water.

Explain your reasoning.

.....

.....

..... [1]

[Total: 7]

- 2 (a) Explain why chromium complexes are coloured.

.....

.....

.....

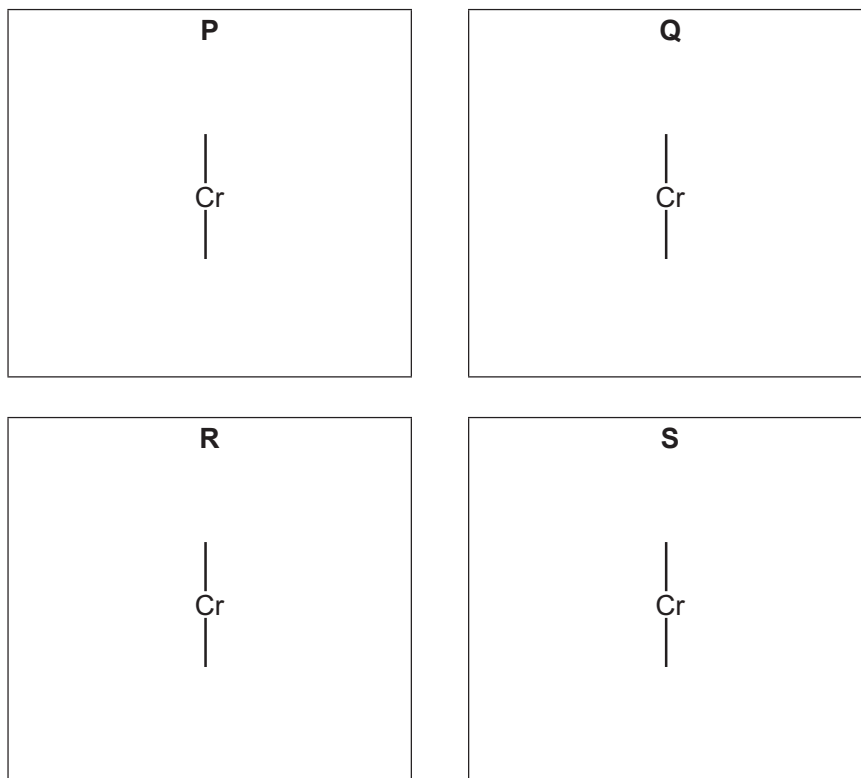
.....

..... [4]

- (b) Four different compounds can be obtained when anhydrous chromium(III) chloride reacts with water under various conditions. When samples of each compound are reacted separately with aqueous silver nitrate, different amounts of silver chloride are precipitated. The precipitation leaves the complex ions **P**, **Q**, **R** and **S** in solution.

formula of compound	moles of AgCl precipitated per mole of complex ion	complex ion	property of complex ion
$\text{CrCl}_3(\text{H}_2\text{O})_6$	3	P	non-polar
$\text{CrCl}_3(\text{H}_2\text{O})_5$	2	Q	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	R	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	S	non-polar

- (i) Draw three-dimensional diagrams for the structures of complex ions **P**, **Q**, **R** and **S**. Include the charges for each complex ion.

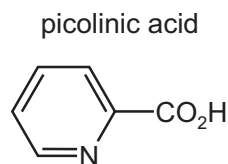


[4]

- (ii) Suggest why complex ion **S** is non-polar.

.....
 [1]

- (c) The structure of picolinic acid is shown.



The conjugate base of picolinic acid is a bidentate ligand, **Z**.

- (i) Define the term *bidentate ligand*.

.....
 [2]

- (ii) Draw the structure of **Z**.

[1]

- (iii) **Z** reacts with aqueous chromium(III) ions, $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$, in a 3 : 1 ratio to form a new neutral complex.

State the coordination number and the geometry of the chromium(III) centre in the complex.

coordination number geometry [1]

- (d) $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ decomposes readily on heating to form Cr_2O_3 , steam and an inert colourless gas.

- (i) Deduce the oxidation numbers of chromium in $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ and in Cr_2O_3 .

$(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ Cr_2O_3 [1]

- (ii) Construct an equation for the thermal decomposition of $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$.

..... [1]

[Total: 15]

3 (a) (i) Define the term *transition element*.

.....
..... [1]

(ii) State how the melting point and density of iron compare to those of calcium.

.....
..... [1]

(b) (i) Define the term *standard cell potential*, $E_{\text{cell}}^{\ominus}$.

.....
.....
..... [2]

(ii) Draw a fully labelled diagram of the apparatus that can be used to measure the cell potential of a cell composed of a Cu(II)/Cu electrode and an Fe(III)/Fe(II) electrode. Include all necessary reactants.

[3]

(c) The reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$ is catalysed by adding a few drops of $\text{Fe}^{3+}(\text{aq})$.

(i) Use equations to show the catalytic role of Fe^{3+} in this reaction.

[2]

(ii) $\text{Fe}^{3+}(\text{aq})$ can oxidise $\text{I}^-(\text{aq})$, whereas $[\text{Fe}(\text{CN})_6]^{3-}(\text{aq})$ cannot oxidise $\text{I}^-(\text{aq})$.

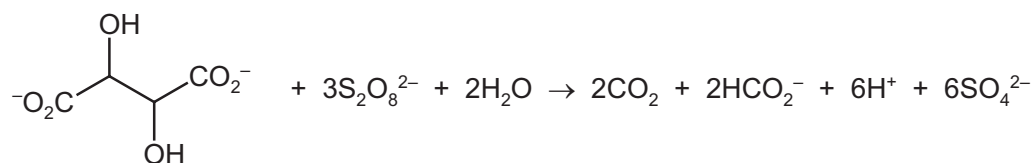
Use E° values to explain these observations.

.....

 [2]

(d) When aqueous solutions of $\text{S}_2\text{O}_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an $\text{Fe}^{3+}(\text{aq})$ catalyst. The overall equation for this reaction is shown.

tartrate ions



(i) Suggest why this reaction is slow without the Fe^{3+} catalyst.

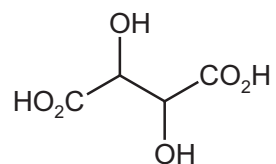
.....
 [1]

(ii) Use the overall equation to deduce the half-equation for the oxidation of tartrate ions, $\text{C}_4\text{H}_4\text{O}_6^{2-}$, to carbon dioxide, CO_2 , and methanoate ions, HCO_2^- .

$\text{C}_4\text{H}_4\text{O}_6^{2-} + \dots \rightleftharpoons \dots$ [1]

- (e) (i) Complete the following table to show the structures of the organic products formed when tartaric acid reacts separately with each reagent. Identify each type of reaction.

tartaric acid



reagent	structure of organic product	type of reaction
an excess of LiAlH_4		
an excess of CH_3COCl		

[3]

- (ii) Tartaric acid reacts with the amine 1-phenylethylamine, $\text{C}_6\text{H}_5\text{CH}(\text{NH}_2)\text{CH}_3$, to form an ionic salt.

Draw the structure of the salt formed in this reaction. Include the charges on the ions.

[1]

[Total: 17]

- 4 (a) Samples of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with an excess of aqueous sodium hydroxide or with an excess of aqueous ammonia.

Give the following information about these reactions.

- (i) reaction 1: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous of sodium hydroxide

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

- (ii) reaction 2: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous ammonia

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

- (b) Copper(I) oxide is added to hot dilute sulfuric acid. A blue solution, **X**, and a red-brown solid, **Y**, form.

Suggest the identities of **X** and **Y**. Name the type of reaction.

X

Y

type of reaction

[2]

[Total: 8]

- 5 Dinitrogen pentoxide, N_2O_5 , is dissolved in an inert solvent (solv) and the rate of decomposition of N_2O_5 is investigated. This reaction produces nitrogen dioxide, which remains in solution, and oxygen gas.



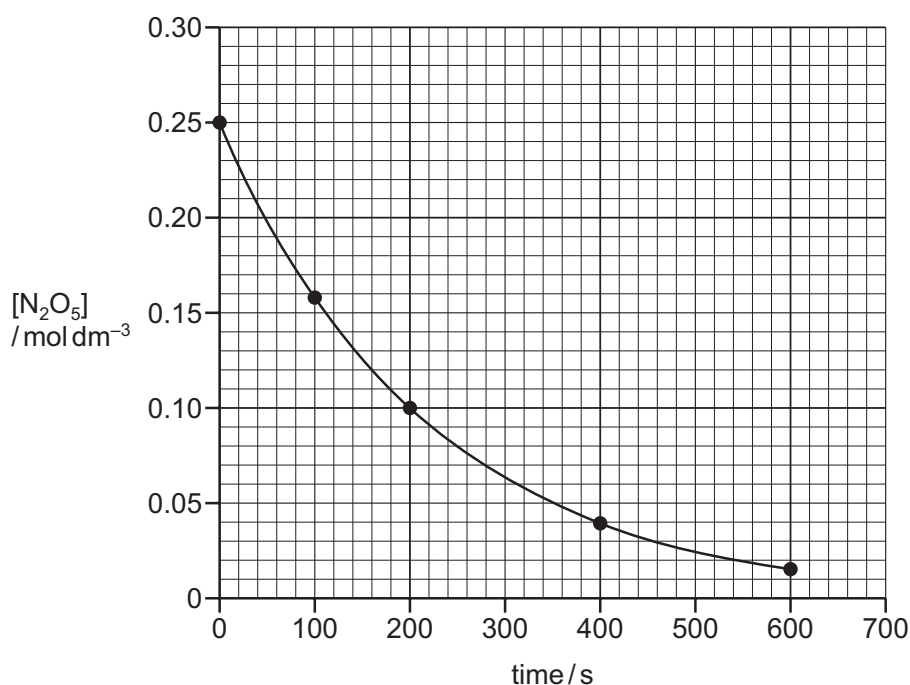
- (a) Suggest what measurements could be used to follow the rate of this reaction from the given information.

.....
 [1]

- (b) In a separate experiment, the rate of the decomposition of $\text{N}_2\text{O}_5(\text{g})$ is investigated.



The graph shows the results obtained.



The reaction is first order with respect to N_2O_5 . This can be confirmed from the graph using half-lives.

- (i) Explain the term *half-life of a reaction*.

.....
 [1]

- (ii) Determine the half-life of this reaction. Show your working on the graph.

half-life = ... s [1]

- (iii) Suggest the effect on the half-life of this reaction if the initial concentration of N_2O_5 is halved.

..... [1]

- (c) (i) Use the graph in **5(b)** to determine the rate of reaction at 200 s. Show your working.

rate = ...

units = ... [2]

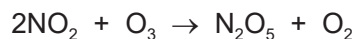
The rate equation for this reaction is shown.

$$\text{rate} = k[\text{N}_2\text{O}_5]$$

- (ii) Use your answer to (c)(i) to calculate the value of the rate constant, k , for this reaction and state its units.

k = ... units [1]

- (d) Nitrogen dioxide reacts with ozone, O_3 , as shown.



The rate equation for this reaction is $\text{rate} = k[\text{NO}_2][\text{O}_3]$.

Suggest a possible two-step mechanism for this reaction.

.....
 [2]

[Total: 9]

- 6 (a) Compare and explain the relative acidities of butanoic acid, ethanol, ethanoic acid and water.

..... > > >
 most acidic least acidic

.....

.....

.....

.....

..... [4]

- (b) Three carboxylic acids, methanoic acid, HCO_2H , ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$, and butanedioic acid, $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$, are compared. Two tests were carried out on separate samples of each organic acid, as shown.

The following results were obtained. ✓ = observed change ✗ = no observed reaction

test	reagents and conditions	HCO_2H	$\text{HO}_2\text{CCO}_2\text{H}$	$\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$	observed change
1		✓	✗	✗	
2		✓	✓	✗	

- (i) Complete the table with the reagents and conditions and the observed change for a positive test.
 Assume these organic acids all have a similar acid strength. [3]

- (ii) Each compound, HCO_2H , $\text{HO}_2\text{CCO}_2\text{H}$ and $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$, is dissolved separately in CDCl_3 . Proton (^1H) NMR and carbon-13 (^{13}C) NMR spectra are then obtained.

Complete the table.

compound	number of peaks in proton NMR	number of peaks in carbon-13 NMR
HCO_2H		
$\text{HO}_2\text{CCO}_2\text{H}$		
$\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$		

[2]

- (iii) The proton NMR spectrum of HCO_2H in D_2O is obtained.

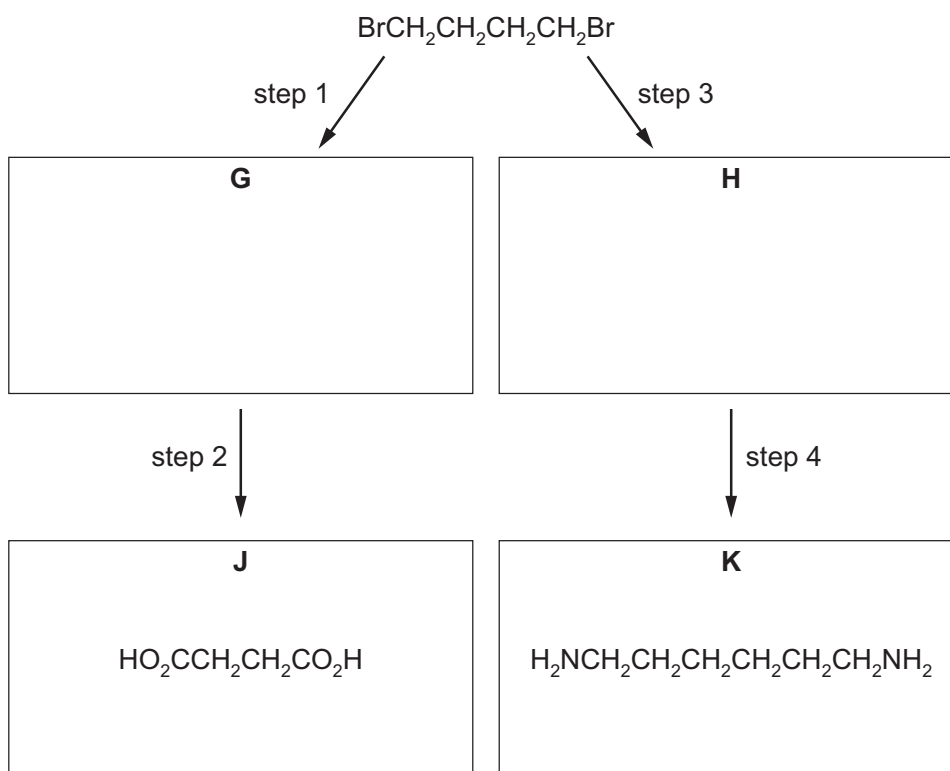
Describe and explain the difference observed between this spectrum and the proton NMR spectrum of HCO_2H in (b)(ii).

.....

.....

..... [1]

- (c) 1,4-dibromobutane, $\text{Br}(\text{CH}_2)_4\text{Br}$, is used in the synthesis of the dicarboxylic acid **J** and diamine **K** as shown.



(i) Draw the structures of **G** and **H** in the boxes. [2]

(ii) Suggest reagents and conditions for each of steps 1 to 4.

step 1

step 2

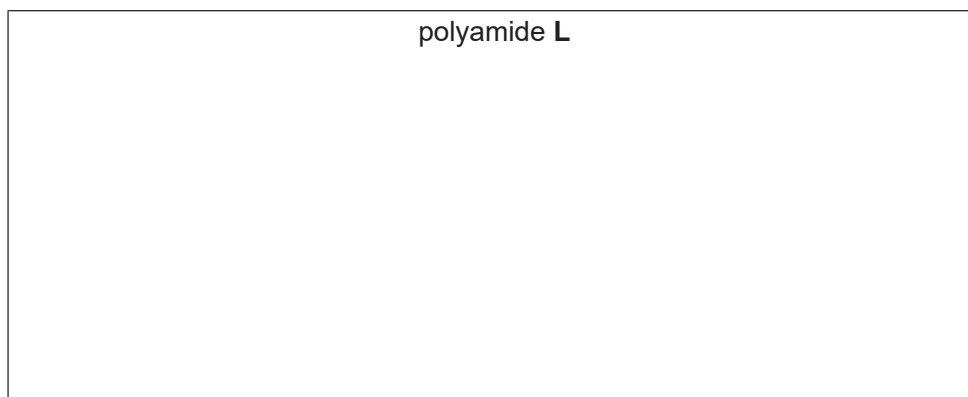
step 3

step 4

[4]

- (d) Polyamide **L** can be synthesised from dicarboxylic acid **J**, $\text{HO}_2\text{C}(\text{CH}_2)_2\text{CO}_2\text{H}$, and diamine **K**, $\text{H}_2\text{N}(\text{CH}_2)_6\text{NH}_2$.

Draw the repeat unit of the polymer formed in the box. Any functional groups should be shown displayed.



[2]

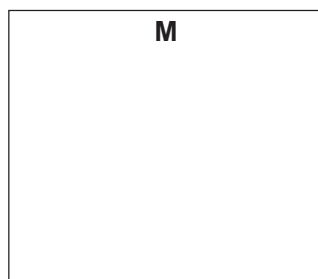
[Total: 18]

- 7 (a) 3-aminobenzoic acid can be synthesised from methylbenzene in three steps.

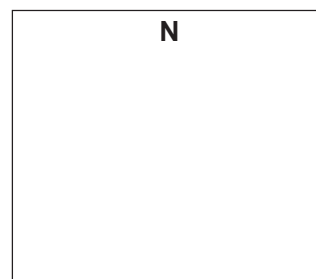
methylbenzene



step 1 →

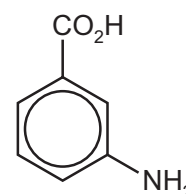


step 2 →



step 3 ↓

3-aminobenzoic acid



- (i) Draw the structures of **M** and **N** in the boxes.

[2]

- (ii) Suggest reagents and conditions for each step of the synthesis.

step 1

step 2

step 3

[3]

(b) A mixture of serine, $\text{HOCH}_2\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, and lysine, $\text{H}_2\text{N}(\text{CH}_2)_4\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, reacts to form several different products.

- (i) Draw the structures of the two structural isomers with the molecular formula $\text{C}_6\text{H}_{12}\text{N}_2\text{O}_5$ that could be present in the product mixture.

The functional group formed in each case should be displayed.

[3]

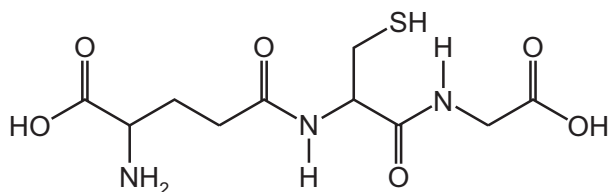
- (ii) Predict the number of different structural isomers with the molecular formula $\text{C}_9\text{H}_{19}\text{N}_3\text{O}_4$ that could be present in the product mixture.

molecular formula	number of structural isomers formed
$\text{C}_9\text{H}_{19}\text{N}_3\text{O}_4$	

[1]

(c) Glutathione is a naturally occurring compound found in plants.

glutathione



- (i) On the diagram of glutathione, label each chiral centre with an asterisk (*). [1]
- (ii) Draw the structures of the three products formed after complete acid hydrolysis of glutathione. Assume the thiol group, $-SH$, does not react.



[2]

- (iii) Glutathione is soluble in water.

By referring to the structure of glutathione, explain why glutathione is soluble in water.

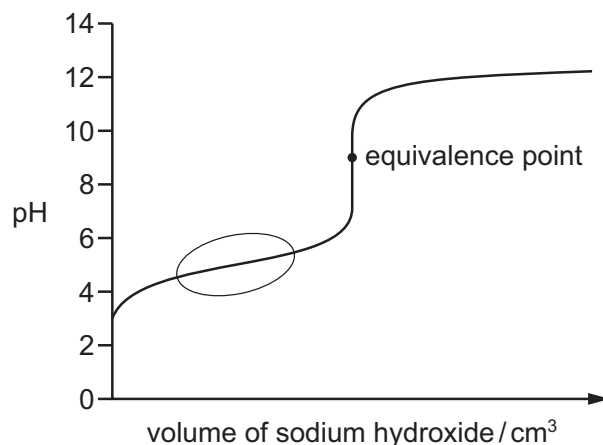
.....

.....

..... [1]

[Total: 13]

- 8 (a) The sketch graph for the titration of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, with sodium hydroxide is shown.



- (i) In the region circled on the graph, identify the **two** organic species that are present in the solution. Explain why the pH of the mixture only changes slowly and gradually in this region when sodium hydroxide is being added.

two species present [3]

.....

.....

.....

- (ii) The equivalence point in this acid-base titration is where the two solutions have been mixed in exactly equal molar proportion.

Suggest why the pH is greater than 7 at the equivalence point in this titration.

..... [1]

.....

.....

- (b) An impure sample of ammonium vanadate(V), NH_4VO_3 , with mass 0.150 g, is dissolved in an excess of dilute acid.

In this solution all vanadium is present as VO_2^+ ions. An excess of zinc powder is added to the solution and all the VO_2^+ ions are reduced to V^{2+} ions. The mixture is filtered to remove any remaining zinc powder.



When the resulting solution is titrated, 20.10 cm^3 of $0.0250 \text{ mol dm}^{-3}$ acidified MnO_4^- oxidises all V^{2+} ions back to VO_2^+ ions.



Calculate the percentage by mass of NH_4VO_3 in the 0.150 g impure sample of NH_4VO_3 .

Give your answer to **three** significant figures.

[M_r : NH_4VO_3 , 116.9]

percentage by mass of NH_4VO_3 = ... % [3]

[Total: 7]

- 9 The carbon-13 (^{13}C) NMR spectrum of compound **A**, $\text{C}_8\text{H}_8\text{O}_2$, contains six peaks.

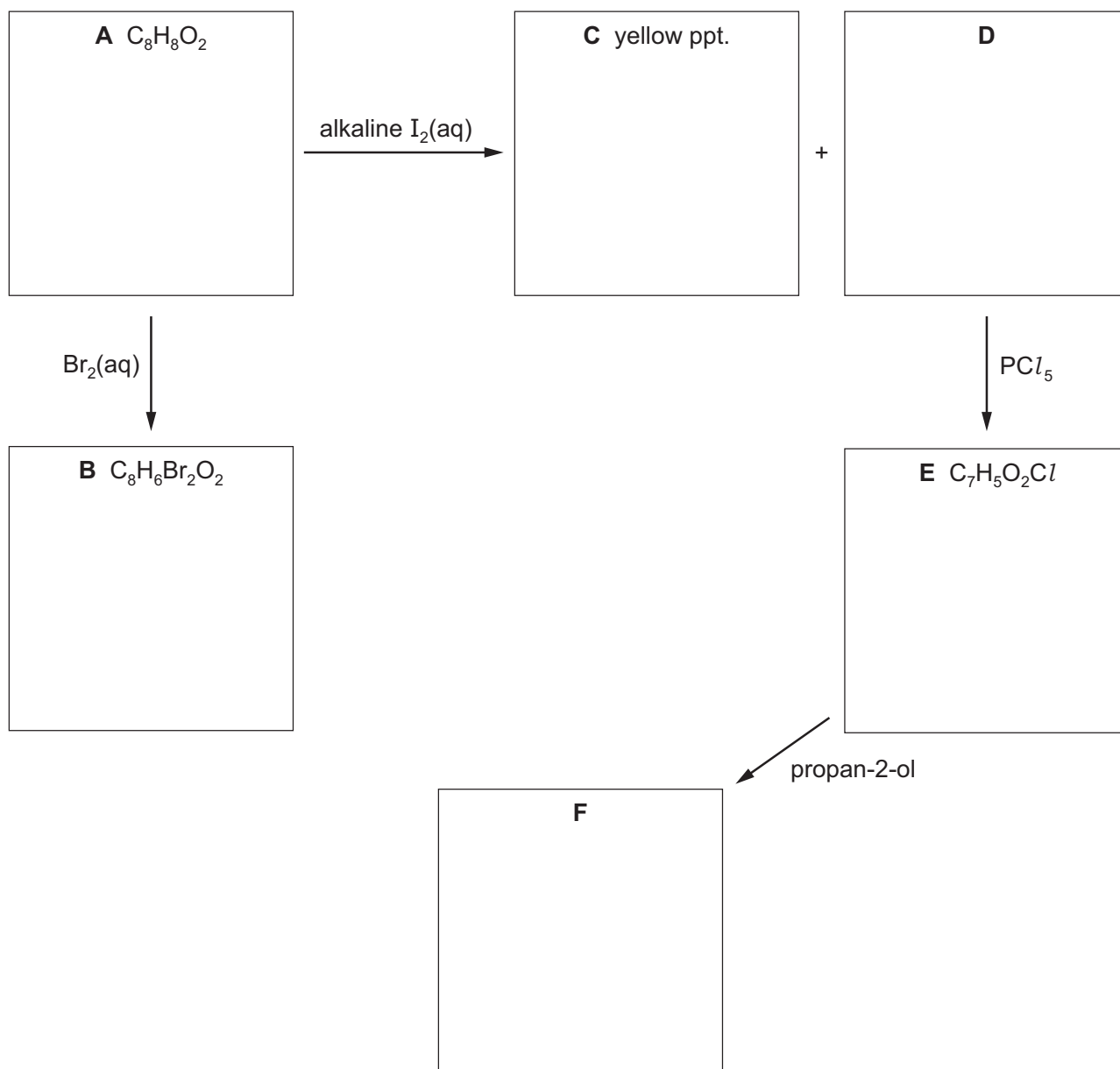
Compound **A** reacts with an excess of bromine water to give compound **B**, $\text{C}_8\text{H}_6\text{Br}_2\text{O}_2$.

Compound **A** reacts with alkaline aqueous iodine to form a yellow precipitate **C** and compound **D**.

Compound **D** reacts with PCl_5 to form compound **E**, $\text{C}_7\text{H}_5\text{O}_2\text{Cl}$.

Compound **E** reacts with propan-2-ol to form compound **F**.

Draw the structures of compounds **A**, **B**, **C**, **D**, **E** and **F** in the boxes.



[6]

BLANK PAGE

Permission to reproduce items where third-party owned material protected by copyright is included has been sought and cleared where possible. Every reasonable effort has been made by the publisher (UCLES) to trace copyright holders, but if any items requiring clearance have unwittingly been included, the publisher will be pleased to make amends at the earliest possible opportunity.

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.

Cambridge Assessment International Education is part of the Cambridge Assessment Group. Cambridge Assessment is the brand name of the University of Cambridge Local Examinations Syndicate (UCLES), which itself is a department of the University of Cambridge.

Cambridge International AS & A Level

CANDIDATE
NAME

--

CENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

May/June 2021

2 hours

You must answer on the question paper.

You will need: Data booklet

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Answer **all** the questions in the spaces provided.

1 (a) An aqueous solution of chromium(III) contains the green $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ complex ion.

(i) Complete the electronic configuration of an isolated, gaseous Cr^{3+} ion.

$1s^2$ [1]

(ii) Define the term *complex ion*.

.....
 [1]

(b) $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ shows some similar chemical properties to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

Samples of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ are reacted separately with either $\text{NaOH}(\text{aq})$, $\text{H}_2\text{O}_2(\text{aq})$, or excess $\text{NH}_3(\text{aq})$.

Use this information and the *Data Booklet* to suggest the formula of the chromium species formed. State the type of reaction taking place in each case.

reagent added to $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$	formula of chromium species formed	type of reaction
$\text{NaOH}(\text{aq})$		
$\text{H}_2\text{O}_2(\text{aq})$		
an excess of $\text{NH}_3(\text{aq})$		

[5]

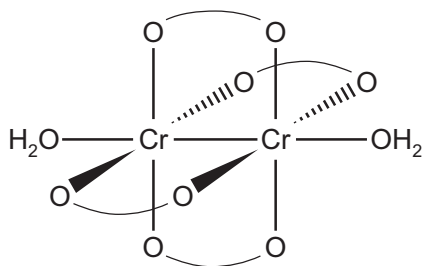
(c) $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ are both complexes of chromium(II) and have different colours.

Explain why the colours of these complexes are different.

.....

 [2]

- (d) The structure of $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ is shown. Ethanoate ions act as ligands in this complex. The ethanoate ligand, CH_3CO_2^- , is shown as $\text{O} \text{---} \text{O}$.



- (i) Water and ethanoate ions behave as different types of ligand in this complex.

Suggest an explanation for this statement.

..... [1]

- (ii) Deduce the coordination number of Cr and the geometry around each Cr atom in this structure.

coordination number

geometry around Cr atom [1]

- (iii) State the type of bond between the two atoms in the Cr–Cr bond.

..... [1]

- (e) The $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ complex reacts with aqueous acid to form $\text{Cr}^{2+}(\text{aq})$ ions.

$\text{Cr}^{2+}(\text{aq})$ ions react with $\text{O}_2(\text{aq})$ under acidic conditions. $\text{Cr}^{3+}(\text{aq})$ ions are formed.

Use the *Data Booklet* to answer the following questions.

- (i) Construct an ionic equation for the reaction of $\text{Cr}^{2+}(\text{aq})$ with $\text{O}_2(\text{aq})$ under acidic conditions.

..... [2]

- (ii) Calculate $E_{\text{cell}}^{\ominus}$ for the reaction in (e)(i).

$E_{\text{cell}}^{\ominus} = \dots\dots\dots \text{V}$ [1]

[Total: 15]

- 2 (a) State and explain the trend observed in the thermal stability of the Group 2 nitrates.

.....

.....

.....

.....

..... [3]

- (b) (i) Lead(II) nitrate, $\text{Pb}(\text{NO}_3)_2$, decomposes on heating in a similar manner to the Group 2 nitrates.

Write an equation for the decomposition of lead(II) nitrate.

..... [1]

- (ii) Suggest how the ease of decomposition of $\text{Pb}(\text{NO}_3)_2$ would compare to that of $\text{Ba}(\text{NO}_3)_2$. Explain your answer. You may find it useful to refer to the *Data Booklet*.

.....

..... [1]

- (c) (i) Barium ethanedioate, BaC_2O_4 , decomposes on heating to produce barium oxide and a mixture of two different gases.

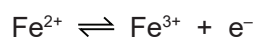
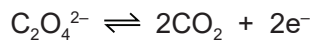
Construct an equation for the decomposition of barium ethanedioate.

..... [1]

- (ii) An impure sample of BaC_2O_4 , of mass 0.500 g, is added to 50.0 cm^3 of $0.0200\text{ mol dm}^{-3}$ acidified MnO_4^- (aq), an excess. A redox reaction takes place and all the BaC_2O_4 reacts.

The resulting solution, containing unreacted acidified MnO_4^- , is titrated with $0.0500\text{ mol dm}^{-3}$ Fe^{2+} (aq).

The end-point is reached when 30.40 cm^3 of $0.0500\text{ mol dm}^{-3}$ Fe^{2+} (aq) has been added.



Calculate the percentage by mass of BaC_2O_4 in the 0.500 g impure sample. Show your working.

[M_r : BaC_2O_4 , 225.3]

percentage by mass of BaC_2O_4 = ... [4]

- (d) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is completely dissociated in aqueous solution.

Calculate the pH of 0.120 mol dm^{-3} $\text{Ba}(\text{OH})_2$ (aq) at 298 K.

pH = ... [2]

[Total: 12]

3 (a) (i) Define the term *standard electrode potential*.

.....

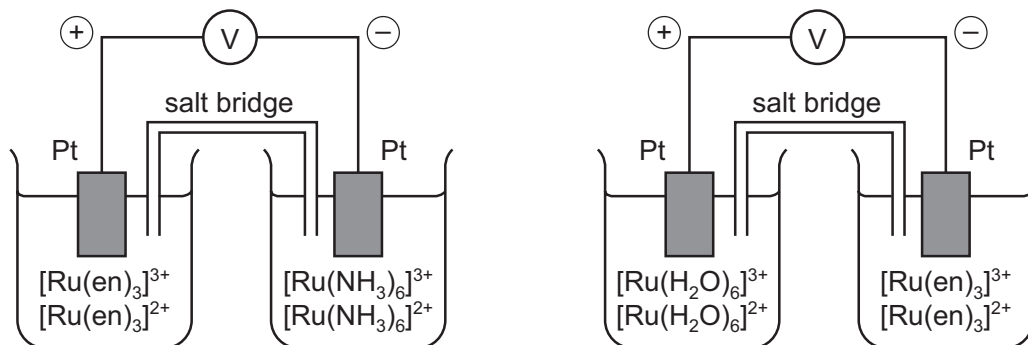
.....

..... [2]

Three redox systems, **A**, **B** and **C**, are shown. The ligand 1,2-diaminoethane, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is represented by en.

A	$[\text{Ru}(\text{H}_2\text{O})_6]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{H}_2\text{O})_6]^{2+}$
B	$[\text{Ru}(\text{NH}_3)_6]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{NH}_3)_6]^{2+}$
C	$[\text{Ru}(\text{en})_3]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{en})_3]^{2+}$

Two electrochemical cells are set up to compare the standard electrode potentials, E° , of three half-cells. The diagrams show the relative potential of each electrode.



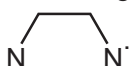
(ii) Use this information to complete the table by adding the labels **A**, **B** and **C** to deduce the order of E° for the three half-cells.

E°	redox system
most negative	
↑	
least negative	

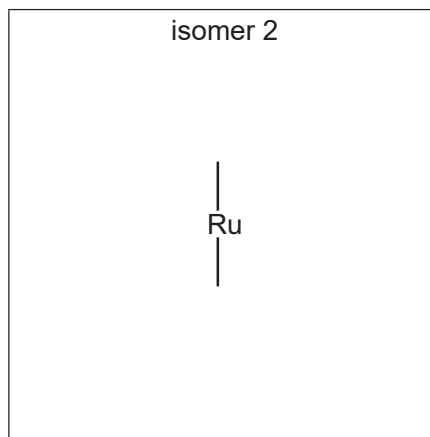
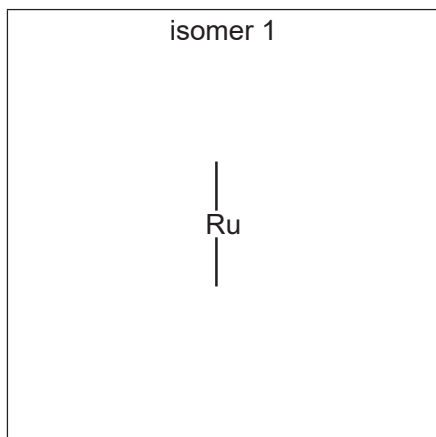
[1]

- (iii) The complex $[\text{Ru}(\text{en})_3]^{3+}$ shows stereoisomerism. The ligand en is bidentate.

Draw three-dimensional diagrams to show the two isomers of $[\text{Ru}(\text{en})_3]^{3+}$. Represent the

ligand en by using .

Name the type of stereoisomerism.



type of stereoisomerism [3]

- (b) (i) An electrochemical cell consists of a Br_2/Br^- half-cell and a Ag^+/Ag half-cell, under standard conditions.

Use the *Data Booklet* to calculate the $E^\ominus_{\text{cell}}$. Deduce the direction of electron flow in the wire through the voltmeter between these two half-cells.

$E^\ominus_{\text{cell}} = \dots\dots\dots \text{ V}$

direction of electron flow from to [1]

- (ii) Water is added to the Ag^+/Ag half-cell in (b)(i).

Suggest the effect of this addition on the E_{cell} . Place a tick (✓) in the appropriate box.

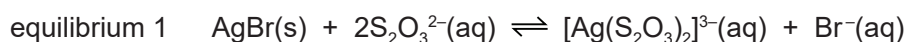
less positive	no change	more positive

Explain your answer.

.....

 [2]

- (c) Silver bromide, AgBr, dissolves in an aqueous solution of $\text{S}_2\text{O}_3^{2-}$ ions to form the complex ion $[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}$. The $\text{S}_2\text{O}_3^{2-}$ ions act as monodentate ligands.



- (i) Define the term *ligand*.

.....
 [1]

- (ii) Write an expression for the equilibrium constant, K_c , for equilibrium 1.

$K_c =$

[1]

- (iii) Some additional data are given about the dissolution of AgBr in $\text{S}_2\text{O}_3^{2-}(\text{aq})$.

equilibrium constant	numerical value
solubility product, K_{sp} , of AgBr	5.4×10^{-13}
stability constant, K_{stab} , of $[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}$	2.9×10^{13}

Use your answer to (c)(ii) and these data to calculate K_c for equilibrium 1. Include the units for K_c .

$K_c =$ units [2]

- (d) The numerical values for the stability constants, K_{stab} , of two other silver(I) complexes are given.

silver(I) complex	numerical value of K_{stab}
$[\text{Ag}(\text{CN})_2]^{-}$	5.3×10^{18}
$[\text{Ag}(\text{NH}_3)_2]^{+}$	1.6×10^7

An aqueous solution containing Ag^{+} is added to a solution containing equal concentrations of $\text{CN}^{-}(\text{aq})$, $\text{NH}_3(\text{aq})$ and $\text{S}_2\text{O}_3^{2-}(\text{aq})$. The mixture is left to reach equilibrium.

Deduce the relative concentrations of $[\text{Ag}(\text{CN})_2]^{-}$, $[\text{Ag}(\text{NH}_3)_2]^{+}$ and $[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}$ present in the resulting mixture. Explain your answer.

..... > >
 highest concentration lowest concentration

.....
 [2]

[Total: 15]

- 4 (a) (i) Define the term *lattice energy*.

.....

 [2]

- (ii) Use the following data to calculate a value for the enthalpy change of solution of copper(II) chloride, $\text{CuCl}_2(\text{s})$. You might find it helpful to construct an energy cycle.

enthalpy change of hydration of Cl^- = -378 kJ mol^{-1}
 enthalpy change of hydration of Cu^{2+} = $-2099 \text{ kJ mol}^{-1}$
 lattice energy of $\text{CuCl}_2(\text{s})$ = $-2824 \text{ kJ mol}^{-1}$

enthalpy change of solution of $\text{CuCl}_2(\text{s})$ = ... kJ mol^{-1} [2]

- (iii) The enthalpy change of hydration of Ca^{2+} is $-1579 \text{ kJ mol}^{-1}$.

Use the *Data Booklet* to suggest why there is a big difference in the values of ΔH_{hyd} for Ca^{2+} and Cu^{2+} .

.....

 [2]

- (b) (i) Identify the substances formed at the anode and at the cathode during the electrolysis of saturated $\text{CaCl}_2(\text{aq})$.

at the anode

at the cathode

[1]

- (ii) Calcium can be produced by the electrolysis of molten calcium chloride, $\text{CaCl}_2(\text{l})$.

Calculate the mass, in g, of Ca formed when a current of 0.75A passes through $\text{CaCl}_2(\text{l})$ for 60 minutes.

[A_r : Ca, 40.1]

mass of Ca = ... g [2]

- (c) (i) Explain what is meant by the term *entropy of a system*.

.....
 [1]

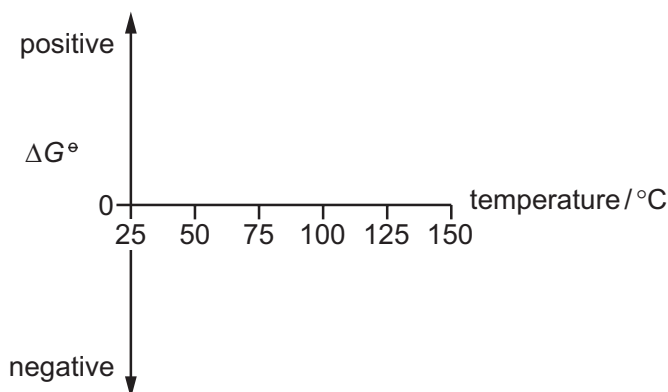
- (ii) Place one tick (✓) in each row of the table to show the sign of each entropy change, ΔS .

process	ΔS is negative	ΔS is zero	ΔS is positive
NaCl dissolving in water			
water solidifying to ice			

[1]

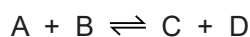
- (iii) The evaporation of one mole of water has a standard Gibbs free energy change, ΔG° , of +8.6 kJ at 25°C.

Sketch a graph on the axes to show how ΔG° changes for this process between 25°C and 150°C at 101 kPa.



[2]

- (d) The reaction between A and B is feasible at low temperatures but is **not** feasible at high temperatures.



Deduce the signs of ΔH and ΔS for this reaction and explain why the feasibility changes with temperature.

sign of ΔH = ... sign of ΔS = ...

.....

 [2]

[Total: 15]

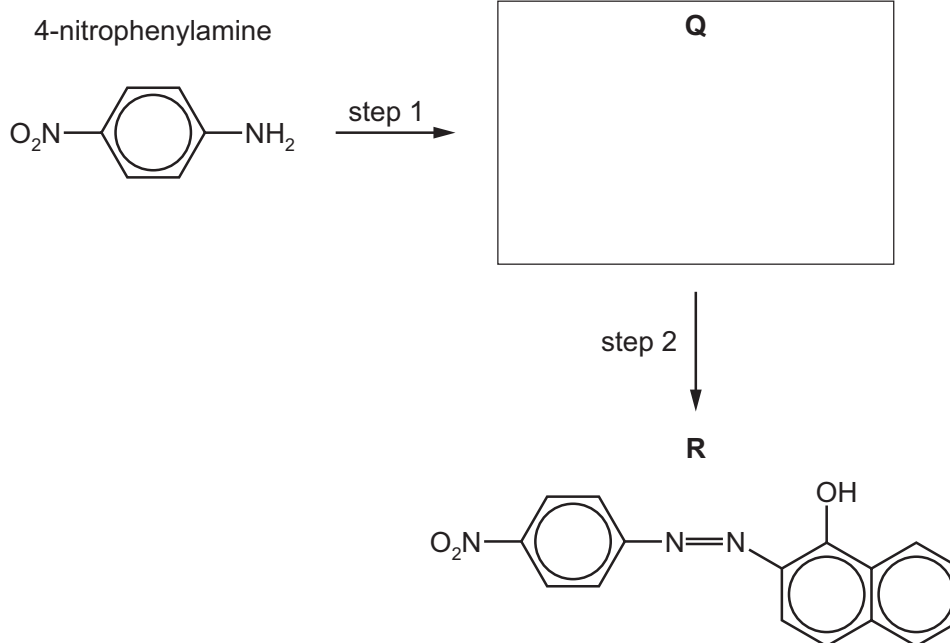
- 5 (a) Describe and explain the relative basicities of phenylamine, ethylamine and 4-nitrophenylamine.

..... > >
 most basic least basic

.....

 [4]

- (b) The dye **R** can be synthesised from 4-nitrophenylamine in two steps.



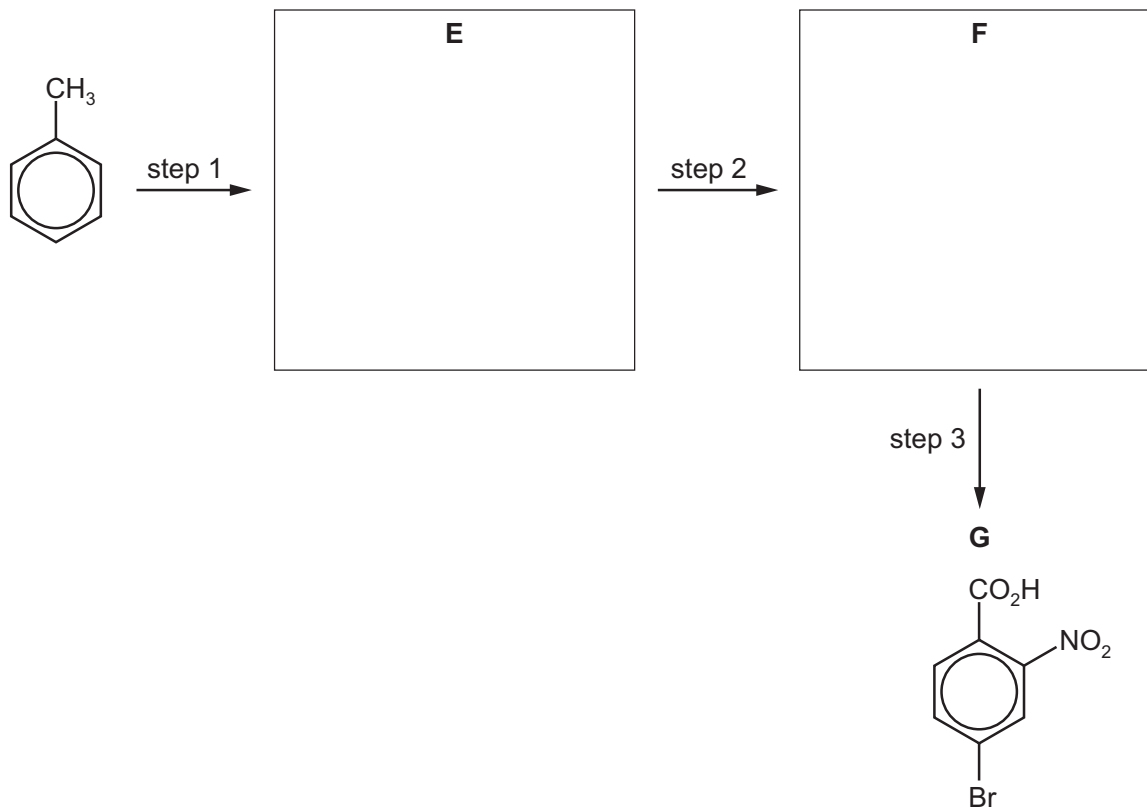
- (i) Deduce and draw the structure of the organic salt **Q** in the box. [1]

- (ii) Suggest reagents and conditions for step 1 and 2 in (b).

step 1

step 2 [2]

(c) Compound **G** can be synthesised from methylbenzene in three steps.



(i) Give the systematic name of compound **G**.

..... [1]

(ii) Deduce the identities of **E** and **F** and draw their structures in the boxes. [2]

(iii) Suggest reagents and conditions for each of steps 1 to 3 in (c).

step 1

step 2

step 3 [3]

[Total: 13]

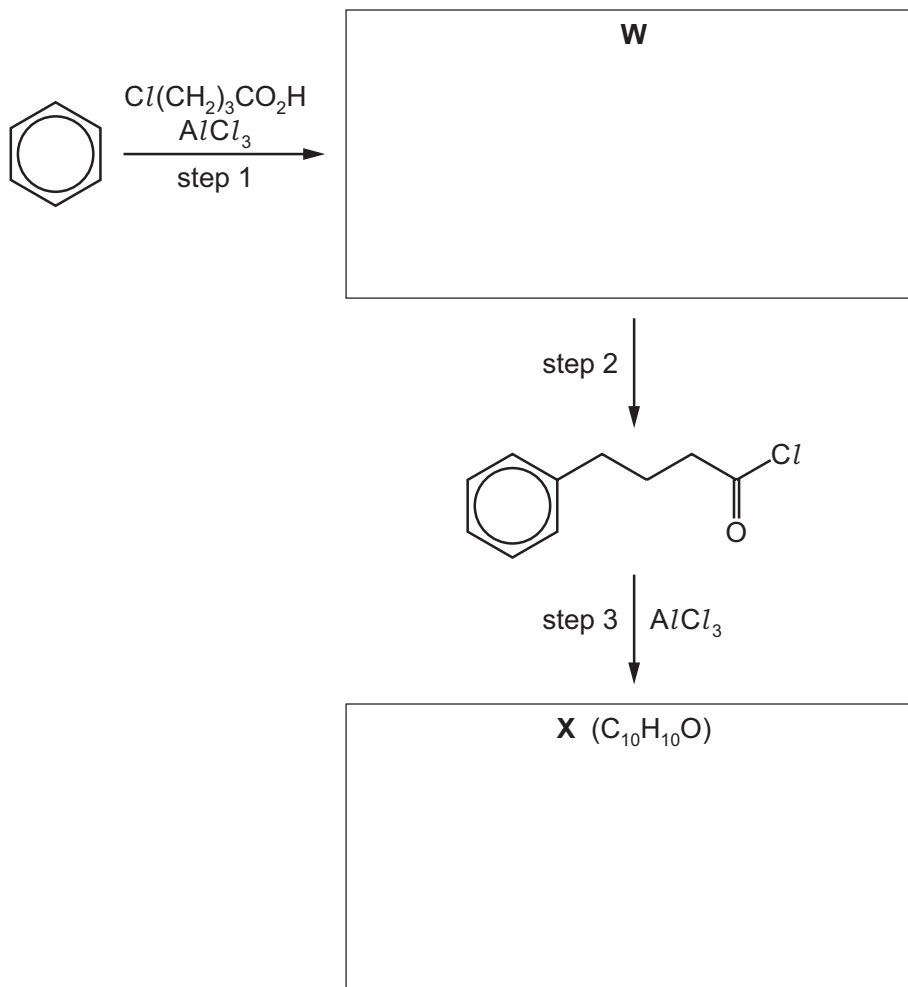
- 6 (a)** There are four possible structural isomers of C_8H_{10} that contain a benzene ring.

Draw the **skeletal** formulae of the four structural isomers in the appropriate boxes. The number of peaks observed in the carbon-13 (^{13}C) NMR spectrum of each compound is given.

isomer 1 three peaks in ^{13}C NMR	isomer 2 four peaks in ^{13}C NMR
isomer 3 five peaks in ^{13}C NMR	isomer 4 six peaks in ^{13}C NMR

[4]

(b) A three-step synthesis of **X** ($C_{10}H_{10}O$) from benzene is suggested as shown.



- (i) Step 1 is the alkylation of benzene by electrophilic substitution.
Use $R-Cl$ to represent $Cl(CH_2)_3CO_2H$.

Write an equation for the formation of an electrophile from $R-Cl$ and $AlCl_3$.

..... [1]

- (ii) Deduce and draw the structures of **W** and **X** in the boxes. [2]

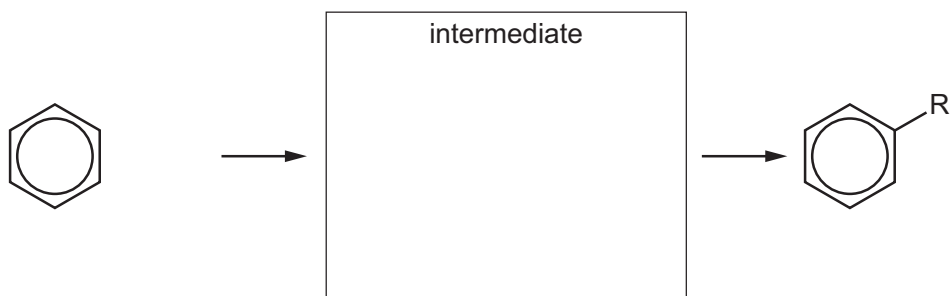
- (iii) Suggest the reagents and conditions for step 2.

..... [1]

- (iv) Complete the mechanism for the reaction of benzene with the electrophile formed in (b)(i).

Include all relevant charges and curly arrows showing the movement of electron pairs.

Draw the structure of the intermediate.



[3]

[Total: 11]

- 7 (a) In aqueous solution, chlorine dioxide, ClO_2 , reacts with hydroxide ions as shown.



A series of experiments is carried out using different concentrations of ClO_2 and OH^- . The table shows the results obtained.

experiment	$[\text{ClO}_2]$ / mol dm^{-3}	$[\text{OH}^-]$ / mol dm^{-3}	initial rate / $\text{mol dm}^{-3} \text{ min}^{-1}$
1	0.020	0.030	7.20×10^{-4}
2	0.020	0.120	2.88×10^{-3}
3	0.050	0.030	4.50×10^{-3}

- (i) Explain the term *order of reaction*.

.....
 [1]

- (ii) Use the data in the table to determine the order of reaction with respect to each reactant, ClO_2 and OH^- .

Explain your reasoning.

.....

 [2]

- (iii) Use your answer to (a)(ii) to construct the rate equation for this reaction.

rate = ... [1]

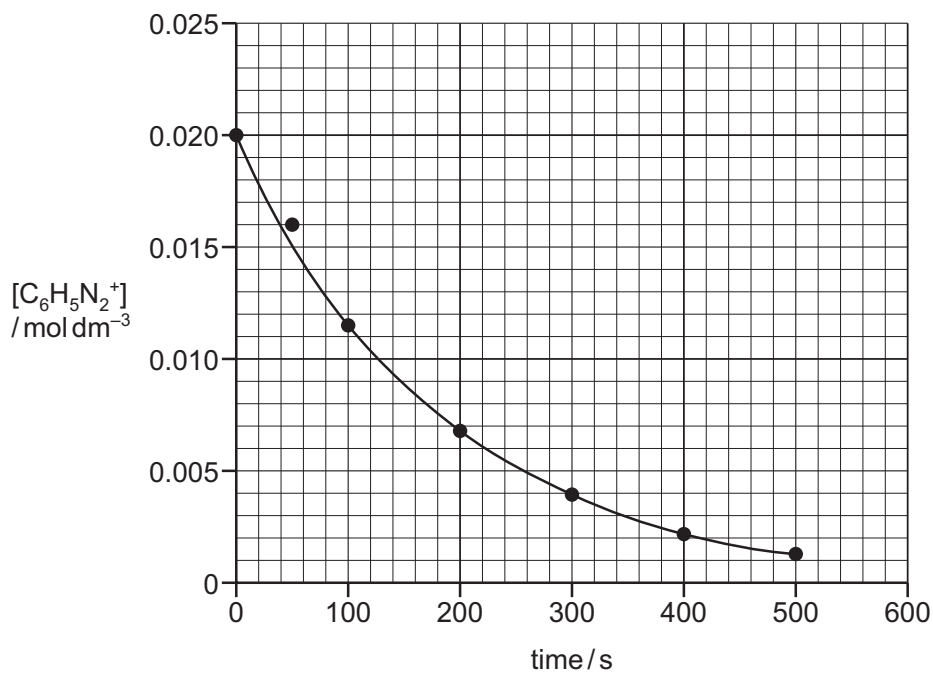
- (iv) Use your rate equation and the data from experiment 1 to calculate the rate constant, k , for this reaction.
 Include the units of k .

k = ... units [2]

Question 7 continues on the next page.

- (b) The decomposition of benzenediazonium ions, $\text{C}_6\text{H}_5\text{N}_2^+$, using a large excess of water, is a first-order reaction.

The graph shows the results obtained.



- (i) Draw the structure of the organic product formed in this reaction.

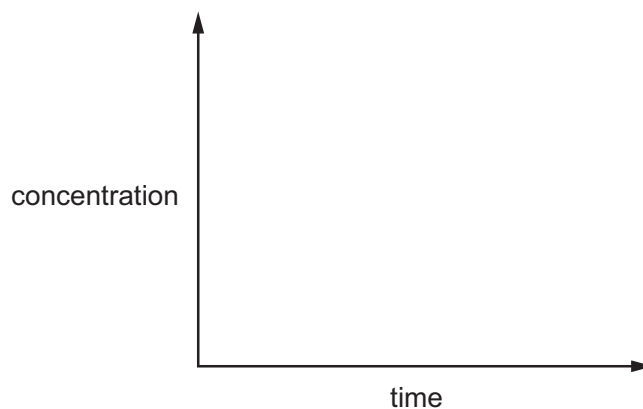
[1]

- (ii) Use the graph to determine the rate of reaction at 100 s. Show your working.

rate = ... $\text{mol dm}^{-3} \text{s}^{-1}$ [1]

(c) Sketch a concentration–time graph for a **zero-order** reaction.

Use your graph to suggest how successive half-lives for a zero-order reaction vary as the concentration of a reactant decreases. Indicate this by placing a tick (✓) in the appropriate box in the table.



successive half-lives decrease	no change in successive half-lives	successive half-lives increase

[1]

[Total: 9]

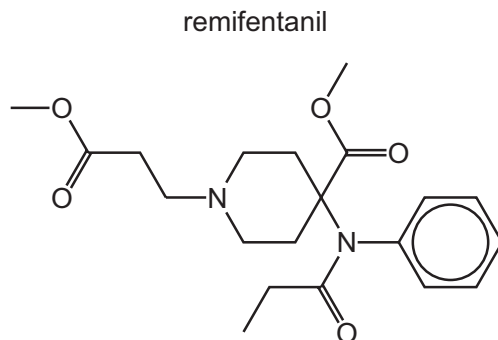
- 8 (a)** State and explain the relative rate of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides.

..... > >

fastest slowest

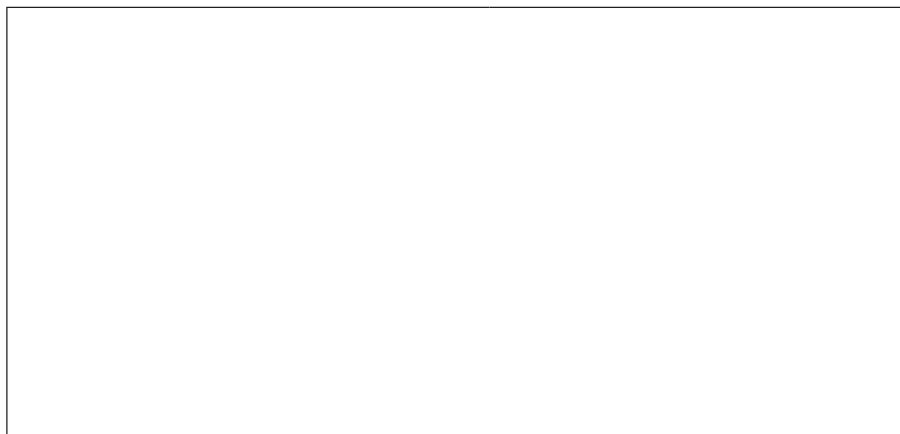
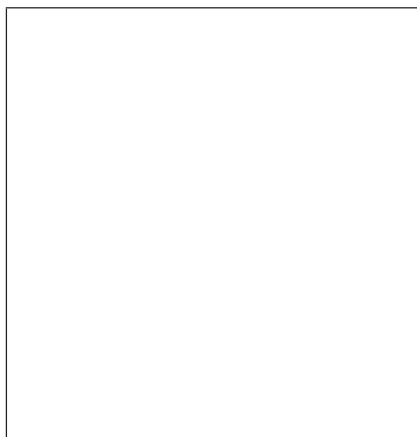
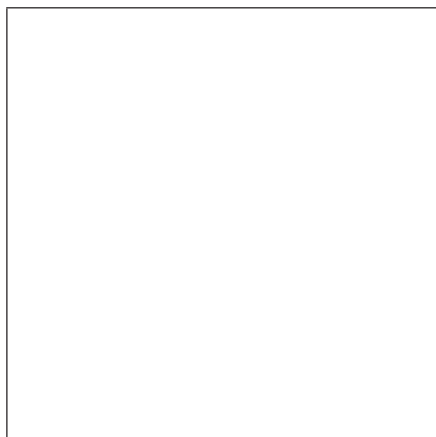
..... [3]

(b) The drug remifentanyl is shown.



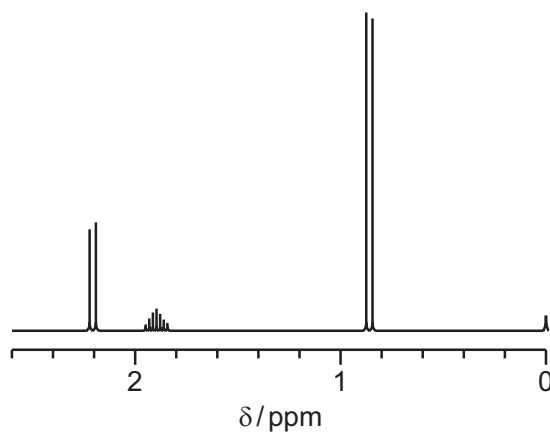
Remifentanyl is **completely** hydrolysed under acidic conditions. Three different organic compounds are formed.

Draw the structures for these organic compounds in the boxes.



[3]

- (c) Compound **Y**, $\text{C}_5\text{H}_{10}\text{O}_2$, reacts with $\text{Na}_2\text{CO}_3(\text{aq})$ to evolve bubbles of gas. The proton (^1H) NMR spectrum of compound **Y** in D_2O is shown.



- (i) Use this information to suggest a structure for **Y**.

[1]

- (ii) Use the *Data Booklet*, the proton (^1H) NMR spectrum and your answer to (c)(i) to complete the table.

chemical shift (δ)	environment of proton	splitting pattern	number of ^1H atoms responsible for the peak
0.95			
1.90			
2.20			

[3]

[Total: 10]

BLANK PAGE

Permission to reproduce items where third-party owned material protected by copyright is included has been sought and cleared where possible. Every reasonable effort has been made by the publisher (UCLES) to trace copyright holders, but if any items requiring clearance have unwittingly been included, the publisher will be pleased to make amends at the earliest possible opportunity.

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.

Cambridge Assessment International Education is part of the Cambridge Assessment Group. Cambridge Assessment is the brand name of the University of Cambridge Local Examinations Syndicate (UCLES), which itself is a department of the University of Cambridge.

Cambridge International AS & A Level

CANDIDATE
NAME

--

CENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY

9701/43

Paper 4 A Level Structured Questions

May/June 2021

2 hours

You must answer on the question paper.

You will need: Data booklet

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Answer **all** the questions in the spaces provided.

- 1 (a) The carbonates and hydroxides of Group 2 elements show similar trends in thermal stability.
Suggest and explain the variation in the trend in the thermal stability of the Group 2 hydroxides.

.....

.....

.....

.....

..... [3]

- (b) Calcium hydroxide is slightly soluble in water.

- (i) Write an equation to show the dissociation of calcium hydroxide, $\text{Ca(OH)}_2(\text{s})$, in aqueous solution. Include state symbols.

..... $\rightleftharpoons$ [1]

- (ii) Calculate the solubility, in mol dm^{-3} , of Ca(OH)_2 .
[K_{sp} : Ca(OH)_2 , $5.02 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9}$]

solubility = ... mol dm^{-3} [2]

- (iii) Suggest how the solubility of Ca(OH)_2 in aqueous NaOH compares to its solubility in water.

Explain your reasoning.

.....

.....

..... [1]

[Total: 7]

- 2 (a) Explain why chromium complexes are coloured.

.....

.....

.....

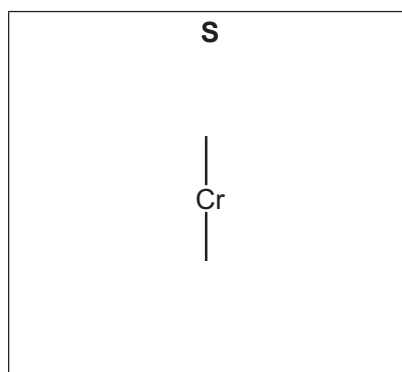
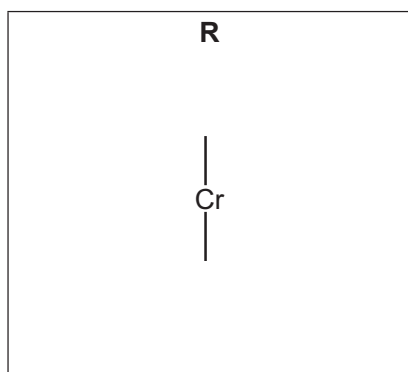
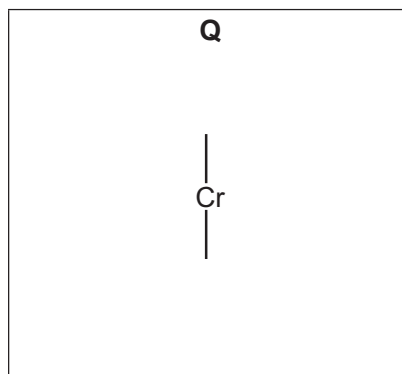
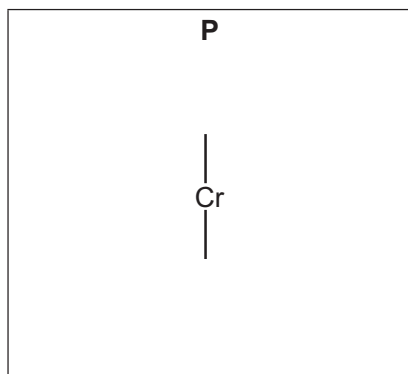
.....

..... [4]

- (b) Four different compounds can be obtained when anhydrous chromium(III) chloride reacts with water under various conditions. When samples of each compound are reacted separately with aqueous silver nitrate, different amounts of silver chloride are precipitated. The precipitation leaves the complex ions **P**, **Q**, **R** and **S** in solution.

formula of compound	moles of AgCl precipitated per mole of complex ion	complex ion	property of complex ion
$\text{CrCl}_3(\text{H}_2\text{O})_6$	3	P	non-polar
$\text{CrCl}_3(\text{H}_2\text{O})_5$	2	Q	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	R	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	S	non-polar

- (i) Draw three-dimensional diagrams for the structures of complex ions **P**, **Q**, **R** and **S**. Include the charges for each complex ion.

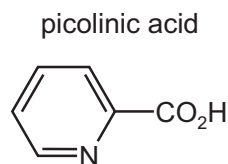


[4]

- (ii) Suggest why complex ion **S** is non-polar.

.....
 [1]

- (c) The structure of picolinic acid is shown.



The conjugate base of picolinic acid is a bidentate ligand, **Z**.

- (i) Define the term *bidentate ligand*.

.....
 [2]

- (ii) Draw the structure of **Z**.

[1]

- (iii) **Z** reacts with aqueous chromium(III) ions, $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$, in a 3 : 1 ratio to form a new neutral complex.

State the coordination number and the geometry of the chromium(III) centre in the complex.

coordination number geometry [1]

- (d) $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ decomposes readily on heating to form Cr_2O_3 , steam and an inert colourless gas.

- (i) Deduce the oxidation numbers of chromium in $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ and in Cr_2O_3 .

$(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ Cr_2O_3 [1]

- (ii) Construct an equation for the thermal decomposition of $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$.

..... [1]

[Total: 15]

3 (a) (i) Define the term *transition element*.

.....
..... [1]

(ii) State how the melting point and density of iron compare to those of calcium.

.....
..... [1]

(b) (i) Define the term *standard cell potential*, $E_{\text{cell}}^{\ominus}$.

.....
.....
..... [2]

(ii) Draw a fully labelled diagram of the apparatus that can be used to measure the cell potential of a cell composed of a Cu(II)/Cu electrode and an Fe(III)/Fe(II) electrode. Include all necessary reactants.

[3]

(c) The reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$ is catalysed by adding a few drops of $\text{Fe}^{3+}(\text{aq})$.

(i) Use equations to show the catalytic role of Fe^{3+} in this reaction.

[2]

(ii) $\text{Fe}^{3+}(\text{aq})$ can oxidise $\text{I}^-(\text{aq})$, whereas $[\text{Fe}(\text{CN})_6]^{3-}(\text{aq})$ cannot oxidise $\text{I}^-(\text{aq})$.

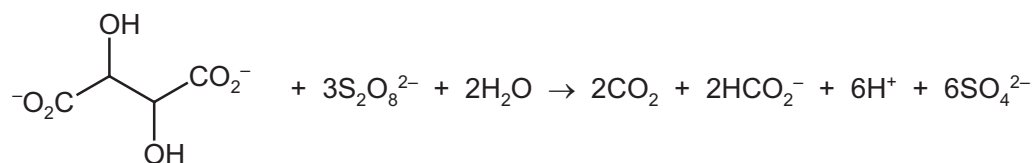
Use E° values to explain these observations.

.....

 [2]

(d) When aqueous solutions of $\text{S}_2\text{O}_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an $\text{Fe}^{3+}(\text{aq})$ catalyst. The overall equation for this reaction is shown.

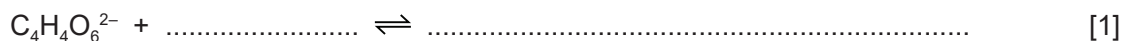
tartrate ions



(i) Suggest why this reaction is slow without the Fe^{3+} catalyst.

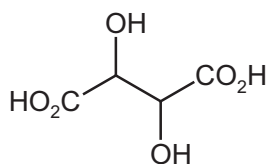
..... [1]

(ii) Use the overall equation to deduce the half-equation for the oxidation of tartrate ions, $\text{C}_4\text{H}_4\text{O}_6^{2-}$, to carbon dioxide, CO_2 , and methanoate ions, HCO_2^- .



- (e) (i) Complete the following table to show the structures of the organic products formed when tartaric acid reacts separately with each reagent. Identify each type of reaction.

tartaric acid



reagent	structure of organic product	type of reaction
an excess of LiAlH_4		
an excess of CH_3COCl		

[3]

- (ii) Tartaric acid reacts with the amine 1-phenylethylamine, $\text{C}_6\text{H}_5\text{CH}(\text{NH}_2)\text{CH}_3$, to form an ionic salt.

Draw the structure of the salt formed in this reaction. Include the charges on the ions.

[1]

[Total: 17]

- 4 (a) Samples of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with an excess of aqueous sodium hydroxide or with an excess of aqueous ammonia.

Give the following information about these reactions.

- (i) reaction 1: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous of sodium hydroxide

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

- (ii) reaction 2: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous ammonia

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

- (b) Copper(I) oxide is added to hot dilute sulfuric acid. A blue solution, **X**, and a red-brown solid, **Y**, form.

Suggest the identities of **X** and **Y**. Name the type of reaction.

X

Y

type of reaction

[2]

[Total: 8]

- 5 Dinitrogen pentoxide, N_2O_5 , is dissolved in an inert solvent (solv) and the rate of decomposition of N_2O_5 is investigated. This reaction produces nitrogen dioxide, which remains in solution, and oxygen gas.



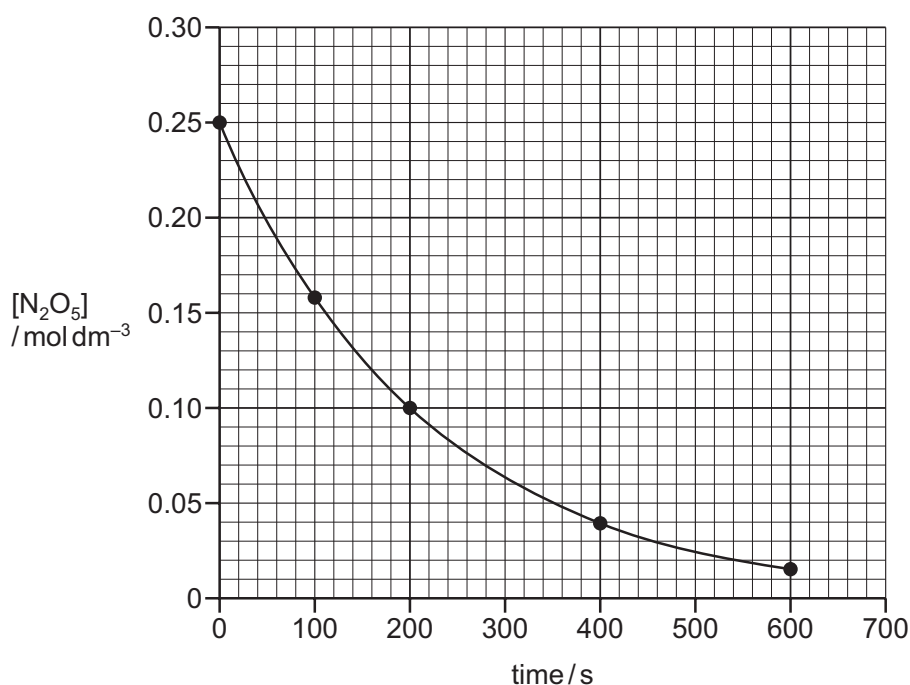
- (a) Suggest what measurements could be used to follow the rate of this reaction from the given information.

.....
 [1]

- (b) In a separate experiment, the rate of the decomposition of $\text{N}_2\text{O}_5(\text{g})$ is investigated.



The graph shows the results obtained.



The reaction is first order with respect to N_2O_5 . This can be confirmed from the graph using half-lives.

- (i) Explain the term *half-life of a reaction*.

.....
 [1]

- (ii) Determine the half-life of this reaction. Show your working on the graph.

half-life = ... s [1]

- (iii) Suggest the effect on the half-life of this reaction if the initial concentration of N_2O_5 is halved.

..... [1]

- (c) (i) Use the graph in **5(b)** to determine the rate of reaction at 200 s. Show your working.

rate = ...

units = ... [2]

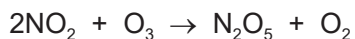
The rate equation for this reaction is shown.

$$\text{rate} = k[\text{N}_2\text{O}_5]$$

- (ii) Use your answer to (c)(i) to calculate the value of the rate constant, k , for this reaction and state its units.

k = ... units [1]

- (d) Nitrogen dioxide reacts with ozone, O_3 , as shown.



The rate equation for this reaction is $\text{rate} = k[\text{NO}_2][\text{O}_3]$.

Suggest a possible two-step mechanism for this reaction.

.....
 [2]

[Total: 9]

- 6 (a) Compare and explain the relative acidities of butanoic acid, ethanol, ethanoic acid and water.

..... > > >
 most acidic least acidic

.....

 [4]

- (b) Three carboxylic acids, methanoic acid, HCO_2H , ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$, and butanedioic acid, $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$, are compared. Two tests were carried out on separate samples of each organic acid, as shown.

The following results were obtained. ✓ = observed change ✗ = no observed reaction

test	reagents and conditions	HCO_2H	$\text{HO}_2\text{CCO}_2\text{H}$	$\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$	observed change
1		✓	✗	✗	
2		✓	✓	✗	

- (i) Complete the table with the reagents and conditions and the observed change for a positive test.
 Assume these organic acids all have a similar acid strength. [3]

- (ii) Each compound, HCO_2H , $\text{HO}_2\text{CCO}_2\text{H}$ and $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$, is dissolved separately in CDCl_3 . Proton (^1H) NMR and carbon-13 (^{13}C) NMR spectra are then obtained.

Complete the table.

compound	number of peaks in proton NMR	number of peaks in carbon-13 NMR
HCO_2H		
$\text{HO}_2\text{CCO}_2\text{H}$		
$\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$		

[2]

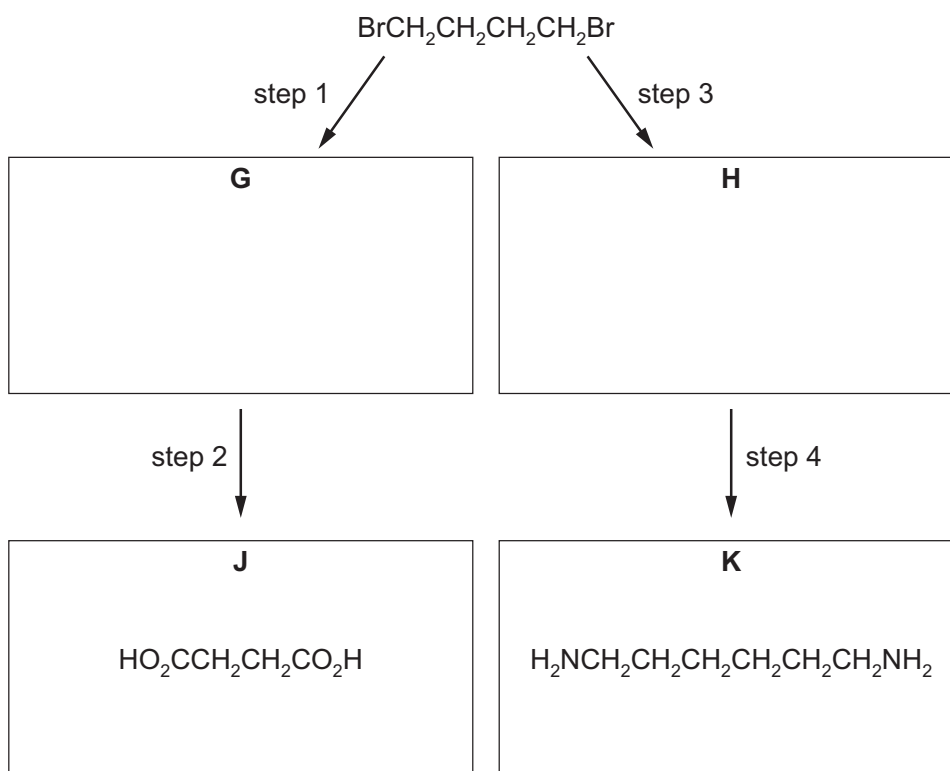
- (iii) The proton NMR spectrum of HCO_2H in D_2O is obtained.

Describe and explain the difference observed between this spectrum and the proton NMR spectrum of HCO_2H in (b)(ii).

.....

 [1]

- (c) 1,4-dibromobutane, $\text{Br}(\text{CH}_2)_4\text{Br}$, is used in the synthesis of the dicarboxylic acid **J** and diamine **K** as shown.



(i) Draw the structures of **G** and **H** in the boxes. [2]

(ii) Suggest reagents and conditions for each of steps 1 to 4.

step 1

step 2

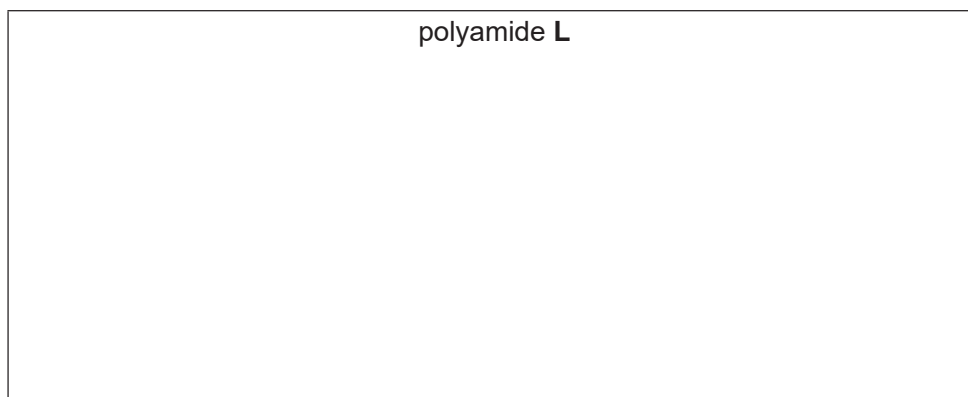
step 3

step 4

[4]

- (d) Polyamide **L** can be synthesised from dicarboxylic acid **J**, $\text{HO}_2\text{C}(\text{CH}_2)_2\text{CO}_2\text{H}$, and diamine **K**, $\text{H}_2\text{N}(\text{CH}_2)_6\text{NH}_2$.

Draw the repeat unit of the polymer formed in the box. Any functional groups should be shown displayed.



[2]

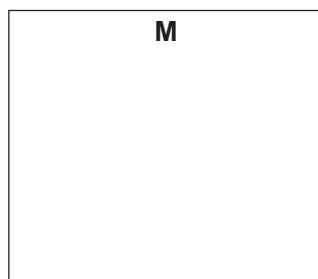
[Total: 18]

- 7 (a) 3-aminobenzoic acid can be synthesised from methylbenzene in three steps.

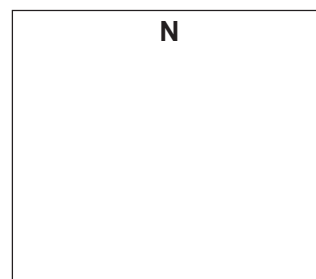
methylbenzene



step 1 →

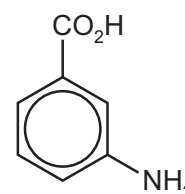


step 2 →



step 3 ↓

3-aminobenzoic acid



- (i) Draw the structures of **M** and **N** in the boxes.

[2]

- (ii) Suggest reagents and conditions for each step of the synthesis.

step 1

step 2

step 3

[3]

(b) A mixture of serine, $\text{HOCH}_2\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, and lysine, $\text{H}_2\text{N}(\text{CH}_2)_4\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, reacts to form several different products.

- (i) Draw the structures of the two structural isomers with the molecular formula $\text{C}_6\text{H}_{12}\text{N}_2\text{O}_5$ that could be present in the product mixture.

The functional group formed in each case should be displayed.

[3]

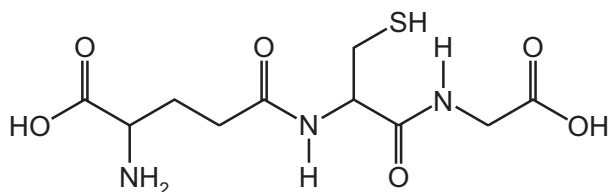
- (ii) Predict the number of different structural isomers with the molecular formula $\text{C}_9\text{H}_{19}\text{N}_3\text{O}_4$ that could be present in the product mixture.

molecular formula	number of structural isomers formed
$\text{C}_9\text{H}_{19}\text{N}_3\text{O}_4$	

[1]

(c) Glutathione is a naturally occurring compound found in plants.

glutathione



- (i) On the diagram of glutathione, label each chiral centre with an asterisk (*). [1]
- (ii) Draw the structures of the three products formed after complete acid hydrolysis of glutathione. Assume the thiol group, $-SH$, does not react.



[2]

- (iii) Glutathione is soluble in water.

By referring to the structure of glutathione, explain why glutathione is soluble in water.

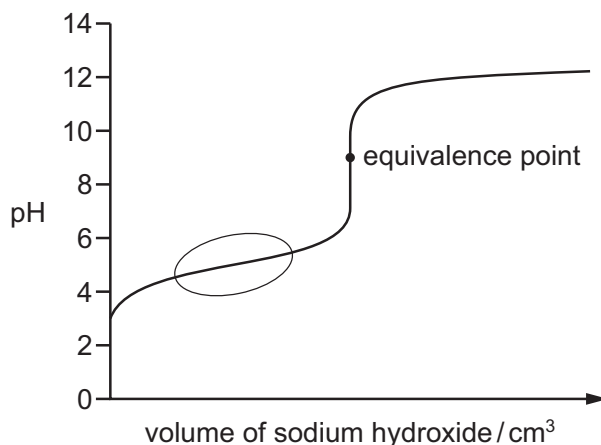
.....

.....

..... [1]

[Total: 13]

- 8 (a) The sketch graph for the titration of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, with sodium hydroxide is shown.



- (i) In the region circled on the graph, identify the **two** organic species that are present in the solution. Explain why the pH of the mixture only changes slowly and gradually in this region when sodium hydroxide is being added.

two species present [3]

.....

.....

.....

- (ii) The equivalence point in this acid-base titration is where the two solutions have been mixed in exactly equal molar proportion.

Suggest why the pH is greater than 7 at the equivalence point in this titration.

..... [1]

.....

.....

- (b) An impure sample of ammonium vanadate(V), NH_4VO_3 , with mass 0.150 g, is dissolved in an excess of dilute acid.

In this solution all vanadium is present as VO_2^+ ions. An excess of zinc powder is added to the solution and all the VO_2^+ ions are reduced to V^{2+} ions. The mixture is filtered to remove any remaining zinc powder.



When the resulting solution is titrated, 20.10 cm^3 of $0.0250 \text{ mol dm}^{-3}$ acidified MnO_4^- oxidises all V^{2+} ions back to VO_2^+ ions.



Calculate the percentage by mass of NH_4VO_3 in the 0.150 g impure sample of NH_4VO_3 .

Give your answer to **three** significant figures.

[M_r : NH_4VO_3 , 116.9]

percentage by mass of NH_4VO_3 = ... % [3]

[Total: 7]

- 9 The carbon-13 (^{13}C) NMR spectrum of compound **A**, $\text{C}_8\text{H}_8\text{O}_2$, contains six peaks.

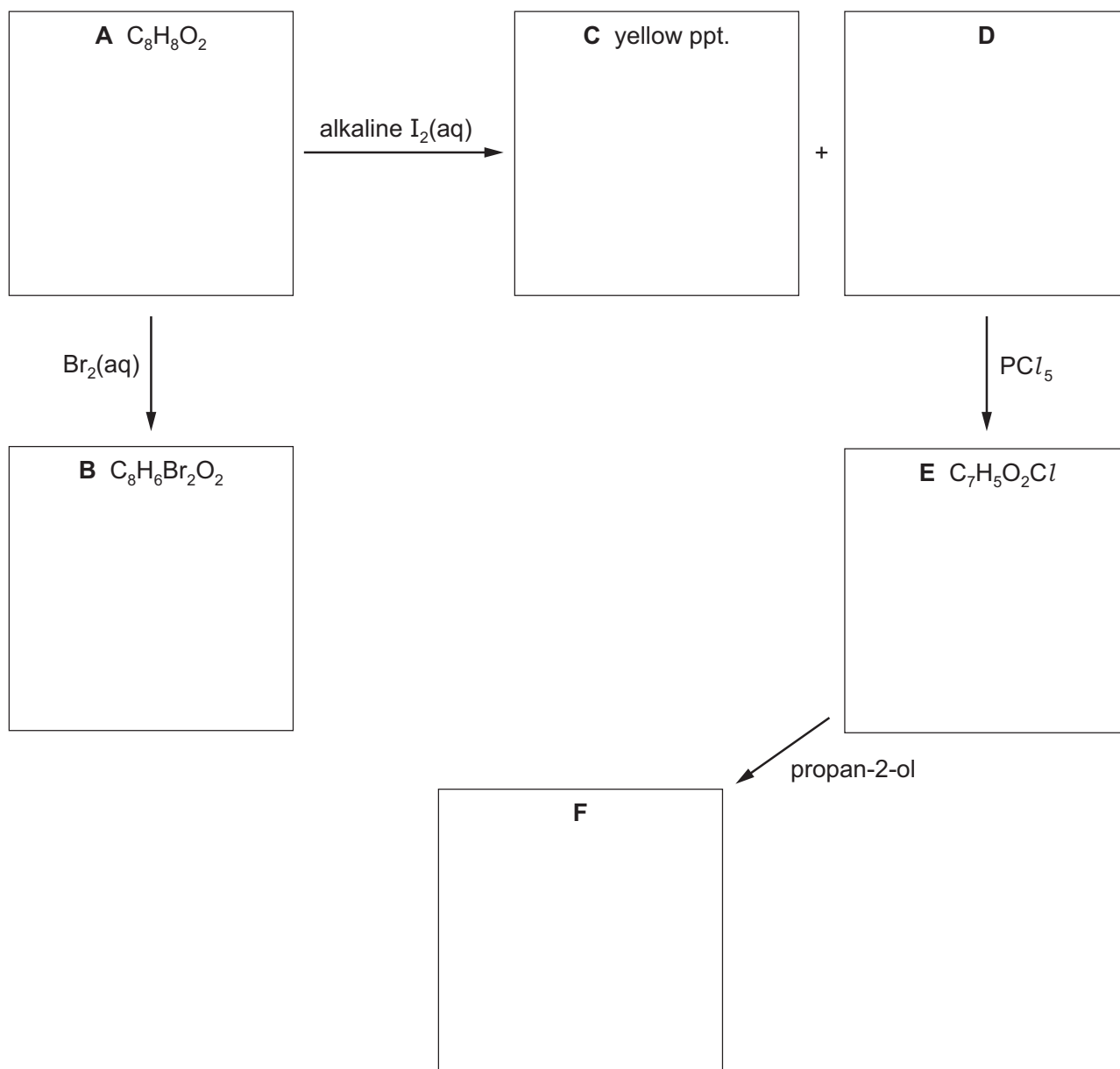
Compound **A** reacts with an excess of bromine water to give compound **B**, $\text{C}_8\text{H}_6\text{Br}_2\text{O}_2$.

Compound **A** reacts with alkaline aqueous iodine to form a yellow precipitate **C** and compound **D**.

Compound **D** reacts with PCl_5 to form compound **E**, $\text{C}_7\text{H}_5\text{O}_2\text{Cl}$.

Compound **E** reacts with propan-2-ol to form compound **F**.

Draw the structures of compounds **A**, **B**, **C**, **D**, **E** and **F** in the boxes.



[6]

Permission to reproduce items where third-party owned material protected by copyright is included has been sought and cleared where possible. Every reasonable effort has been made by the publisher (UCLES) to trace copyright holders, but if any items requiring clearance have unwittingly been included, the publisher will be pleased to make amends at the earliest possible opportunity.

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.

Cambridge Assessment International Education is part of the Cambridge Assessment Group. Cambridge Assessment is the brand name of the University of Cambridge Local Examinations Syndicate (UCLES), which itself is a department of the University of Cambridge.