

**JURONG PIONEER JUNIOR COLLEGE**  
**JC2 PRELIMINARY EXAMINATION 2025****CHEMISTRY****9729/03****Higher 2****17 September 2025**

Paper 3 Free Response

**2 hour**

Candidates answer on the Question paper.

Additional Materials: Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your name, class and index number in the spaces at the top of this page.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.**Section A**Answer **all** questions.**Section B**Answer **one** question.

Write the Question number of the Question you have attempted, in the box provided below.

A Data Booklet is provided.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	17
2	19
3	24
4 or 5	20
<b>Penalty</b> (delete accordingly)	
Lack <b>3sf</b> in final answer	<b>-1 / NA</b>
Missing/wrong <b>units</b> in final ans	<b>-1 / NA</b>
Bond linkages	<b>-1 / NA</b>
<b>Total</b>	<b>80</b>

This document consists of **28** printed pages.

For  
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Use

Describe and explain what happens when  $\text{NaCl}$  and  $\text{SiCl}_4$  are separately added to excess water. State the pH of the resultant mixtures and give relevant equations.

[illegible]

- Arrange these three compounds in order of increasing pH value of their aqueous solution. Explain your answer.

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- Explain the above observations and include relevant equations. [3]

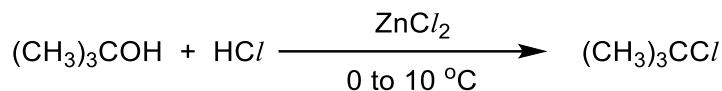
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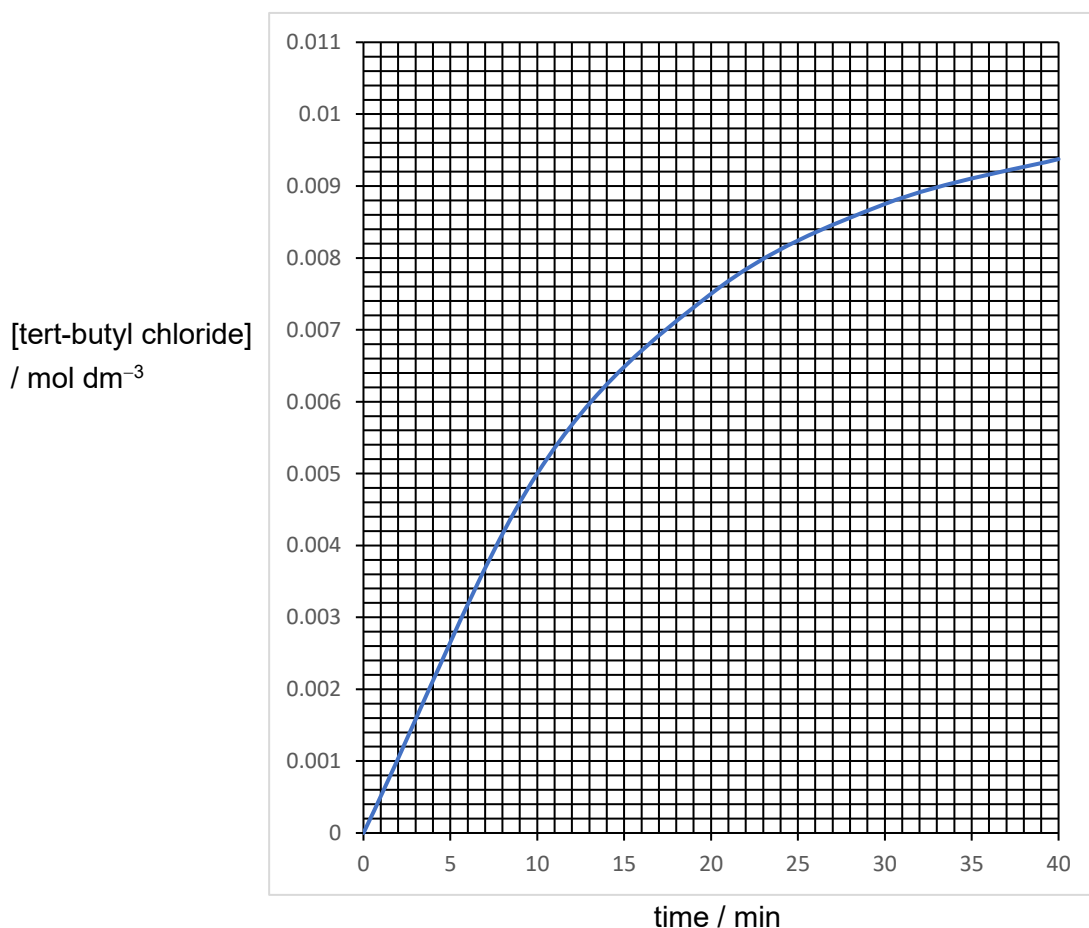
**[Turn Over**

- 2 Lucas Test, named after an American chemist, Howard Luca, is a simple qualitative test, using concentrated  $\text{HCl}$  in the presence of  $\text{ZnCl}_2$ , to classify alcohols by observing the rate of turbidity, indicating the formation of insoluble alkyl halides.

(a) The rate of the Lucas Test is investigated, using tert-butanol,  $(\text{CH}_3)_3\text{COH}$ .



When  $1 \text{ dm}^3$  of  $0.0100 \text{ mol dm}^{-3}$  of tert-butanol is reacted with  $5.00 \text{ mol}$  of  $\text{HCl}$  in the presence of  $\text{ZnCl}_2$ , the concentration of tert-butyl chloride,  $(\text{CH}_3)_3\text{CCl}$ , formed over time is shown in the graph below.

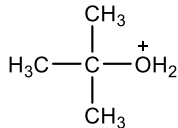


- (i) Define the term *order of reaction*. [1]
- (ii) The same graph was obtained when the test was repeated with  $7.5 \text{ mol}$  of  $\text{HCl}$  in  $1 \text{ dm}^3$  of  $0.0100 \text{ mol dm}^{-3}$  of tert-butanol. Using the information provided and the graph, deduce the orders with respect to  $[(\text{CH}_3)_3\text{COH}]$  and  $[\text{HCl}]$ . Show clearly your working and any construction lines on the graph. [3]
- (iii) Hence, write the rate equation for the Lucas Test, and calculate a value for the rate constant. Include units in your answer. [3]

[illegible]

$$(\text{CH}_3)_3\text{COH} + \text{HCl} \xrightarrow[0 \text{ to } 10^\circ \text{C}]{\text{ZnCl}_2} (\text{CH}_3)_3\text{CCl}$$

- Tert-butanol reacts with  $\text{HCl}$  to generate the following reaction intermediate in the first step.



- This intermediate subsequently loses water to form a carbocation, which reacts further to form the product, tert-butyl chloride.
- $\text{HCl}$  is acting as a Lewis acid in the first step and as a source for *nucleophile* in the subsequent steps.

- (ii) Use the data and information given above, draw the mechanism for the Lucas Test.

[3]

- [2]

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- [3]

[illegible]

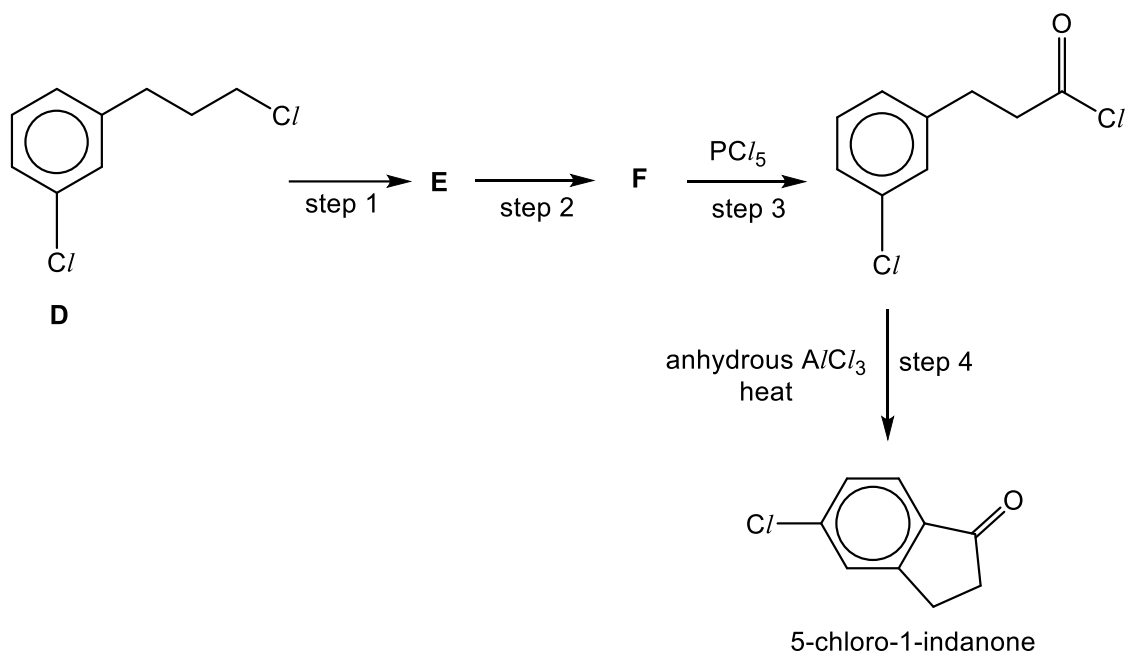
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Write equations for any reactions described.

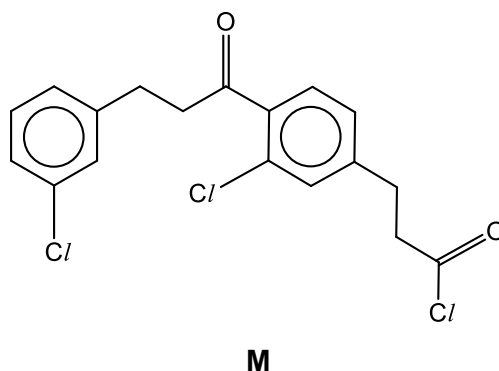
[illegible]

- (b) 5-chloro-1-indanone is mainly used as a chemical intermediate in pharmaceuticals, agrochemicals, and material sciences. It serves as a building block for drugs, pesticides like indoxacarb, and advanced materials such as fluorescent dyes.

5-chloro-1-indanone can be synthesised from compound **D** as shown below.



- (i) Deduce the structures of organic product **E** and **F**. [2]
- (ii) Suggest reagents for step 1 and step 2. [2]
- (iii) Name and describe the reaction mechanism for Step 4. [3]
- (iv) In step 4, another by-product **M** can be formed.



By considering the structure of the starting reactant and the overall entropy change of the reaction, explain **two** reasons why the formation of 5-chloro-1-indanone is preferred over **M**. [2]

- (v) In step 4, anhydrous AlCl<sub>3</sub> must be used, and no water can be introduced. With the aid of appropriate equations, explain why this is so. [1]
- (vi) When 5-chloro-1-indanone is oxidised with acidified KMnO<sub>4</sub>, CO<sub>2</sub> is evolved as a side product. Suggest the structure of the organic product formed. [1]

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Samples of compound **G** are reacted separately with

- NaOH(aq) and heat to form product **H** and a pungent gas.
- 2,4-DNPH forming an orange precipitate **J**,  $C_{11}H_{13}N_5O_6$
- Fehling's reagent to form a brick red precipitate
- Alkaline aqueous iodine and heat forming a yellow precipitate
- $K_2Cr_2O_7$  in the presence of sulfuric acid and heat to form an organic compound, **K**,  $C_5H_6O_5$ .
- An excess of  $LiAlH_4$  forming an organic compound **L**,  $C_5H_{13}NO_2$

Deduce the structures for **G**, **H**, **J**, **K** and **L**, explaining the reactions described. [10]

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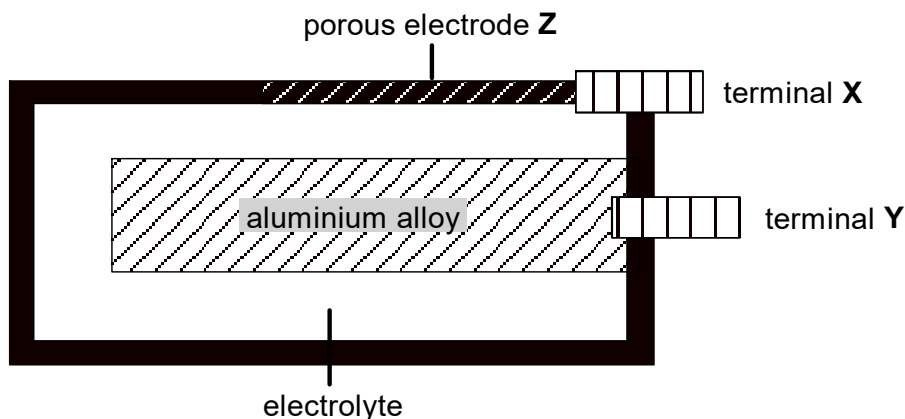
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## Section B

Answer **one** question from this section.

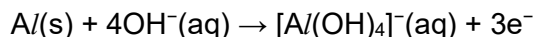
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- 4 Aluminium-air batteries are used as back-up power supplies in many telephone exchanges. The structure of one such battery is shown in **Fig 4.1** below.



**Fig 4.1**

The electrolyte used is aqueous potassium hydroxide. During discharge, oxygen in air is reduced while aluminium is oxidised as shown by the following equation:



- (a) (i) State, with a reason, the polarity of terminal Y. [1]
- (ii) Write a balanced equation with state symbols for the reaction that takes place at the porous electrode Z. [1]
- (iii) State why electrode Z must be porous. [1]
- (iv) In this battery, aluminium may be replaced by zinc.  
Using data from the *Data Booklet*, suggest an advantage of using aluminium rather than zinc. [1]
- (v) When aqueous potassium hydroxide is replaced by aqueous sodium chloride, it is noticed that white  $\text{Al(OH)}_3$  solid is formed around the aluminium electrode instead.  
Explain why it is formed. [1]

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- (b)** The aluminium-air battery was used as an electrical source to electroplate an article with copper.

- (i) Draw a labelled diagram of an electrolytic cell setup to show how an article can be electroplated with copper.

In your diagram, state clearly the choice of anode, cathode, electrolyte to be used and the direction of electron flow.

You may use the standard battery symbol  to represent the aluminium-air battery in your diagram.

[2]

- (ii) If the mass of aluminium electrode in the aluminium-air battery as described earlier in (a) decreased by 5.4 g, calculate the mass of copper that was deposited on the article.

[2]

- (iii)** The electroplating process took 468 min.

Calculate the current delivered by the aluminium-air battery.

[1]

- (iv)** In some batteries, graphite can be used as electrodes.

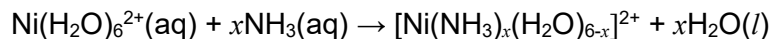
Describe and explain, in terms of structure and bonding, how graphite can serve this role.

[2]

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- 4 (c) A ligand exchange reaction occurs when aqueous ammonia is added to a solution of green  $\text{Ni}^{2+}(\text{aq})$ .

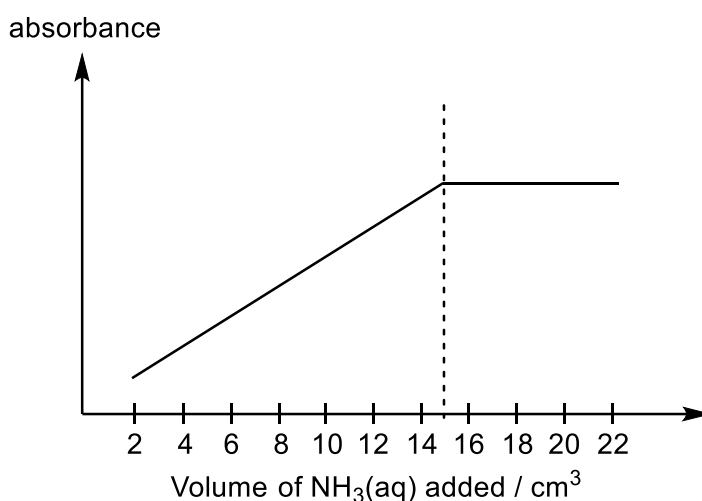


The formula of a nickel-ammonia complex that is blue in colour can be found using a colorimeter.

Eleven tubes containing  $20 \text{ cm}^3$  of  $0.05 \text{ mol dm}^{-3}$  of  $\text{Ni}^{2+}(\text{aq})$  had  $0.4 \text{ mol dm}^{-3}$  aqueous ammonia added. The first tube has  $2 \text{ cm}^3$  of aqueous ammonia added, the second tube  $4 \text{ cm}^3$  and so on. Distilled water was added to bring the total volume to  $50 \text{ cm}^3$ .

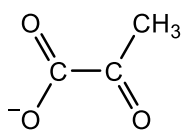
Each tube was then placed in a calorimeter and the absorbance recorded. The absorbance intensity is proportional to the concentration of the complex.

The results are shown in **Fig 4.2** below.



**Fig 4.2**

- (i) Explain why the absorbance value in **Fig 4.2** remains constant after  $15 \text{ cm}^3$  of  $\text{NH}_3(\text{aq})$  is added. [1]
- (ii) Deduce the formula of the complex based on the stoichiometry information that could be inferred from the graph. [2]
- (iii) **Z** is a bidentate ligand, and experiments show that two mole of **Z** react with each mole of  $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$  to form an octahedral complex.



ligand **Z**

Given that the octahedral complex has no dipole moment, draw the structure of the complex formed, showing the 3-dimensional arrangement around the nickel ion. Indicate the overall charge, if any, on this complex.

[2]

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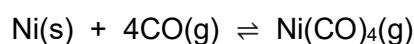
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- (d) Nickel (Ni) readily forms a tetracarbonyl complex,  $\text{Ni(CO)}_4$ , where four carbon monoxide (CO) molecules act as ligands.



- (i) State two physical properties of nickel, apart from the colour of the metal, in which it differs from calcium. Explain the reasons for those differences. [2]
- (ii) Explain why carbon monoxide, CO, is poisonous. [1]

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[Total: 20]

(a) The compound **B** can act as a *bidentate ligand* can form a complex with  $\text{Co}^{3+}$  ions in the mole ratio 3:1.


$$\text{H}_2\text{C}=\text{CH}_2 \xrightarrow{\text{step 1}} \text{A} \xrightarrow{\text{step 2}} \text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$$

ethene **B**

- (i) What can be understood by the term *bidentate ligand*? [1]
- (ii) Suggest the structure of compound **A** and the reagents and conditions for Step 1 and 2. [3]
- (iii) State the coordination number of the cobalt(III) complex. [1]

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- Different proportions of chloride are precipitated when each of the complexes is treated with aqueous silver nitrate.

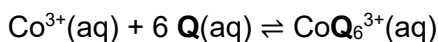
complex	empirical formula	No. of moles of AgCl/ precipitated per mole of complex	Does the complex have a dipole moment?
<b>S</b>	$\text{CoCl}_3(\text{NH}_3)_5$	2	yes
<b>T</b>	$\text{CoCl}_3(\text{NH}_3)_4$	1	yes

Suggest the structures of complexes **S** and **T**, showing clearly the three-dimensional arrangement of the ligands around the metal ion centre.

[2]

[illegible]

- (c) When an aqueous solution of the ligand **Q** is mixed with an aqueous solution of cobalt salt, the following equilibrium is set up:

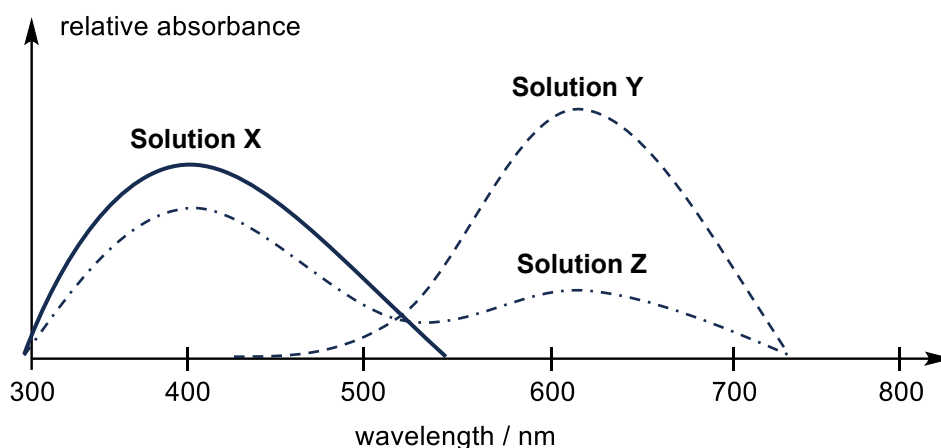


A similar equilibrium occurs with the ligand **R**, forming  $\text{CoR}_6^{3+}(\text{aq})$ .

Solutions **X**, **Y** and **Z** were made by mixing  $0.1 \text{ mol dm}^{-3}$  solutions of  $\text{Co}^{3+}$ , **Q** and **R**. The table below gives the volumes of each used.

Solution	Volumes of $0.1 \text{ mol dm}^{-3}$ solution / $\text{cm}^3$		
	$\text{Co}^{3+}(\text{aq})$	<b>Q</b> (aq)	<b>R</b> (aq)
<b>X</b>	4	96	0
<b>Y</b>	4	0	96
<b>Z</b>	4	48	48

The visible absorption spectra of the three solutions **X**, **Y** and **Z** are shown in **Fig 5.1**.



**Fig 5.1**

The wavelength at which the maximum absorbance is observed is inversely proportional to the energy gap between the two sets of d orbitals in an octahedral complex.

- (i) The spectra show that the peak in the curve for solution **Y** is at a longer wavelength than is the peak in the curve for solution **X**.

What deduction can be made from this fact about the size of the d-orbital splitting in the two complexes?

[1]

- (ii) The absorbance of a solution at a particular wavelength is proportional to the concentration of the ion responsible for the absorption.

Use this information and the given absorption spectra in **Fig 5.1** to suggest and explain which ligand, **Q** or **R**, forms the stronger bond with  $\text{Co}^{3+}$ .

[2]



- Paramagnetic materials have one or more unpaired electrons in their electron configuration. These unpaired electrons spin and create a magnetic dipole moment, making the molecule magnetic.

By considering the electronic configuration of  $\text{Co}^{3+}$  and your answers in **(c)(ii)**, suggest and explain which of the two complexes,  $\text{CoQ}_6^{3+}$  or  $\text{CoR}_6^{3+}$ , have the higher tendency to be paramagnetic.

[2]

[illegible]

- An aqueous solution of  $\text{Co}^{2+}$  can catalyse the reaction between iodide and peroxodisulfate,  $\text{S}_2\text{O}_8^{2-}$  whereas  $\text{Ca}^{2+}$  cannot.

- (iii) With reference to the *Data Booklet*, show how  $\text{Co}^{2+}$  can catalyse the above reaction.

[2]

[illegible]

- (e) Stellite alloys are cobalt–chromium alloys prized for their hardness, wear, and corrosion resistance. The corrosion resistance is largely due to the chromium content, which forms a stable, protective  $\text{Cr}_2\text{O}_3$  oxide layer. In contrast, cobalt does not form a stable protective oxide and therefore reacts more readily in acidic environments.

A 5.00 g sample of the cobalt–chromium alloy is being analysed to determine its cobalt content. The sample is dissolved in excess dilute sulfuric acid, forming a pink solution containing  $\text{Co}^{2+}$  ions while chromium remains as green insoluble  $\text{Cr}_2\text{O}_3$  sludge.

The resulting solution was made up to  $100\text{ cm}^3$  and a  $25.0\text{ cm}^3$  aliquot of this solution is titrated with  $0.120\text{ mol dm}^{-3}$   $\text{KMnO}_4$  solution. The volume of  $\text{KMnO}_4$  required for complete reaction is  $22.00\text{ cm}^3$ .

Calculate the percentage, by mass, of cobalt in the alloy.

[4]

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**Additional answer space**

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