



CANDIDATE
NAME

CG

INDEX NO

CHEMISTRY

9729/03

Paper 3 Free Response

16 September 2025

2 hours

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 an 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.

A Data Booklet is provided.

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

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use		
Section A		
1	/ 17	
2	/ 18	
3	/ 25	
Section B		
4 or 5	/ 20	
Penalty	units	significant figures
Overall	/ 80	

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

1 (a) Explain, with the aid of a labelled Boltzmann distribution diagram, the effect on a rate constant of increasing temperature from T_1 to T_2 . [3]

[illegible]

- (b)** Hydrogen bromide, HBr, undergoes addition reaction with alkenes.

With but-1-ene, 2-bromobutane is produced rather than 1-bromobutane.

- (i) Draw a mechanism for this reaction and use it to explain the preferential production of 2-bromobutane. [3]
- (ii) Using the mechanism, write the rate equation for this reaction. [1]
- (iii) Sketch a graph to show how the rate of reaction varies with the concentration of but-1-ene when hydrogen bromide is in excess. Explain your answer. [2]

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- (c)** But-2-ene is a positional isomer of but-1-ene.

But-2-ene occurs in two isomeric forms, **A** and **B**.

- (i) Explain how **A** and **B** are stereoisomers of each other but but-1-ene does **not** show stereoisomerism. [2]
- (ii) Describe a chemical test, with appropriate observations, that could distinguish between but-1-ene and but-2-ene. [2]

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- (d)** But-1-ene can be converted into an ether (--C--O--C--) via the steps shown in Fig. 1.1.

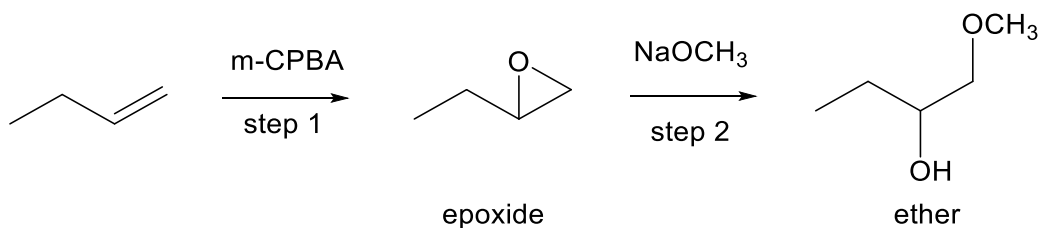


Fig. 1.1

In step 1, an epoxide functional group is formed when an O atom adds across the double bond through reaction with m-CPBA.

In step 2, the epoxide formed reacts with sodium methoxide, a nucleophile, to form an ether functional group (-C-O-C-).

- (i) The resulting mixture of the ether contains equal quantities of two isomers. The mixture does not rotate plane-polarised light.

Draw the three-dimensional structures of these two isomers.

[2]

- (ii) Suggest the structure of the ether formed when but-2-ene is subjected to the same reaction as in Fig. 1.1. [1]

- (iii) A primary amine can also be used as the nucleophile in step 2, but the final product will be a secondary amine, as shown in Fig. 1.2, instead of an ether.

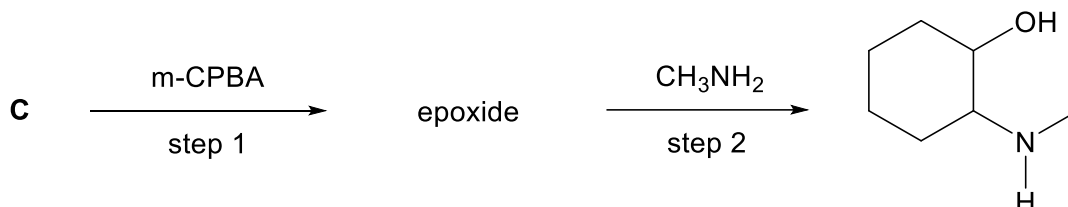


Fig. 1.2

Suggest the structure of alkene **C**.

[1]

[illegible]

[Total: 17]

- 2 (a)** Compound **D** has molecular formula $C_xH_yO_z$. Its relative molecular mass is 90.0. When 2.25 g of **D** was burnt in excess oxygen, 4.40 g of CO_2 and 2.25 g of H_2O were obtained.

Calculate the empirical formula of **D** and determine its molecular formula.

[4]

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- (b)** **D** can undergo controlled oxidation to form **E** ($\text{C}_4\text{H}_6\text{O}_2$). **E** can be further oxidised to form **F** ($\text{C}_4\text{H}_6\text{O}_3$). No oxygen atoms are present in the carbon backbone of **E** and **F**.

Four chemical tests are carried out on portions of **E** and **F** and the results are described in Table 2.1.

Table 2.1

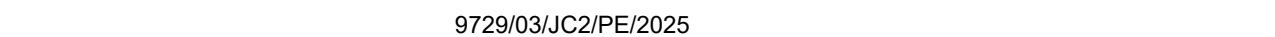
	with Na ₂ CO ₃ (aq)	with Tollens' reagent	with 2,4-DNPH	with alkaline I ₂ (aq)
E	no reaction	silver mirror	orange precipitate	no reaction
F	effervescence	no reaction	orange precipitate	no reaction

Deduce the displayed structures of **E** and **F**.

[5]

This image shows a full page of white paper with horizontal dashed lines. The lines are evenly spaced and run across the width of the page, providing a guide for handwriting practice. There are no margins, text, or other markings on the page.

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- (d) (i) Some ionic radii are listed in the *Data Booklet*.

State and explain the differences between the ionic radii of Na, Si and P.

[3]

- (ii) Describe the reactions, if any, of the oxides Na_2O , SiO_2 and P_4O_{10} with water. Write an equation for any reaction and state the pH of the resultant mixtures. [3]

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[Total: 18]

3 (a) Chromium, a transition metal, is widely used in stainless steel production for its corrosion resistance.

(i) State the electronic configurations of a Cr atom and of a Cr^{3+} cation. [2]

(ii) Describe two ways in which compounds containing Cr^{3+} ions are different from those containing Ca^{2+} ions in terms of their chemical behaviour. [2]

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(b) Chromium(III) bromide, CrBr_3 , is a dark-coloured solid used in chemical synthesis and research, particularly for studying magnetic and electronic properties of transition metal halides.

(i) Define the term *lattice energy*. [1]

(ii) Use data from Table 3.1 and the *Data Booklet* to calculate a value for the lattice energy of $\text{CrBr}_3(\text{s})$. Show your working. [3]

Table 3.1

	value/ kJ mol^{-1}
first electron affinity of bromine	–324.6
standard enthalpy change of vapourisation of bromine molecules	+29.6
standard enthalpy change of atomisation of chromium	+397
standard enthalpy change of formation of $\text{CrBr}_3(\text{s})$	–400.4

(iii) Chromium(III) bromide and chromium(III) iodide have the same crystal structure.

There is closer agreement between the experimental and theoretical values of lattice energy for CrBr_3 than for CrI_3 . Suggest a reason for this. [1]

- (c)** Potassium dichromate(VI), $\text{K}_2\text{Cr}_2\text{O}_7$, is an oxidising agent.

Outline how you would obtain a sample of propanal from propan-1-ol using potassium dichromate(VI). [1]

[illegible]

- (d)** The cobalt(II) ion, Co^{2+} , is another oxidising agent.

- (i) With the aid of relevant half equations from the *Data Booklet*, draw a fully labelled diagram of the electrochemical cell set-up used to measure the relative oxidising powers of $\text{Cr}_2\text{O}_7^{2-}$ and Co^{2+} under standard conditions, and calculate the E^\ominus_{cell} of the electrochemical cell. [4]

- (ii) Write the overall equation for when current flows. [1]

- (iii) Use your answer to **(d)(ii)** to calculate the standard Gibbs free energy change, ΔG^\ominus , for this electrochemical reaction. [1]

- (iv) Using relevant data from the *Data Booklet*, deduce how the value of E^\ominus_{cell} will change when aqueous ammonia is added to the Co^{2+}/Co half-cell. [1]

[illegible]

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Diagram illustrating the energy levels of d-orbitals for Co^{2+} in an octahedral complex, $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

The diagram shows the energy gap, ΔE , between the d-orbitals of an isolated Co^{2+} ion and the d-orbitals of Co^{2+} in the octahedral complex.

The d-orbitals of an isolated Co^{2+} ion are shown as a single energy level. The d-orbitals of Co^{2+} in the octahedral complex are shown as two energy levels, separated by the energy gap, ΔE .

(i) Use Fig. 3.1 to outline the origin of colour of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$. [2]

(ii) Draw separate labelled diagrams for each of the two higher energy d-orbitals in an octahedral complex. [2]

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When all the six H_2O ligands are changed to six NH_3 ligands, the Co^{2+} ion changes its electronic configuration from a 'high spin' state to a 'low spin' state.

In a 'high spin' state, the electrons occupy all the d-orbitals singly, before starting to pair up in the lower energy d-orbitals.

In a 'low spin' state, the lower energy d-orbitals are filled first, by pairing up if necessary, before the higher energy d-orbitals are used.

- (iii) Suggest why electrons usually fill empty orbitals singly before pairing up in the same orbital. [1]
- (iv) Use diagrams like the one in Fig. 3.1 to show how electrons are distributed in the d-orbitals of a Co^{2+} cation for both a high-spin complex and a low-spin complex. [1]
- (v) Using the explanation in (e)(iii), and the information about the spin states of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Co}(\text{NH}_3)_6]^{2+}$, state and explain which complex will contain the larger energy gap, ΔE , between its d-orbitals. [2]

[illegible]

[Total:25]

4 (a) Beryllium chloride, BeCl_2 , is a covalent compound with structural and chemical properties that differ from other Group 2 chlorides such as BaCl_2 . It is used in synthesis reactions and in the electrolysis industry to obtain metallic beryllium.

- Explain, in terms of its structure and bonding, the relatively high melting point of BeCl_2 . [1]

[illegible]

- (b)** The hydrolysis of BeCl_2 in water is similar to that of AlCl_3 . Both form an acidic solution in water.

During hydration, $AlCl_3$ forms $[Al(H_2O)_6]^{3+}$ while $BeCl_2$ forms $[Be(H_2O)_4]^{2+}$.

- (i) Suggest an equation for the hydrolysis of BeCl_2 and state the pH of the solution formed. [2]

- (ii) Draw the structure of $[\text{Be}(\text{H}_2\text{O})_4]^{2+}$, showing the shape clearly. [1]

[illegible]

- (c) Group 2 carbonates decompose when heated. Write an equation for the decomposition of the carbonate ion, CO_3^{2-} . Describe and explain the variation in the thermal stability of Group 2 carbonates. [3]

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- (d)** Using your understanding of the trend in reducing power of Group 2 metals, predict and explain the standard electrode potential, E^\ominus , for the Be^{2+}/Be half-cell. [2]

[illegible]

- (e) When solid beryllium chloride is heated, it breaks down to form ions. The molten beryllium chloride is then electrolysed using inert electrodes.

- (i) Write the equations for the reactions occurring at both electrodes. [1]

- (ii) A current of 1.50 A was passed through the cell for 20 minutes and the electrodes were removed, washed, dried and weighed. It was found that the cathode had increased in mass.

Calculate the expected increase in mass of the cathode. [3]

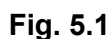
[illegible]

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- (i) Write an equation for step 1. [1]
- (ii) Suggest the mechanism for step 2 and step 3. Use curly arrows to show the movement of electrons. [2]
- (iii) Suggest which of the steps you have drawn in (f)(ii) is the slowest step. Explain your reasoning. [1]
- (iv) BeCl_2 has two roles during this reaction. State and describe the roles of BeCl_2 during the reaction. [2]



[Turn over



- [illegible]

- (b) Many organic compounds contain more than one functional group. With certain reagents and conditions, more than one functional group could react. Sometimes, this is undesirable as chemists only want a particular functional group to be transformed.

For example, in Fig. 5.2, when the keto-ester methyl 3-oxobutanoate reacts with a reagent known as the Grignard reagent, CH_3MgBr , both the ketone functional group and the ester functional group could react. This results in a mixture of products and a low yield of the desired compound.

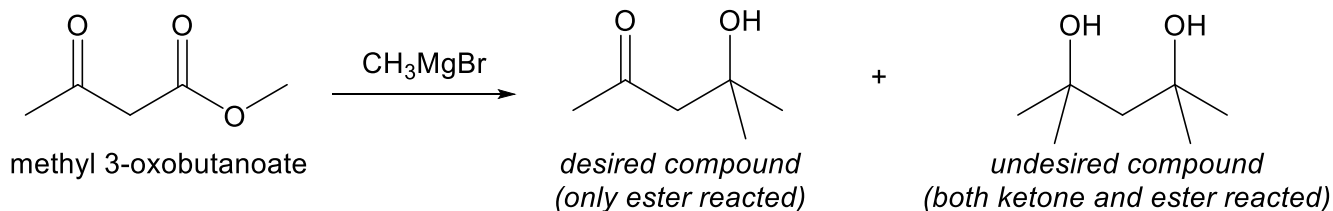


Fig. 5.2

If a chemist wants only the ester to react, the chemist must first convert the ketone into an acetal functional group that does not react with the Grignard reagent. This acetal-ester compound is then reacted with the Grignard reagent, before the acetal is converted back to the ketone. The acetal is thus known as a *protecting group*, as it seems to have “protected” the ketone functional group from undesired reactions.

The formation of an acetal from a ketone and an alcohol under acidic conditions is a reversible reaction. An example is shown in Fig. 5.3 using butanone and methanol.

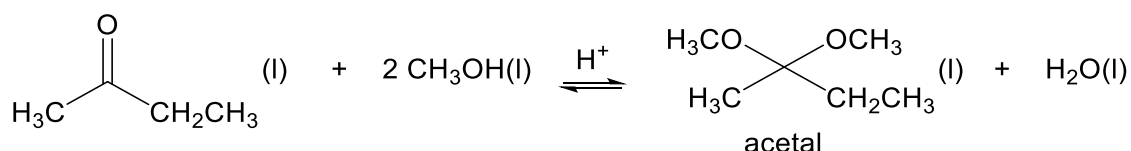


Fig. 5.3

0.100 mol of butanone and 0.100 mol of methanol are mixed in a 1.00 dm^3 flask with H^+ as a catalyst. After equilibrium is established, 0.020 mol of the acetal is present.

- (i) Explain what is meant by *reversible reaction*. [1]
- (ii) Write the expression for the equilibrium constant, K_c , for the equilibrium in Fig. 5.3, stating its units. [1]
- (iii) Use the information provided to calculate a value for K_c . [3]
- (iv) A Dean-Stark apparatus is a piece of laboratory glassware used in organic synthesis to remove water produced in an organic reaction.

Suggest why the use of a Dean-Stark apparatus improves the yield of acetal formation. [1]

- (v) Sketch two labelled graphs, on the same axes, to show how [acetal] changes over time with and without a catalyst for the equilibrium. Explain your answer. [2]

