



EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2025
General Certificate of Education Advanced Level
Higher 2

CANDIDATE
NAME

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CIVICS
GROUP

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CHEMISTRY

Paper 3 Free Response

9729/03

15 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and registration number on the work you hand in.

Write in dark blue or black pen.

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

Do not use staplers, 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	
Paper 3	
A1	/ 20
A2	/ 20
A3	/ 20
B4 or 5	/ 20
Total	/ 80

This document consists of **32** printed pages.

Section A

Answer **all** the questions in this section.

- 1 Indirect calorimetry is used to estimate energy expenditure in humans by measuring the difference in oxygen concentration between inhaled and exhaled air. During aerobic respiration at 37 °C, glucose, $\text{C}_6\text{H}_{12}\text{O}_6$, is oxidised to carbon dioxide and water while producing energy as shown in reaction 1 below.



- (a) (i) It is assumed that there are negligible intermolecular forces of attraction between gas particles in an ideal gas.

State **two** other basic assumptions of kinetic theory as applied to an ideal gas.
[2]

- (ii) Air contains about 21% oxygen, by volume. Exhaled air contains 14% oxygen. At complete rest, a typical adult exchanges approximately 500 cm³ of air per breath at a rate of 12 times per minute at a temperature of 37 °C at 1 atmospheric pressure.

By assuming oxygen to be an ideal gas, calculate the volume of oxygen gas consumed per minute. Hence, determine amount of oxygen gas used per minute.
[3]

- (iii) Assuming that the oxygen inhaled is used for respiration directly, use relevant information in reaction 1 and your answer in (a)(ii), calculate the approximate amount of energy released per minute.
[1]

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(b) Glucose, $\text{C}_6\text{H}_{12}\text{O}_6$, is the ubiquitous source of energy for cells in the body.

(i) Define the standard enthalpy change of formation of glucose, $\text{C}_6\text{H}_{12}\text{O}_6(\text{s})$. [1]

(ii) Use the following data, reaction 1 and appropriate data from the *Data Booklet*, to construct an energy cycle and calculate the standard enthalpy change of atomisation of $\text{C}(\text{s})$. Show your working.

enthalpy change of formation of $\text{C}_6\text{H}_{12}\text{O}_6(\text{s})$ $= -1270 \text{ kJ mol}^{-1}$
enthalpy change of combustion of $\text{H}_2(\text{g})$ $= -286 \text{ kJ mol}^{-1}$

[3]

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- (c) Glucose exists in two forms, α -glucose and β -glucose as shown in Fig. 1.1. If a solution of α -glucose is left some time, it will come into dynamic equilibrium with β -glucose.

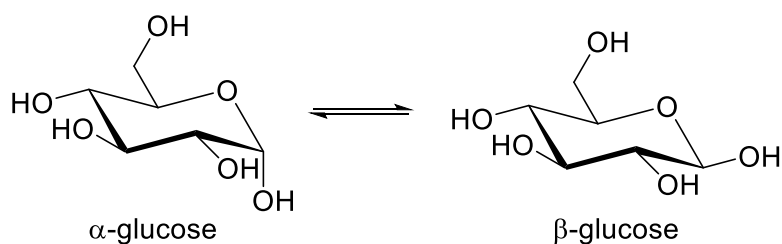


Fig. 1.1

When plane-polarised light is passed through an aqueous solution of glucose, the angle of rotation of the light is dependent upon the structure of the molecule. The angles of rotations of plane-polarised light caused by the two forms of glucose solutions under identical conditions are shown in Table 1.1.

Table 1.1

solution	angle of rotation of plane-polarised light
1.0 mol dm ⁻³ of α -glucose	+111°
1.0 mol dm ⁻³ of β -glucose	+19°

- (i) When 1 dm³ of a freshly prepared solution of 1.0 mol dm⁻³ α -glucose is left till equilibrium is achieved, the measured rotation is +53°. Assuming that the angle of rotation due to each glucose is directly proportional to its concentration, calculate a value for the equilibrium constant, K_c , for the conversion of α -glucose into β -glucose. [2]

- (ii) The conversion of α -glucose into β -glucose is catalysed by acids. State and explain the effect on the final measured rotation if the conversion is now carried out in the presence of dilute sulfuric acid. [2]

This image shows a full page of white paper with horizontal dashed lines, typical of primary-ruled notebook paper. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

$$\text{equilibrium 1} \quad \text{Hb(aq)} + 4\text{O}_2(\text{aq}) \rightleftharpoons \text{Hb(O}_2)_4(\text{aq}) \quad \Delta H^\ominus = -630.9 \text{ kJ mol}^{-1}$$
$$\Delta G^\ominus = -160.7 \text{ kJ mol}^{-1}$$

- (ii)** During the initial stage of vigorous exercise, rapid muscle contractions generate heat that spreads through the body, raising core temperature.

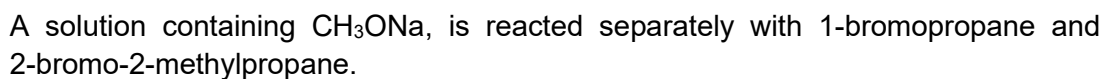
Using Le Chatelier's Principle, explain how the initial increase in temperature affects equilibrium 1. [1]

- (iii) Suggest how the magnitude of K_c for equilibrium 1 is likely to be and explain its significance. [2]

- (iv)** Carbon monoxide, CO, can bind to haemoglobin at the same binding site as oxygen. Explain why CO is poisonous. [2]

This image shows a full page of white paper with ten horizontal dashed lines, typical of primary school handwriting practice paper. The lines are evenly spaced and extend across the entire width of the page. There is no text or other markings on the paper.

[Turn Over



- (i) Predict the predominant mechanism for:
- I)** the reaction of 1-bromopropane with CH_3ONa
- II)** the reaction of 2-bromo-2-methylpropane with CH_3ONa

Explain your reasoning. [3]

- (ii) For each mechanism, state and explain the stereochemical outcome of the nucleophilic substitution reaction. [2]

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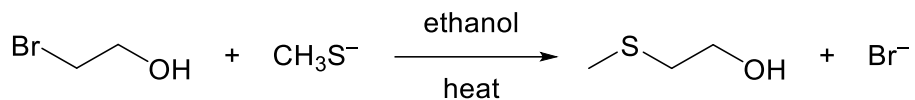
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Question 2 continues on the next page.

- (b) Thiolates such as methyl thiolate, CH_3S^- , act similarly to alkoxides in the nucleophilic substitution of halogenoalkanes, forming a sulfide.

The synthesis of 2-hydroxyethyl methyl sulfide from 2-bromoethanol using CH_3S^- can be seen from the following reaction scheme:



- (i) Describe a simple chemical test to distinguish between 2-bromoethanol and 2-hydroxyethyl methyl sulfide. [2]

The kinetics of the reaction was studied with the results given in Table 2.1.

Table 2.1

experiment	$[\text{CH}_3\text{S}^-]$ / mol dm^{-3}	$[\text{CH}_2\text{BrCH}_2\text{OH}]$ / mol dm^{-3}	relative rate
1	0.100	0.150	1.00
2	0.150	0.150	1.50
3	0.200	0.200	2.67

- (ii) Define the term *order of reaction*. [1]
- (iii) Use the data to determine the order of reaction with respect to both CH_3S^- and $\text{CH}_2\text{BrCH}_2\text{OH}$. [2]
- (iv) Hence, write a rate equation for the reaction. [1]
- (v) Using your answer in (b)(iv), describe the mechanism for the reaction. [3]

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- (c) Sodium methoxide, CH_3ONa , can also be used to synthesis 2-hydroxyethyl methyl sulfide from 2-bromoethanol. The rate of reaction was found to be slower than when sodium methanethiol, CH_3SNa , is used.

By considering the strength of the nucleophile, suggest why the rate of reaction is slower when using sodium methoxide. [1]

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- (d) The rate of reaction for the synthesis increases when the temperature is increased. With the aid of a clearly labelled Maxwell-Boltzmann distribution curve, explain this observation. [3]

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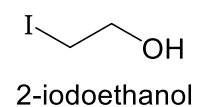
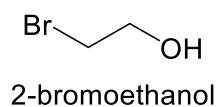
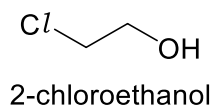
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- (e) Another series of experiments were done to study the difference in the rates of nucleophilic substitution for the following compounds using methyl thiolate.



Deduce the order of increasing rate of reaction of the following compounds. Explain your answer. [2]

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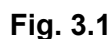
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The phosphine-modified cobalt catalyst, $\text{HCo}(\text{CO})_3(\text{PR}_3)$, was developed to increase the linear : branched aldehyde selectivity. This catalyst also functions as an effective aldehyde hydrogenation catalyst to produce the corresponding alcohol.

The diagram illustrates the catalytic cycles for the hydroformylation and hydrogenation of an alkene, catalyzed by a rhodium complex with a phosphine ligand (PR₃) and carbonyl ligands (CO).

Catalytic Cycle 1: Hydroformylation

- Intermediate A:** A rhodium complex with a terminal alkene, a hydride ligand, a phosphine ligand (PR₃), and a carbonyl ligand (CO).
- Step 1-1:** Loss of CO from Intermediate A to form the **catayst** (rhodium complex with a terminal alkene, a hydride ligand, and a phosphine ligand).
- Step 1-2:** Addition of CO to the catalyst to form **Intermediate B** (rhodium complex with a terminal alkene, a carbonyl ligand, and a phosphine ligand).
- Intermediate B:** Undergoes a rearrangement to form **Intermediate C** (rhodium complex with a terminal aldehyde, a hydride ligand, a phosphine ligand, and a carbonyl ligand).
- Intermediate C:** Undergoes a rearrangement to form the **aldehyde** product (R'-CH₂-CH₂-CH₂-CHO).

Catalytic Cycle 2: Hydrogenation

- Catayst:** Undergoes addition of H₂ to form an intermediate (not explicitly shown).
- Intermediate:** Undergoes a rearrangement to form the **alcohol** product (R'-CH₂-CH₂-CH₂-OH).

Fig. 3.2

An important step in catalytic cycle 1 is **step 1-2**, which involves addition of a Co–H bond adds across the C=C double bond within intermediate **A**, with binding of a carbon monoxide ligand, to give intermediate **B**.

Intermediate **B** reacts with more carbon monoxide, eventually giving intermediate **C**. Finally, intermediate **C** breaks down to give the aldehyde with regeneration of the catalyst.

The aldehyde formed from catalytic cycle 1 then enters catalytic cycle 2 and is reduced to give the corresponding alcohol.

- (b) (i) State the type of reaction in **step 1-1**. [1]
- (ii) State the type of bond between the alkene and Co in intermediate **A** and suggest how it is formed. [2]
- (iii) State the shapes of intermediate **B** and intermediate **C** about Co. [1]
- (iv) Given that the Co in intermediate **C** is in the +3 oxidation state. State its full electronic configuration. [1]

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- (c) The linear and branched product arises in **step 1-2** as the addition of Co–H across the C=C double bond can occur in two ways as shown in Fig. 3.3.

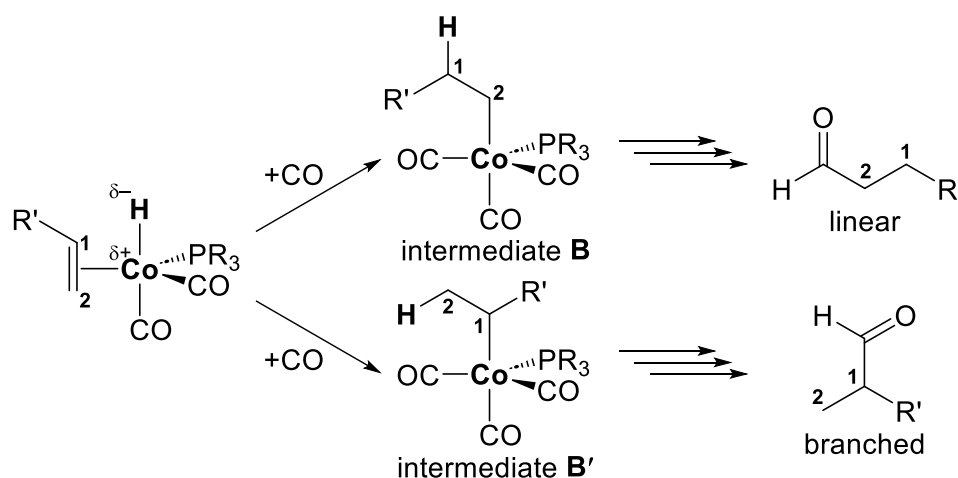
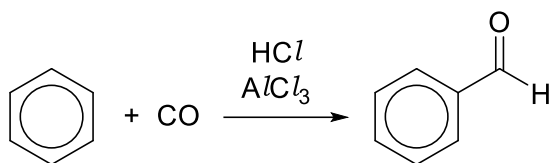


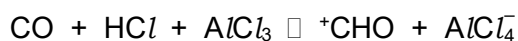
Fig. 3.3

[illegible]

The Friedel-Crafts formylation of benzene using carbon monoxide can be achieved by the Gatterman-Koch reaction in which CO(g) and HCl(g) are used *in-situ* with a Lewis acid catalyst such as AlCl_3 .



Assuming that CO(g) and HCl(g) reacts in the presence of AlCl_3 as shown.



- (d) Describe the mechanism for the Friedel-Crafts formylation of benzene to give benzaldehyde. Show the displayed structure of the electrophile, the structure of the intermediate and the movement of electron pairs by using curly arrows. [3]

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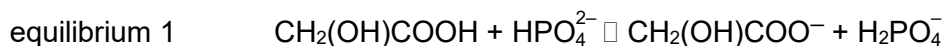
Question 4 starts on the next page.

Section B

Answer **one** question from this section.

- 4 (a) Glycolic acid, $\text{CH}_2(\text{OH})\text{COOH}$, is an α -hydroxy acid used in some skincare products.

Sodium glycolate can be prepared by adding disodium hydrogen phosphate to a solution of glycolic acid in a cosmetic formulation. The reaction establishes the following equilibrium in water:

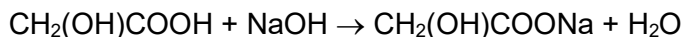


The K_a values for $\text{CH}_2(\text{OH})\text{COOH}$ and H_2PO_4^- are given in Table 4.1.

Table 4.1

acid	K_a
$\text{CH}_2(\text{OH})\text{COOH}$	1.48×10^{-4}
H_2PO_4^-	6.20×10^{-8}

- (i) Write down the IUPAC name for glycolic acid. [1]
- (ii) Identify the two different conjugate acid-base pairs in equilibrium 1. [1]
- (iii) Use the K_a values in Table 4.1 to calculate the equilibrium constant, K_c , for equilibrium 1. [2]
- (iv) In an experiment, a buffer solution of pH 4.00 is prepared using 50.0 cm^3 of $0.0500 \text{ mol dm}^{-3}$ glycolic acid and $x \text{ cm}^3$ of $0.100 \text{ mol dm}^{-3}$ NaOH.



Assume that all NaOH reacts with glycolic acid, what is the volume, $x \text{ cm}^3$, of $0.100 \text{ mol dm}^{-3}$ NaOH required to make the buffer? [4]

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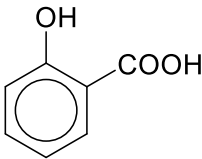
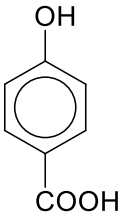
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- (b) Table 4.2 shows the pK_a values of two isomeric benzoic acids: salicylic acid and 4-hydroxybenzoic acid.

Table 4.2

acid	pK_{a1}	pK_{a2}
 salicylic acid	3.0	13.4
 4-hydroxybenzoic acid	4.1	9.7

Explain the following:

- (i) pK_{a2} is larger than pK_{a1} of salicylic acid. [1]
- (ii) pK_{a1} of salicylic acid is smaller than pK_{a1} of 4-hydroxybenzoic acid. [1]

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(d) Hexagonal boron nitride, h-BN, consist of planar sheets of alternate boron and nitrogen atoms, similar in arrangement to the carbon atoms in graphite. Its softness and sheen make powdered h-BN widely used in cosmetics.

(i) h-BN is often referred to as “white-graphite”. With reference to chemical bonding and structure, explain why both h-BN and graphite have a soft and slippery feel.

[2]

(ii) Explain, with reference to electronegativity, why h-BN does not conduct electricity readily, whereas graphite does.

[2]

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Question 5 starts on the next page.

- 5 In an effort to address pollution caused by industrial nitroaromatics and agricultural nitrates, researchers have developed a dual-function electrochemical system that converts these nitrogen-containing wastes into useful products. At the cathode, the electrolytic reduction of nitrobenzene to phenylamine is described in Fig. 5.1.

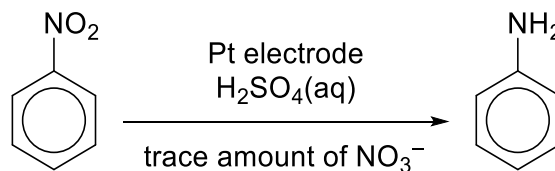


Fig 5.1

- (a) State the reagents and conditions for the conversion of nitrobenzene to phenylamine in a laboratory. [1]

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- (b) (i) Given the nitrogen in nitrobenzene has an oxidation state of +3, describe the change in oxidation state of the nitrogen, in Fig. 5.1. [1]

- (ii) Hence or otherwise, write the half-equation for this reaction. [1]

- (iii) During a 4-hour electrolysis, a steady current of 2 A was passed. However, only 2.79 g of phenylamine was formed.

Using your answer to (b)(ii), calculate the theoretical amount of electrons required to form 2.79 g of phenylamine. [1]

- (iv) Faradaic efficiency describes the efficiency with which charge is transferred in an electrolysis system and is given by the equation below.

$$\text{Faradaic efficiency} = \frac{\text{charge required}}{\text{charge passed}} \times 100\%$$

Hence, calculate the Faradaic efficiency of the electrolysis in (b)(iii). [3]

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(c) The use of the *Data Booklet* is relevant to this question.

- (i) A student suggests that the trace amounts of NO_3^- ions at the cathode could also be reduced to NH_4^+ ions. Discuss how electrode potential and concentration might influence this competition.

(The $E^\ominus(\text{nitrobenzene} \mid \text{phenylamine})$ is +0.79 V.) [3]

- (ii) Suggest other possible side products at the cathode. [1]

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- (d) Rank the following compounds in order of increasing basicity and explain your reasoning.

phenylamine, methylamine, ethanamide

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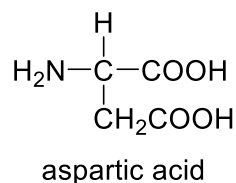
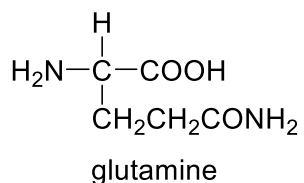
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(e) The structures of two amino acids, glutamine and aspartic acid are given below.



(i) Suggest a simple chemical test to distinguish between glutamine and aspartic acid. [2]

(ii) The three pK_a values associated with aspartic acid are 1.99, 3.90 and 9.90.

Draw the structures of the predominant species of aspartic acid at

- pH 3
- pH 8
- pH 11

[3]

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