Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 2

3 November 2023

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

1 hour 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[50 marks]**.

8823–6111

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Methanoic acid (HCOOH) is the first member of the homologous series of carboxylic acids.

(a) Outline what is meant by the term “homologous series”. [1]

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(b) Draw the Lewis (electron dot) structure of methanoic acid. [1]

(c) Calculate the percentage, by mass, of oxygen in methanoic acid. [2]

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(Question 1 continued)

(d) Methanoic acid and ethanal (CH_3CHO) both contain a carbonyl group and have similar molar masses.

(i) Explain why, in terms of the strongest intermolecular forces between the molecules, ethanal has a much lower boiling point than methanoic acid. [2]

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(ii) Outline why ethanal and methanoic acid are both fully miscible with water. [1]

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(iii) Predict, giving an explanation, the relative electrical conductivity of solutions of methanoic acid, ethanal and hydrochloric acid of the same concentration. [3]

Relative electrical conductivity: _____ < _____ < _____

Explanation: . . . . . .

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2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(a) Explain why this process has been extensively investigated in recent years. [2]

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(b) State the equilibrium constant expression for this reaction. [1]

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(Question 2 continued)

(c) Bond enthalpies are a useful way of finding approximate enthalpy changes for reactions.

(i) Determine the enthalpy change, $\Delta H^{\ominus}$, of this reaction, using section 11 of the data booklet. [3]

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(ii) Assuming a 0.1 % uncertainty for each bond enthalpy, determine the resultant percentage uncertainty of the calculated enthalpy change of the reaction. [2]

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(Question 2 continued)

(d) Deduce how the value of K_c would be affected by increases in temperature. [1]

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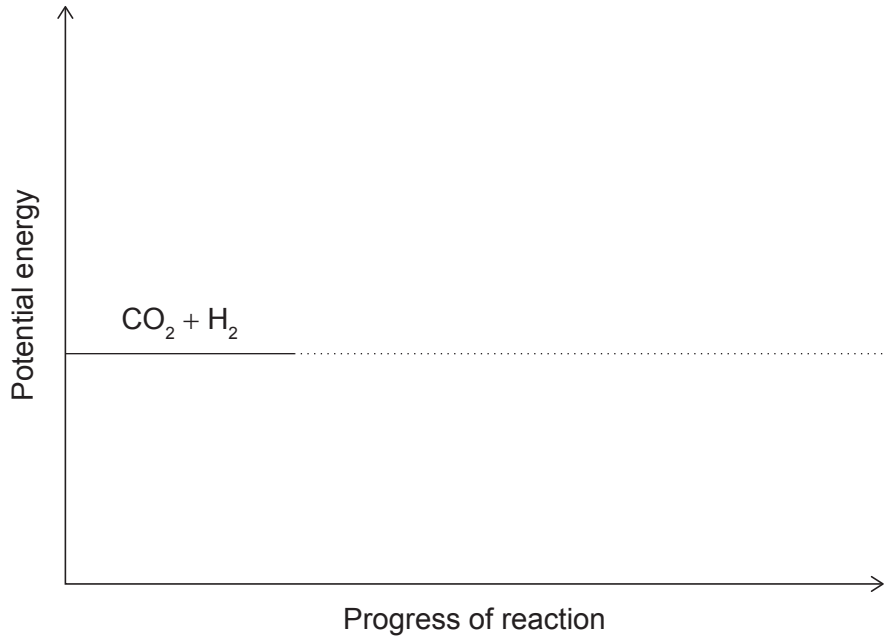
(e) The conversion of carbon dioxide to methanoic acid is usually carried out over an iridium-based catalyst.

(i) Sketch, on the axes provided, energy profiles of the reaction both with and without a catalyst, indicating ΔH and the activation energies. [3]



(ii) State **one** change, other than carrying out the reaction over a catalyst at high temperature, that would increase the reaction rate. [1]

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(Question 2 continued)

(f) Determine the oxidation state of carbon in methanoic acid. [1]

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3. Methanoic acid can be converted into methyl methanoate, $HCOOCH_3$.

(a) State the name of the reagent and catalyst required. [2]

Reagent: . . . . . .

Catalyst: . . . . . .

(b) 1.72 g of methyl methanoate is produced from 2.83 g of methanoic acid and excess of the other reagent. Determine the percentage yield. [2]

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(Question 3 continued)

(c) The conversion of methanoic acid to methyl methanoate can be followed by changes in spectra.

(i) State **one** similarity and **one** difference you would expect in the infrared (IR) spectra of methanoic acid and methyl methanoate in the region of 1500–3500 cm^{-1}. Use section 26 of the data booklet. [2]

Similarity: . . . . . .

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Difference: . . . . . .

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(ii) Deduce, referring to the integration trace, whether the ^{1}H NMR spectrum shown is that of methanoic acid or methyl methanoate. [1]

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Answers written on this page
will not be marked.

(Question 3 continued)

(d) State the class of compounds to which methyl methanoate belongs. [1]

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(e) Draw the full structural formula of the carboxylic acid isomer of methyl methanoate. [1]

(f) State the name of a compound that produces the isomer in (e) when refluxed with acidified potassium dichromate (VI). [1]

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4. Carbon disulfide, CS_2, undergoes gas phase hydrolysis according to the overall equation

$$CS_2(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 2H_2S(g)$$

(a) Calculate the enthalpy change in this reaction from section 12 of the data booklet and the given values: [2]

	$CS_2(g)$	$H_2S(g)$
$\Delta H_f^{\ominus}$	$+88.7\,kJ\,mol^{-1}$	$-20.6\,kJ\,mol^{-1}$

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(b) Deduce the molecular geometries of CS_2 and H_2S, and the reason why they are different. [2]

Molecular geometry CS_2: . . . . . .

Molecular geometry H_2S: . . . . . .

Reason for difference: . . . . . .

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(Question 4 continued)

(c) Sulfur has a number of natural isotopes and a sample of sulfur was enriched in $^{36}_{16}S$, to produce a mixture with the following composition:

Isotope	Percent
$^{32}_{16}S$	90 %
$^{33}_{16}S$	1 %
$^{34}_{16}S$	4 %
$^{36}_{16}S$	5 %

(i) Calculate the relative atomic mass of this enriched sample, correct to two decimal places. [2]

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(ii) State the technique by which the percentages of different isotopes in this sample could have been determined. [1]

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(iii) In naturally occurring sulfur, the relative abundance of $^{36}_{16}S$ is only 0.0100 %. Calculate the number of atoms of this isotope that would be present in 1.00 g of natural sulfur. Use sections 2 and 6 of the data booklet. [2]

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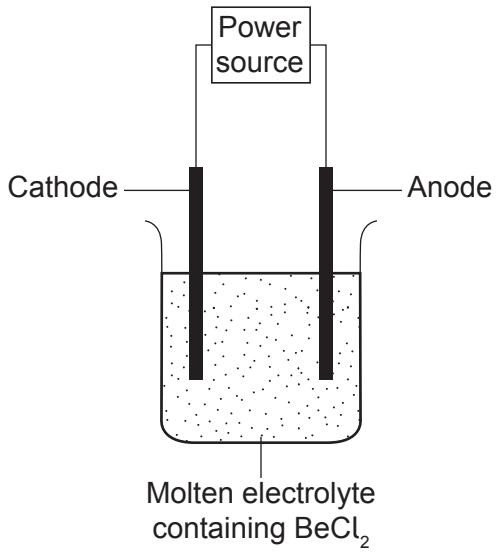
5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(a) The production of beryllium is illustrated in the diagram.



(i) Outline why molten $BeCl_2$ is considered an electrolyte. [1]

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(ii) Identify the electrode at which beryllium will be produced, **and** the polarity of that electrode. [1]

Electrode: . . . . . .

Polarity: . . . . . .

(iii) Write a balanced equation for the reaction occurring at the other electrode, to the one you identified in 5(a)(ii). [1]

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(Question 5 continued)

(b) Explain, in terms of nuclear charge, electron subshells and the shielding provided by filled electron shells, why the first ionization energy increases from Li to Be, but decreases from Be to B. [4]

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References: