Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 2

3 November 2025

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

Candidate session number

1 hour 30 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]**.

8825–6212

12 pages

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

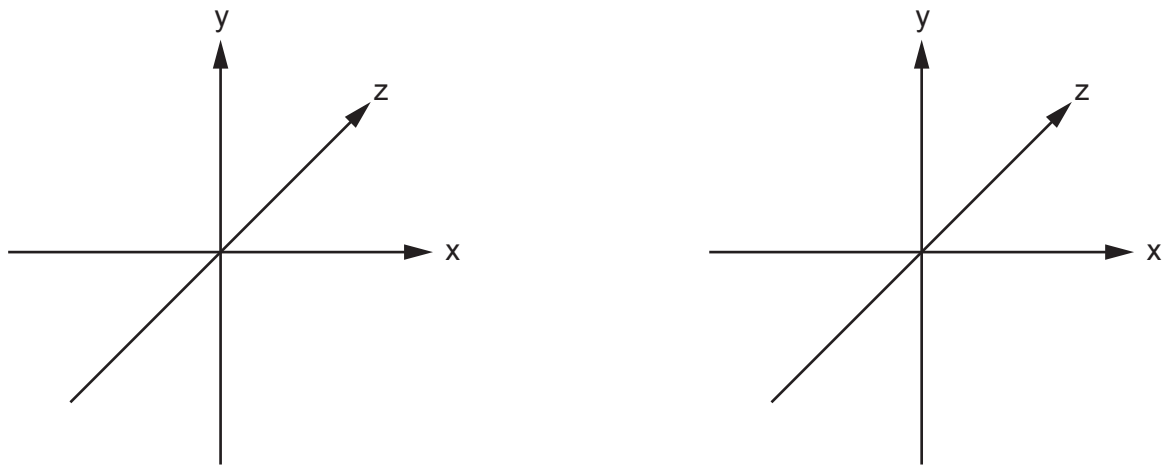
1. Phosphorus is an element that is an essential part of the biological molecules involved in both respiration and photosynthesis.

(a) (i) Draw the orbital diagram of the phosphorus atom in the ground state by adding, filling and labelling the orbitals. Use section 7 of the data booklet. [2]

2s

1s

(ii) Sketch the shapes of two different orbital types in the second energy level and label each orbital. [2]



(This question continues on the following page)

(Question 1 continued)

(iii) Explain why the first ionization energy decreases as you descend group 15 from nitrogen to bismuth. [2]

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(b) 7.75 g of phosphorus was combusted in a limited supply of oxygen, the mass of the oxide produced was 13.75 g.

(i) Calculate the number of atoms in 7.75 g of phosphorus. Use sections 2 and 7 of the data booklet. [1]

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(ii) Determine the empirical formula of the oxide formed, show your working. Use section 7 of the data booklet. [3]

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(Question 1 continued)

(iii) The M_r of the oxide formed in (b)(ii) was known to be 219.88 g mol^{-1}.

Determine the molecular formula of the oxide formed, showing your working. Use section 7 of the data booklet. [1]

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(iv) This oxide of phosphorus has a melting point of 296.9 K.

Outline, with reference to structure and bonding, the reasons why the melting point of this oxide is low. [2]

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(v) Describe the nature of the bond between oxygen and phosphorus. Use sections 9 and 17 of the data booklet. [2]

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(Question 1 continued)

(c) Another compound of phosphorus is phosphine, PH_3, it forms a phosphonium ion, PH_4^+.

State the types of bonds present in the phosphonium ion, PH_4^+, and explain how these bonds are formed. [2]

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(d) Phosphorus trichloride, PCl_3, is a common compound of phosphorus.

Deduce the Lewis formula of PCl_3. [1]

2. Nitrous acid, $HNO_2(aq)$ and hydrochloric acid, $HCl(aq)$ are both inorganic acids.

(a) A $0.01\,mol\,dm^{-3}$ solution of $HNO_2(aq)$ has a pH of 2.63 while a solution of $HCl(aq)$ of the same concentration has a pH of 2.00.

(i) Explain the difference in pH. [2]

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(ii) Describe what would be observed if an excess of magnesium, Mg, was added to equal volumes of the same concentration of nitrous and hydrochloric acids. [2]

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(iii) A solution of nitrous acid contains two conjugate acid–base pairs.

State the formulas of the conjugate acid and conjugate base in each pair. [2]

Conjugate acid: . . . . . Conjugate base: . . . . . .

Conjugate acid: . . . . . Conjugate base: . . . . . .

(iv) State the oxidation state of nitrogen in nitrous acid, HNO_2. [1]

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(This question continues on the following page)

(Question 2 continued)

(b) Picric acid, carbolic acid and aspirin are trivial names of chemical substances.

They can cause misunderstanding when communicating information internationally.

(i) Outline how modern chemists have improved communication when naming chemical substances. [2]

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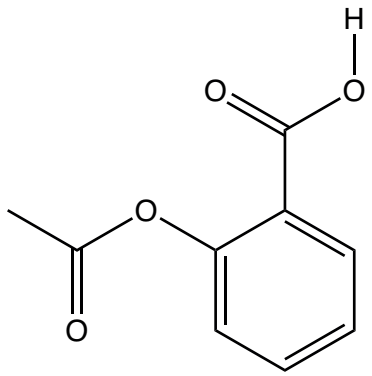
(ii) The molecule of aspirin, shown below, contains an ester functional group.



State the names of the other two functional groups. [2]

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(Question 2 continued)

(iii) Ethyl ethanoate, $C_4H_8O_2$ ($CH_3CO_2CH_2CH_3$) is another ester.

Deduce the structure and name for a functional group isomer of ethyl ethanoate. [2]

Name of isomer: . . . . . .

(iv) A catalyst, usually concentrated sulfuric acid, H_2SO_4, is used in the manufacture of this ester.

Explain the action of a catalyst. [2]

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(v) Ethyl ethanoate can be produced by the reaction of ethanol with ethanoic acid. Both reactants can be synthesized from ethane through a series of reactions, the first of which is shown.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

The first step in this reaction, initiation, is given by the following equation.

$$Cl_2 \rightarrow 2Cl\bullet$$

State an essential condition for this reaction. [1]

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(Question 2 continued)

(vi) Deduce **two** propagation steps and **one** termination step for this reaction. [3]

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(c) The overall reaction for the synthesis of ethyl ethanoate from ethane is:

$$2C_2H_6(g) + Cl_2(g) + \frac{3}{2}O_2(g) \rightarrow C_4H_8O_2(g) + 2HCl(g) + H_2O(g)$$

(i) Calculate the enthalpy change for the reaction, ΔH. Use section 12 of the data booklet. [3]

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(ii) One student used bond enthalpy data and correctly calculated the enthalpy change for the reaction between ethanol and ethanoic acid as $0\,kJ\,mol^{-1}$. Another student used Hess's law and correctly calculated the enthalpy change for the same reaction as $-4\,kJ\,mol^{-1}$.

$$C_2H_6O(l) + C_2H_4O_2(l) \rightleftharpoons C_4H_8O_2(l) + H_2O(l)$$

Explain how the two students can carry out a calculation for the same reaction and obtain different results when both calculations are correct. [1]

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(Question 2 continued)

(d) Calculate the atom economy for the synthesis of ethyl ethanoate by the reaction below. Use sections 1 and 7 of the data booklet. [2]

$$2C_2H_6(g) + Cl_2(g) + \frac{3}{2}O_2(g) \rightarrow C_4H_8O_2(l) + 2HCl(aq) + H_2O(l)$$

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3. The reaction between ethanoic acid and ethanol is homogeneous and reversible.

$$C_2H_6O(l) + C_2H_4O_2(l) \rightleftharpoons C_4H_8O_2(l) + H_2O(l) \qquad \Delta H^{\theta}_r = -4\,kJ\,mol^{-1}$$

(a) (i) Deduce the expression for the equilibrium constant, *K*, for this reaction. [1]

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(ii) 0.6 moles each of ethanol and ethanoic acid at 60°C reacted in the presence of an acid catalyst. The volume remained constant. At equilibrium 0.2 moles of ethanoic acid remained in the reaction mixture.

Calculate the amounts, in mol, of ethanol, ethyl ethanoate and water at equilibrium. [2]

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(iii) Explain the effect of reducing the temperature on the value of the equilibrium constant. [1]

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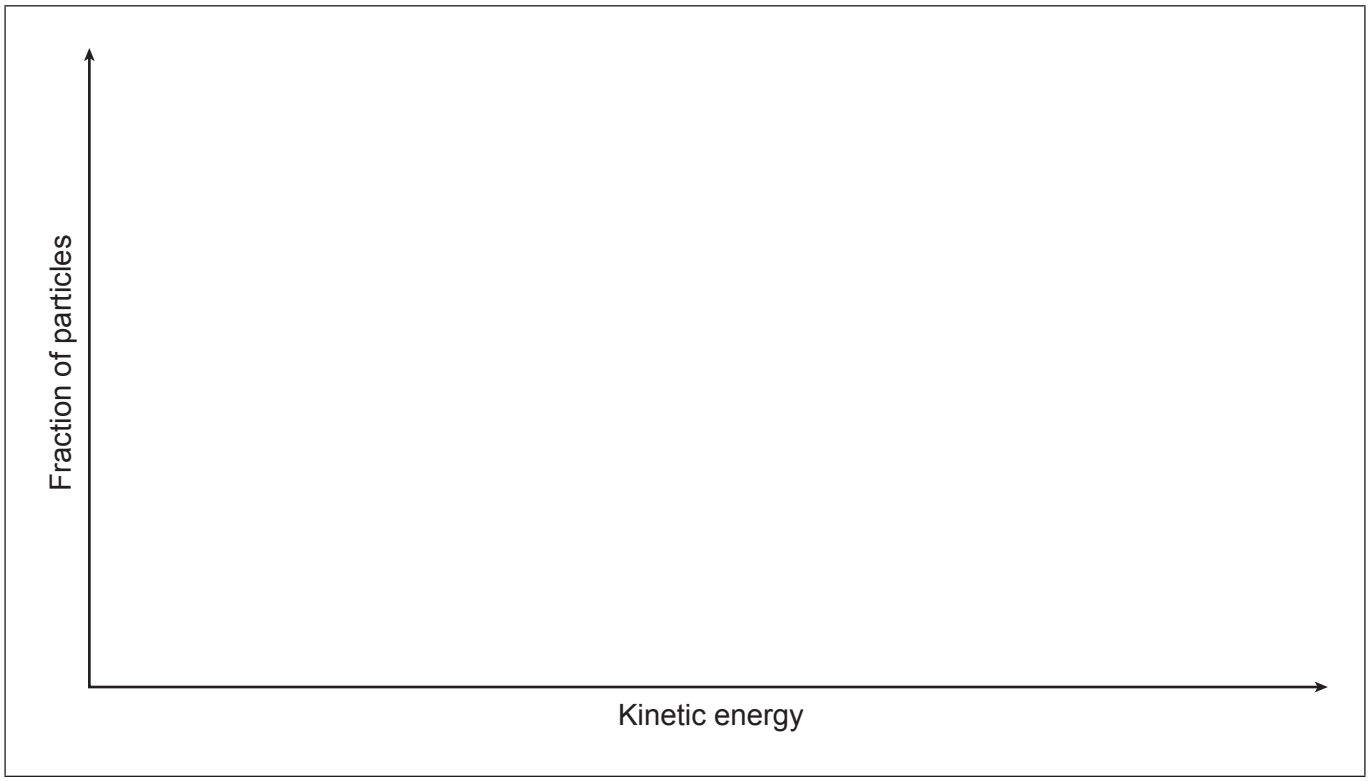
(Question 3 continued)

(b) (i) Sketch the Maxwell–Boltzmann energy distribution curve for this reaction. Label the activation energy with and without a catalyst on the diagram. [2]



(ii) Sketch and label the second Maxwell–Boltzmann curve for the same reaction at room temperature, on the axes given in part (b)(i). [1]