



Chemistry Standard level Paper 2

3 November 2025

Zone A morning | Zone B morning | Zone C morning

Candidate session number

1 hour 30 minutes

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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]**.

282

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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]

282

The diagram shows the following orbital filling:

- 1s: one orbital with two electrons (up and down arrows).
- 2s: one orbital with two electrons (up and down arrows).
- 2p: three orbitals, each with two electrons (up and down arrows).
- 3s: one orbital with two electrons (up and down arrows).
- 3p: three orbitals, each with one electron (up arrow).

Handwritten notes in red ink:

- (1) correct configuration
- (1) Pauli's exclusion principle + Hund's rule

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

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The sketches show:

- A spherical $2s$ orbital centered at the origin of the x, y, z coordinate system.
- A dumbbell-shaped $2p (y)$ orbital oriented along the y -axis.

Handwritten labels and notes:

- $2s$
- $2p (y)$
- (1)

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(Question 1 continued)

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

(1) Moving down a group increases the number of electron orbitals, increasing distance of valence electrons from nucleus.
 (1) Greater distance from nucleus, and inner electron shielding, weaker the attraction of valence e^- to nucleus, making it easier to remove e^- , \therefore less energy needed.

- (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]

$$n_P = \frac{7.75 \text{ g}}{30.97 \text{ g mol}^{-1}} = 0.250 \text{ mol}$$

$$\# \text{ of atoms} = n_P \times N_A$$

$$= 0.250 \times 6.022 \times 10^{23} = 1.51 \times 10^{23} \text{ P atoms (1)}$$

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

$$m_O = 13.75 \text{ g} - 7.75 \text{ g} = 6.00 \text{ g (1)}$$

$$n_O = \frac{6.00 \text{ g}}{16.00 \text{ g mol}^{-1}} = 0.375$$

$$n_P = 0.250$$

$$\frac{0.375}{0.250} = 1.5 \qquad \frac{0.250}{0.250} = 1 \qquad (1)$$

$$\times 2 \qquad \qquad \qquad \times 2$$

$$3 \qquad \qquad \qquad 2 \therefore \text{P}_2\text{O}_3 \text{ (1)}$$

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(Question 1 continued)

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

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

[1]

$$\begin{aligned} \text{MM } P_2O_3 &= 2(30.97) + 3(16.00) = 109.94 \\ \frac{219.88}{109.94} &= 2 \quad \therefore P_2O_3 \times 2 \\ &= \underline{P_4O_6} \quad (1) \end{aligned}$$

- (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]

(1) Low melting point as P_4O_6 is a discrete covalently bonded molecule.

(1) As it is a non-polar covalent molecule it only forms weak dispersion forces with other P_4O_6 molecules, which require minimal energy to break, thus breaking solid lattice to form a liquid.

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

[2]

$$\begin{aligned} \chi_P &= 2.19 \quad \chi_O = 3.4 \\ \Delta X &= 3.4 - 2.19 = 1.25 \\ \text{Avg } \chi_P &= \frac{2.19 + 3.4}{2} = 2.85 \end{aligned}$$

$P-O$ polar covalent (1)

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(Question 1 continued)

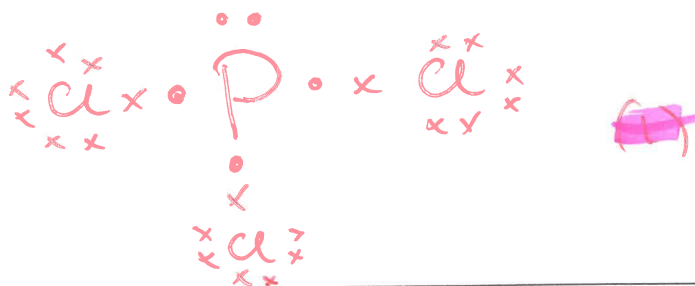
- (c) Another compound of phosphorus is phosphine, PH_3 , it forms a phosphonium ion, PH_4^+ .

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

There are 4 covalent bonds (sharing of e^-) between one P atom and 4 hydrogen atoms.
3 of the P-H bonds form from P and H donating 1 e^- each to form a bond, while one is formed from P sharing 2 e^- with a H^+ ion (dative bond)

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

Deduce the Lewis formula of PCl_3 . [1]



2. Nitrous acid, $\text{HNO}_2(\text{aq})$ and hydrochloric acid, $\text{HCl}(\text{aq})$ are both inorganic acids.

(a) A 0.01 mol dm^{-3} solution of $\text{HNO}_2(\text{aq})$ has a pH of 2.63 while a solution of $\text{HCl}(\text{aq})$ of the same concentration has a pH of 2.00.

(i) Explain the difference in pH.

[2]

HNO_2 is a weak acid so does not fully dissociate to produce $< 0.01 \text{ mol dm}^{-3} \text{ H}^+$.
 HCl is a strong acid and so fully dissociates to produce $0.01 \text{ mol dm}^{-3} \text{ H}^+$.

(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]

The Mg would dissolve faster and produce $\text{H}_2(\text{g})$ at a quicker rate (more vigorous) in the HCl . Reaction would be slower in HNO_2 .

(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: HNO_2 Conjugate base: NO_2^-
 Conjugate acid: H_3O^+ Conjugate base: H_2O

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

[1]

$(+1) + N + 2(-2) = 0$
 $\therefore N = +3$

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282

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(Question 2 continued)

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

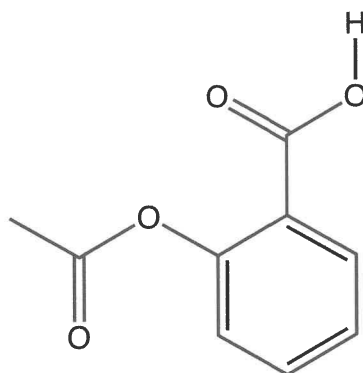
They can cause misunderstanding when communicating information internationally.

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

[2]

IUPAC systematic nomenclature (I) uses internationally agreed upon rules (prefixes, suffixes, priority) for naming chemicals. This removes any ambiguity in identifying compounds and gives all chemicals a unique identifying name (I)

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



State the names of the other two functional groups.

[2]

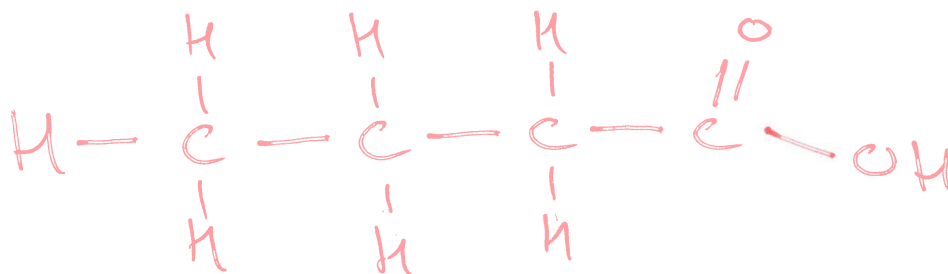
Carboxyl (I)
phenyl (I)

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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:

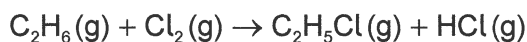
butanoic acid

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

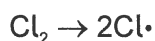
Explain the action of a catalyst. [2]

Catalysts speed up the rate of reaction by providing an alternate reaction pathway that has a lower activation energy than the uncatalysed reaction.

- (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.



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



State an essential condition for this reaction. [1]

UV light.

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(Question 2 continued)

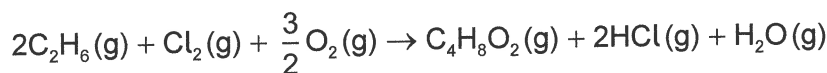
- (vi) Deduce **two** propagation steps and **one** termination step for this reaction. [3]

Propagation: $Cl \cdot + C_2H_6 \rightarrow C_2H_5 \cdot + HCl$ (1)

$C_2H_5 \cdot + Cl_2 \rightarrow C_2H_5Cl + Cl \cdot$ (1)

Termination: $C_2H_5 \cdot + Cl \cdot \rightarrow C_2H_5Cl$ (1)

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



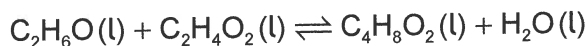
- (i) Calculate the enthalpy change for the reaction, ΔH . Use section 12 of the data booklet. [3]

$2 \left(\begin{array}{c} H & H \\ | & | \\ H-C & -C-H \\ | & | \\ H & H \end{array} \right) + Cl-Cl + \frac{3}{2} (O=O) \rightarrow \begin{array}{c} H & & O & & H \\ | & & || & & | \\ H-C & - & C & - & C-H \\ | & & & & | \\ H & & & & H \end{array} + 2(H-Cl)$

$\Delta H = [2(3416) + 12(414) + (242) + \frac{3}{2}(498)] - [8(414) + 3(346) + 2(358) + 804 + 2(427) + 2(463)]$

$\Delta H_r = 6649 - 7658 = -1009 \text{ kJ mol}^{-1}$ (1)

- (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} .



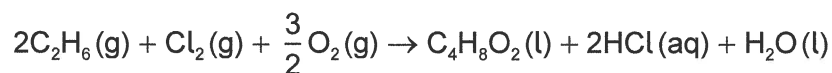
Explain how the two students can carry out a calculation for the same reaction and obtain different results when both calculations are correct. [1]

Bond enthalpy values are an average at that type of bond, not the specific value of a particular molecule. If there is no net difference in bond type the enthalpy change will be 0.

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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]

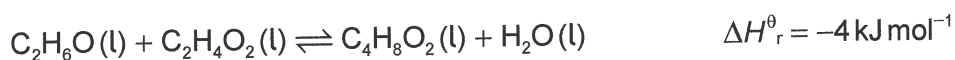


Atom Economy = $\frac{\text{Mol. mass of desired product}}{\text{Total mol. mass of reactants}}$

$$= \frac{4(12.01) + 8(1.01) + 2(16.00)}{4(12.01) + 12(1.01) + 2(35.45) + \frac{3}{2}(32.00)}$$

$$= \frac{88.12}{179.06} \times 100\% = \underline{\underline{49.2\%}}$$

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



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

$$K = \frac{[\text{C}_4\text{H}_8\text{O}_2][\text{H}_2\text{O}]}{[\text{C}_2\text{H}_6\text{O}][\text{C}_2\text{H}_4\text{O}_2]} \quad (1)$$

(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]

	ALCOHOL	ACID	ESTER	WATER
i	0.6	0.6	0	0
Δ	-0.4	-0.4	+0.4	+0.4
≡	0.2	0.2	0.4	0.4

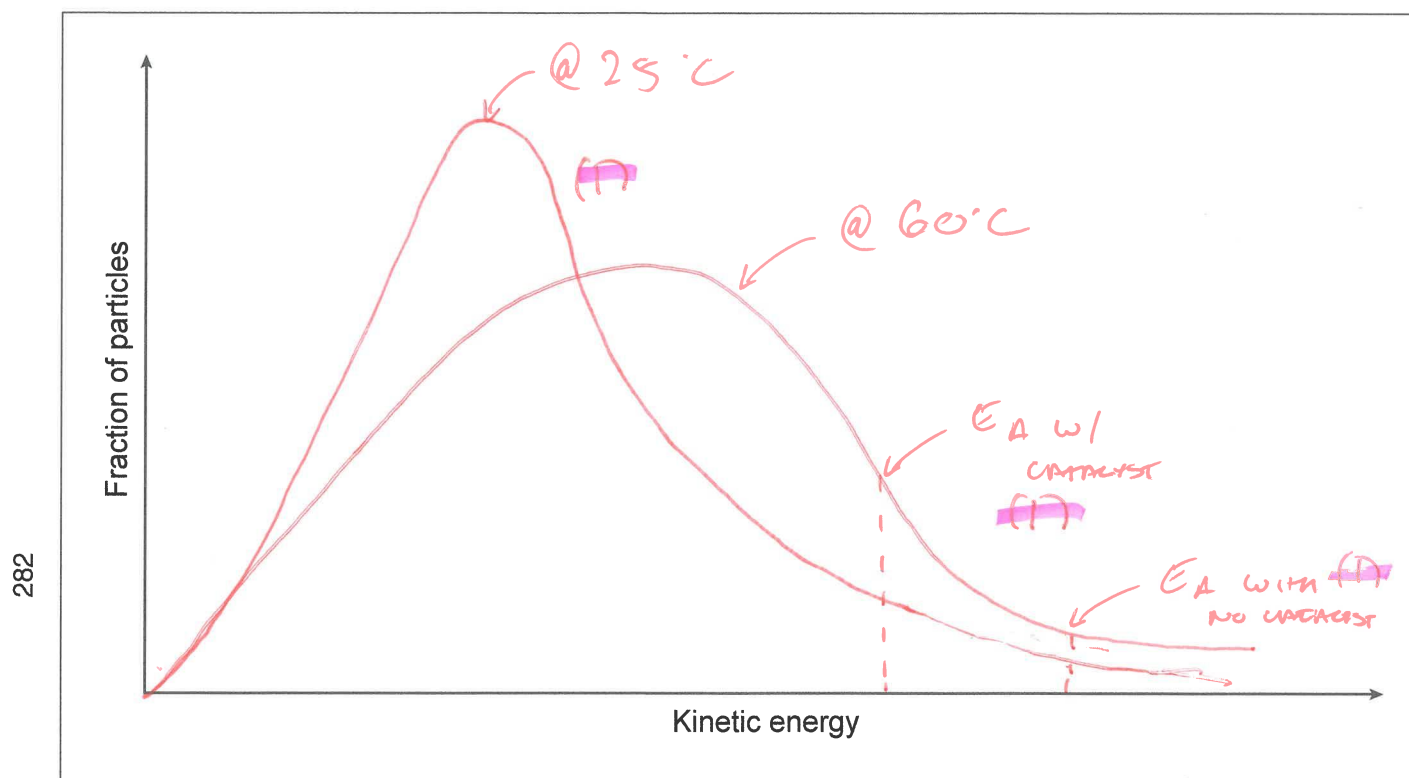
(iii) Explain the effect of reducing the temperature on the value of the equilibrium constant. [1]

Lowering the temperature will favour the exothermic reaction (forward) increasing the amount of product and lowering the amount of reactant. $\uparrow [\text{product}]$ & $\downarrow [\text{reactant}]$ will cause the K value to increase. (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]

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References:

2. (b)(ii) National Center for Biotechnology Information, 2024. *PubChem compound summary for CID 2244, Aspirin*. [online] Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/aspirin#section=2D-Structure> [Accessed 22 October 2024]. SOURCE ADAPTED.