Chemistry

Higher level

Paper 2

2 hours 30 minutes

Instructions to candidates

- Do not open the examination paper until instructed to do so.
- Answer all questions
- Answers must be written in 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 **[90 marks]**.

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

1. An organic compound consists of carbon, hydrogen and oxygen only. The percent composition by mass of the compound is shown in the table.

Element	**Percent composition by mass (%)**
Carbon	40.00
Hydrogen	6.70
Oxygen	53.30

(a) Determine the empirical formula of the compound. [3]

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(b) The relative formula mass, M_r, of the compound is 60. Determine the molecular formula of the compound. [1]

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2. Zinc reacts with nitric acid. The **unbalanced** equation for the reaction is shown below.

$$......Zn(s) + ...HNO_3(aq) \rightarrow ......Zn(NO_3)_2(aq) + ...H_2(g)$$

(a) Balance the equation using whole number coefficients. [1]

(b) 3.00 g of solid zinc is reacted with 50.0 cm^3 of 1.00 mol dm^{-3} $HNO_3(aq)$. Determine the limiting reactant, showing your working. [2]

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(c) Calculate the volume of hydrogen gas produced, in dm^3, if the reaction is carried out at STP. Use section 1 of the data booklet. [2]

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(d) State two conditions required for a successful collision between reactant particles. [2]

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(e) Explain the effect on the rate of reaction if the concentration of the $HNO_3(aq)$ is increased. [2]

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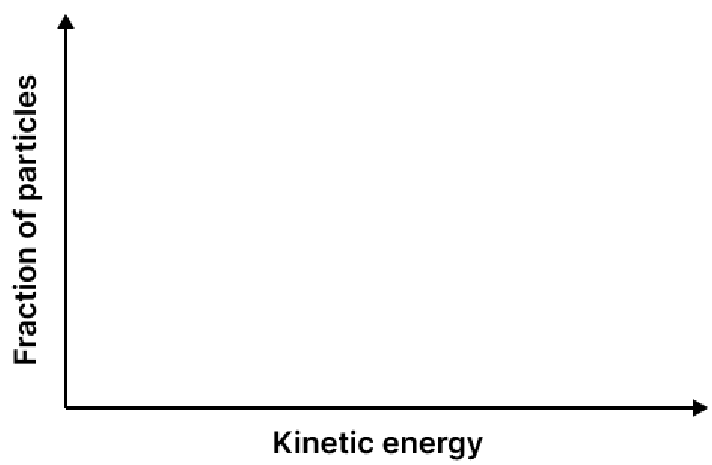
(f) Rates of reaction are also affected by temperature. On the axis below, sketch Maxwell–Boltzmann energy distribution curves at two temperatures T_1 and T_2, where $T_2 > T_1$. [1]



3. Hydrogen and iodine react to form hydrogen iodide.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

The following experimental data was obtained.

Experiment	**Initial $[H_2]$ mol dm^{-3}**	**Initial $[I_2]$ mol dm^{-3}**	**Initial rate of reaction mol dm^{-3} s^{-1}**
1	0.100	0.100	5.00
2	0.300	0.100	45.0
3	0.100	0.200	10.0

(a) Use the data in the table to determine the order of reaction with respect to H_2 and I_2. [2]

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(b) Deduce the rate equation for the reaction. [2]

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(c) Determine the value of the rate constant, *k*, together with the units. [2]

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4. Elements on the periodic table are arranged in groups and periods.

(a) Outline the relationship between the group number and the electron configuration of an element. [1]

(b) State the full electron configuration of a magnesium atom and the block to which it belongs. [2]

(c) Explain why chlorine has a higher first ionisation energy than magnesium. [2]

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(c) Sketch the shape of a 2s orbital and a 2p orbital. [2]

2s orbital	**2p orbital**

(e) Copper, a transition element, forms complex ions. The copper(II) ion forms the complex ion $[Cu(NH_3)_4Cl_2]^x$.

(i) Determine the charge on the complex ion. [1]

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(ii) Outline the bonding between the ligands and the central metal ion. [2]

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(iii) Deduce, with a reason, if the copper(II) ion is magnetic. [1]

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(iv) Explain why transition elements exhibit variable oxidation states. [2]

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5. Sulfur trioxide decomposes to form sulfur dioxide and oxygen according to the following equation.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

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

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(b) The reaction mixture at equilibrium is composed of a higher concentration of products. Suggest a value for the equilibrium constant, K, for the reaction, giving a reason for your answer. [2]

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(c) 4.50 mol of SO_3 is added to a 1.00 dm^3 reaction vessel and allowed to reach equilibrium. At equilibrium, 3.00 mol of SO_3 remains. Calculate the value of the equilibrium constant K for the reaction. [2]

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(d) Use your answer to part (b) to determine the standard Gibbs energy change, $\Delta G^{\ominus}$, for the reaction at 300 K. Use section 1 of the data booklet. [2]

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(e) Comment on the spontaneity of the reaction at 300 K. [1]

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Explain the effect on the yield of SO_2(g) when the volume of the reaction vessel is decreased at constant temperature. [2]

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(f) SO_3(g) can form acid deposition, also known as acid rain.

(i) Write an equation, including state symbols, for the reaction between SO_3 and water. [1]

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(ii) Deduce if the product of the reaction in part (i) is a strong or weak acid. Give a reason for your answer. [1]

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6. Carbonic acid, $H_2CO_3(aq)$, is a weak acid.

(a) Deduce the conjugate base of carbonic acid. [1]

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(b) Sketch the Lewis formula of the carbonate ion, showing all bonding and non-bonding electrons. [1]

(c) Explain the molecular geometry of the carbonate ion. [2]

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(d) Calculate the pH of a 0.0500 mol dm^{-3} solution of carbonic acid. The K_a of carbonic acid is 4.5×10^{-7} at 298 K. [2]

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7. The element carbon forms compounds with different properties.

(a) State **two** reasons why ethanol and propan-1-ol belong to the same homologous series. [1]

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(b) Draw the full structural formula of the product formed in the partial oxidation of ethanol. [1]

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(c) State the reaction conditions for the reaction in part (b). [1]

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(d) The boiling points of ethanol and ethanal are 78.4 °C and 20.2 °C respectively. Explain the difference in the boiling points of the two compounds. [2]

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(e) Ethanol can be produced by the hydration of ethene, C_2H_4. Determine the enthalpy change, ΔH, for this reaction, in kJ mol^{-1}, using section 11 of the data booklet. [2]

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(f) Propene reacts with hydrogen bromide, HBr.

(i) State the IUPAC name of the major product formed. [1]

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(ii) Explain the formation of the major product in part (i). [2]

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(iii) Using curly arrows to represent electron pairs, show the reaction of the major product in part (i) with aqueous sodium hydroxide, NaOH. Assume the reaction proceeds via the S_N1 mechanism. [3]

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(g) Halogens reacts with alkanes.

(i) State the type of reaction **and** the mechanism when chlorine reacts with methane. [1]

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(ii) Use single headed arrows to represent the type of bond fission that occurs in the initiation step of the reaction in part (i). [2]

(h) Carbon also forms allotropes such as diamond and graphite. Explain the electrical conductivity of the two substances. [2]

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8. An aqueous concentrated lithium chloride solution undergoes electrolysis.

(a) Deduce half-equations for the reactions at the anode and the cathode. [2]

Cathode (negative electrode):

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Anode (positive electrode):

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(b) State two ways in which current is conducted in the cell. [2]

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(c) Describe the bonding in solid lithium chloride. [1]

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(d) Outline why the melting point of lithium chloride is higher than that of sodium chloride. [1]

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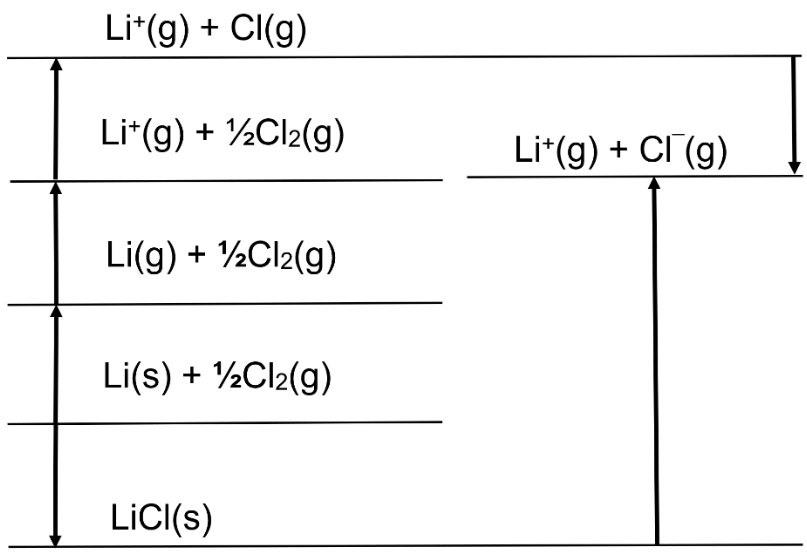
(e) The Born-Haber cycle for lithium chloride is shown.



Calculate the enthalpy of formation, ΔH_f, of lithium chloride. [3]

9. A voltaic cell is made with a zinc half-cell and a nickel half-cell.

(a) Deduce the equation for the reaction that takes place when the two half-cells are connected by a salt bridge and an external circuit. [1]

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(b) Calculate the cell potential, $E^{\ominus}_{cell}$, for the voltaic cell. [1]

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(c) Determine the Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for the reaction at 298 K. [2]

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(d) Comment on the spontaneity of the reaction, giving a reason for your answer. [1]

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(e) Electrode potential values are determined using a hydrogen half-cell. State two conditions of the hydrogen half-cell. [2]

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(f) Chromium is often used in electroplating. Deduce the half-equations taking place at the anode and the cathode when a piece of iron is plated with chromium. [2]

Anode:

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Cathode:

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10. N_2O reacts with water as follows.

$$N_2O(g) + 2H_2O(g) \rightarrow NH_4NO_3(s)$$

The table lists the standard enthalpies of formation and absolute entropy values for the reaction.

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$NH_4NO_3(s)$	-366	151
$N_2O(g)$	82	220
$H_2O(g)$	-242	189

(a) Determine the value of the ΔH, in kJ mol^{-1}, for the reaction using the values in the table. [1]

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(b) Calculate the standard entropy change for the reaction, $\Delta S^{\ominus}$, in J K^{-1} mol^{-1}. [1]

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(c) Calculate the standard free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for the reaction at 25.0 °C. [1]

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(d) Explain why the reaction is non-spontaneous at any temperature. [1]

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