(b) Both boron nitride, BN, and carbon, C, form hexagonal graphite-type structures. Explain why

- BN and C can both adopt the same hexagonal structure;
- both BN and C exhibit lubricating properties;
- C is an electrical conductor but BN is an insulator at room temperature. [6]

(QWC) [2]

Total [20]

5. *(a)* *Bordeaux Mixture* is one of the earliest fungicides, first used about 1885. It can be prepared by mixing copper sulfate solution with excess limewater (calcium hydroxide solution).

(i) State what you would observe when copper sulfate solution is mixed with limewater. [2]

(ii) Write an equation for the reaction that occurs. [1]

(b) A sample of *Bordeaux Mixture* was analysed to determine its copper content. Firstly, it was reacted with excess potassium iodide

$$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$

and the iodine produced was then titrated against sodium thiosulfate solution.

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

(i) Name the indicator used for the titration and state the colour change at the end-point. [2]

(ii) If a 31.2 g sample of *Bordeaux Mixture* required 12.25 cm^3 of sodium thiosulfate solution with concentration 0.100 mol dm^{-3} $Na_2S_2O_3$ to react with the liberated iodine, calculate the mass of copper in the sample and hence the % Cu by mass in *Bordeaux Mixture*. Your answers should be given to **three** significant figures. [3]

(c) Copper can exist as Cu^{2+} or Cu^+ compounds.

(i) Write the full electron configurations for Cu^{2+} ions **and** Cu^+ ions. [2]

(ii) Explain why most Cu^{2+} compounds are coloured blue in the presence of water. [4]

(iii) Briefly explain why most Cu^+ compounds are colourless or white. [1]

(d) (i) State what would be observed, and give equations for any reactions, when tetrachloromethane, CCl_4, and silicon(IV) chloride, $SiCl_4$, are separately added to water. [3]

(ii) Explain why lead forms a solid chloride $PbCl_2$, but the corresponding CCl_2 and $SiCl_2$ are too unstable to exist. [2]

Total [20]

Examiner only

(d) Aluminium chloride is a compound of the amphoteric element aluminium, whilst magnesium chloride contains the non-amphoteric element magnesium. Explain how sodium hydroxide can be used to distinguish between solutions of these two compounds. [3]

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(e) Aluminium chloride, $AlCl_3$, commonly exists as the dimer Al_2Cl_6.

(i) Draw the structure of the dimer formed, and explain why the two $AlCl_3$ monomers join together. [3]

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(ii) Aluminium chloride monomer may combine with another chloride ion to form tetrachloroaluminate(III) ions, $AlCl_4^-$. Using valence shell electron pair repulsion theory (VSEPR), state and explain the shape of this anion. [2]

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Total [14]

5. *(a)* Give a current use for a named compound of chlorine. [1]

(b) Chlorine gas, Cl_2, is used in the industrial preparation of bromine, Br_2. Sea water contains small amounts of bromide ions and by bubbling chlorine gas through the sea water these can be converted to Br_2.

(i) Write an ionic equation for the reaction occurring. [1]

(ii) Use the standard electrode potentials, $E^{\ominus}$, listed below to explain why chlorine can react with bromide ions but iodine cannot react with bromide ions. [3]

Half-equation	$E^{\ominus}$ / V
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.09
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36

(c) Sodium chloride and sodium iodide are both compounds which contain halide ions.

(i) Silver nitrate solution may be used to differentiate between solutions of sodium chloride and sodium iodide. Give the observations that would be expected in **both** cases. [1]

(ii) Both sodium chloride and sodium iodide react with concentrated sulfuric acid. The observations made during both reactions are very different. Discuss the reactions occurring. Your answer should include

- the observations made during both reactions,
- the identities of any products,
- the reasons for any differences in the reactions that occur. [5]

(QWC) [1]

(d) Chlorine produces a range of oxoacids, including chloric(I) acid, HOCl, and chloric(VII) acid, $HClO_4$. Chloric(I) acid is considered to be a weak acid whilst chloric(VII) acid is considered to be a strong acid.

(i) What is meant by the term *strong acid*? [1]

(ii) Write an expression for the acid dissociation constant, K_a, of chloric(I) acid, HOCl. [1]

(iii) The pH of a solution of chloric(I) acid of concentration 0.100 mol dm^{-3} was found to be 4.23. Calculate the concentration of hydrogen ions in this solution. [2]

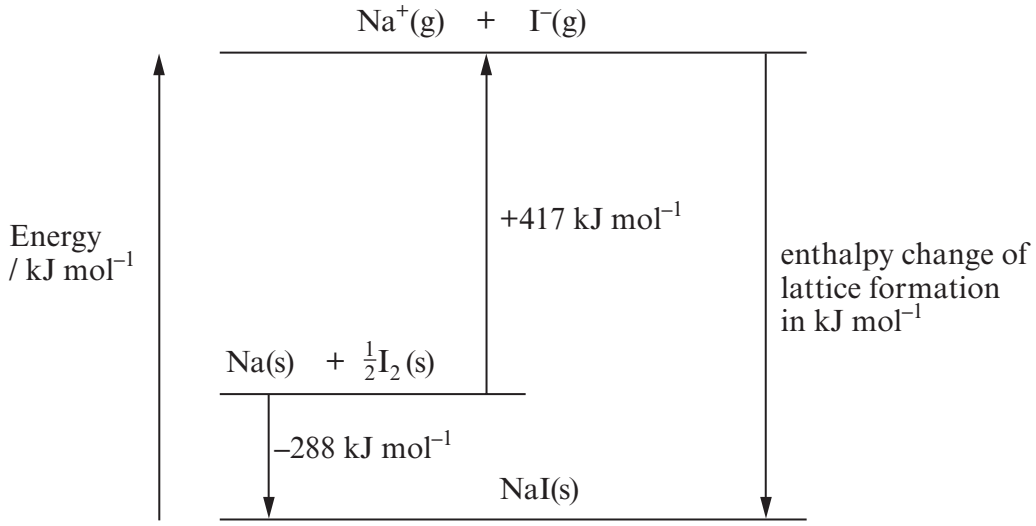
(iv) Using the information from part (iii), calculate the value of the acid dissociation constant, K_a, for chloric(I) acid. [2]

(v) When the weak acid HOCl reacts with the strong base sodium hydroxide it forms the salt sodium chlorate(I), NaOCl. Suggest a pH value for a solution of NaOCl, giving a reason for your answer. [2]

Total [20]

Examiner only

2. *(a)* The diagram shows an outline of the Born-Haber cycle for the formation of sodium iodide (NaI) from its elements.



Use the information given to calculate the enthalpy change of lattice formation (in kJ mol^{-1}) of sodium iodide. [2]

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1095 010005

(b) Sodium iodide is very soluble in water at room temperature.

(i) Complete the sentence below using the relevant enthalpy terms.

For a compound to be very soluble in water the value of the enthalpy of

..... will be greater than the enthalpy of .....

[1]

(ii) Aqueous solutions of sodium iodide become yellow in the presence of oxygen due to the slow production of iodine.
One suggested reason for this is that a low concentration of hydrogen ions in the solution produces iodine according to the equation below.

$$4H^+(aq) + 4I^-(aq) + O_2(aq) \rightleftharpoons 2I_2(aq) + 2H_2O(l)$$

Use Le Chatelier's principle to suggest a reagent that you could add, apart from water, to decrease the amount of yellow iodine present. Explain your choice. [2]

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Examiner only

(c) Sodium chloride and sodium iodide both react with concentrated sulfuric acid to give the corresponding hydrogen halide e.g.

$$NaI + H_2SO_4 \longrightarrow NaHSO_4 + HI$$

However, the reaction with sodium iodide continues, giving hydrogen sulfide and iodine as two of the products. This further type of reaction does not occur when sodium chloride is used in place of sodium iodide.

(i) Describe what is **seen** when solid sodium iodide is added to concentrated sulfuric acid. [2]

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(ii) The following equations show the standard electrode potentials for the Cl_2/Cl^- and I_2/I^- systems.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \qquad E^{\ominus} = +1.36\,V$$

$$I_2 + 2e^- \rightleftharpoons 2I^- \qquad E^{\ominus} = +0.54\,V$$

Use these values to explain why only hydrogen iodide (represented as I^- in the equation) is able to further react with concentrated sulfuric acid in this way. [2]

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(d) The reaction of chlorine with sodium hydroxide solution gives aqueous sodium chlorate(I) as one of the chlorine-containing products.

(i) Give the equation for this reaction. [1]

.....

(ii) State **one** use for a solution of sodium chlorate(I). [1]

.....

Total [11]

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* In the reaction below carbon monoxide is acting as a reducing agent.

$$5CO + I_2O_5 \longrightarrow 5CO_2 + I_2$$

Use oxidation states (numbers) to show that carbon monoxide is acting as a reducing agent in this reaction. [2]

(b) State how the stabilities of the +II and +IV oxidation states vary down Group 4. [1]

(c) You are given two solutions. One contains aqueous aluminium ions, Al^{3+}, and the other contains aqueous lead(II) ions, Pb^{2+}.

(i) Describe a reaction to show that both of these ions exhibit amphoteric behaviour. Your answer should state the reagent(s) used, the names of any precipitates and any relevant observations. *Chemical equations are not required.* [4]
QWC [1]

(ii) Describe what is **seen** when iodide ions are added to an aqueous solution of Pb^{2+} ions. Give the **ionic** equation for the reaction that occurs. [2]

(d) Monomeric aluminium chloride is described as containing an electron-deficient species.

(i) Explain, using monomeric covalent aluminium chloride, what is meant by *electron deficient* and why this leads to the ready formation of the Al_2Cl_6 dimer.
You should show the structure of this dimer as part of your answer. [3]

(ii) The electron-deficient nature of the aluminium chloride monomer results in the compound having an affinity for chlorine-containing species. This is important in catalysis and also in the production of specialised solvents.
Give **one** example of the use of the monomer in either of these ways. [1]

(iii) On heating, gaseous dimeric aluminium chloride molecules dissociate into the monomer.

$$Al_2Cl_6(g) \rightleftharpoons 2AlCl_3(g)$$

I State **one** reason why the entropy of this gaseous system is increasing. [1]

II Use the equation

$$\Delta G = \Delta H - T\Delta S$$

to calculate the temperature at which the dissociation of gaseous Al_2Cl_6 molecules into gaseous $AlCl_3$ molecules just occurs spontaneously.
The entropy change for this reaction, ΔS, is 88 J mol^{-1} K^{-1} and the enthalpy change, ΔH, is 60 kJ mol^{-1}. [2]

Examiner only

SECTION A

Answer **all** *questions in the spaces provided.*

1. Halogens and their compounds take part in a wide variety of reactions.

(a) Give the chemical name of a chlorine-containing compound of commercial or industrial importance. State the use made of this compound. [1]

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(b) Hydrogen reacts with iodine in a reversible reaction.

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

An equilibrium was established at 300 K, in a vessel of volume 1 dm^3, and it was found that 0.311 mol of hydrogen, 0.311 mol of iodine and 0.011 mol of hydrogen iodide were present.

(i) Write the expression for the equilibrium constant in terms of concentration, K_c. [1]

(ii) Calculate the value of K_c at 300 K. [1]

K_c = ...

(iii) What are the units of K_c, if any? [1]

.....

(iv) Equilibria of H_2, I_2 and HI were set up at 500 K and 1000 K and it was found that the numerical values of K_c were 6.25×10^{-3} and 18.5×10^{-3} respectively.

Use these data to deduce the sign of ΔH for the forward reaction. Explain your reasoning. [3]

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(b) Many metal oxides can be reduced to the metal by carbon monoxide. The equation for the reduction of magnesium oxide is given below.

$$MgO(s) + CO(g) \longrightarrow Mg(s) + CO_2(g)$$

The conditions under which reactions will occur can be predicted using enthalpy and entropy changes. The entropies of the substances involved in this reaction are shown in the table.

Substance	MgO(s)	CO(g)	Mg(s)	$CO_2(g)$
Entropy / $JK^{-1}mol^{-1}$	26.9	197.7	32.7	213.7

(i) Suggest a reason why the entropies of carbon monoxide and carbon dioxide are much higher than those of magnesium and magnesium oxide. [1]

(ii) Calculate the entropy change in this reaction. [1]

(iii) The enthalpy change, ΔH, for the reduction of magnesium oxide is $318.0\,kJ\,mol^{-1}$. Calculate the minimum temperature at which this reduction could occur. [3]

(c) Magnesium oxide, MgO, lead(II) oxide, PbO, and aluminium oxide, Al_2O_3, all react with dilute acids to form aqueous ions – $Mg^{2+}(aq)$, $Pb^{2+}(aq)$ and $Al^{3+}(aq)$.

Suggest tests that would enable you to distinguish between solutions containing one of each of these ions. You should include the expected result for **each** test and are advised to record your tests and expected results in a table. [5]

QWC [2]

(d) Aluminium chloride, $AlCl_3$, can be used to produce compounds including the chloroaluminate(III) ion, $AlCl_4^-$.

(i) Draw a dot and cross diagram to show the electron arrangement in the $AlCl_4^-$ ion. You should show outer electrons only. [1]

(ii) Give **one** industrially important use in which the $AlCl_4^-$ ion is involved. State the role of the ion in this use. [2]

Total [20]

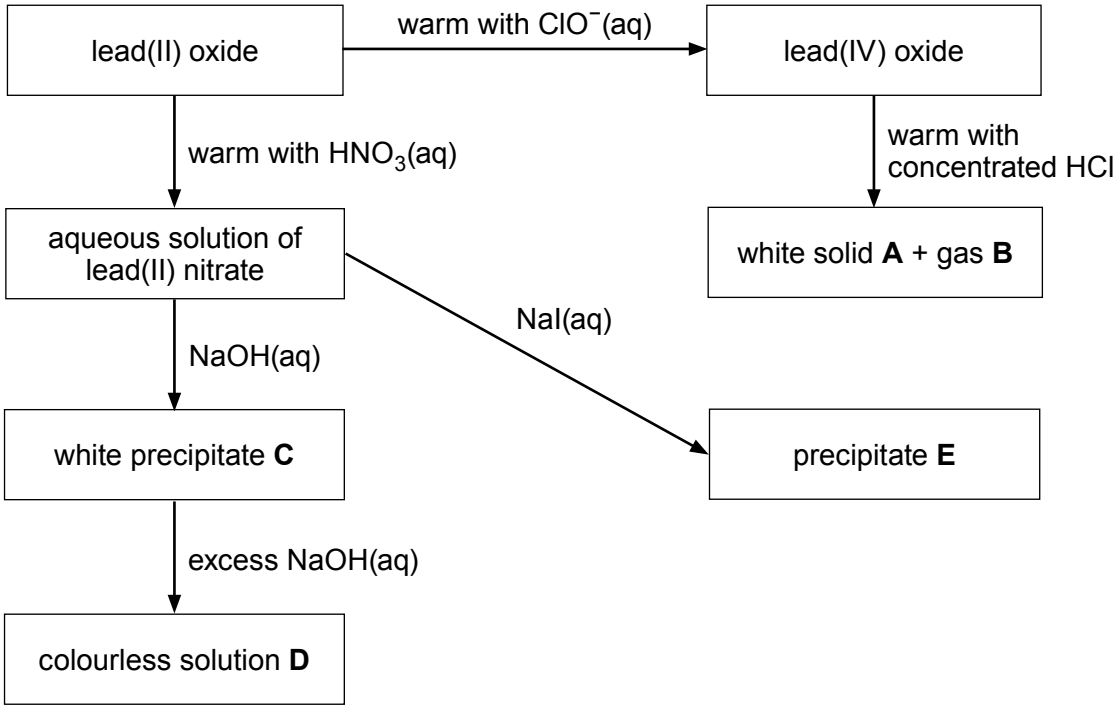
Total Section B [40]

END OF PAPER

SECTION B

Answer **both** *questions in the separate answer book provided.*

4. *(a)* The diagram shows some of the reactions of lead compounds.



(i) State the role of lead(IV) oxide in the reaction with concentrated hydrochloric acid. [1]

(ii) Name white solid **A** and gas **B**. [2]

(iii) Give the formula of the lead-containing species present in colourless solution **D**. [1]

(iv) Give the colour of precipitate **E**. [1]

(v) Write the equation for the formation of lead(II) nitrate from lead(II) oxide. [1]

(b) Carbon is the first element in Group 4. Two of its allotropes are diamond and graphite. A compound that forms structures corresponding to diamond and graphite is boron nitride.

(i) Describe the structure of graphite and explain why **hexagonal** boron nitride can adopt the same structure yet have different electrical conductivity properties. [4]
QWC [1]

(ii) State **one** use for the **cubic** boron nitride structure. [1]

(c) Another element in Group 4 is tin. At low temperatures tin exists as its grey form. At higher temperatures the white form is stable. The change can be represented by the equation:

$$Sn_{(grey)} \longrightarrow Sn_{(white)} \qquad \Delta H^{\ominus} = 1.92\,kJ\ mol^{-1}$$

The standard entropy values are $44.8\,J\,K^{-1}\,mol^{-1}$ for grey tin and $51.5\,J\,K^{-1}\,mol^{-1}$ for white tin.

(i) Calculate the minimum temperature needed to cause grey tin to change to white tin. [3]

(ii) During Napoleon's disastrous campaign in Russia from June to December in 1812 the tin buttons on his infantry's uniforms disintegrated. Suggest a reason why this might have happened. [1]

(d) An important technological development in recent years has been the hydrogen fuel cell. This uses electrochemical methods to get energy from hydrogen.

(i) Write the half-equations for the processes occurring at the electrodes and an equation for the overall reaction. [3]

(ii) Give **one** disadvantage of using hydrogen fuel cells to power vehicles. [1]

Total [20]

