(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

SECTION A

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

1. Chromium and aluminium both form amphoteric compounds.

(a) State what is meant by the term *amphoteric*. [1]

....

....

(b) Use arrows in boxes to show the electronic structures of the chromium atom and the Cr^{3+} ion. [2]

Chromium atom, Cr

1s	2s	2p			3s	3p			3d					4s

Chromium(III) ion, Cr^{3+}

1s	2s	2p			3s	3p			3d					4s

(c) When sodium hydroxide solution is added to a solution of potassium dichromate(VI), $K_2Cr_2O_7$, the following reaction occurs.

$$Cr_2O_7^{2-} + 2OH^- \longrightarrow 2CrO_4^{2-} + H_2O$$

(i) State the colour change that is seen. [1]

....

(ii) Use the oxidation states of chromium to show that this is not a redox reaction. [2]

....

....

SECTION B

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

4. *(a)* (i) State what is meant by the term *transition element*. [1]

(ii) Explain why both iron and copper are classed as transition elements, whilst zinc is not. [1]

(b) Transition elements such as copper frequently form coloured complexes. Copper(II) complexes are usually blue, but the exact colour can vary, with $[Cu(H_2O)_6]^{2+}$ being pale blue and $[Cu(NH_3)_4(H_2O)_2]^{2+}$ being royal blue. Copper(I) complexes are usually colourless.

Explain why transition metal complexes are usually coloured. Your answer should include details of:

- The origin of colour in transition metal complexes;
- Why the copper(II) species above are coloured blue;
- Why the colours seen in different copper(II) complexes are different;
- Why copper(I) complexes do not form coloured compounds. [6]

(QWC) [2]

(c) Iron is usually extracted from iron(III) oxide, Fe_2O_3, in a blast furnace using carbon monoxide, CO, as a reducing agent, releasing metallic iron and the gas carbon dioxide.

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

(ii) Explain in terms of oxidation states why carbon monoxide is considered to be the reducing agent in this reaction. [2]

(iii) Explain why carbon monoxide, CO, can be used as a reducing agent but the corresponding oxide of lead, PbO, cannot. [2]

3. *Read the passage below and then answer the questions (a) to (e) in the spaces provided.*

Copper – an essential element

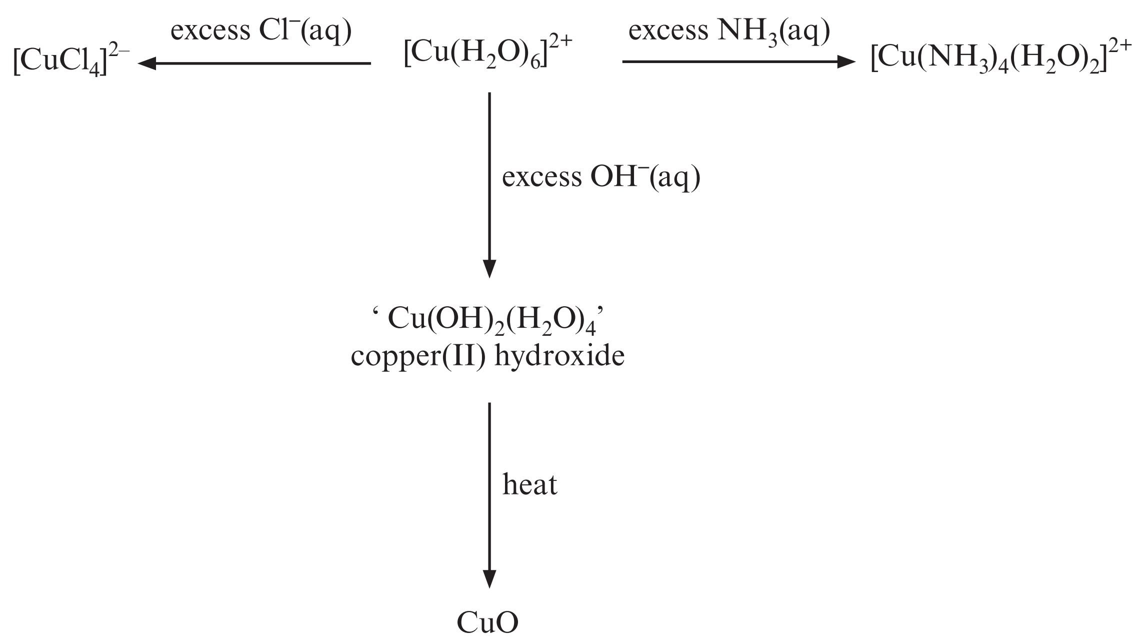
There is an ever-increasing world demand for copper and this has driven its cost upwards. This has led to the extraction of copper from sources once thought to be uneconomic. One such source of copper is the spoil heaps from old mines. The spoil heap material is crushed and then sprayed with acidified water in the presence of the bacterium *Thiobacillus ferrooxidans*. These bacteria convert any iron present to aqueous iron(III) ions, which then oxidise sulfide ions to aqueous sulfate(VI) ions, SO_4^{2-}. A solution containing copper(II) sulfate is produced that is then treated with iron to leave copper.

$$Cu^{2+}(aq) \quad + \quad Fe(s) \longrightarrow Cu(s) \quad + \quad Fe^{2+}(aq)$$

The concentration of copper in this copper(II) sulfate solution can be found by a variety of methods, which include

- precipitating the copper and weighing it
- reacting the solution with an excess of iodide ions and titrating the liberated iodine with aqueous sodium thiosulfate
- titrating the copper(II) ions with ethylenediaminetetra-acetic acid (EDTA)
- using instrumental methods such as atomic absorption and X- ray fluorescence spectroscopy

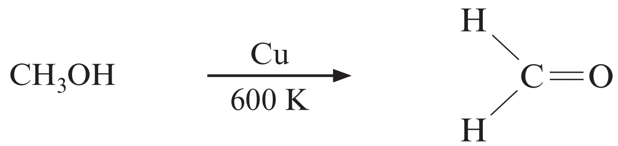
Copper(II) sulfate continues to be a familiar and commonly used substance in schools and colleges and its reactions are typical of many transition metal compounds. For example, in aqueous solution the copper ions are present as the complex cation, $[Cu(H_2O)_6]^{2+}$. The water molecules in this complex ion can be replaced by other ligands.



Copper is a relatively unreactive metal and is easy to obtain by the smelting of its ores, as was carried out in the Bronze Age. Small quantities of many transition metals can be produced by strongly heating the oxide with aluminium or magnesium. One application of this is the reaction of aluminium with iron(III) oxide to give molten iron that can be used to weld together lengths of railway track. A similar reaction occurs when magnesium is strongly heated with copper(II) oxide.

$$Mg(s) \quad + \quad CuO(s) \quad \longrightarrow \quad Cu(l) \quad + \quad MgO(s) \qquad \Delta H = -431\,kJ\,mol^{-1}$$

Transition metals also have important uses as catalysts and copper can be used as an economical catalyst in a number of organic processes, for example in the production of methanal.



- End of passage -

(a) The percentage of copper in a sample from a spoil heap was found by a titration using ethylenediaminetetra-acetic acid (EDTA).
19.20 cm^3 of an EDTA solution of concentration 0.010 $mol\,dm^{-3}$ reacted with 50.00 cm^3 of a solution containing copper(II) ions.
EDTA reacts with copper(II) ions in a 1:1 mole ratio.

(i) Calculate the number of moles of EDTA solution used in the titration. [1]

....

....

(ii) State the number of moles of copper(II) ions present in 50.00 cm^3 of the copper-containing solution. [1]

....

(iii) Calculate the concentration of copper in the solution in **g dm^{-3}**. [2]

....

....

....

Examiner only

(iv) The mass of the copper-containing sample was 11.56 g. All the copper in this sample was present in a solution of volume 1.00 dm^3.
Calculate the percentage of copper in the sample. [1]

....

....

(b) Both copper and zinc are d-block elements. Explain, using electron configurations, why copper is described as a transition metal and zinc (whose compounds contain Zn^{2+} ions) is not. [2]
(QWC) [1]

....

....

....

....

(c) The passage shows the formulae of some copper-containing species formed by ligand exchange *(line 20)*.
Complete the table below, stating the approximate shape and colour of the complex ions shown. [2]

Complex ion	Shape	Colour
$[CuCl_4]^{2-}$		
$[Cu(NH_3)_4(H_2O)_2]^{2+}$		

(d) Standard enthalpy of formation values, $\Delta H_f^\ominus$, can be used to calculate enthalpy changes, such as the reduction of copper(II) oxide by magnesium, described in the article *(line 27)*.
Some $\Delta H_f^\ominus$ values are given in the table below.

Metal oxide	$\Delta H_f^\ominus / kJ\ mol^{-1}$
CuO	–157
PbO	–217

State and explain how the $\Delta H_f^\ominus$ values for these two oxides give an indication of their relative stability. [2]

....

....

....

(e) Many transition metals and their compounds act as catalysts. The article describes copper acting as a catalyst in the oxidation of methanol *(line 30)*.

(i) Give **two** reasons why transition metals and their compounds can act as catalysts. [2]

....

....

(ii) Give a reason, in terms of Green Chemistry, why scientists often seek new catalysts for established chemical processes. [1]

....

....

Total [15]

Total Section A [40]

Examiner only

(c) When concentrated hydrochloric acid is added to a pink aqueous solution of cobalt(II) chloride, the colour changes to blue.

Cobalt takes part in an equilibrium reaction.

$$[Co(H_2O)_6]^{2+}(aq) \quad + \quad 4Cl^-(aq) \quad \rightleftharpoons \quad [CoCl_4]^{2-}(aq) \quad + \quad 6H_2O(l)$$

(i) What is the oxidation state of cobalt in $[CoCl_4]^{2-}$? [1]

....

(ii) What type of bonding is present in $[CoCl_4]^{2-}$? [1]

....

(iii) Use the equation to identify the ions responsible for the pink and blue colours described above. Explain why the colour change occurs when concentrated hydrochloric acid is added to the pink solution. [3]

....

....

....

....

(iv) Draw diagrams to clearly show the shape of the $[Co(H_2O)_6]^{2+}$ ion and the $[CoCl_4]^{2-}$ ion. [2]

$[Co(H_2O)_6]^{2+}$ $[CoCl_4]^{2-}$

Total [14]

SECTION B

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

4. *(a)* Electrochemical cells are used as power sources in many everyday applications. To decide what to use in a cell, it is necessary to know the standard electrode potential for electrodes. This is measured using a standard hydrogen electrode as a reference standard.

Draw a labelled diagram of the apparatus you would use to measure the standard electrode potential of an Fe^{3+}/Fe^{2+} electrode. [5]

(b) Vanadium is a transition metal that can form compounds with a variety of oxidation states. Zinc however forms compounds with an oxidation state of +2 only.

(i) Why can transition elements form compounds with a variety of oxidation states? [1]

(ii) Give the electronic structure of Zn. [1]

(iii) State why zinc forms Zn^{2+}. [1]

You will need the standard electrode potentials in the table below to answer part *(c)*.

Oxidation state of vanadium at start of reaction	Reaction	$E^\ominus$/V
+5	$VO_3^-(aq) + 4H^+(aq) + e \rightleftharpoons VO^{2+}(aq) + 2H_2O(l)$	+1.00
+4	$VO^{2+}(aq) + 2H^+(aq) + e \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
+3	$V^{3+}(aq) + e \rightleftharpoons V^{2+}(aq)$	–0.26
+2	$V^{2+}(aq) + 2e \rightleftharpoons V(s)$	–1.13
	$Zn^{2+}(aq) + 2e \rightleftharpoons Zn(s)$	–0.76
	$Cu^{2+}(aq) + 2e \rightleftharpoons Cu(s)$	+0.34

3. *Read the passage below and then answer the questions in the spaces provided.*

Hydrogen Peroxide

If a non-scientist knows only one chemical formula it is most likely to be H_2O for water but how much do you know about another hydrogen oxide, hydrogen peroxide? A molecule of hydrogen peroxide has the molecular formula H_2O_2.

Most chemistry students first meet hydrogen peroxide as a colourless solution that is used to prepare oxygen. Bottles of hydrogen peroxide from a pharmacist are often labelled ‘20 volume’. This means that one volume of solution decomposes to give 20 volumes of oxygen gas. The equation for the decomposition is:

$$\underset{1\,dm^3}{2H_2O_2(aq)} \longrightarrow 2H_2O(l) + \underset{20\,dm^3}{O_2(g)}$$

This reaction is very slow at room temperature. However the addition of a suitable catalyst increases the rate of decomposition phenomenally. Manganese(IV) oxide, potatoes and blood are all effective. Potatoes and blood both contain the enzyme catalase and one catalase molecule decomposes 50 000 molecules of H_2O_2 per second!

Is hydrogen peroxide an oxidising agent or a reducing agent?

Both in the laboratory and at home hydrogen peroxide is most commonly used as an oxidising agent (so the hydrogen peroxide itself is reduced). The half-equation is:

Reduction $\quad H_2O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O$

Since some colouring matter is bleached by oxidation and the product of hydrogen peroxide’s reduction is water, it is used as a safe bleaching agent particularly in hair treatment. A peroxide blonde is someone with almost white hair, usually as a result of treatment with hydrogen peroxide.

However, if hydrogen peroxide reacts with a more powerful oxidising agent such as potassium manganate(VII), the hydrogen peroxide will act as a reducing agent and will itself be oxidised. The half-equation is:

Oxidation $\quad H_2O_2 \longrightarrow 2H^+ + O_2 + 2e^-$

Therefore hydrogen peroxide can act as both oxidising agent and reducing agent. In fact, it can react with itself so that alternate molecules are oxidised and reduced. The overall equation is obtained by adding the half-equations for the reduction and oxidation, giving

$$2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$$

which is the standard decomposition equation!

- End of passage -

Examiner only

(a) Using outer electrons only, draw a dot and cross diagram to show the bonding in a hydrogen peroxide molecule *(line 3)*. [1]

(b) Use the equation for the decomposition of hydrogen peroxide *(line 8)* to calculate the concentration, in mol dm^{-3}, of aqueous hydrogen peroxide solution in a bottle of '20 volume hydrogen peroxide' at 25 °C. [2]

[1 mol of oxygen occupies 24 dm^3 at 25 °C]

Concentration = ... mol dm^{-3}

(c) Manganese(IV) oxide *(line 10)* and potassium manganate(VII) *(lines 20-21)* are typical transition metal compounds.

(i) Give **two** reasons why transition metal compounds can act as catalysts. [2]

....

....

....

(ii) Explain why transition metal complex ions appear coloured. [4]
QWC [1]

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