# WJEC Chemistry A-level

## 3.4: Chemistry of the *d*-block Transition Metals

### Practice Questions

Wales Specification

1.

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

**Copper – an essential element**

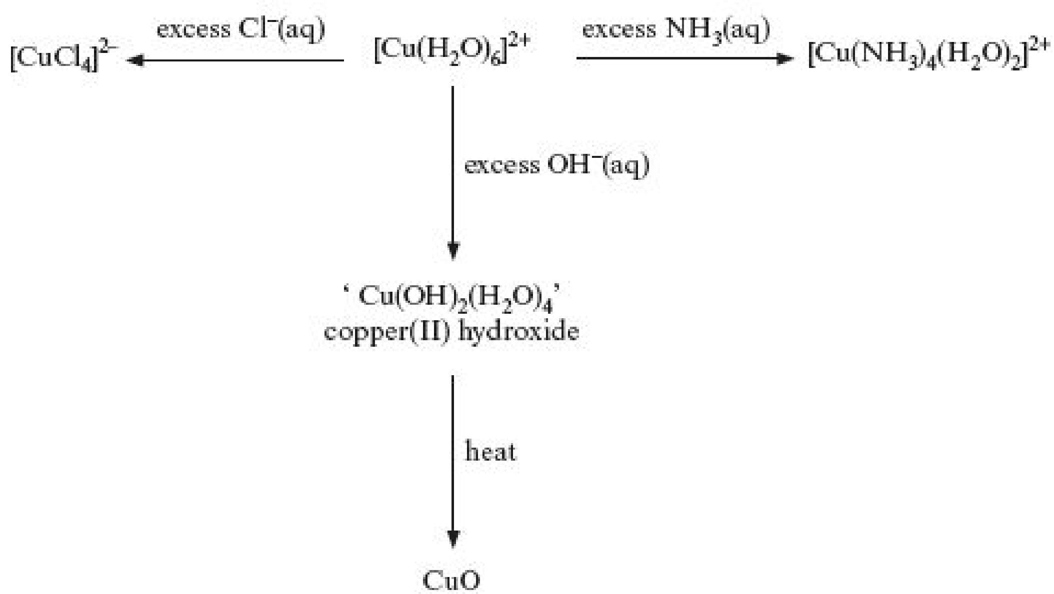
There is an ever-increasing world demand for copper and this has driven its cost upwards. This has led to the extraction of copper from sources once thought to be uneconomic. One such source of copper is the spoil heaps from old mines. The spoil heap material is crushed and then sprayed with acidified 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

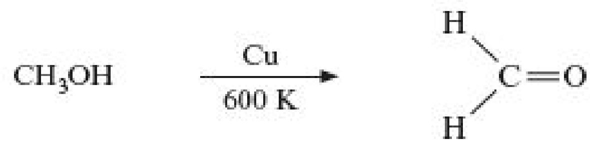
Copper(II) sulfate continues to be a familiar and commonly used substance in schools and colleges and its reactions are typical of many transition metal compounds. For example, in aqueous solution the copper ions are present as the complex cation, $[Cu(H_2O)_6]^{2+}$. The water molecules in this complex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

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

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 $\mathbf{g\,dm^{-3}}$. [2]

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

(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]

2.

*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 -*

(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.

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

[2]

*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]

(d) In an acidic solution, hydrogen peroxide is oxidised to oxygen by potassium manganate (VII) *(lines 20-23).*

(i) Write the half-equation for the reduction of $MnO_4^-$ to $Mn^{2+}$ ions in acidic solution.

[1]

(ii) Use your answer to (i) and the half-equation given in *line 23* to deduce the overall equation for this reaction.

[2]

(iii) 20.0 $cm^3$ of an acidified solution of hydrogen peroxide required 14.80 $cm^3$ of a 0.020 mol $dm^{-3}$ solution of potassium manganate(VII) for complete reaction. Calculate the concentration, in mol $dm^{-3}$, of the hydrogen peroxide solution.

[3]

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

(e) Explain, using oxidation states, why the decomposition of hydrogen peroxide *(line 27)* can be classified as a redox reaction.

[2]

**(Total 18)**

3. Many industrial processes use catalysts.

Explain how a catalyst increases the rate of a chemical reaction.

[2]

State **one** example of an industrially or environmentally important heterogeneous catalyst. You should identify the reaction catalysed and name the catalyst.

[1]

**(Total 3)**

4. *(a)* Copper ions combine with a range of ligands to form complex ions, including $[CuCl_4]^{2-}$ and $[Cu(H_2O)_6]^{2+}$.

(i) State what is meant by a *ligand*. [1]

---------------------------------------------------------------------------

---------------------------------------------------------------------------

(ii) Draw the structures of $[CuCl_4]^{2-}$ and $[Cu(H_2O)_6]^{2+}$ ions. [2]

(iii) A solution containing $[Cu(H_2O)_6]^{2+}$ ions is blue. Explain the origin of this colour. [3]

---------------------------------------------------------------------------

---------------------------------------------------------------------------

---------------------------------------------------------------------------

---------------------------------------------------------------------------

---------------------------------------------------------------------------

---------------------------------------------------------------------------

(iv) When excess ammonia is added to a solution containing $[Cu(H_2O)_6]^{2+}$ ions, the colour of the solution changes as a new complex ion is formed. Give the formula of the new complex ion and the colour of the solution formed. [2]

---------------------------------------------------------------------------

---------------------------------------------------------------------------

*(b)* Phosphorus forms two chlorides, $PCl_3$ and $PCl_5$, and there is a dynamic equilibrium between these compounds in the gas phase. This is represented by the equation below.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

(i) Write an expression for the equilibrium constant, $K_p$, for this reaction. [1]

(ii) A sealed vessel is filled with $PCl_5$ at a pressure of $3.0 \times 10^5$ Pa. Upon heating, the system comes to equilibrium to form a mixture that contains $PCl_3$ at a partial pressure of $1.3 \times 10^5$ Pa.

I. State the partial pressure of $Cl_2$ at equilibrium. [1]

..............................................................................................................................

II. Calculate the value of the equilibrium constant, $K_p$, giving its units. [3]

$K_p$ = ..............................

*Units* ..............................

III. As the temperature is increased the value of $K_p$ increases. State what information this provides about the enthalpy change of this reaction, giving a reason for your answer. [1]

..............................................................................................................................

..............................................................................................................................

*(c)* Silicon(IV) chloride reacts with water whilst $CCl_4$ does not. Give the equation for the reaction of $SiCl_4$ with water and explain why the behaviour of $CCl_4$ and $SiCl_4$ with water is so different. [2]

..............................................................................................................................

..............................................................................................................................

..............................................................................................................................

Total [16]

5.

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]

....................................................................................................

....................................................................................................

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

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

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 $6.25 \times 10^{-3}$ and $18.5 \times 10^{-3}$ respectively.

Use these data to deduce the sign of $\Delta H$ for the forward reaction. Explain your reasoning. [3]

....................................................................................................

....................................................................................................

....................................................................................................

....................................................................................................

*(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]