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# CHEMISTRY

## Topic Questions

## OCR
## AS & A LEVEL

**Module 5: Physical chemistry and transiton elements**

**1** Iron, copper and platinum are examples of transition elements.

**(a)** Define the term *transition element*.

Show that iron fits this definition by use of full electron configurations of iron as the element and in its common oxidation states.

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..... **[4]**

**(b)** Describe **one** precipitation reaction and **one** ligand substitution reaction of copper in the +2 oxidation state.

Your answer should include reagents, relevant observations and balanced equations.

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..... **[6]**

**(c)** Platinum is an extremely unreactive transition element. However, platinum does take part in a redox reaction with '*aqua regia'*, a mixture of concentrated hydrochloric and nitric acids. Two products of this reaction are hexachloroplatinic acid, $H_2PtCl_6$, and nitrogen dioxide, $NO_2$.

**(i)** Use oxidation states to show that this is a redox reaction.

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..... **[2]**

**(ii)** Write an equation for the reaction of platinum metal with *aqua regia*.

..... **[2]**

**(d)** Ammonium hexachloroplatinate, $(NH_4)_2PtCl_6$, is a complex of platinum used in platinum plating. Ammonium hexachloroplatinate contains the hexachloroplatinate ion.

Draw a 3-D diagram to show the shape of a hexachloroplatinate ion.

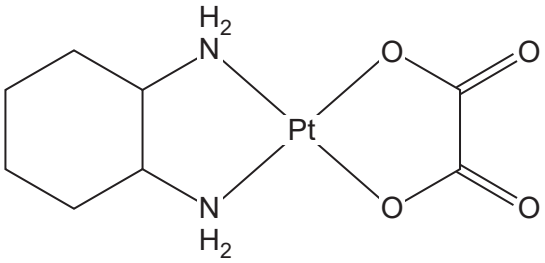
On your diagram, show

- the charge on the ion
- the value of the bond angle.

**[3]**

**(e)** Oxaliplatin is a neutral complex of platinum(II) used in cancer treatment.

A molecule of oxaliplatin has a square planar shape about the metal ion with two bidentate ligands. The structure of oxaliplatin is shown below.




**(i)** What is meant by a *bidentate ligand*?

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..... **[2]**

**(ii)** In the boxes below, show the structures of the two bidentate ligands in oxaliplatin.

| | |
|---|---|
| | |

**[2]**

**[Total: 21]**

**2** Nickel is a typical transition element in the d-block of the Periodic Table. Many nickel ions are able to interact with ligands to form complex ions, such as $[Ni(H_2O)_6]^{2+}$.

**(a)** Using the information about nickel above, explain the meaning of the terms *d-block element*, *transition element*, *ligand* and *complex ion*.

Include electron structures and diagrams in your answer.

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**(b)** A student dissolves nickel(II) sulfate in water. A green solution forms containing the complex ion $[Ni(H_2O)_6]^{2+}$.

The student then reacts separate portions of the green solution of nickel(II) sulfate as outlined below.

- Concentrated hydrochloric acid is added to the green solution of nickel(II) sulfate until there is no further change. The solution turns a lime-green colour and contains the four-coordinate complex ion **A**.
- Aqueous sodium hydroxide is added to the green solution of nickel(II) sulfate. A pale-green precipitate **B** forms.
- Concentrated aqueous ammonia is added to the green solution of nickel(II) sulfate until there is no further change. The solution turns a violet colour and contains the complex ion **C**.
  **C** has a molar mass of $160.7\,g\,mol^{-1}$.

**(i)** Draw a 3-D diagram for the $[Ni(H_2O)_6]^{2+}$ ion.
Show a value for the bond angles on your diagram.

**[2]**

**(ii)** Suggest the formulae of **A** and **B**.

**A** .....

**B** ..... **[2]**

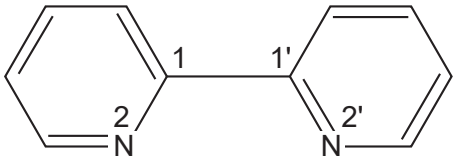
**(iii)** Deduce the formula of **C**.

**C** ..... **[1]**

**(iv)** Write an equation for the formation of **C** from $[Ni(H_2O)_6]^{2+}$.

..... **[2]**

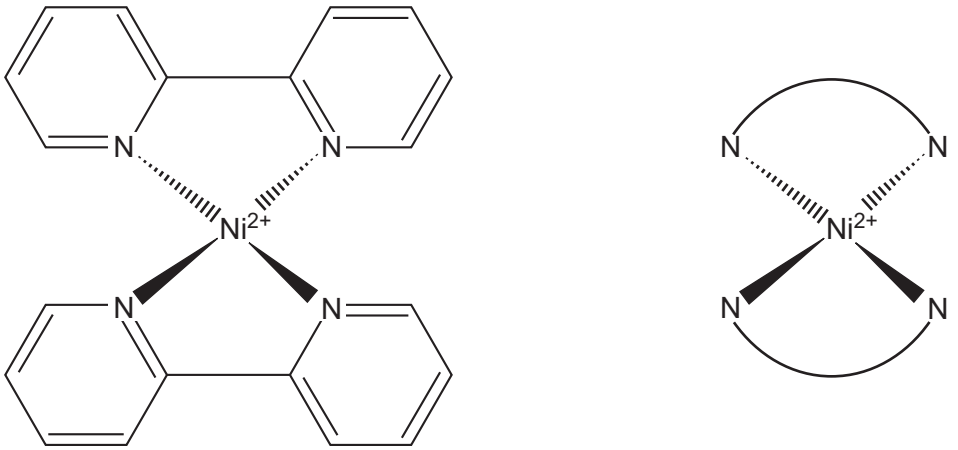
**(c)** 2,2'-Bipyridine (or 'bipy') is a bidentate ligand that forms complexes with many transition metals. The structure of 2,2'-bipyridine is shown below.




**2,2'-bipyridine**

In the naming of bipyridines, the numbering starts at the carbon atom that links to the other ring.

2,2'-Bipyridine forms a complex, $[Ni(bipy)_2]^{2+}$. The structure of $[Ni(bipy)_2]^{2+}$ is shown in **Fig 6.1** below.




structure simplified diagram

**$[Ni(bipy)_2]^{2+}$**

**Fig 6.1**

**(i)** What is the molecular formula of 2,2'-bipyridine?

..... **[1]**

**(ii)** What is the coordination number of the $[Ni(bipy)_2]^{2+}$ complex ion?

..... **[1]**

**(iii)** 2,2'-Bipyridine forms a complex with the transition metal ruthenium with the formula $[Ru(bipy)_3]^{2+}$. This complex exists as two stereoisomers.

Draw 3-D diagrams to predict the structures for these stereoisomers of $[Ru(bipy)_3]^{2+}$. You can represent the 2,2'-bipyridine ligands as in the simplified diagram for $[Ni(bipy)_2]^{2+}$ in **Fig 6.1**.

**[2]**

**(iv)** 4,4'-Bipyridine (4,4'-bipy) can also form complexes with transition metal ions. Because of its structure, 4,4'-bipyridine can bridge between metal ions to form 'coordination polymers'. For example, nickel(II) can form a coordination polymer with 4,4'-bipyridine containing $\{[Ni(H_2O)_4(4,4'\text{-bipy})]^{2+}\}_n$ chains.

Draw a 3-D diagram to predict the repeat unit in this coordination polymer of nickel(II). Your diagram should show the complete structure of 4,4'-bipyridine and all coordinate bonds.

**[3]**

**[Total: 21]**

**3** Brass is an alloy which contains copper.
The percentage of copper in brass can be determined using the steps below.

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|---|---|
| **Step 1** | 2.80 g of brass is reacted with an excess of concentrated nitric acid, $HNO_3$.<br>The half-equations taking place are shown below.<br><br>$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$<br>$2HNO_3(l) + e^- \longrightarrow NO_3^-(aq) + NO_2(g) + H_2O(l)$ |
| **Step 2** | Excess aqueous sodium carbonate is added to neutralise any acid. The mixture effervesces and a precipitate forms. |
| **Step 3** | The precipitate is reacted with ethanoic acid to form a solution which is made up to 250 $cm^3$ with water. |
| **Step 4** | A 25.0 $cm^3$ sample of the solution is pipetted into a conical flask and an excess of aqueous potassium iodide is added.<br>A precipitate of copper(I) iodide and a solution of iodine, $I_2(aq)$, forms. |
| **Step 5** | The resulting mixture is titrated with 0.100 mol $dm^{-3}$ sodium thiosulfate to estimate the iodine present:<br><br>$I_2(aq) + 2S_2O_3^{2-}(aq) \longrightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$ |
| **Step 6** | **Steps 4** and **5** are repeated to obtain an average titre of 29.8 $cm^3$. |

- For **steps 1**, **2** and **4**, write ionic equations, including state symbols, for the reactions taking place.
- Determine the percentage, by mass, of copper in the brass.
  Give your answer to **one** decimal place.

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**[Total: 9]**

**4** Chromium shows typical properties of a transition element. The element's name comes from the Greek word 'Chroma' meaning colour because of its many colourful compounds.

**(a)** Write down the electron configuration of

**(i)** a Cr atom, ..... **[1]**

**(ii)** a $Cr^{3+}$ ion. ..... **[1]**

**(b)** An acidified solution containing orange $Cr_2O_7^{2-}$ ions reacts with zinc in a redox reaction to form a solution containing $Zn^{2+}$ ions and blue $Cr^{2+}$ ions.

The unbalanced half-equations are shown below.

$$Zn \longrightarrow Zn^{2+} + e^-$$

$$Cr_2O_7^{2-} + H^+ + e^- \longrightarrow Cr^{2+} + H_2O$$

Balance these equations and construct an overall equation for this reaction.

..... **[3]**

**(c)** Aqueous solutions of $Cr^{3+}$ ions contain ruby-coloured $[Cr(H_2O)_6]^{3+}$ complex ions. If an excess of concentrated ammonia solution is added, the solution changes to a violet colour as the hexaammine chromium(III) complex ion forms.

**(i)** What type of reaction has taken place?

..... **[1]**

**(ii)** Suggest an equation for this reaction.

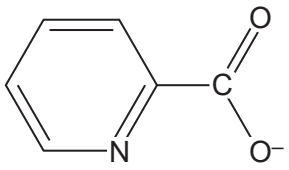
..... **[2]**

**(d)** Chromium picolinate, $Cr(C_6H_4NO_2)_3$, is a bright red complex, used as a nutritional supplement to prevent or treat chromium deficiency in the human body.

In this complex,

- chromium has the +3 oxidation state,
- picolinate ions, $C_6H_4NO_2^-$, act as bidentate ligands.

The structure of the picolinate ion is shown below.




$Cr(C_6H_4NO_2)_3$ exists as a mixture of stereoisomers.

**(i)** What is meant by the term *ligand*?

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..... **[1]**

**(ii)** How is the picolinate ion able to act as a **bidentate** ligand?

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..... **[2]**

**(iii)** Why does $Cr(C_6H_4NO_2)_3$ exist as a mixture of stereoisomers?
Draw diagrams of the stereoisomers as part of your answer.

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..... **[3]**

**(e)** Compound **A** is an orange ionic compound of chromium with the percentage composition by mass N, 11.11%; H, 3.17%; Cr, 41.27%; O, 44.45%. Compound **A** does **not** have water of crystallisation.

On gentle heating, compound **A** decomposes to form three products, **B**, **C** and water.
**B** is a green oxide of chromium with a molar mass of 152.0 g $mol^{-1}$.
**C** is a gas. At RTP, each cubic decimetre of **C** has a mass of 1.17 g.

In the steps below, show all your working.

- Calculate the empirical formula of compound **A**.
- Deduce the ions that make up the ionic compound **A**.
- Identify substances **B** and **C**.
- Write an equation for the decomposition of compound **A** by heat.

**[8]**

**[Total: 22]**