

1 This question looks at properties of transition elements, ions and complexes.

(a) What is the oxidation number of Cr in the complex ion  $[\text{CrOCl}_5]^{2-}$ ?

..... [1]

(b) Write the equation for a reaction catalysed by a named transition element, compound or ion.

Equation: .....

Catalyst: ..... [1]

(c) An octahedral complex ion **A**,  $\text{C}_9\text{H}_{30}\text{N}_6\text{Ni}^{3+}$ , exists as two optical isomers.

In complex ion **A**,  $\text{Ni}^{3+}$  is bonded to three molecules of a bidentate ligand **B**.

(i) State what is meant by a *bidentate ligand*.

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

(ii) What is the molecular formula of the bidentate ligand **B**?

..... [1]

(iii) Draw a possible structure for **B** and explain how **B** is able to act as a bidentate ligand.

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

(iv) What is the coordination number of complex ion **A**?

..... [1]



2 Elements in the d-block of the Periodic Table form ions that combine with ligands to form complex ions. Most d-block elements are also classified as transition elements.

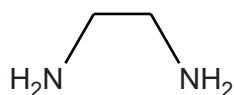
(a) Explain why two of the Period 4 d-block elements (Sc–Zn) are **not** also transition elements.

In your answer you should link full electron configurations to your explanations.

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

(b) The cobalt(III) ion,  $\text{Co}^{3+}$ , forms a complex ion **A** with two chloride ligands and two ethanediamine,  $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ , ligands.

The structure of ethanediamine is shown below.



(i) Explain how ethanediamine is able to act as a bidentate ligand.

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

(ii) Write the formula of complex ion **A**.

..... [1]

(iii) What is the coordination number of cobalt in complex ion **A**?

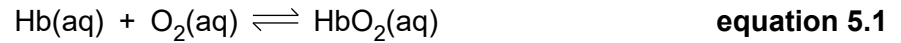
..... [1]

(iv) Complex ion **A** has *cis* and *trans* stereoisomers. One of these stereoisomers also has an optical isomer.

Draw 3-D diagrams to show the three stereoisomers.

[3]

- (c) The equilibrium reaction for the transport of oxygen by haemoglobin (Hb) in blood can be represented as **equation 5.1**.



- (i) Explain how ligand substitution reactions allow haemoglobin to transport oxygen in blood.

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

- (ii) Write an expression for the stability constant,  $K_{\text{stab}}$ , for the equilibrium involved in the transport of oxygen by haemoglobin.

Use the simplified species in **equation 5.1**.

[1]

- (iii) In the presence of carbon monoxide, less oxygen is transported in the blood.

Suggest why, in terms of bond strength and stability constants.

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

[Total: 18]

3 Iron is heated with chlorine to form an orange–brown solid, **A**.

Solid **A** is dissolved in water to form an orange–brown solution, **X**, containing the complex ion  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ .

Separate portions of solution **X** are reacted as shown in **Experiments 1–4** below.

**Experiment 1**

Aqueous sodium hydroxide is added to solution **X**. An orange–brown precipitate **B** forms.

**Experiment 2**

Excess zinc powder is added to solution **X** and the mixture is heated. The excess zinc is removed leaving a pale-green solution containing the complex ion **C** and aqueous  $\text{Zn}^{2+}$  ions.

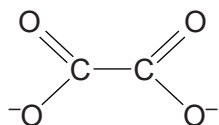
**Experiment 3**

An excess of aqueous potassium cyanide,  $\text{KCN}(\text{aq})$ , is added to solution **X**. The solution turns a yellow colour and contains the complex ion **E**. **E** has a molar mass of  $211.8 \text{ g mol}^{-1}$ .

**Experiment 4**

An aqueous solution containing ethanedioate ions,  $(\text{COO}^-)_2$ , is added to solution **X**. A coloured solution forms containing a mixture of optical isomers **F** and **G**.

The structure of the ethanedioate ion is shown below.



(a) Write an equation for the formation of solid **A**.

..... [1]

(b) In **Experiment 1**, write an ionic equation for the formation of precipitate **B**.

..... [1]

(c) In **Experiment 2**,

(i) write an equation for the formation of complex ion **C**

..... [2]

(ii) state the type of reaction taking place.

..... [1]

(d) In **Experiment 3**,

(i) write an equation for the formation of complex ion **E**

..... [2]

(ii) state the type of reaction taking place.

..... [1]

(e) In **Experiment 4**, optical isomers **F** and **G** are formed.

Show the 3-D shapes of **F** and **G**.

In your diagrams, show the ligand atoms that are bonded to the metal ions and any overall charges.

[3]

(f) In a separate experiment, iron metal is heated with potassium nitrate,  $\text{KNO}_3$ , a strong oxidising agent. A reaction takes place and the resulting mixture is poured into water. A dark red solution forms containing ferrate(VI) ions. The ferrate(VI) ion has a 2- charge.

Suggest a possible formula for the ferrate(VI) ion.

..... [1]

[Total: 12]

4 Dimethylglyoxime, DMGH, can be used to analyse nickel(II)

An excess of a solution of DMGH is added to an acidic solution of a nickel(II) compound. Aqueous ammonia is added which precipitates out a nickel(II) complex, Ni(DMG)<sub>2</sub>, as a red solid.

A sample of a hydrated nickel(II) salt is analysed using the procedure below.

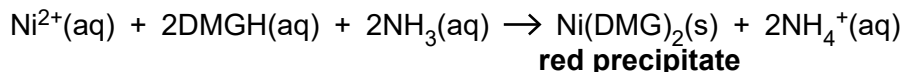
**Step 1**

2.50 g of the hydrated nickel(II) salt is dissolved in dilute acid.  
An excess of an aqueous solution of DMGH is added.

**Step 2**

An excess of aqueous ammonia is added and the mixture is heated.  
A red precipitate of Ni(DMG)<sub>2</sub> forms.

An equation for the reaction is shown below.



**Step 3**

The red precipitate is filtered, washed with water, dried and then weighed.  
The precipitate of Ni(DMG)<sub>2</sub> has a mass of 2.57 g.  
Assume that all Ni<sup>2+</sup>(aq) ions have been converted into Ni(DMG)<sub>2</sub>(s).  
 $M[\text{Ni}(\text{DMG})_2] = 288.7 \text{ g mol}^{-1}$ .

**Step 4**

A second 2.50 g sample of the hydrated nickel(II) salt is heated in a crucible to remove the water of crystallisation.  
1.38 g of the anhydrous salt remains.

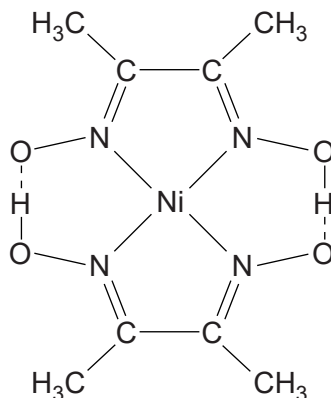
(a) Complete the electron configurations of nickel as the element and in the +2 oxidation state.

nickel as the element:  $1s^2 2s^2 2p^6$  .....

nickel in the +2 oxidation state:  $1s^2 2s^2 2p^6$  ..... **[2]**



(b) The structure of  $\text{Ni}(\text{DMG})_2$  is shown below.



(i) State and explain the role of ammonia in **step 2** of this experiment.

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

(ii) State the coordination number of Ni in  $\text{Ni}(\text{DMG})_2$ .

..... [1]

(iii) Why does the  $\text{Ni}(\text{DMG})_2$  complex have no overall charge?

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

(iv) Draw the structure of dimethylglyoxime, DMGH.

[1]

(c) Determine a possible formula of the hydrated nickel(II) salt.

Your answer **must** show relevant working.

[7]

[Total: 13]