Transition Metals

3 Transition elements have characteristic properties due to their partially-filled d orbitals.

(a) (i) Which **two** elements in the first row of the d-block have only one electron in the 4s orbital of their neutral atoms?

.....

(ii) The d orbitals in an isolated transition metal atom or ion are described as being degenerate.

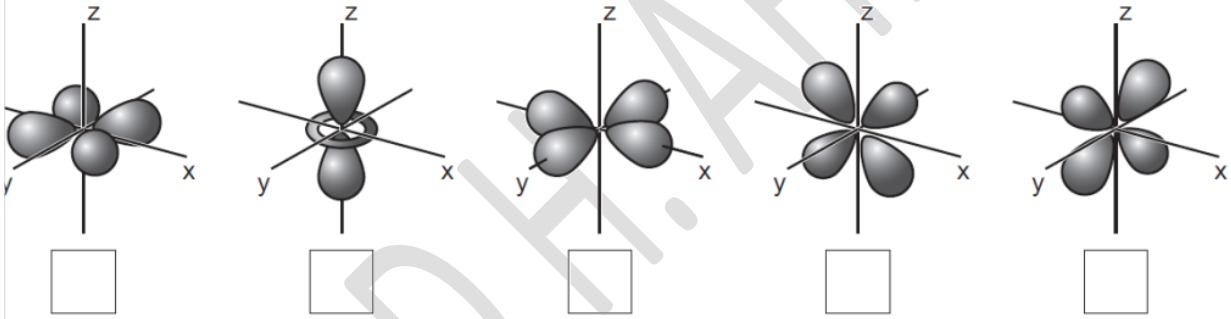
What is meant by the term *degenerate*?

.....

(iii) Sketches of the shapes of the atomic orbitals from the d subshell are shown.

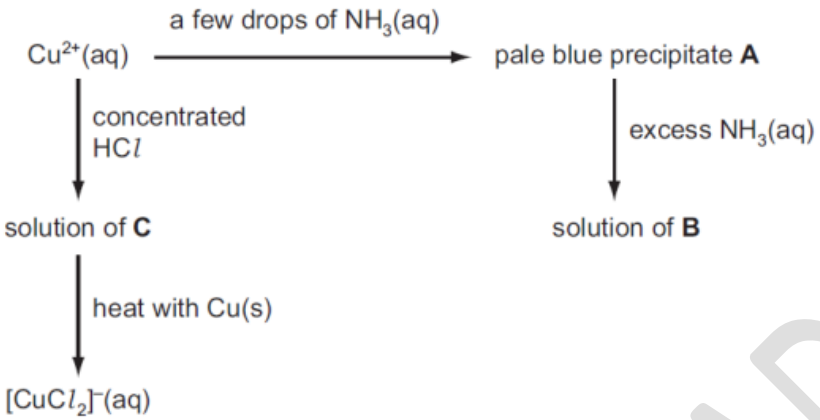
In an octahedral complex, the d orbitals are split into two groups at different energy levels.

On the diagram below, write an 'H' in the box under each of the orbitals at the higher energy level.



[4]

(b) The following scheme shows some reactions of $Cu^{2+}(aq)$.



(i) Suggest the formula of each of the following.

A .....

B .....

C .....

(ii) State the colour of the following solutions.

solution of **B** .....

solution of **C** .....

(iii) Name the type of reaction that occurs when **C** is heated with copper.

.....

Deduce the role of the copper metal in this reaction.

.....

[6]

(c) When the solution containing the complex $[CuCl_2]^-$ is poured into water, a precipitate of $CuCl$ is formed. $CuCl$ is white because it does not absorb visible light.

Explain why $CuCl$ does **not** absorb visible light.

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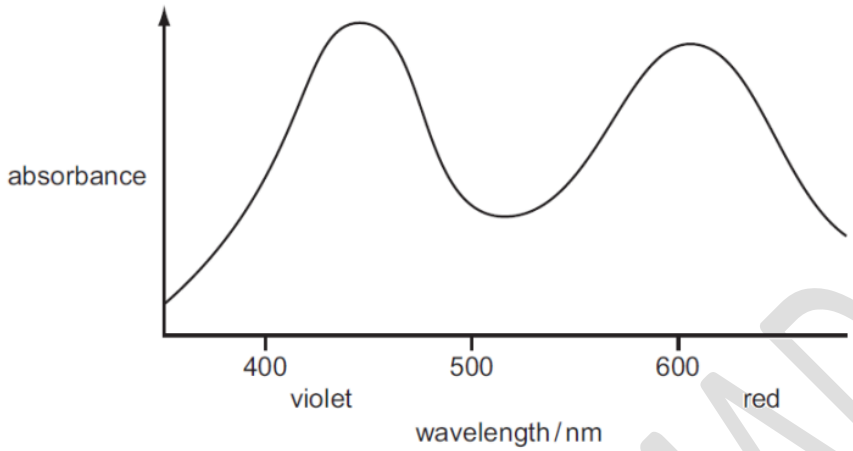
..... [2]

(d) The complex ion $[Cr(H_2O)_6]^{3+}$ is coloured because it **absorbs** visible light. The absorption spectrum for $[Cr(H_2O)_6]^{3+}$ is shown below.



Suggest the colour of this complex ion. Explain your answer.

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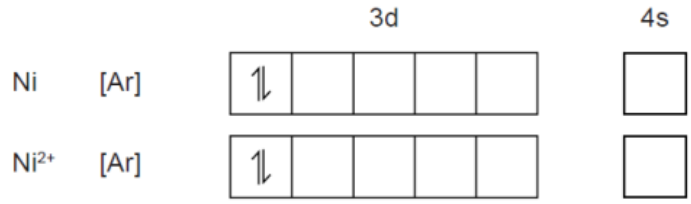
..... [2]

[Total: 14]

9701_w/14/qp43

2 **(a)** Complete the electron configurations for Ni and Ni^{2+}.



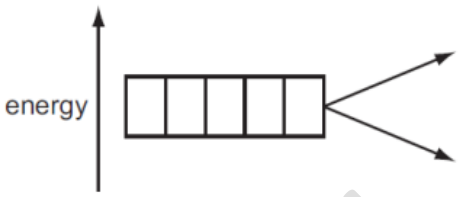
[2]

(b) The presence of electrons in d orbitals is responsible for the colours of transition element compounds.

(i) The d orbitals in an isolated transition metal atom or ion are all at the same energy level. What term is used to describe orbitals that are at the same energy level?

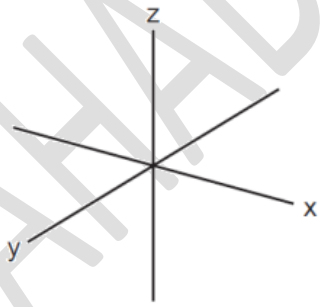
.....

(ii) Complete the diagram to show the splitting of the d orbital energy levels in an octahedral complex ion.

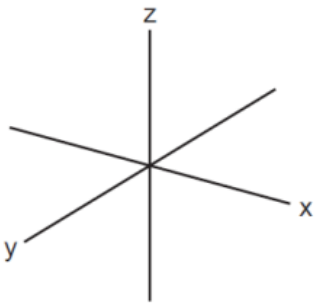


(iii) On the axes below, sketch the shapes of one d orbital from the lower energy level and one d orbital from the higher energy level.

lower energy level



higher energy level



[4]

(c) The octahedral complex $[Ni(H_2O)_6]^{2+}$ is green. Explain the origin of the colour of this complex.

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..... [3]

(d) When $NH_3(aq)$ is added to the green solution containing $[Ni(H_2O)_6]^{2+}$, a grey-green precipitate, **A**, is formed. This precipitate dissolves in an excess of $NH_3(aq)$ to give a blue-violet solution, **B**. Suggest formulae for **A** and **B** and write equations for the two reactions producing **A** and **B**.

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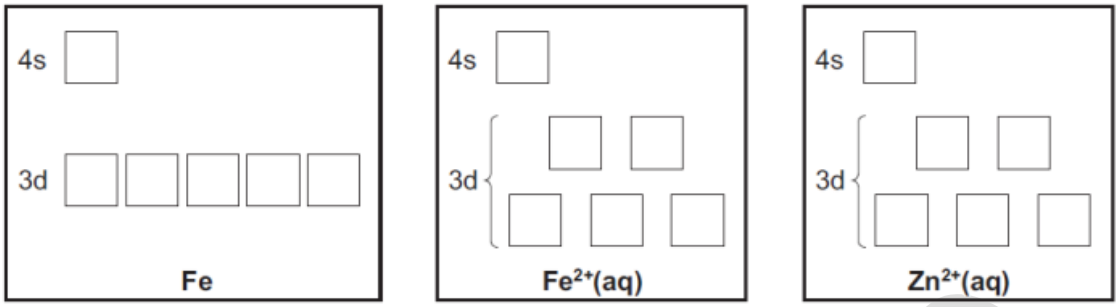
..... [4]

[Total: 13]

9701_w/14/qp41

1 **(a)** **(i)** On the diagrams below, show the outer electron arrangements of the atoms and ions indicated. (Use the symbol ↑↓ to represent a pair of electrons in an orbital.)



(ii) Use the above diagrams to explain why $Fe^{2+}(aq)$ ions are coloured, whereas $Zn^{2+}(aq)$ ions are colourless.

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[4]

(b) When concentrated HC*l* is added to a solution of $Cu^{2+}(aq)$ ions, the solution turns yellow.

(i) State the formula of the species responsible for the yellow colour and name the *type of reaction* that has occurred.

.....

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(ii) Ammonia can react as a base or as a ligand.
Describe the colour changes that occur when $NH_3(aq)$ is **gradually** added, with stirring, to the yellow solution, until the $NH_3(aq)$ is in excess.
Identify the **three** ions or compounds responsible for the new colours.

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[7]

(c) When aqueous solutions of KI and $K_2S_2O_8$ are mixed almost no reaction occurs, but when a few drops of $Fe^{2+}(aq)$ or $Fe^{3+}(aq)$ are added, iodine, $I_2(aq)$, is produced at a steady rate.

(i) Write an equation for the overall reaction.

.....

(ii) State the precise role of the iron ions during this reaction.

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(iii) By means of equations or otherwise, explain why the presence of *either* Fe^{2+} *or* Fe^{3+} is able to speed up the reaction.

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[3]

[Total: 14]

9701_s/14/qp42

2 The ions of transition elements form *complexes* by reacting with *ligands*.

(a) (i) State what is meant by the terms:

complex, ...

.....

ligand. .....

.....

(ii) Two of the complexes formed by copper are $[Cu(H_2O)_6]^{2+}$ and $CuCl_4^{2-}$.
Draw three-dimensional diagrams of their structures in the boxes and name their shapes.

$[Cu(H_2O)_6]^{2+}$	$CuCl_4^{2-}$
shape:	shape: .....

(iii) Platinum forms square-planar complexes, in which all four ligands lie in the same plane as the Pt atom.
There are two isomeric complexes with the formula $Pt(NH_3)_2Cl_2$.
Suggest the structures of the two isomers, and, by comparison with a similar type of isomerism in organic chemistry, suggest the type of isomerism shown here.

Structures of isomers:

isomer 1	isomer 2

Type of isomerism: .....

[7]

(b) Copper forms two series of compounds, one containing copper(II) ions and the other containing copper(I) ions.

(i) Complete the electronic structures of these ions.

Cu(II) [Ar] .....

Cu(I) [Ar] .....

(ii) Use these electronic structures to explain why

copper(II) salts are usually coloured,

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copper(I) salts are usually white or colourless.

.....

.....

[5]

9701_s/14/qp41

1 **(a)** **(i)** State how the melting point and density of iron compare to those of calcium.

melting point of iron: .....

density of iron: .....

(ii) Explain why these differences occur.

melting point: .....

.....

density: .....

.....

[4]

(c) The iron(II) complex *ferrous bisglycinate hydrochloride* is sometimes prescribed, in capsule form, to treat iron deficiency or anaemia.
A capsule containing 500 mg of this iron(II) complex was dissolved in dilute H_2SO_4 and titrated with 0.0200 mol dm^{-3} $KMnO_4$.
18.1 cm^3 of $KMnO_4$ solution were required to reach the end point.

The equation for the titration reaction is as follows.

$$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

(i) Describe how you would recognise the end point of this titration.

.....

(ii) Calculate

- the number of moles of Fe^{2+} in the capsule,

- the mass of iron in the capsule,

- the molar mass of the iron(II) complex, assuming 1 mol of the complex contains 1 mol of iron.

[4]

9701_w/14/qp41

4 **(a)** **(i)** Suggest why transition elements show variable oxidation states in their compounds whereas s-block elements like calcium do not.

.....

.....

(ii) Calculate the oxidation number of the metal in each of the following ions.

VO_2^+ .....

CrF_6^{2-} .....

MnO_4^{2-} .....

[4]

(b) Explain why transition element complexes are often coloured whereas compounds of s-block elements such as calcium and sodium are not.

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[4]

(c) SO_2 and MnO_4^- react together in acidic solution.

(i) Use the *Data Booklet* to construct a balanced equation for this reaction.

.....

(ii) Describe the colour change you would see when SO_2(aq) is added to a sample of acidified $KMnO_4$ until the SO_2 is in excess.

from ..... to .....

[3]

(d) Describe the observations you would make when NH_3(aq) is added gradually to a solution containing Cu^{2+} ions, until the NH_3 is in an excess.

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[3]

[Total: 14]

3 **(a)** **(i)** What is meant by the *density* of a substance?

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(ii) Use data from the *Data Booklet* to explain why the density of iron is greater than that of calcium.

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[3]

(b) In general, reactions of the compounds of transition elements can be classified under one or more of the following headings.

acid-base
ligand exchange
precipitation
redox

Choose the most suitable heading to describe each of the following reactions, by placing a tick (✓) in the appropriate column in the table below.
Only one tick should be placed against each reaction.

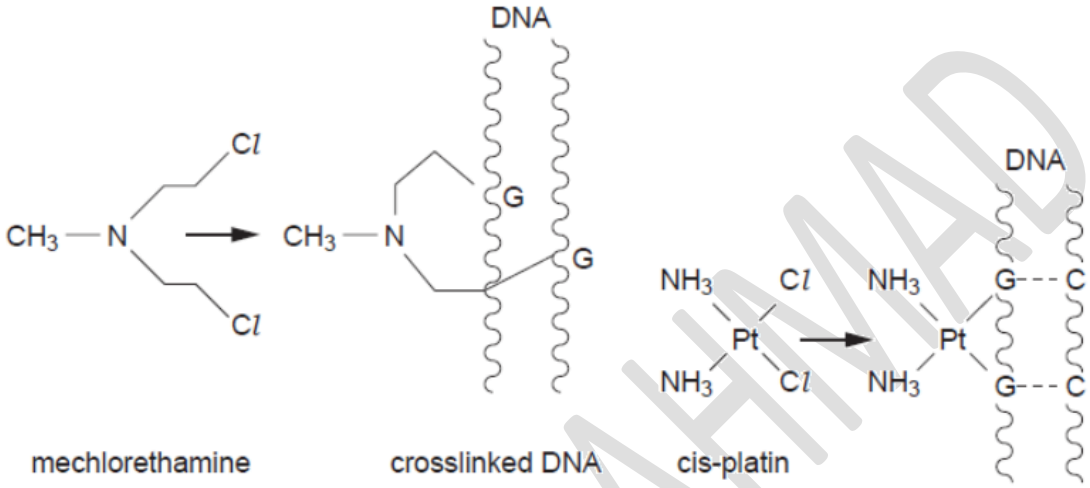
reaction	acid-base	ligand exchange	precipitation	redox
$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4]^{2+} + 6H_2O$				
$[Cu(H_2O)_6]^{2+} + 4HCl \rightarrow [CuCl_4]^{2-} + 4H^+ + 6H_2O$				
$2FeCl_2 + Cl_2 \rightarrow 2FeCl_3$				
$[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow Fe(OH)_2 + 6H_2O$				
$2Fe(OH)_2 + ½O_2 + H_2O \rightarrow 2Fe(OH)_3$				
$CrO_3 + 2HCl \rightarrow CrO_2Cl_2 + H_2O$				
$Cr(H_2O)_3(OH)_3 + OH^- \rightarrow [Cr(H_2O)_2(OH)_4]^- + H_2O$				
$[Cr(OH)_4]^- + 1½H_2O_2 + OH^- \rightarrow CrO_4^{2-} + 4H_2O$				

[8]

9701_s/13/qp41

9 In recent years a great deal of research has been carried out into finding different anti-cancer drugs. Tumours, which are often symptoms of cancer, are produced when cells replicate uncontrollably. This in turn is brought about by the replication of DNA in these cells.

Two anti-cancer agents are mechlorethamine and *cis*-platin. They work by binding to the DNA and preventing replication.



mechlorethamine crosslinked DNA cis-platin

(a) (i) What type of bonding attaches both anti-cancer agents to the DNA?

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(ii) Suggest how **each** of the anti-cancer agents prevents replication of the DNA.

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[5]

[Total: 5]

9701_w/09/qp41

4 **(a)** Explain what is meant by the term *transition element.*

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..... [1]

(b) **(i)** How do the atomic radii of the transition elements vary from chromium to copper?

.....

(ii) Predict, with a reason, the variation in the densities of the transition elements from chromium to copper.

.....

..... [3]

(c) Complete the following electronic configuration of the Cu^{2+} ion.

$1s^2 2s^2 2p^6 3s^2 3p^6$ _____ [1]

(d) Copper ions in aqueous solution are pale blue, due to the formation of a complex ion.

(i) Explain what is meant by the term *complex ion.*

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.....

(ii) Draw the structure of the complex ion formed in a solution of $Cu^{2+}(aq)$.

[2]

(e) When dilute aqueous ammonia is added to a solution of $Cu^{2+}(aq)$, the colour changes as a new complex ion is formed.

(i) State the colour of the new complex .....

(ii) Write an equation showing the formation of the new complex.

..... [2]

(f) When concentrated hydrochloric acid is added to a solution of $Cu^{2+}(aq)$, the colour changes to yellow-green. On adding water, the colour returns to pale blue.

Suggest an explanation for these changes.

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.....[3]

[Total: 12]

9701_w/04/qp4

3 **(a)** A transition element **X** has the electronic configuration [Ar] $4s^2$ $3d^3$.

(i) Predict its likely oxidation states.

.....

(ii) State the electronic configuration of the ion X^{3+}.

.....

[2]

(b) Potassium manganate(VII), $KMnO_4$, is a useful oxidising agent in titrimetric analysis.

(i) Describe how you could use a 0.0200 mol dm^{-3} solution of $KMnO_4$ to determine accurately the [Fe^{2+}] in a solution. Include in your description how you would recognise the end-point in the titration, and write an equation for the titration reaction.

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(ii) A 2.00 g sample of iron ore was dissolved in dilute H_2SO_4 and all the iron in the salts produced was reduced to Fe^{2+}(aq). The solution was made up to a total volume of 100 cm^3.

A 25.0 cm^3 portion of the solution required 14.0 cm^3 of 0.0200 mol dm^{-3} $KMnO_4$ to reach the end-point.

Calculate the percentage of iron in the ore.

.....

[8]

(c) High-strength low-alloy (HSLA) steels are used to fabricate TV masts and long span bridges. They contain very low amounts of phosphorus and sulphur, but about 1% copper, to improve resistance to atmospheric corrosion. When dissolved in nitric acid, a sample of this steel gives a pale blue solution.

(i) What species is responsible for the pale blue colour?

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(ii) Describe and explain what you would see when dilute aqueous ammonia is added to this solution.

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[4]

[Total: 14]

9701_s/06/qp4

4 (a) (i) State the electronic configuration of the iron atom.

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(ii) Apart from its electronic structure, state **two** properties of iron or its compounds that are characteristic of a transition element.

.....

.....

[3]

(b) Acidified solutions of iron(II) salts can be titrated using a dilute solution of potassium manganate(VII), $KMnO_4$.

(i) Use the *Data Booklet* to calculate the standard cell potential and to write a balanced ionic equation for the reaction that takes place during the titration.

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(ii) Explain why no indicator is required for this titration. What colour change would you see at the end point?

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[4]

(c) Use the reaction between Fe^{3+} ions and water molecules to explain the meanings of the terms *ligand* and *complex formation*.

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..... [2]

9701_s/05/qp4

6 **(a)** Titanium is an important transition metal. The metal itself is a component of many high-strength low-weight alloys, and its oxide is used as an opaque agent in many paints and pigments.

(i) Write out the electronic configuration of the titanium atom.

.....

(ii) Titanium forms two chlorides. Suggest possible formulae for them.

.....

[2]

(b) Anhydrous copper sulphate, $CuSO_4(s)$, is a white powder that readily dissolves in water.

(i) Describe and explain what is seen when $CuSO_4(s)$ is stirred with water.

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(ii) Describe and explain the final colour change seen when an excess of $NH_3(aq)$ is added to $CuSO_4(aq)$.

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[4]

[Total : 6]

9701_s/03/qp4

3 **(a)** Complete the following electronic configuration of the Cu^{2+} ion.

$1s^2\ 2s^2\ 2p^6$ ..... [1]

(b) In a free, gas-phase transition metal ion, the d-orbitals all have the same energy, but when the ion is in a complex the orbitals are split into two energy levels.

(i) Explain why this happens.

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(ii) How does this splitting help to explain why transition metal complexes are often coloured?

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(iii) Why does the colour of a transition metal complex depend on the nature of the ligands surrounding the transition metal ion?

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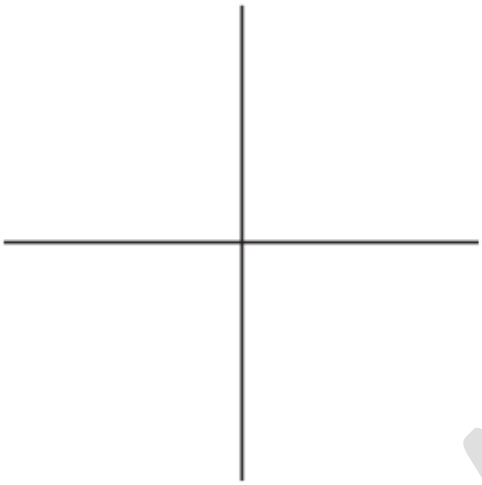
[5]

9701_w/12/qp43

3 **(a)** On the following diagram draw a clear **labelled** sketch to describe the shape and symmetry of a typical d-orbital.



[2]

(b) Although the five d-orbitals are at the same energy in an isolated atom, when a transition element ion is in an octahedral complex the orbitals are split into two groups.

(i) Draw an orbital energy diagram to show this, indicating the number of orbitals in each group.

(ii) Use your diagram as an aid in explaining the following.

- Transition element complexes are often coloured.

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- The colour of a complex of a given transition element often changes when the ligands around it are changed.

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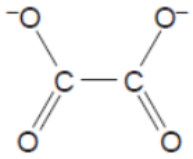
[7]

(c) Heating a solution containing potassium ethanedioate, iron(II) ethanedioate and hydrogen peroxide produces the light green complex $K_3Fe(C_2O_4)_3$, which contains the ion $[Fe(C_2O_4)_3]^{3-}$.

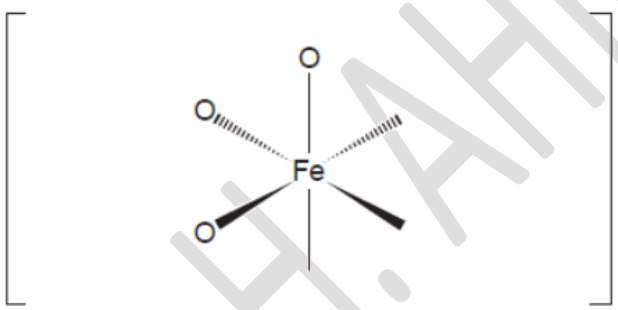
The structure of the ethanedioate ion is as follows.



(i) Calculate the oxidation number of carbon in this ion. .....

(ii) Calculate the oxidation number of iron in $[Fe(C_2O_4)_3]^{3-}$. .....

(iii) The iron atom in the $[Fe(C_2O_4)_3]^{3-}$ ion is surrounded octahedrally by six oxygen atoms. Complete the following **displayed** formula of this ion.



(iv) In sunlight the complex decomposes into potassium ethanedioate, iron(II) ethanedioate and carbon dioxide.

Use oxidation numbers to help you balance the following equation for this decomposition.

$$K_3Fe(C_2O_4)_3 \rightarrow \text{.....}K_2C_2O_4 + \text{.....}FeC_2O_4 + \text{.....}CO_2$$

[5]

[Total: 14]

9701_w/11/qp41

2 **(a)** Explain why complexes of transition elements are often coloured.

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.....[3]

(b) When water is added to white anhydrous $CuSO_4$, the solid dissolves to give a blue solution. The solution changes to a yellow-green colour when concentrated $NH_4Cl(aq)$ is added to it. Concentrating the solution produces green crystals of an ammonium salt with the empirical formula $CuN_2H_8Cl_4$.
Explain these observations, showing your reasoning.

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.....[3]

(c) Copper can be recovered from low-grade ores by 'leaching' the ore with dilute H_2SO_4, which converts the copper compounds in the ore into $CuSO_4(aq)$. The concentration of copper in the leach solution can be estimated by adding an excess of aqueous potassium iodide, and titrating the iodine produced with standard $Na_2S_2O_3(aq)$.

$$2Cu^{2+} + 4I^- \longrightarrow 2CuI + I_2$$
$$I_2 + 2S_2O_3^{2-} \longrightarrow 2I^- + S_4O_6^{2-}$$

When an excess of KI(aq) was added to a $50.0\,cm^3$ sample of leach solution, and the resulting mixture titrated, $19.5\,cm^3$ of $0.0200\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ were required to discharge the iodine colour.
Calculate the $[Cu^{2+}(aq)]$, and hence the percentage by mass of copper, in the leach solution.

percentage of copper = ...% [3]

[Total: 9]

2 (a) (i) What is meant by the term *ligand* in the context of transition element chemistry?

.....

.....

(ii) Decide which of the following species could be a ligand, and which could not be. Place a tick (✓) in the appropriate column.

species	can be a ligand	cannot be a ligand
OH^-		
NH_4^+		
CH_3OH		
CH_3NH_2		

[3]

(b) Read the following description of some reactions of copper(II) sulfate, and answer the questions that follow.

When 0.1 mol of white anhydrous $CuSO_4$ is dissolved in liquid ammonia at –33 °C, a deep blue solution **C** results.
When 0.2 mol of solid NaOH is added to solution **C**, and the ammonia solvent allowed to evaporate, a solid residue is obtained.
Heating this residue to 200 °C produces a dark coloured mixture of two solids.
When water is added to this mixture, a black solid **D** and a colourless solution **E** are formed. Neither **D** nor **E** contains nitrogen.
Adding $BaCl_2(aq)$ to solution **E** produces a white precipitate **F**.
Solid **D** dissolves in $HNO_3(aq)$ on warming, without evolution of gas, to give a pale blue solution containing $Cu(NO_3)_2(aq)$.

(i) Suggest the formula of the compound contained in each of the following.

solution **C** .....

solid **D** .....

solution **E** .....

white precipitate **F** .....

(ii) Name the type of reaction that is occurring when **D** reacts with $HNO_3(aq)$.

.....

[5]

(c) (i) Describe what you would observe when a solid sample of anhydrous $Cu(NO_3)_2$ is strongly heated.

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.....

(ii) Write an equation for this reaction.

.....

[2]

[Total: 10]

9701_w/10/qp41

3 Iron metal and its compounds are useful catalysts in certain reactions.

(a) **Apart from its catalytic activity**, state **two** properties of iron or its compounds that show that it is a transition element.

.....

.....[2]

(b) You are provided with a solution of $KMnO_4$ of known concentration in a burette.
Outline how you could use this solution to find out the concentration of $Fe^{2+}(aq)$ in a solution. You should include relevant equations for any reactions you describe.

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.....[4]

(c) For each of the following equations, write the oxidation number of the element printed **in bold** underneath its symbol, and balance the equation by adding appropriate numbers before each species.

(i) ..... $\mathbf{MnO_4^-}$ + ... $\mathbf{SO_2}$ + ... $H_2O \rightarrow$ ..... $\mathbf{Mn^{2+}}$ + ... $\mathbf{SO_4^{2-}}$ + ... H^+

oxidation numbers: ....

(ii) ..... $\mathbf{Cr_2O_7^{2-}}$ + ... $\mathbf{NO_2}$ + ... $H^+ \rightarrow$ ..... $\mathbf{Cr^{3+}}$ + ... $\mathbf{NO_3^-}$ + ... H_2O

oxidation numbers: ....

[6]

(d) Outline the role that Fe^{3+} ions play in catalysing the reaction between iodide ions and peroxydisulfate(VI) ions.

$$2I^- + S_2O_8^{2-} \longrightarrow I_2 + 2SO_4^{2-}$$

.....

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.....[2]

[Total: 14]

9701_w/09/qp42

3 One major difference between the properties of compounds of the transition elements and those of other compounds is that the compounds of the transition elements are often coloured.

(a) Explain in detail why many transition element compounds are coloured.

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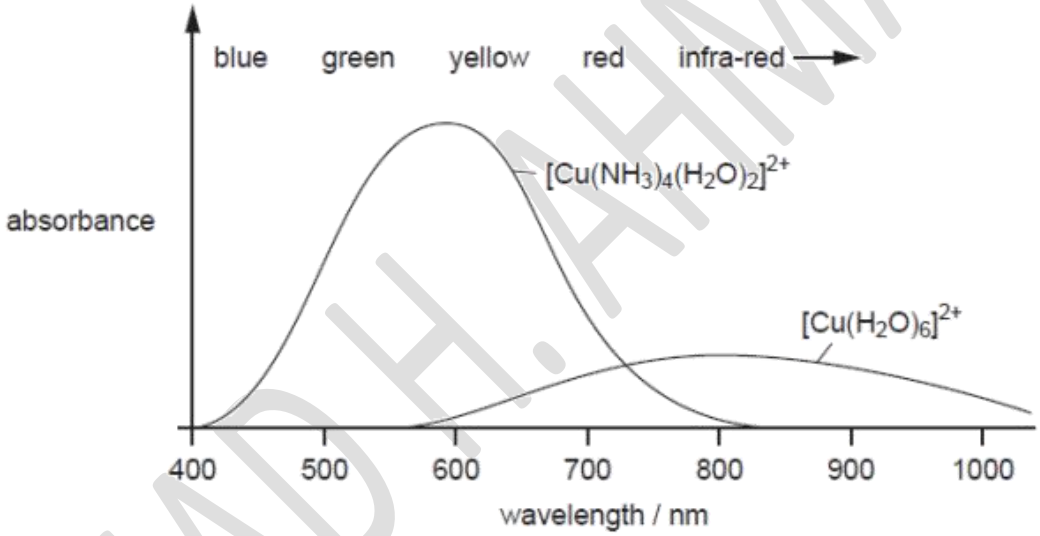
..... [3]

(b) The following graph shows the absorption spectrum of two complexes containing copper.



(i) State the colours of the following complex ions.

$[Cu(H_2O)_6]^{2+}$ .....

$[Cu(NH_3)_4(H_2O)_2]^{2+}$ .....

(ii) Using the spectra above give **two** reasons why the colour of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ion is deeper (more intense) than that of the $[Cu(H_2O)_6]^{2+}$ ion.

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(iii) Predict the absorption spectrum of the complex $[Cu(NH_3)_2(H_2O)_4]^{2+}$, and sketch this spectrum on the above graph. [6]

(c) Copper forms a complex with chlorine according to the following equilibrium.

$$Cu^{2+}(aq) + 4Cl^{-}(aq) \rightleftharpoons [CuCl_4]^{2-}(aq)$$

(i) Write an expression for the equilibrium constant, K_c, for this reaction, stating its units.

K_c = ... units .....

(ii) The numerical value of K_c is 4.2×10^5.
Calculate the $[[CuCl_4]^{2-}]/[Cu^{2+}]$ ratio when $[Cl^-] = 0.20\,mol\,dm^{-3}$.

.....

.....

[3]

[Total: 12]

9701_w/09/qp41

(b) Malachite is an ore of copper. It contains the following percentages by mass.

copper	57.7%
oxygen	36.2%
carbon	5.4%
hydrogen	0.9%

Malachite reacts with dilute H_2SO_4 producing a gas **B** that turns limewater milky and leaving a blue solution **C**.

When heated in the absence of air, malachite produces gas **B** and steam, and leaves a black solid **D**. **D** reacts with dilute H_2SO_4 to produce the same blue solution **C**.

Adding iron filings to **C** produces a pink solid **E** and a pale green solution **F**.

(i) Calculate the empirical formula of malachite.

.....

(ii) Suggest the formula of the ion responsible for the blue colour of solution **C**.

.....

(iii) Identify the black solid **D** and calculate the mass of **D** that could be obtained by heating 10 g of malachite.

.....

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.....

(iv) Use data from the *Data Booklet* to identify the pink solid **E** and the solution **F**, and suggest an equation for the reaction producing them.

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(v) What type of reaction is the reaction that produces **E** and **F**?

.....

(vi) Describe and explain what you would see happen when dilute $NH_3(aq)$ is added slowly to the solution **C** until it is in an excess.

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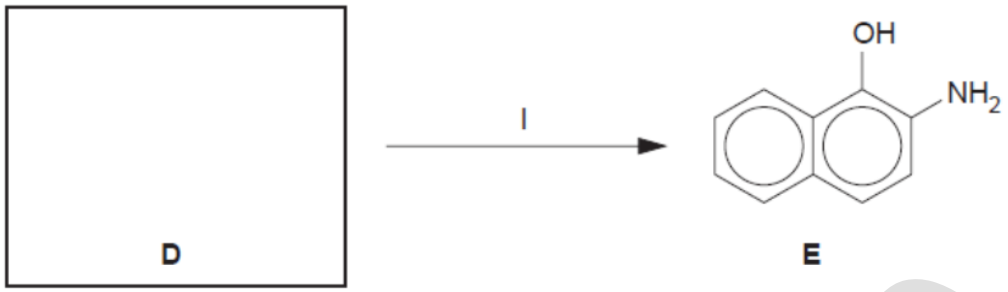
[13]

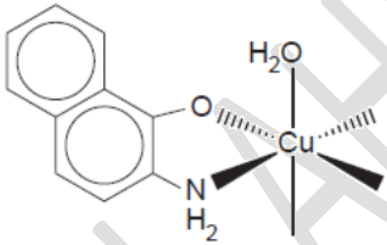
[Total: 19]

(c) Compound **D** is an isomer of 4-nitro-1-naphthol. **D** is formed as a by-product during the reaction in **b(ii)**. It can be converted into 2-amino-1-naphthol, **E**.



(d) When an alkaline solution of compound **E** is added to a solution containing $Cu^{2+}(aq)$ ions, a pale green-blue precipitate **F** forms. Analysis of **F** shows that its formula is $Cu(C_{10}H_8NO)_2(H_2O)_2$.

(i) Complete the following structural formula of **F**.



When an excess of concentrated $NH_3(aq)$ is added to **F**, the precipitate dissolves to form a deep blue solution.

(ii) State the formula of the ion responsible for the deep blue colour.

.....

(iii) What type of reaction is occurring here?

.....

[3]

9701_w/07/qp4

(c) Carbon monoxide reacts with a ruthenium(II) chloride complex according to the equation

$$[Ru(H_2O)_2Cl_4]^{2-} + CO \rightarrow [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O.$$

(i) Describe the *type of reaction* that is occurring here.

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(ii) During the reaction, the colour of the solution changes from deep blue to green. Explain the origin of colour in transition element complexes, and why different complexes often have different colours.

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9701_s/12/qp42

(iii) Nitrogen monoxide forms a dark brown complex with an excess of $FeSO_4(aq)$. What kind of bonding is involved in the complex formation?

.....

(iv) Suggest a formula for this complex.

.....

[4]

9701_s/12/qp41

(c) Many commercial copper and brass polishes contain ammonia. The tarnish that forms on the surface of copper is often copper sulfide, CuS. In the presence of O_2 from the air, NH_3 can combine with this copper sulfide to produce the soluble cuprammonium sulfate, $[Cu(NH_3)_4]SO_4$.

(i) Construct an equation for this reaction.

.....

(ii) State the colour of cuprammonium sulfate solution.

.....

(iii) Describe what you would see if a solution of cuprammonium sulfate was diluted with water. Explain your answer.

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.....

[3]

(d) When sulfuric acid is added to $Cu^{2+}(aq)$, no colour change occurs, but when concentrated hydrochloric acid is added to $Cu^{2+}(aq)$, the solution turns yellow-green. The solution reverts to its original colour when it is diluted with water.

Suggest the type of reaction occurring with HCl(aq), suggest what is formed during the reaction, and write an equation for the change.

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.....[3]

9701_s/11/qp43

2 **(a)** Describe **three** characteristic chemical properties of transition elements that are not shown by Group II elements.

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.....[3]

(b) When $NH_3(aq)$ is added to a green solution containing $Ni^{2+}(aq)$ ions, a grey-green precipitate is formed. This precipitate dissolves in an excess of $NH_3(aq)$ to give a blue-violet solution.
Suggest an explanation for these observations, showing your reasoning and including equations for the reactions you describe.

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.....[4]

(c) Dimethylglyoxime, DMG, is a useful reagent for the quantitative estimation of nickel. It forms an insoluble salt with nickel ions according to the following equation.

$$Ni^{2+}(aq) + \underset{\text{DMG}}{C_4H_8N_2O_2} \longrightarrow \underset{\text{Ni-DMG}}{NiC_4H_6N_2O_2(s)} + 2H^+(aq)$$

A small coin of mass 3.40 g was dissolved in nitric acid and an excess of DMG was added. The precipitated Ni-DMG was filtered off, washed and dried. Its mass was 4.00 g.
Calculate the % of nickel in the coin.

percentage of nickel = ...% [3]

[Total: 10]

9701_s/10/qp41

3 **(a)** Explain what is meant by the term *transition element*.

.....

..... [1]

(b) Complete the electronic configuration of

(i) the vanadium atom, $1s^2 2s^2 2p^6$ .....

(ii) the Cu^{2+} ion. $1s^2 2s^2 2p^6$ .....

[2]

(c) List the **four** most likely oxidation states of vanadium.

..... [1]

(d) Describe what you would see, and explain what happens, when dilute aqueous ammonia is added to a solution containing Cu^{2+} ions, until the ammonia is in an excess.

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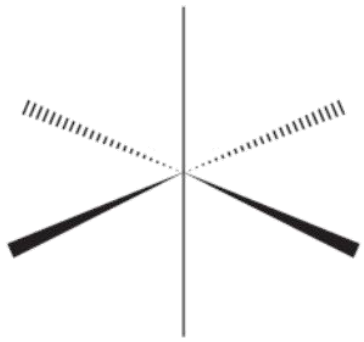
..... [5]

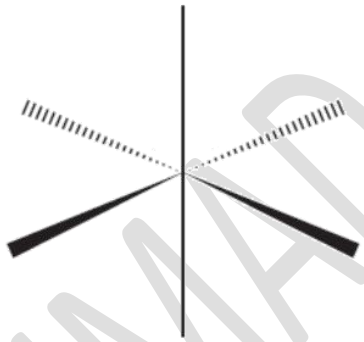
9701_s/09/qp4

4 The following passage is taken from an A level Chemistry text book.

"In an isolated atom, the five d-orbitals have the same energy. In an octahedral complex ion, however, the presence of the ligands splits the five orbitals into a group of three and a group of two. These two groups have slightly different energies."

(a) Use the following sets of axes to draw the shape of **one** d-orbital in **each** of the two groups mentioned above.





[2]

(b) Explain how the presence of the six ligands, ***L***, in $[FeL_6]^{3+}$ splits the 3d orbitals into two groups of different energy, and explain whether the two-orbital group or the three-orbital group has the higher energy.

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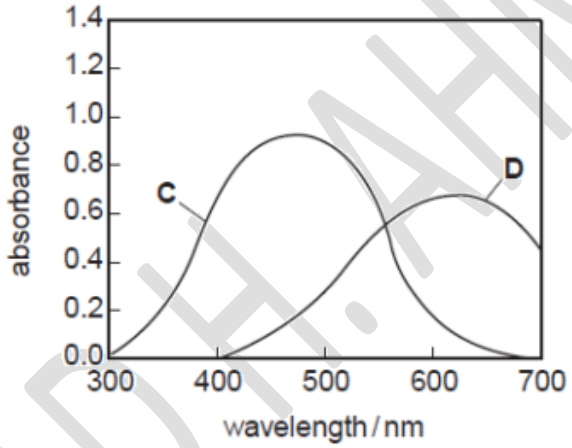
.....[3]

(c) The following table lists the colours and energies of photons of light of certain wavelengths.

wavelength / nm	energy of photon	colour of photon
400	high	violet
450	↓	blue
500	lower	green
600	↓	yellow
650	low	red

The visible spectra of solutions of two transition metal complexes **C** and **D** are shown in the diagram below.



(i) A list of possible colours for these complexes is as follows.

yellow red green blue

Choose **one** of these words to describe the observed colour of each solution.

solution **C** ..... solution **D** .....

(ii) In which complex, **C** or **D**, will the energy gap between the two groups of orbitals be the larger? Explain your answer.

.....

.....

[3]

[Total: 8]