

### 5.3.1 Transition Elements

#### General properties of transition metals

transition metal characteristics of elements Ti → Cu arise from an **incomplete d sub-level** in ions

these characteristics include

- formation of coloured ions,
- variable oxidation state
- catalytic activity.
- Complex ion formation,

Sc  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$   
Ti  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$   
V  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$   
Cr  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$   
Mn  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$   
Fe  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$   
Co  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^7$   
Ni  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$   
Cu  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$   
Zn  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10}$

→  
When forming ions lose 4s before 3d

Sc  $3+ [Ar] 4s^0 3d^0$   
Ti  $3+ [Ar] 4s^0 3d^1$   
V  $3+ [Ar] 4s^0 3d^2$   
Cr  $3+ [Ar] 4s^0 3d^3$   
Mn  $2+ [Ar] 4s^0 3d^5$   
Fe  $3+ [Ar] 4s^0 3d^5$   
Co  $2+ [Ar] 4s^0 3d^7$   
Ni  $2+ [Ar] 4s^0 3d^8$   
Cu  $2+ [Ar] 4s^0 3d^9$   
Zn  $2+ [Ar] 4s^0 3d^{10}$

#### Why is Zn not a transition metal?

Zn can only form a +2 ion. In this ion the  $Zn^{2+}$  has a **complete** d orbital and so does not meet the criteria of having an incomplete d orbital in one of its ions.

#### Why is Sc not a transition metal?

Sc can only form a +3 ion. In this ion the  $Sc^{3+}$  has an **empty** d orbital and so does not meet the criteria of having an incomplete d orbital in one of its ions.

#### Typical Properties of Transition metals

##### The existence of more than one oxidation state for each element in its compounds

For example iron commonly forms +2 and +3, chromium commonly forms +2,+3 and +6 see page 5 of this guide for more detail

##### The formation of coloured ions

There are characteristic colours for each transition metal element and the colours can vary in the different oxidation state. See the rest of the guide for many examples

##### The catalytic behaviour of the elements and their compounds and their importance in the manufacture of chemicals by industry

Iron is used as a catalyst in the Haber process to produce ammonia. Manganese dioxide  $MnO_2$  catalyses the decomposition of hydrogen peroxide. Vanadium pentoxide  $V_2O_5$  catalyses the contact process. See 3.2.2 reaction rates for some more detail

#### Complex formation

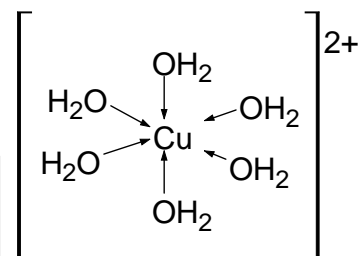
**complex** :is a central metal ion surrounded by ligands.

**ligand**.: An atom, ion or molecule which can donate a **lone electron pair**

Co-ordinate bonding is involved in complex formation.

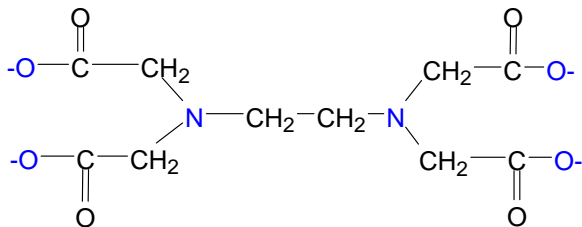
Co-ordinate bonding is when **the shared pair of electrons** in the covalent bond come from **only one of the bonding atoms**.

**Co-ordination number**: The number of co-ordinate bonds formed to a central metal ion.



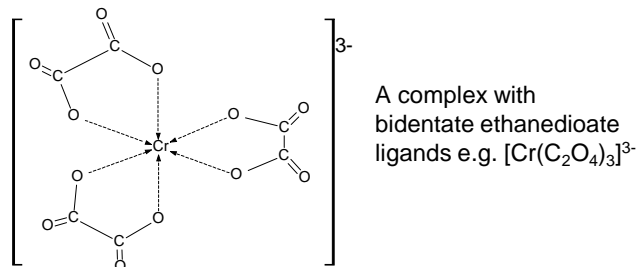
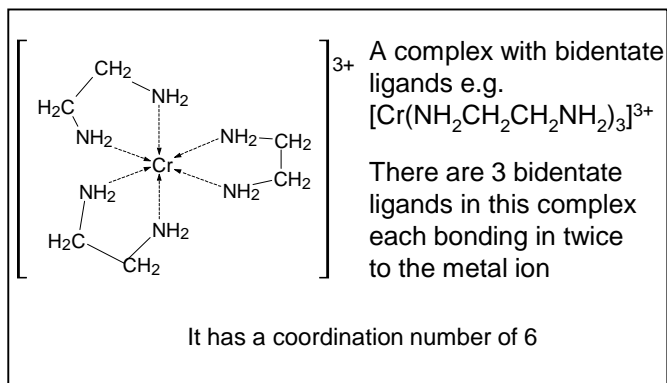
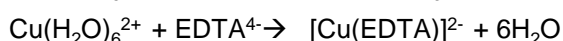
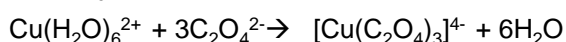
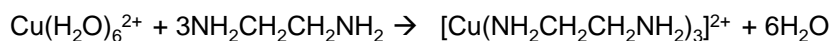
ligands can be **unidentate** (e.g.  $\text{H}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{Cl}^-$ ) which can form one coordinate bond per ligand or **bidentate** (e.g.  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  and ethanedioate ion  $\text{C}_2\text{O}_4^{2-}$ ) which have two atoms with lone pairs and can form two coordinate bonds per ligand or **multidentate** (e.g.  $\text{EDTA}^{4-}$  which can form six coordinate bonds per ligand).

The  $\text{EDTA}^{4-}$  anion has the formula



with six donor sites (4O and 2N) and forms a 1:1 complex with metal(II) ions

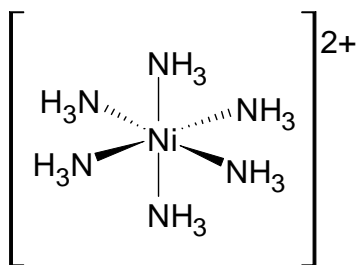
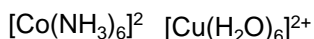
Equations to show formation of bidentate and multidentate complexes



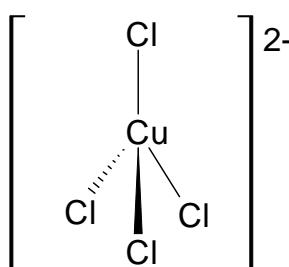
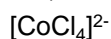
*Learn the two bidentate ligands mentioned above but it is not necessary to remember the structure of EDTA*

## Shapes of complex ions

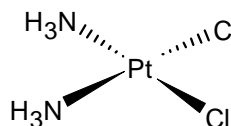
transition metal ions commonly form **octahedral** complexes with small ligands (e.g.  $\text{H}_2\text{O}$  and  $\text{NH}_3$ ).



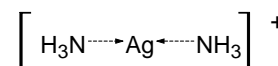
transition metal ions commonly form **tetrahedral** complexes with larger ligands (e.g.  $\text{Cl}^-$ ).



**square planar** complexes are also formed, e.g. cisplatin



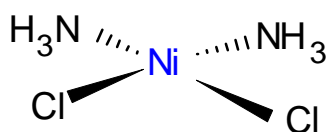
$\text{Ag}^+$  commonly forms **linear** complexes e.g.  $[\text{Ag}(\text{NH}_3)_2]^+$ ,  $[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}$  and  $[\text{Ag}(\text{CN})_2]^-$  (all colourless).



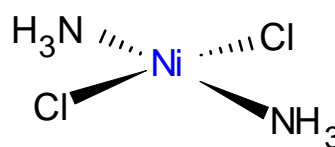
## Isomerism in complex ions

Complexes can show two types of stereoisomerism: cis-trans isomerism and optical isomerism

### Cis-trans isomerism



Cis- $[\text{Ni}(\text{NH}_3)_2\text{Cl}_2]$



trans- $[\text{Ni}(\text{NH}_3)_2\text{Cl}_2]$





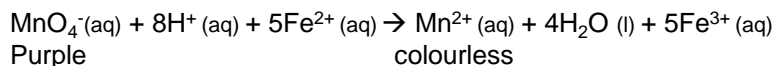
## Variable Oxidation States

Transition elements show variable oxidation states

When transition metals form ions they lose the 4s electrons before the 3d

### Iron (II) Oxidation

Fe<sup>2+</sup> (green solution) can be easily oxidised to Fe<sup>3+</sup> (brown solution) by various oxidising agents. We commonly use potassium manganate (VII), although oxygen in the air will bring about the change



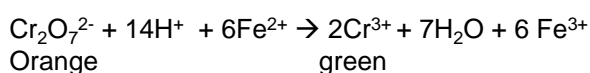
### Iron (III) Reduction

Fe<sup>3+</sup> (brown solution) can be reduced to Fe<sup>2+</sup> (green solution) by various reducing agents. We commonly use potassium iodide solution. The brown colour of the iodine formed can mask the colour change of the Iron.

$$2\text{Fe}^{3+} (\text{aq}) + 2\text{I}^- (\text{aq}) \rightarrow \text{I}_2 (\text{aq}) + 2\text{Fe}^{2+} (\text{aq})$$

### Reducing Chromium

Cr<sup>3+</sup> (green) and then Cr<sup>2+</sup> (blue) are formed by reduction of Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> (orange) by the strong reducing agent zinc in (HCl) acid solution. Fe<sup>2+</sup> is a less strong reducing agent and will **only** reduce the dichromate to Cr<sup>3+</sup>

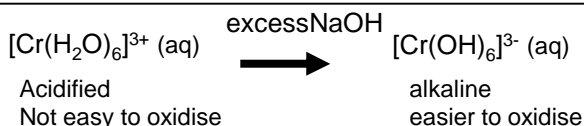


The Fe<sup>2+</sup> and Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> in acid solution reaction can be used as a quantitative redox titration. This does not need an indicator

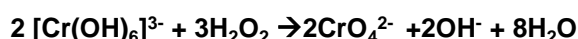
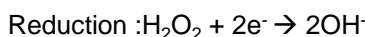
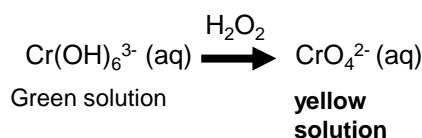
### Oxidising Chromium

When transition metals in low oxidation states are in alkaline solution they are more easily oxidised than when in acidic solution

It is easier to remove an electron from a negatively charged ion



Alkaline chromium(III) can be oxidised by using oxidising agents such as hydrogen peroxide to the (yellow solution) chromate ion

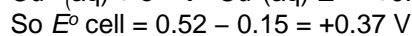
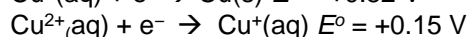


### Reduction of Cu<sup>2+</sup> to Cu<sup>+</sup>

Cu<sup>2+</sup> (blue solution) can be reduced to Cu<sup>+</sup> (colourless solution) by various reducing agents. We commonly use potassium iodide solution.  $2\text{Cu}^{2+} (\text{aq}) + 2\text{I}^- (\text{aq}) \rightarrow \text{I}_2 (\text{aq}) + 2\text{Cu}^+ (\text{aq})$

### Disproportionation of copper(I) ions

Copper(I) ions when reacting with sulphuric acid will disproportionate to Cu<sup>2+</sup> and Cu metal



As  $E^\circ \text{ Cu}^+/\text{Cu} > E^\circ \text{ Cu}^{2+}/\text{Cu}^+$  and  $E_{\text{cell}}$  has a positive value of +0.37V, Cu<sup>+</sup> disproportionates from +1 oxidation state to 0 in Cu and +2 in Cu<sup>2+</sup>