

## Colour in complex ions

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## Colour in complex ions

Transition metal ions can be identified by their colour. The aqueous complexes have characteristic colours.

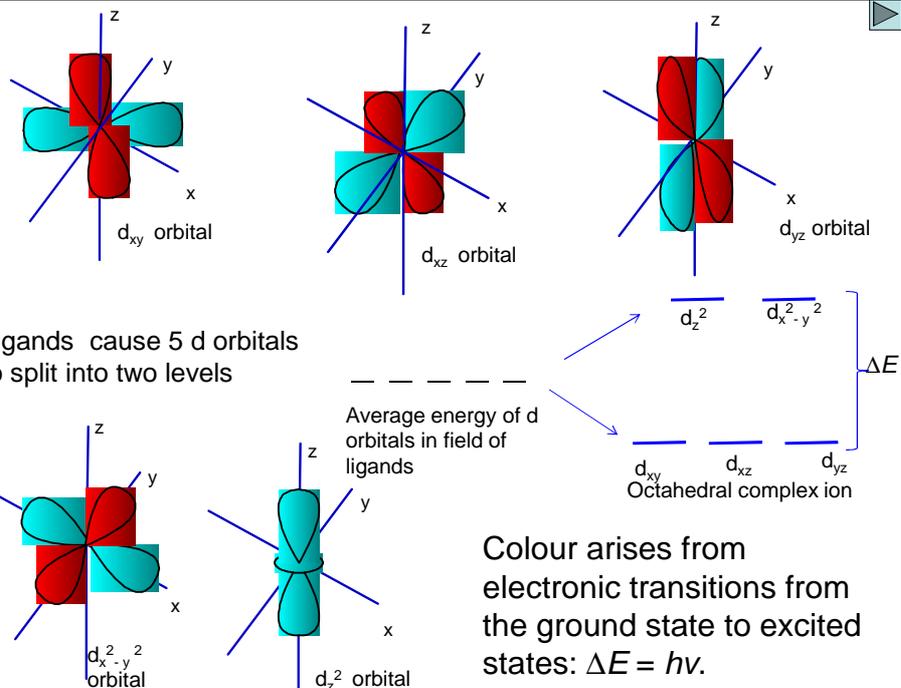
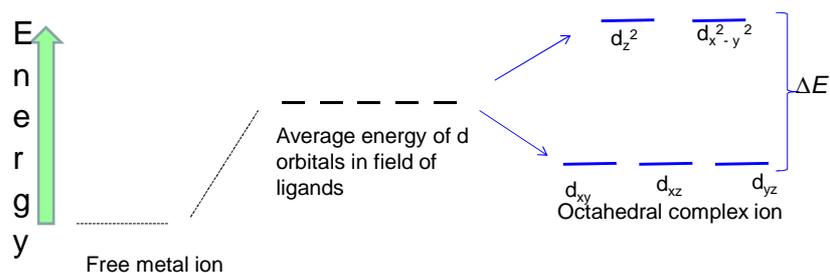
Complex	Colour
$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} (\text{aq})$	blue solution
$[\text{Co}(\text{H}_2\text{O})_6]^{2+} (\text{aq})$	pink solution
$[\text{Fe}(\text{H}_2\text{O})_6]^{2+} (\text{aq})$	green solution
$[\text{Fe}(\text{H}_2\text{O})_6]^{3+} (\text{aq})$	violet solution
$[\text{Cr}(\text{H}_2\text{O})_6]^{3+} (\text{aq})$	red-blue solution
$[\text{V}(\text{H}_2\text{O})_6]^{3+} (\text{aq})$	green solution

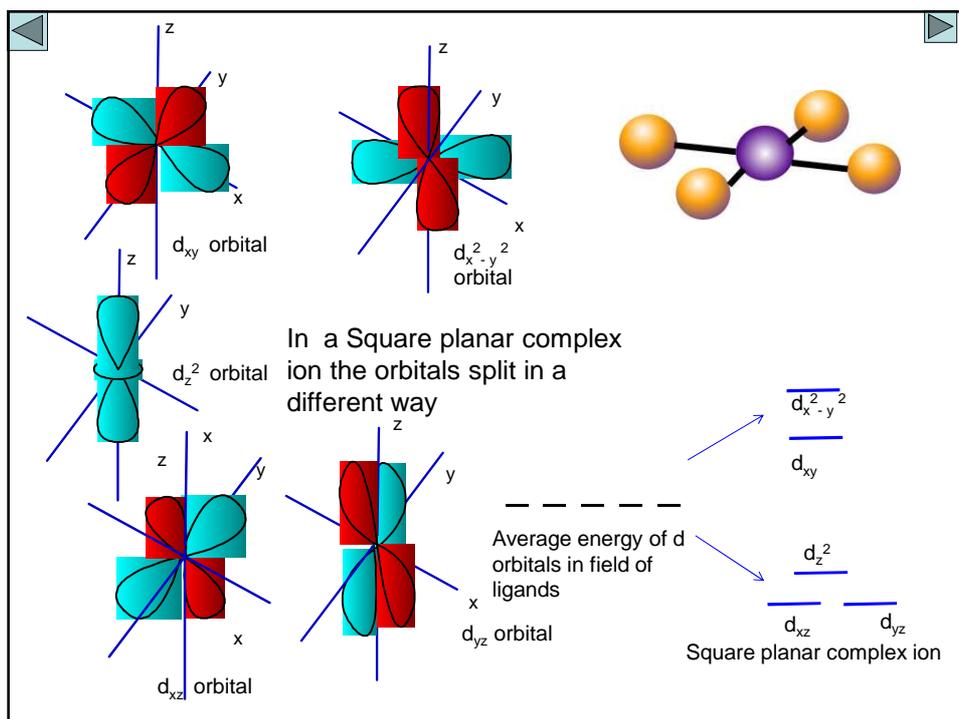
## Coloured inorganic compounds

Often contain transition metals.

Ligands cause 5 d orbitals to split into different levels

The energy needed to excite electrons to a higher level depends on the oxidation state of the metal and the type of ligand.





Colour arises from **electronic transitions** from the **ground state** to **excited states**: between different d orbitals

A **portion of visible light is absorbed** to promote d electrons to higher energy levels. The **light that is not absorbed is transmitted** to give the substance colour.

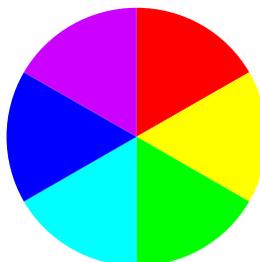
Octahedral complex ion

$\Delta E = h\nu$ . ( $\nu$  = frequency of light absorbed) ( $h$  = Planck's constant) ( $\Delta E$  = energy difference between split d orbitals)

The equation links the colour and frequency of the light absorbed with the energy difference between d orbitals

## Colour Wheel

If one colour is absorbed then the solution will appear to be the colour on the opposite side of the colour wheel



In Copper(II) ions, yellow light is absorbed to promote the electrons in the d-orbital. This is because the frequency of yellow light supplies the correct energy gap.  $\Delta E = h\nu$ . ( $\nu$  = frequency of light absorbed) ( $h$  = planck's constant) ( $\Delta E$  energy difference between split orbitals)

The remaining light is not absorbed and passes through the solution and the solution appears blue

## Compounds without colour

Non-transition metals don't have partly filled d orbitals. Visible light is only absorbed if some energy from the light is used to promote an electron over exactly the right energy gap. Non-transition metals don't have any electron transitions which can absorb wavelengths from visible light.

Scandium is a member of the d block, its ion ( $\text{Sc}^{3+}$ ) hasn't got any d electrons left to move around. This is no different from an ion based on  $\text{Mg}^{2+}$  or  $\text{Al}^{3+}$ . Scandium(III) complexes are colourless because no visible light is absorbed.

## Zinc and copper (I) compounds

In the zinc case, the 3d level is completely full - there aren't any gaps to promote an electron in to. Zinc complexes are also colourless.

Copper (I) compounds are also white. Copper (I) ion has the electronic structure  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ . Like zinc the 3d shell is completely full, and so there can not be any electron transfers between d orbitals

## Changing Colour of ions

When a colour change occurs in the reaction of a transition metal ion, there is a change in at least one of the following:-

**Oxidation state**

**Co-ordination number**

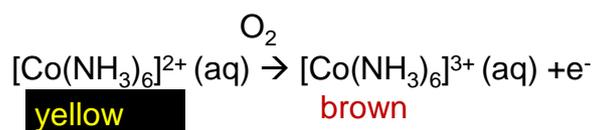
**Ligand**

**Changing a ligand or coordination number will alter the energy split between the d- orbitals, changing  $\Delta E$  and hence change the frequency of light absorbed and so changing the colour**

## Changing Colour

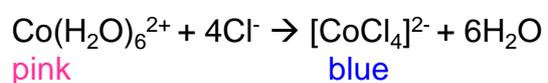
The size of the energy gap between the d-orbitals, and so the colour is affected by changes in:

- 1) the oxidation state



In this equation only oxidation state is changing

- 4) the co-ordination number

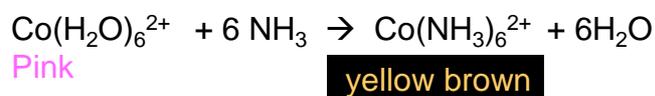


In this equation both ligand and co-ordination number are changing

## Changing the colour

The size of the energy gap between the d-orbitals, and so the colour is affected by changes in:

- 3) the ligands



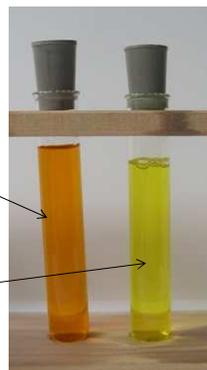
In this equation only the ligand is changing

## Other coloured ions

Intensely coloured ions with the metal in its highest oxidation state (e.g. Mn(VII), Cr(VI), Fe(VI)) derive the colour from electron transitions between the metal and the oxygen atoms.

Eg . Deep purple of manganate (VII)  $\text{MnO}_4^-$   
Intense Orange of dichromate(VI)  $\text{Cr}_2\text{O}_7^{2-}$

Yellow of chromate(VI)  $\text{CrO}_4^{2-}$



## Ultraviolet and visible Spectrophotometry

If ultraviolet or visible light of increasing frequency is passed through a sample of a coloured complex ion, some of the light is absorbed.

The amount of light absorbed is proportional to the concentration of the absorbing species

Some complexes have only pale colours and do not absorb light strongly. In the cases a suitable ligand is added to intensify the colour.

## Exam Question

You are provided with a  $1.00 \text{ mol dm}^{-3}$  solution of iron(III) ions and a visible-light spectrophotometer (colorimeter). Outline a plan for experiments using this solution and this apparatus which would enable you to determine the concentration of iron(III) ions in a solution of unknown concentration.

## Method for Spectrophotometry

Add an appropriate ligand to intensify  
Make up solutions of known concentration  
Measure absorption or transmission  
Plot graph of results or calibration curve  
Measure absorption of unknown and compare

