

2.6 Reactions of ions in aqueous solution

Hydration of metal ions

- These are **complex ions** where the ligand is water.
- Often referred to as the **metal – aqua complex ion**

Recap:

Complex ion:

A central metal ion surrounded by ligands

Ligand:

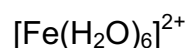
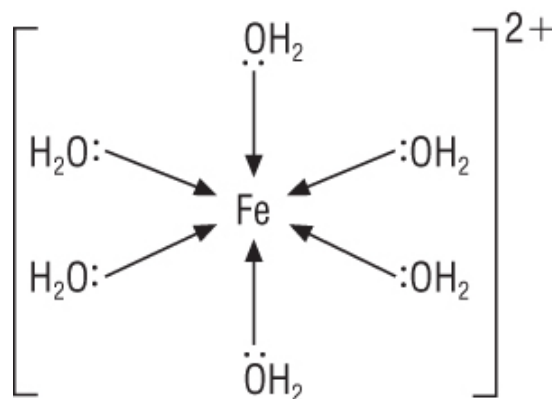
A molecule or ion that forms a dative covalent bond with a central metal ion by donating a pair of electrons

Dative covalent bond (co-ordinate bond)

A covalent bond where the pair of electrons have been donated by the same atom / molecule

Co-ordination number:

Is the number of dative (co-ordinate) bonds to the central metal ion



- Fe^{2+} is the **Transition metal ion**.
- **Ligands** are the **water** molecules.
- **Coordination number** is the number of coordinate bonds to the central metal ion = **6**.
- **Square brackets** group the species and the **overall charge** is written outside the brackets.
- **Overall charge** is the sum of the charges of the metal ion and the ligands (if the ligands have a charge)

Coloured solutions:

- Most transition metal solutions exist as hexa-aqua complex ions.
- With an incomplete d sub shell they will form coloured solutions.
- This is because specific frequencies (wavelengths) of light are absorbed.
- This happens as electrons move from the **ground state** to an **excited state**.
- The remaining frequencies (and therefore colours) are transmitted:

Metal ion	Formula of hexa-aqua ion	Colour
Fe^{2+}	$[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$	Green
Cu^{2+}	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	Blue
Fe^{3+}	$[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$	Purple (may look yellow – brown)
Al^{3+}	$[\text{Al}(\text{H}_2\text{O})_6]^{3+}$	Colourless

The acidic nature of metal aqua ions (recap from Period 3):

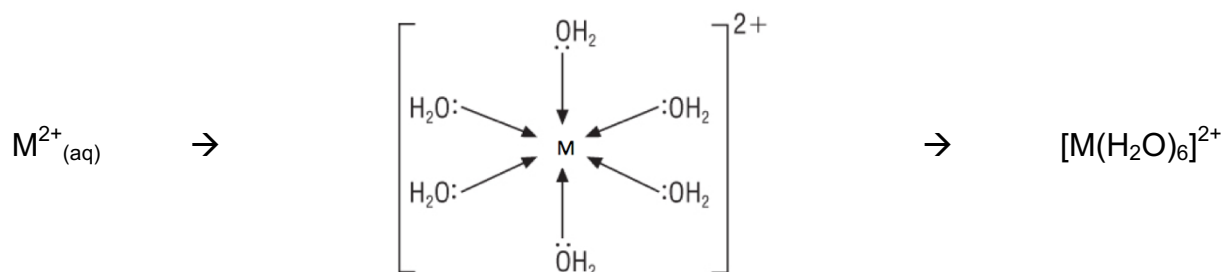
Bronsted – Lowry acid:

Acids are proton donors

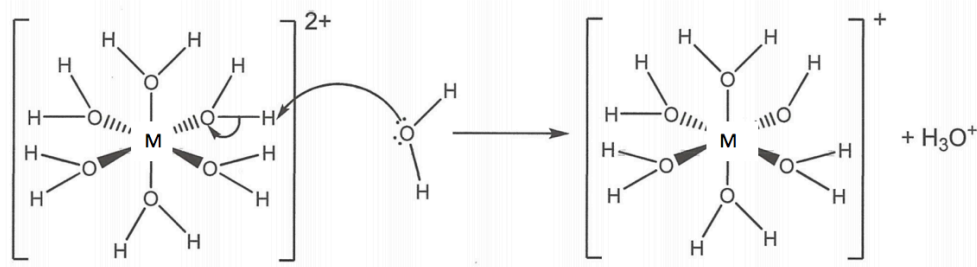
Hydrolysis:

Breaking of a bond with water

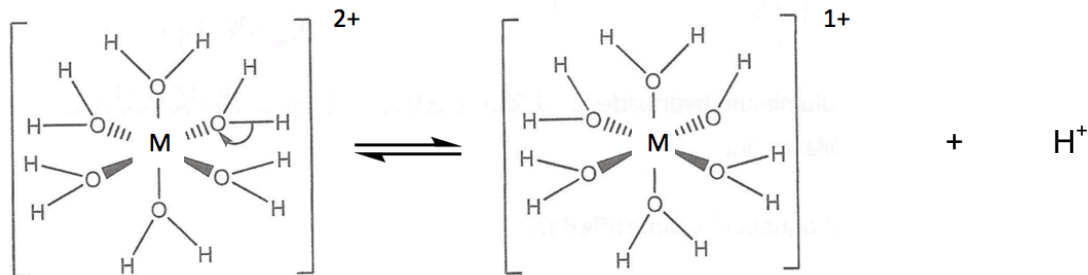
- Consider a dissolved 2+ ion:



Proton donor:



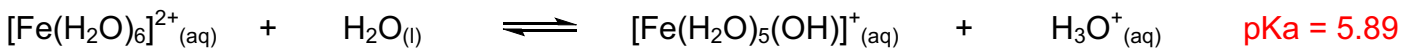
- M^{2+} is a **small highly charged ion**, M^{2+} therefore has a **high charge density**.
- This **high charge density** will **polarise** the water molecule.
- This **weakens the O – H bond**.
- The O – H bond breaks **releasing H^+ ions**, a **proton donor**, making the complex ion **acidic**:



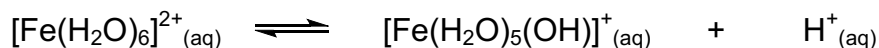
- This reaction is often referred to as **hydrolysis** or **acidity** reaction as there is a reaction with water producing an acidic solution

Acidity of the metal aqua 2+ and 3+ ions:

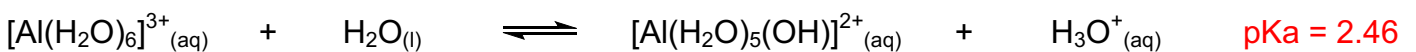
Example of a 2+ ion:



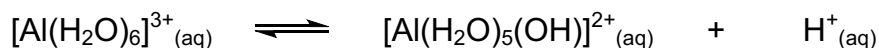
Can be written as:



Example of a 3+ ion:



Can be written as:

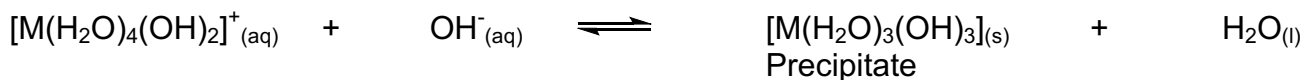
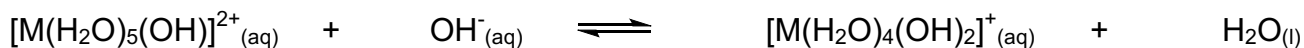
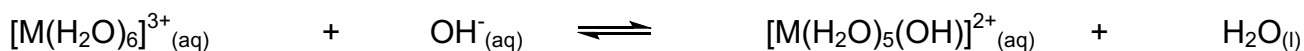


- 3+ ions are smaller and more highly charged ion.
- Polarises water ligand more.
- More protons donated.
- Dissociates more.
- Larger K_a .
- Smaller pK_a

Acid base reactions:

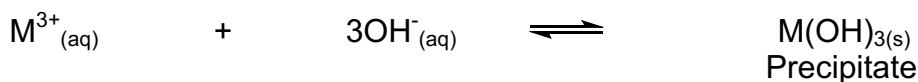
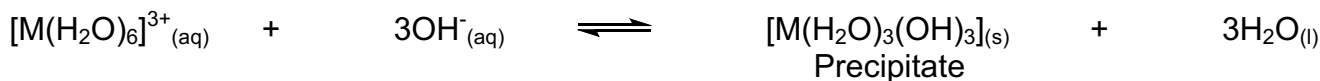
1) Reactions with hydroxides, OH⁻

M³⁺ ion: Consider the dissolved metal 3+ ion:

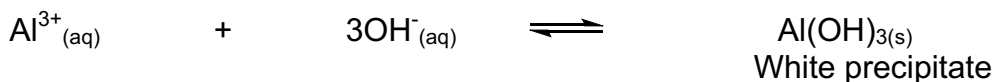
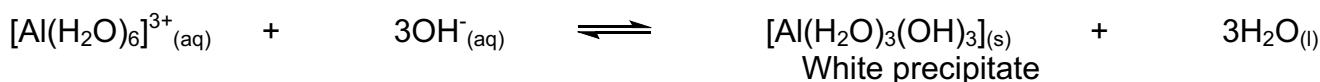
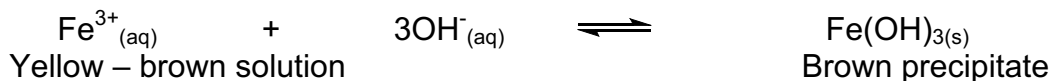
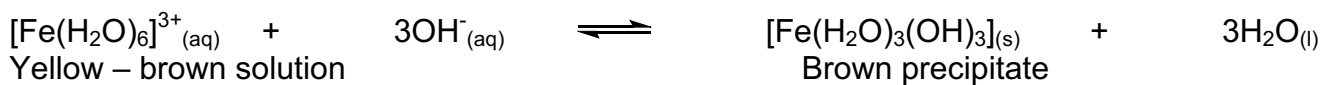


- Adding more OH⁻ shifts the equilibrium to the right
- The product has neutral charge and therefore precipitates out of solution.

Simplifying to:



Examples:



- Adding acid will reverse these reactions.

The amphoteric nature of aluminium hydroxide, Al(OH)₃:

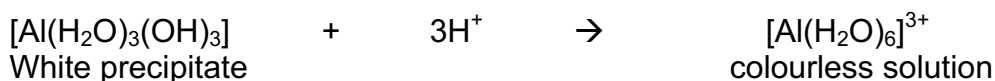
Amphoteric:

A species that can behave as an acid or a base

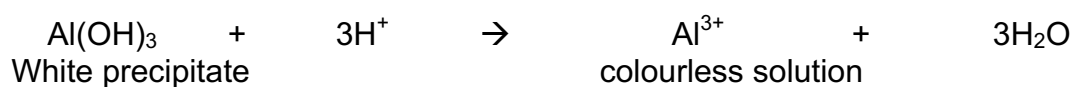
- Remember, aluminium hydroxide can be written as:



With an acid:



Can be simplified to:

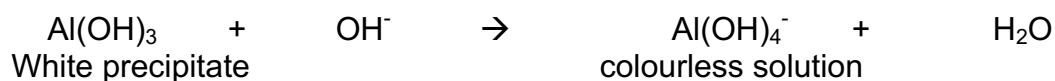


- White precipitate dissolves to give a clear colourless solution

With a base:

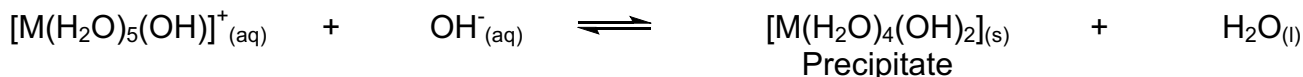
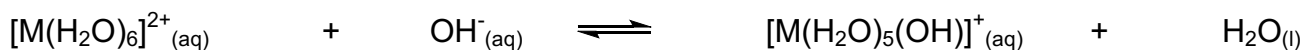


Can be simplified to:



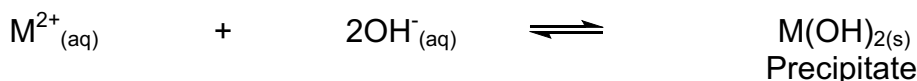
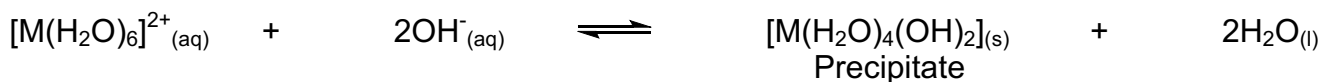
- White precipitate dissolves to give a clear colourless solution

M²⁺ ion: Consider the dissolved metal 2+ ion:

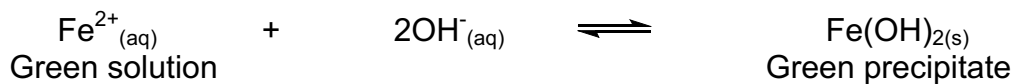
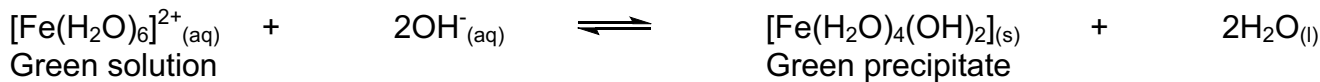
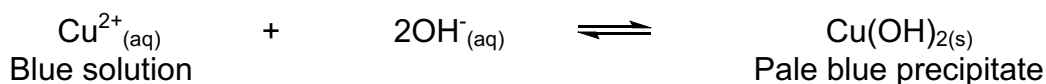
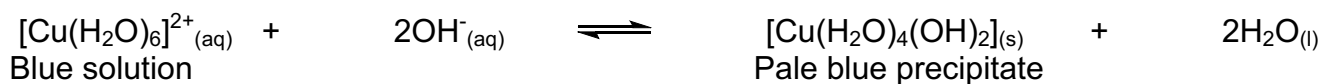


- The product has neutral charge and therefore precipitates out of solution.

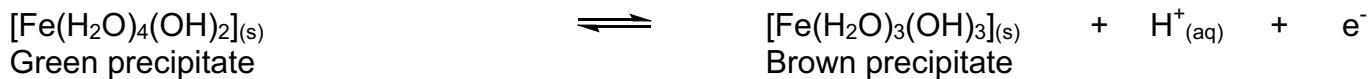
Simplifying to:



Examples:



- The green precipitate goes brown in air as it is oxidised by the air

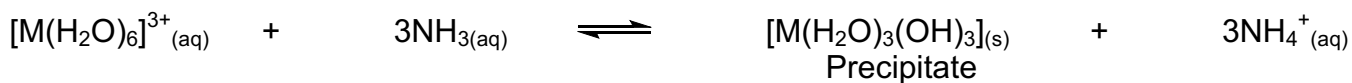


- Adding acid will reverse these reactions.

2) Reactions with ammonia, NH₃:

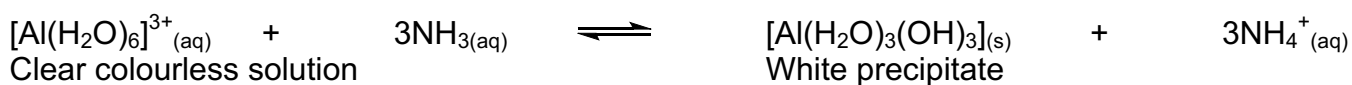
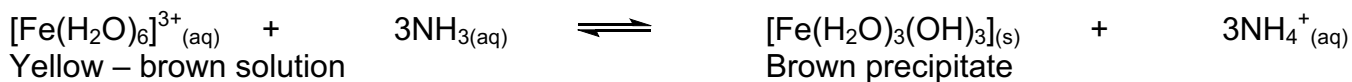
M³⁺ ion:

- Reacts with ammonia in the same way as the hydroxide:
- Each NH₃ accepts a proton from the waters in the complex ion until a neutral salt is made:



- The product has neutral charge and therefore precipitates out of solution.

Examples:

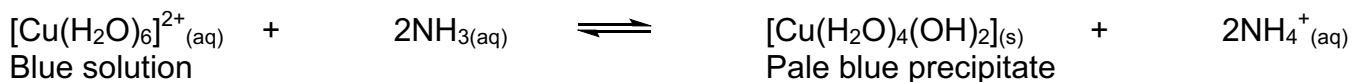
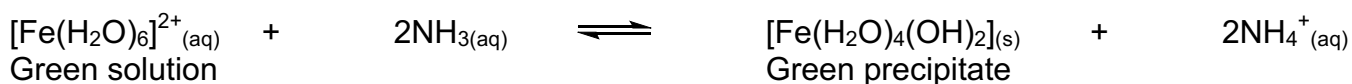


M²⁺ ion:



- The product has neutral charge and therefore precipitates out of solution.

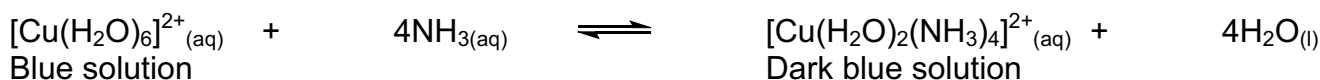
Examples:



With excess NH₃, Ligand substitution follows:



Overall:



3) Reactions with carbonates, CO_3^{2-} :

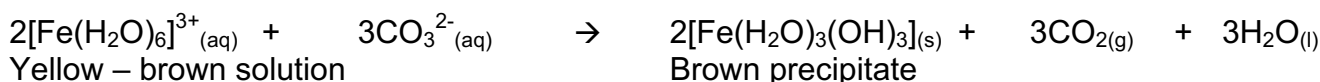
M^{3+} ion:

- Reacts in the same way as the hydroxide but, as it is more acidic, it reacts with the carbonate forming CO_2 and H_2O .
- Each CO_3^{2-} accepts a proton from the waters forming CO_2 and H_2O . The complex ion forms the neutral salt:



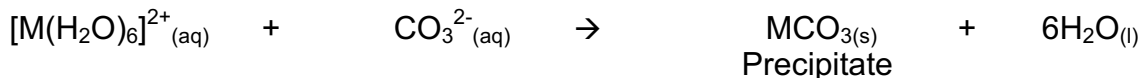
- The product has neutral charge and therefore precipitates out of solution.
- CO_2 gas is made so you will also see fizzing.

Examples:



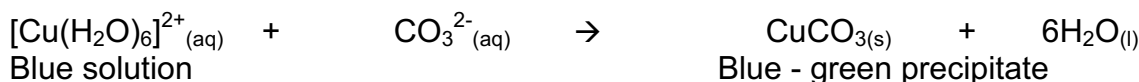
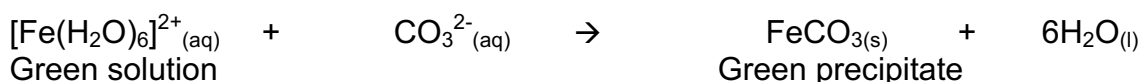
M^{2+} ion:

- The M^{2+} is not acidic enough to produce CO_2 with the carbonates.
- They react to form the insoluble metal carbonate:



- The product has neutral charge and therefore precipitates out of solution.

Examples:



➤ **Generally: Transition metal carbonates with an oxidation state of 3+ do not exist**

Summary – Required practical 11: Carry out test tube reactions to identify metal ions in solution:

Metal	Aqueous ion	Addition of NaOH	Addition of excess NaOH	Addition of NH₃(aq)	Addition of excess NH₃ (aq)	Addition of Na₂CO₃ (aq)
Fe(II)						
Cu(II)						
Fe(III)						
Al(III)						

