Identification of Al^{3+}(aq)

Aluminium ions (Al^{3+}) in solution can be identified through the use of solubility rules and the ability of some metal cations to form complex ions with hydroxide and/or ammonia.

To identify the presence of aluminium ions in solution, the base sodium hydroxide (NaOH) is added to the solution. This would cause the aluminium ions to react with the hydroxide ions, OH^-(aq), to form a white, gelatinous precipitate of aluminium hydroxide, $Al(OH)_3$(s), according to the following equation:

$$Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$$

However, this reaction alone is not specific enough to conclusively identify the presence of aluminium ions in solution, as other cations such Mg^{2+}, Ba^{2+}, Zn^{2+} and Pb^{2+}(aq) can also form white precipitates with hydroxide ions. This is because all metal hydroxides except those of Na^+ are insoluble (solubility rule #6). The other ions such as Cu^{2+}(aq), Fe^{2+}(aq), and Fe^{3+}(aq) can be excluded as their insoluble hydroxides are coloured, as well as excluding Ag^+(aq) which forms an insoluble brown precipitate of silver oxide when Ag^+(aq) reacts with hydroxide ions in solution.

Some cations can form stable, soluble complex ions with excess hydroxide solution. These are Zn^{2+}(aq), Pb^{2+}(aq) and Al^{3+}(aq). This allows Mg^{2+}(aq) and Ba^{2+}(aq) to be eliminated as they do not form these soluble complex ions.

$$Al^{3+}(aq) + 4OH^-(aq) \rightarrow [Al(OH)_4^-(aq)]$$

The Solubility Rules

1. All Group 1 compounds (sodium) are soluble.
2. All **nitrate** compounds are soluble.
3. Most **sulfates** are soluble **except** for calcium sulfate, barium sulfate and lead sulfate.
4. Most **chlorides** and **iodides** are soluble **except** for those with silver and lead.
5. All **carbonates** are insoluble **except** those of sodium.
6. All **oxides** and **hydroxides** are insoluble **except** those of Group 1 (sodium).

Formulae of potential complex ions

$[Ag(NH_3)_2]^+$ (aq)
$[Cu(NH_3)_4]^{2+}$ (aq)
$[Zn(NH_3)_4]^{2+}$ (aq)
$[Al(OH)_4]^-$ (aq)
$[Pb(OH)_4]^{2-}$ (aq)
$[Zn(OH)_4]^{2-}$ (aq)
$[FeSCN]^{2+}$ (aq)

To confirm the presence of lead or aluminium ions, an additional test using ammonia (NH_3) as a complexing agent is carried out. Initially when 2 drops of ammonia is added to Zn^{2+}(aq), Al^{3+}(aq) or Pb^{2+}(aq), a white precipitate forms, which is the insoluble metal hydroxide.

When ammonia is added to the precipitate of zinc hydroxide, it will dissolve due to the formation of a complex ion, $[Zn(NH_3)_4]^{2+}$, which is soluble in water ($Zn^{2+}(aq) + 4NH_3(aq) \rightarrow [Zn(NH_3)_4]^{2+}(aq)$)

The formation of this complex ion is however specific to zinc ions, as the other cations Pb^{2+} and Al^{3+} listed above do **not** form stable complexes with ammonia, and therefore the insoluble precipitates of lead and aluminium hydroxide remain. Therefore, the ability to dissolve the zinc hydroxide precipitate in the presence of ammonia is a positive confirmation of the presence of zinc ions in the solution. If the white precipitate does not dissolve then the ions are either lead or aluminium.

To distinguish between Pb^{2+} and Al^{3+} ions in solution, we can use dilute sulfuric acid to selectively precipitate Pb^{2+} ions as lead sulfate ($PbSO_4$), while leaving Al^{3+} ions in solution.

To do this, we can add dilute sulfuric acid to the solution and observe whether a white precipitate forms. If a white precipitate does form, it indicates the presence of Pb^{2+} ions in the solution, which have reacted with the sulfate ions, SO_4^{2-}(aq) to form lead sulfate. If no precipitate forms, then Al^{3+} ions are present.

$$Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)$$

Lead sulfate is an insoluble salt that will precipitate out of solution, and the presence of the white precipitate indicates the presence of lead ions in the solution. This is as predicted from the solubility rule #3 which states that most sulfates are soluble except those of lead, barium and calcium. Since aluminium sulfate is soluble, no precipitate will form and so this allows Al^{3+}(aq) to be confirmed.