

Complex Ions

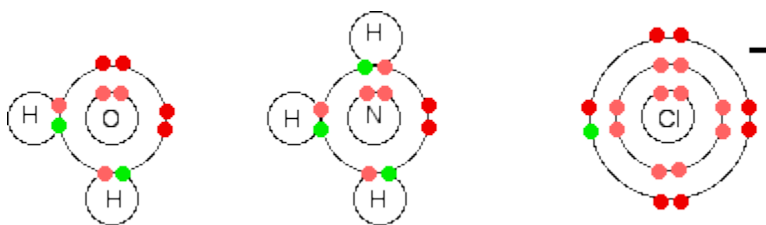
What is a complex metal ion?

A complex ion has a metal ion at its center with a number of other molecules or ions surrounding it. These can be considered to be attached to the central ion by co-ordinate covalent bonds. (In some cases, the bonding is actually more complicated than that.)

The molecules or ions surrounding the central metal ion are called **ligands**.

The nature of ligands

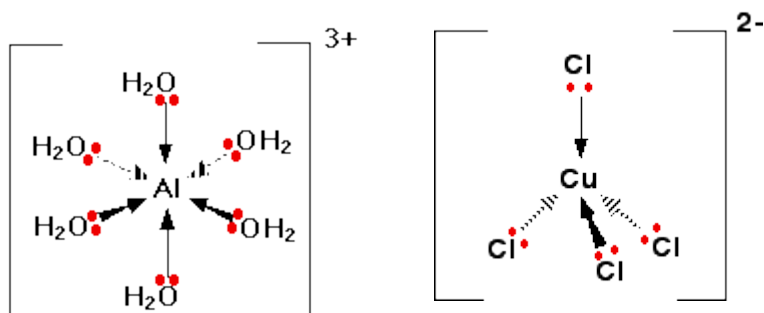
Simple ligands include water, ammonia and chloride ions.



What all these have in common is active lone pairs of electrons in the outer energy level. These are used to form co-ordinate covalent bonds with the metal ion.

All ligands are lone pair donors. In other words, all ligands function as **Lewis bases**.

Examples:



Written as $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$

Written as $[\text{Cu}(\text{Cl})_4]^{2-}$

Frequently Seen on the AP Chemistry Test...

The most common number of ligands attached to a metal ion are 2,4, and especially 6. Six is generally the maximum number of ligands that will bond. If the ligands are large ions such as Cl^- , you may find that only 2 or 4 will bond to the central atom. This has to do with the electron cloud repulsion that would occur if 6 large ions were all attached to the same atom. The key thing AP graders are looking for is whether or not the overall charge on the complex ion makes sense.

The silver ammine complex, $\text{Ag}(\text{NH}_3)_2^+$, is a relatively frequent visitor on AP tests. Many cations (Ag^+ , Cu^{2+} , Cd^{2+} , Zn^{2+} , and many others) form complexes with ammonia. These sometimes are called ammine complexes.

Common cations that form complex ions with excess NH_3 are:

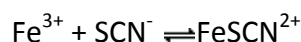
1. $\text{Ag}^+(aq) + 2\text{NH}_3(aq) \rightleftharpoons \text{Ag}(\text{NH}_3)_2^+(aq)$
2. $\text{Cu}^{2+}(aq) + 4\text{NH}_3(aq) \rightleftharpoons \text{Cu}(\text{NH}_3)_4^{2+}(aq)$
3. $\text{Ni}^{2+}(aq) + 6\text{NH}_3(aq) \rightleftharpoons \text{Ni}(\text{NH}_3)_6^{2+}(aq)$
4. $\text{Zn}^{2+}(aq) + 4\text{NH}_3(aq) \rightleftharpoons \text{Zn}(\text{NH}_3)_4^{2+}(aq)$

Another reaction type frequently seen is the formation of a hydroxide followed by the formation of a soluble hydroxide complex ion. $\text{Fe}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$ do not form soluble complexes, but aluminum and zinc do:

Common cations that form complex ions with excess OH^- are:

1. $\text{Pb}^{2+}(aq) + 4\text{OH}^-(aq) \rightleftharpoons \text{Pb}(\text{OH})_4^{2-}(aq)$
2. $\text{Al}^{3+}(aq) + 4\text{OH}^-(aq) \rightleftharpoons \text{Al}(\text{OH})_4^-(aq)$
3. $\text{Zn}^{2+}(aq) + 4\text{OH}^-(aq) \rightleftharpoons \text{Zn}(\text{OH})_4^{2-}(aq)$

Another common reaction is that of ferric ion with thiocyanate ion (SCN^-):



Examples:

1. Solid silver chloride is added to a solution of concentrated hydrochloric acid, forming a complex ion.
2. A concentrated solution of ammonia is added to a suspension of zinc hydroxide.
3. Solid aluminum hydroxide is added to a concentrated solution of potassium hydroxide.
4. Excess concentrated aqueous ammonia is added to a solution of nickel(II) bromide.
5. Excess saturated sodium fluoride solution is added to a solution of aluminum sulfate.
6. Excess concentrated aqueous ammonia is added to solid silver chloride.
7. Excess concentrated potassium hydroxide solution is added to a solution of nickel(II) chloride.

Answers:

1. $\text{AgCl} + 3\text{Cl}^- \rightarrow [\text{Ag}(\text{Cl})_4]^{3-}$
2. $4\text{NH}_3 + \text{Zn}(\text{OH})_2 \rightarrow 2\text{OH}^- + [\text{Zn}(\text{NH}_3)_4]^{2+}$
3. $\text{Al}(\text{OH})_3 + 4\text{OH}^- \rightarrow [\text{Al}(\text{OH})_4]^-$
4. $\text{Ni}^{2+} + 6\text{NH}_3 \rightarrow [\text{Ni}(\text{NH}_3)_6]^{2+}$
5. $\text{Al}^{3+} + 6\text{F}^- \rightarrow [\text{AlF}_6]^{3-}$
6. $\text{AgCl} + 2\text{NH}_3 \rightarrow [\text{Ag}(\text{NH}_3)_2]^+ + \text{Cl}^-$
7. $\text{Ni}^{2+} + 4\text{OH}^- \rightarrow [\text{Ni}(\text{OH})_4]^{2-}$