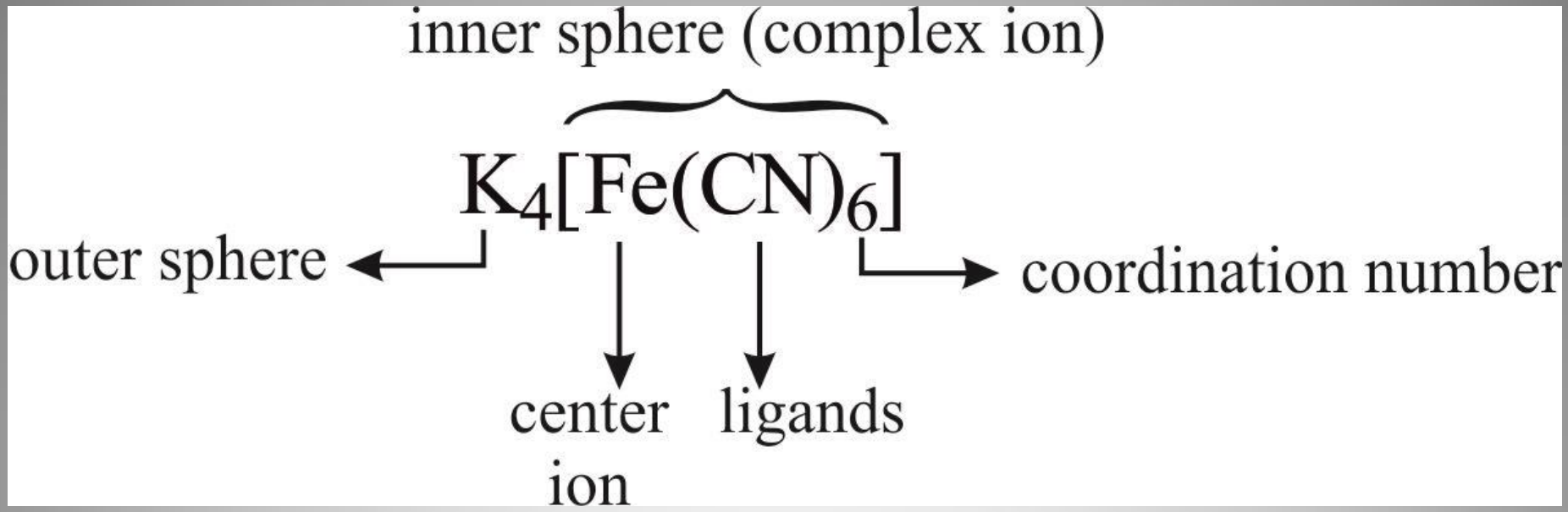
COORDINATION COMPOUNDS

Coordination compounds (complex compounds, complexes) are the compounds that contain complex ions that retain their stability when dissolved.


inner sphere (complex ion)
$K_4[Fe(CN)_6]$
outer sphere
coordination number
center ion
ligands

According to the coordination theory, in the centre of a molecule of a coordination compound the central atom (ion) is situated.

Around the central atom (ion), there are oppositely charged ions or neutral molecules, called **ligands**, or **addends**.

The central atom (ion) together with its ligands is called a **complex ion**.

Coordination number reflects the number of bonds formed between the metal ion and the ligands in the complex ion.

The complex ion makes the **inner sphere** of a coordination compound, denoted by square brackets.

The ions, that do not enter the inner sphere, form the **outer sphere**

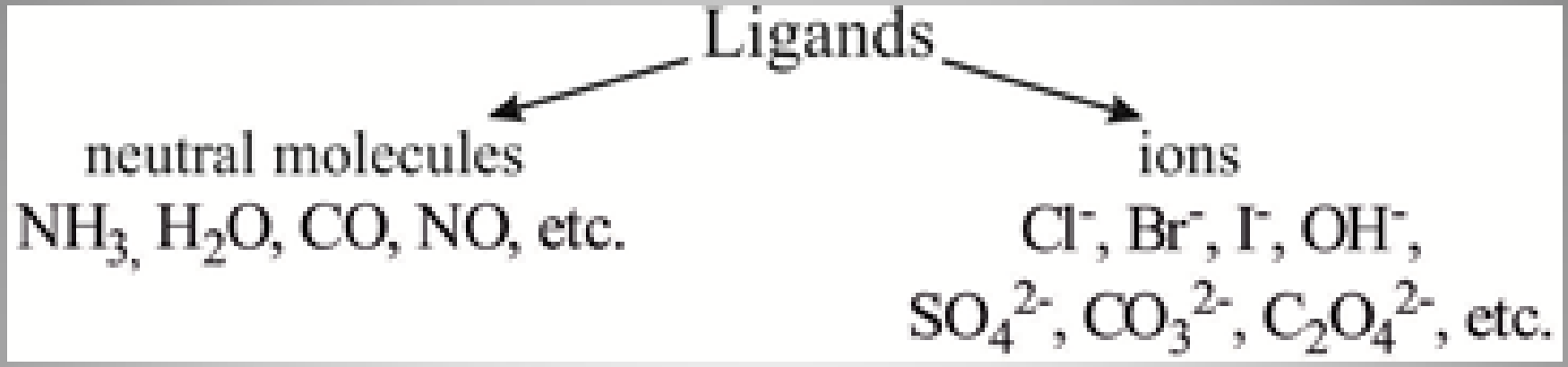
The **charge of the complex ion** is equal to the algebraic sum of the charges of the central atom (ion) and ligands.

If the ligands are electrically neutral molecules, the charge of the complex ion is equal to the charge of the central ion. **A molecule of a complex compound is electrically neutral.**

Central atom (ion). d-block elements (transition elements) or ions (Pt, Pd, Fe, Co, Ni, Cu, Ag, Zn, Cd, Hg) show the highest complex formation tendency. Most of the transition element complexes have coordination number 2, 4 or 6.

Relationship between the oxidation state of the central ion and its coordination number

Oxidation state of the central ion	Coordination number (CN)	Example	
		ion	complex compound
+1	**2**, 3	Cu^{+}, Ag^{+}, Au^{+}	$[Ag(NH_3)_2]Cl$
+2	3, **4**, 6	Cu^{2+}, Co^{2+}, Ni^{2+}, Pd^{2+}, Pt^{2+}, Fe^{2+}	$[Cu(NH_3)_4]Cl_2$, $K_4[Fe(CN)_6]$
+3	4, 5, **6**	Fe^{3+}, Cr^{3+}, Co^{3+}	$K_3[Co(NO_2)_6]$
+4	**6**, 8	Sn^{+4}, Pt^{+4}	$K_2[PtCl_6]$, $H_2[SnCl_6]$


Ligands
neutral molecules
NH3, H2O, CO, NO, etc.
ions
Cl-, Br-, I-, OH-,
SO4 2-, CO3 2-, C2O4 2-, etc.

All complex ions are divided into 3 groups: **complex ion – cation** – $[Cu^{2+}(NH_3)_4]^{2+}$, $[Co^{+3}Br(NH_3)_5]^{2+}$; **complex ion – anion** – $[Fe^{2+}(CN)_6]^{4-}$; **complex neutral molecule** – $[Co^{3+}(NH_3)_3Cl_3^-]^0$, $[Pt^{+2}(NH_3)_4Br_2]^0$.

Classification of coordination compounds

According to the charge of the complex ions, coordination compounds are divided into neutral coordination compounds, anionic coordination compounds and cationic coordination compounds.

For example, a **neutral complex** is a complex ion which is neutral in charge: $[Cu(NH_3)_2Cl_2]^0$, $[Pt(NH_3)_4Br_2]^0$.

An anionic complex is a complex ion which is negative in charge: $K_4[Fe(CN)_6]^{4-}$, $Na[Ag(CN)_2]^-$.

A cationic complex is a complex ion which is positive in charge: $[Cu(NH_3)_4]^{2+}Cl_2$, $[Ag(NH_3)_2]^+Cl$.

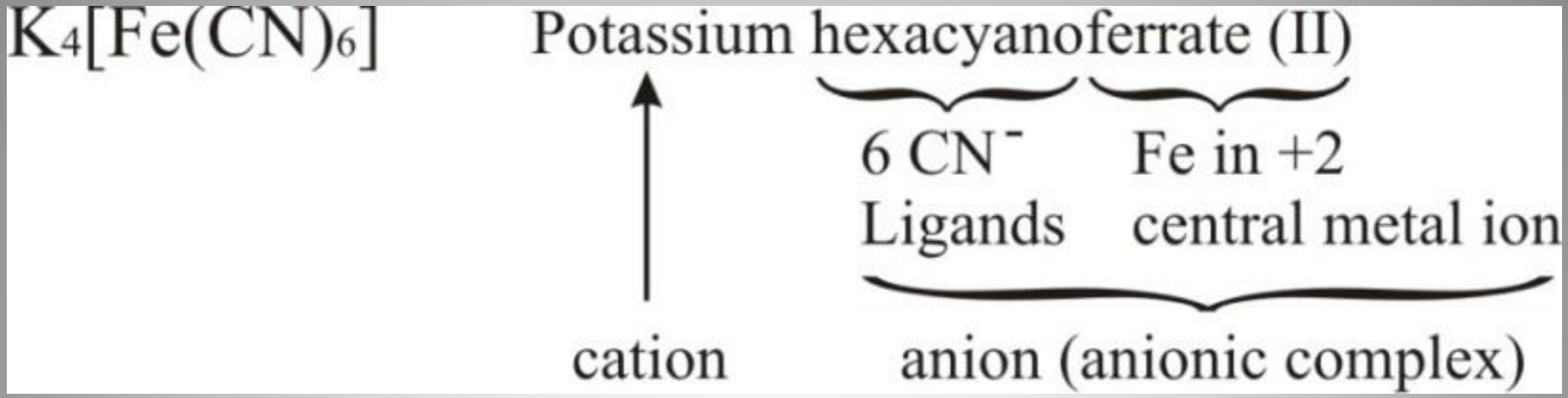
According to **ligands** coordination compounds are divided into **hydroxo complexes, acido complexes, ammines, aqua complexes**.

Ligand	Name of the coordination compound type	Example
hydroxo ions OH^-	hydroxo complexes	$Na_2[Zn(OH)_4]$
anions of acid residues: CN^-, NO_2^-, Cl^-, I^-, Br^- and others	acido complexes	$K_4[Fe(CN)_6]$, $K_2[HgI_4]$, $Na_3[Co(NO_2)_6]$
neutral molecules: NH_3, H_2O	ammines aqua complexes	$[Ag(NH_3)_2]Cl$, $[Al(H_2O)_6]Cl_3$

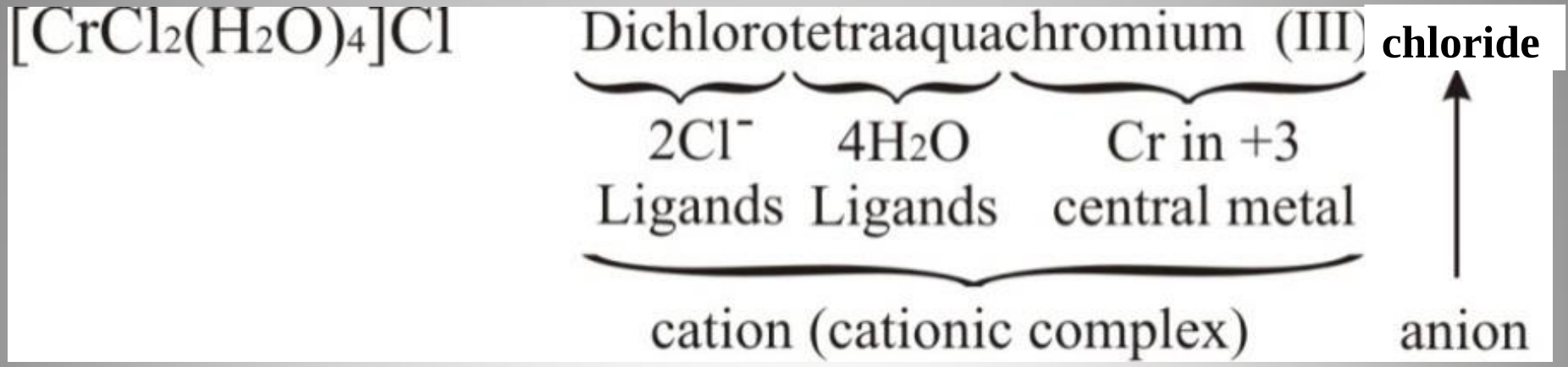
Nomenclature of Coordination Compounds

Coordination compounds are named according to the nomenclature, recommended by the International Union of Pure and Applied Chemistry (IUPAC). The following examples illustrate how the rules are applied.

Anionic coordination compounds:



Cationic coordination compounds



Neutral coordination compounds:

$[CoCl_3(NH_3)_3]$

Trichlorotriamminecobalt (III)

$3Cl^-$ Ligands $3NH_3$ Ligands Co in +3 **central metal ion**

neutral complex

The nomenclature can be summarized as follows:

1. **Naming of a coordination compound:**

   a) if the coordination compound is ionic, then the cation is named before the anion:

   $K_3[Fe(CN)_6]$ – potassium hexacyanoferrate (III);

   $[CrCl_2(H_2O)_4]Cl$ – dichlorotetraaquachromium (III) chloride.

   b) if the coordination compound is neutral, then the name of the complex ion is the name of the compound:

   $[CoCl_3(NH_3)_3]$ trichlorotriamminecobalt (III).

1. **Naming of a complex ion in a coordination compound**

All present ligands and the central atom (ion) are named together as one word. The ligands are named before the central atom (ion):

$[CrCl_2(H_2O)_4]^+$ – dichlorotetraaquachromium (III).

1. **Naming of the ligands in a complex ion:**

a) the order of the ligands is anionic, neutral, or cationic:

$[PtCl_2(NH_3)_4]^{2+}$ dichlorotetraammineplatinum (IV)

- the names of anionic ligands end in – o:

CN^- – cyano;

Cl^- – chloro.

- the names of neutral ligands are the names of the molecules, except NH_3, H_2O, CO and NO:

NH_3 – ammine;

H_2O – aqua.

Names of some common ligands

Anionic Ligand	Ligand Name	Neutral Ligands	Ligand Name
bromide (Br^-),	bromo,	ammonia (NH_3),	ammine,
chloride (Cl^-),	chloro,	water (H_2O),	aqua (aquo),
cyanide (CN^-),	cyano,	carbon monoxide (CO),	carbonyl,
fluoride (F^-),	fluoro,	$NH_2CH_2CH_2NH_2$	ethylenediamine
hyroxide (OH^-),	hydroxo,		
sulphate (SO_4^{2-}),	sulphato,		
amide (NH_2),	amido,		
nitrite (NO_2^-),	nitro,		
nitrate(NO_3^-)	nitrato		

a) within each type of ligand (cationic, anionic or neutral):
   - if the number of a particular ligand is more than one, then the number is indicated with the appropriate Greek prefix as shown in table 2.3;

Table 2.3 – Greek prefix of a number

Number	Greek prefix	Number	Greek prefix
2	Di-	5	Penta-
3	Tri-	6	Hexa-
4	Tetra-		

   - the ligands are arranged in alphabetical order, ignoring the numbering prefixes:

     $[Cu(H_2O)_2(NH_3)_4]^{2+}$ – tetraamminediaquacopper (II).

1. **Naming of the central atom (ion) in a complex:**

a) if the complex is anionic, then the name of the metal ends in -ate:

$[Fe(CN)_6]^{3-}$ hexacyanoferrate (III) (table 2.4).

Table 2.4 – Names of some common metals in anionic complexes

Metal	Name in Anionic Complex	Metal	Name in Anionic Complex
Titanium (Ti)	Titanate	Nickel (Ni)	Nickelate
Chromium (Cr)	Chromate	Zinc (Zn)	Zincate
Manganese (Mn)	Manganate	Platinum (Pt)	Platinate
Cobalt (Co)	Cobaltate		

For the following metals the English name is replaced by the Latine name, to which the “ate” ending is added:

(Sn) Tin – Stannate;

(Fe) Iron – Ferrate;

(Cu) Copper – Cuprate;

(Pb) Lead – Plumbate;

(Ag) Silver – Argentate;

(Au) Gold – Aurate.