

Kurdistan region-Iraq
University of Salahaddine
College of Science
Chemistry Department



Coordinate Bond Theories

Third stage Chemistry
2022-2023

Lecturer

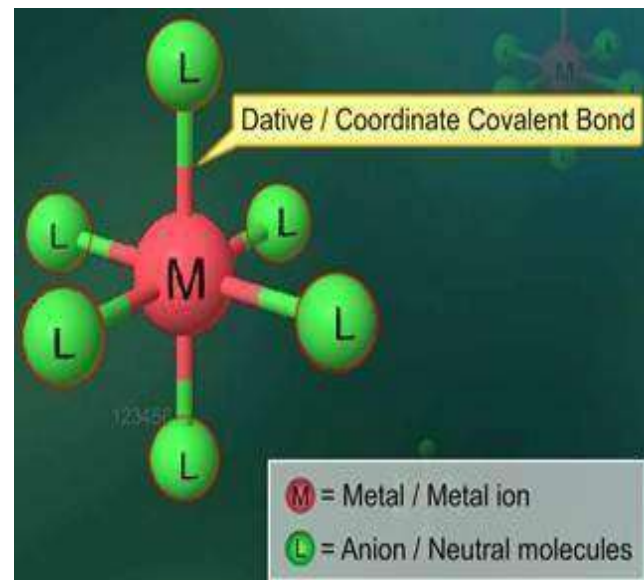
M.Sc. Muhammad Haji

Coordination Chemistry

Introduction and Historical Development

• **Coordination Compounds , Metal Complexes or just Complexes .** These are compounds that contain a central atom or ion, usually a metal surrounded by a cluster of ions or molecules. It may be a cation , anion or nonionic (neutral), depending on the sum of the charges of the central atom and the surrounding ions and molecules. In modern terminology, these compounds are called coordination compounds.

• **Coordination compounds (or) complexes**
compounds are a type of addition compounds.



Application of coordination compounds

1-Chemical industria.

2-Extraction of metals.

3-Analytical chemistry.

4-Biological importance.

5- In medicine.

6-In electroplating.

7-For estimation of hardness of water .

8-In modifying the redox behavior of metalions.

1-chemical industry and in life itself:

ex: Ziegler-Natta catalyst for low–pressure polymerization of ethylene ,which is a complex of the metals aluminum and titanium (AlR_3 & TiCl_4 complex).

2-Extraction of metal:

- Technique used for noble metal like Ag & Au.
- Noble metals like silver and gold are extracted from their ore by the formation of cyanide complexes - dicyanoargentate(I) and dicyanoaurate (I).
- $\text{Ag}_2\text{S} + 4\text{NaCN} \rightleftharpoons 2\text{Na}[\text{Ag}(\text{CN})_2] + \text{Na}_2\text{S}$
- $2\text{Na}[\text{Ag}(\text{CN})_2] + \text{Zn} \rightleftharpoons \text{Na}_2[\text{Zn}(\text{CN})_4] + 2\text{Ag}\downarrow$

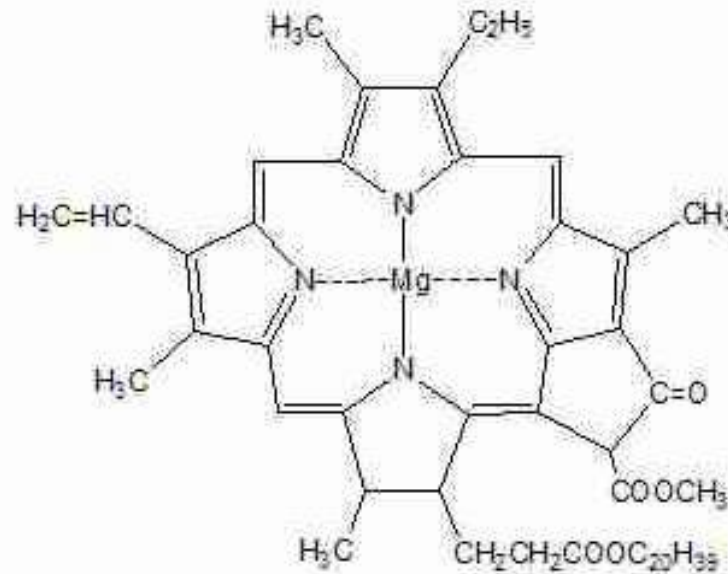
- **3- Analytical chemistry.**
- **Qualitative analysis:**
- Complexes were used for separating certain metal ions and as means of positively identifying certain unknown ions.
- For ex. $\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl} \downarrow$ ppt. salt, which dissolves in
- excess of aqueous ammonia forming a clear solution which is a complex ion.
- $\text{AgCl} + 2\text{NH}_3 \rightarrow [\text{Ag}(\text{NH}_3)_2]^+$ (clear solution)
- If to the clear solution is added an excess of HNO_3 the white ppt. is formed again (due the equilibrium).
- $\text{H}^+ + \text{NH}_3 \rightarrow \text{NH}_4^+$

4- Biological Importance

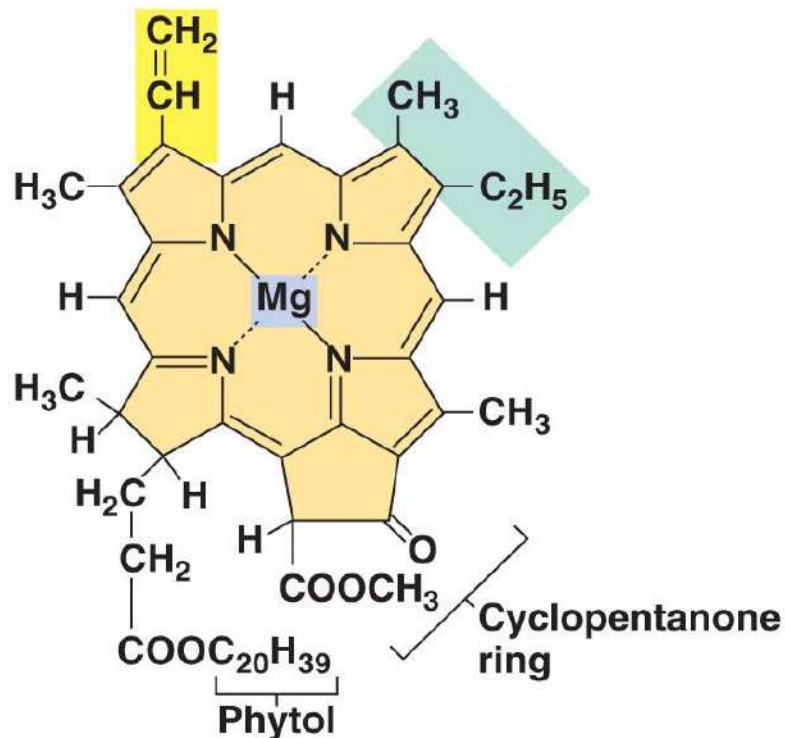
- Significant role in plant(chlorophyll-Mg) and animal Vitamin-B12.
- Haemoglobin, red pigment of blood that acts as the Oxygen carrier is a coordination compound of iron



***Chlorophyll** which is vital to photosynthesis in plants is a magnesium(II) complex ion.*

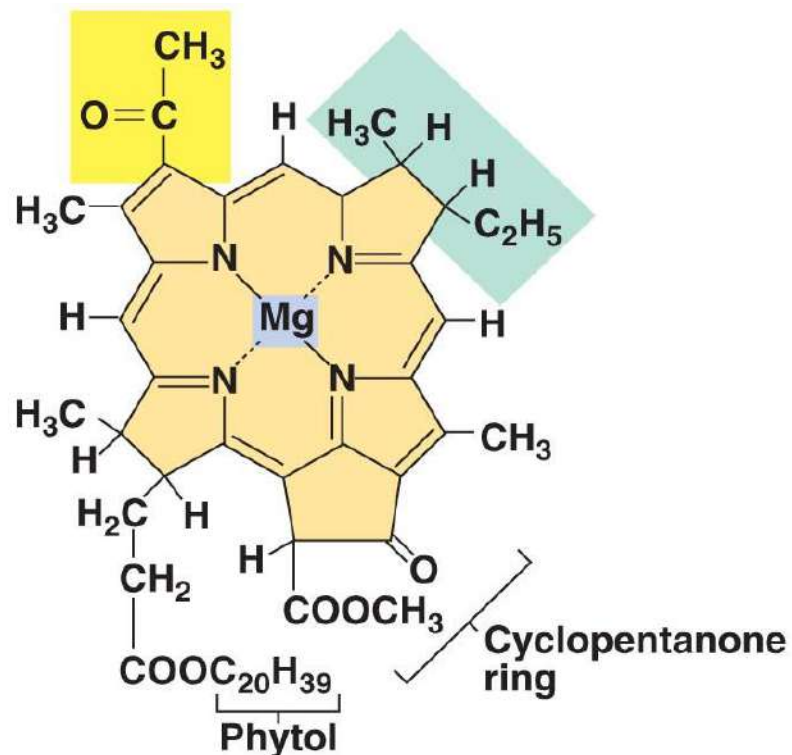


Structure and Spectra of Chloro- and Bacteriochlorophyll



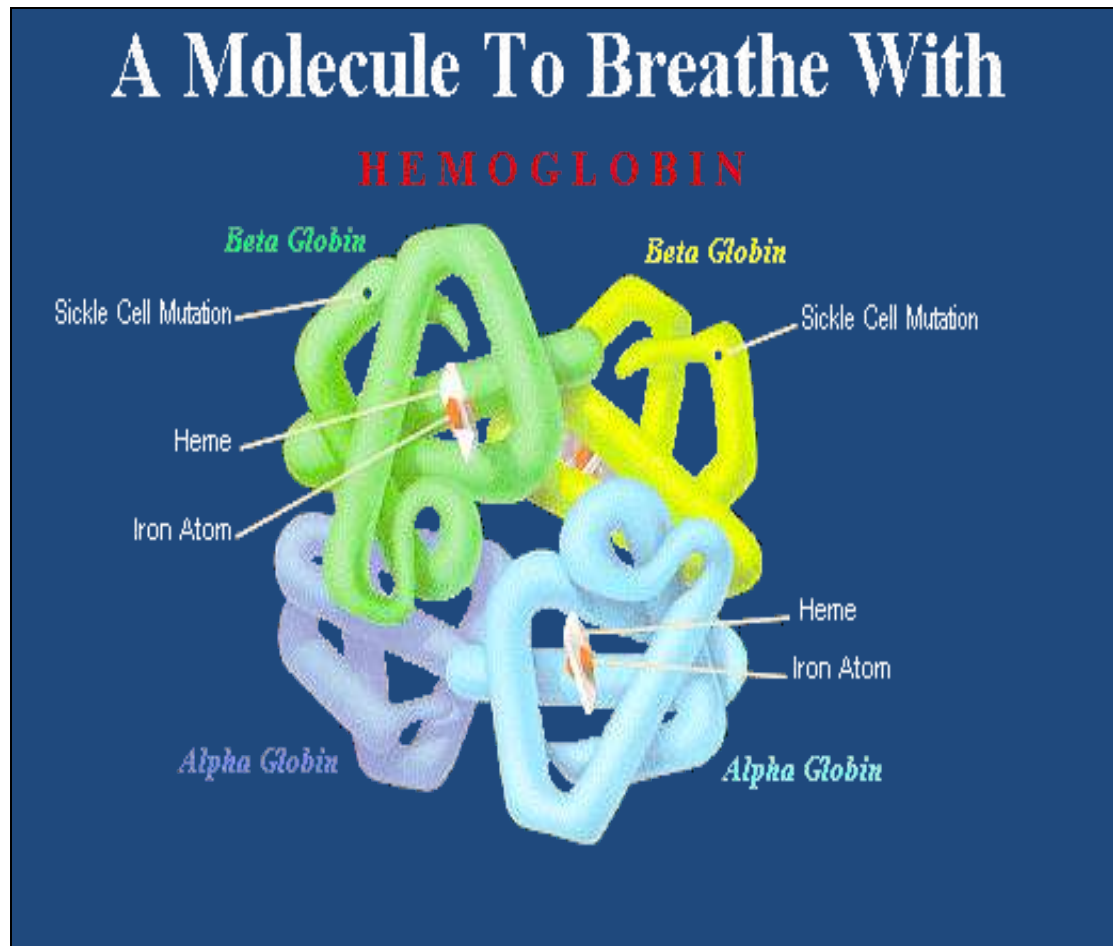
Chlorophyll *a*

(a)



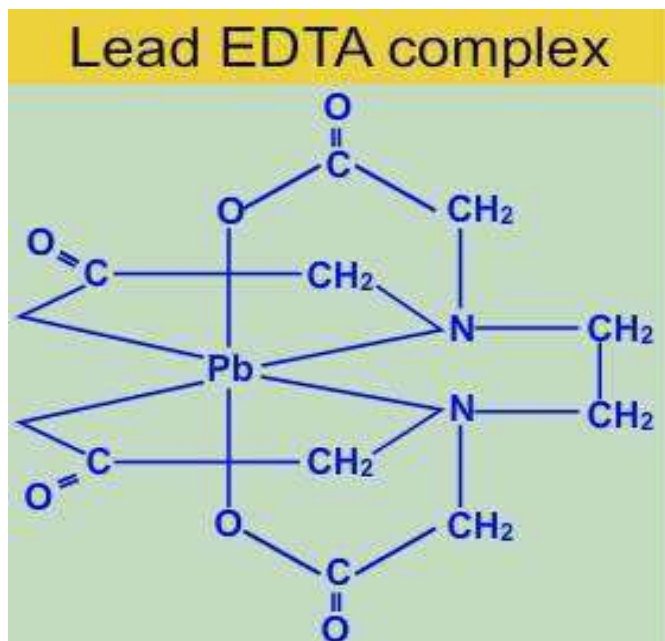
Bacteriochlorophyll *a*

Hemoglobin carries oxygen to human and animal cells is an Fe^{2+} complex(Heme)



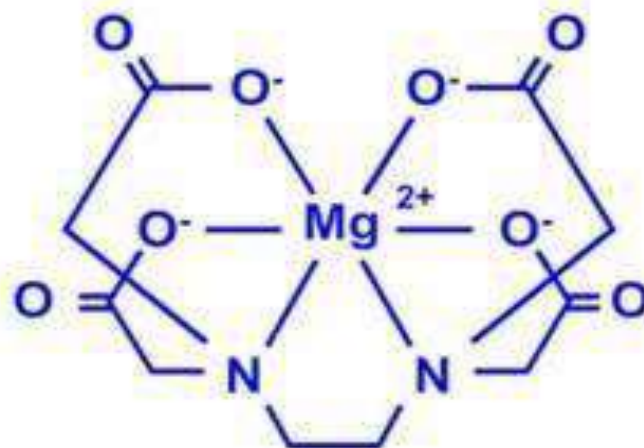
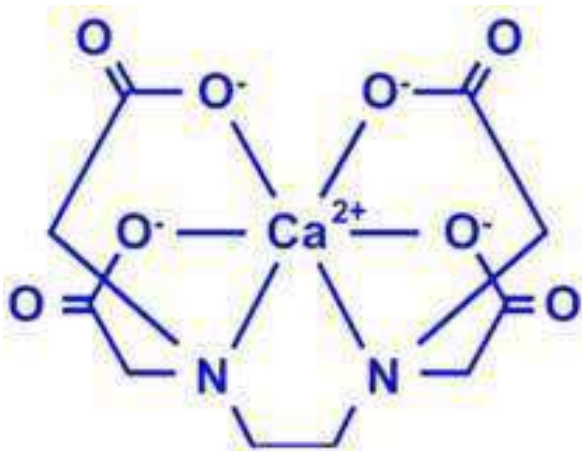
5. In medicine

- Treatment of cancer – cisplatin
- Platinum, cis $[\text{PtCl}_2(\text{NH}_3)_2]$
- EDTA is used to treat lead poisoning.



6 . Hardness of water

- The hardness of water is estimated by titration with the sodium salt of EDTA. During titration, the calcium and magnesium ions in hard water form the stable complexes, Calcium EDTA and Magnesium EDTA. Stability is different.



- **Use of CoCl_2 solution as invisible ink:**
- $2[\text{Co}(\text{H}_2\text{O})_6]\text{Cl}_2 \rightleftharpoons \text{Co}[\text{CoCl}_4] \text{ (blue)} + 12 \text{ H}_2\text{O}$
ink(colourless when dilute)
- what is written with this solution is not visible until the paper on which it is written is heated(because the H_2O is driven off and the blue complex is formed).
- Upon standing ,water is slowly taken up from the atmosphere and the original colorless complex is regenerated, which makes the writing again invisible.
- These examples indicate that coordination compounds are common, but the nature of these compounds was not
- Understood, until the beginning of the 20th century, therefore these compounds were referred to as complex compounds, this term still used.

Historical Development

- Discovery: It is difficult to state exactly when the first metal complex was discovered.
- Perhaps the earliest one on record is **prussian blue**, $\text{KCN.Fe(CN)}_2 \cdot \text{Fe(CN)}_3$, by the artist's colour maker Diesbach, in Berlin at the beginning of 18th century.
- however, the date usually cited is that of the discovery of **hexaammine cobalt(III) chloride**, $\text{CoCl}_3 \cdot 6\text{NH}_3$ by Tassaret (1798) this discovery marks the real beginning of coordination chemistry.
- Although Tassaret's discovery was accidental, he realized that there was something new and certainly no accident,

- **Tassaert's** experimental observations could not be explained on the basis of the chemical theory available at that time. It was necessary to understand how CoCl_3 and NH_3 each a stable compound of presumably saturated valence, could combine to make yet another very stable compound.
- The answer was not to be found until approximately 100 years later.
- **Preparation and Properties:**
- The preparation of metal complexes generally involves the reaction between a salt and some other molecule or ion. At first each compound was named after the chemist who originally prepared it as shown in the Table below :

<u>Compound</u>	<u>Name</u>	<u>Present formula</u>
$\text{PtCl}_2 \cdot \text{KCl} \cdot \text{C}_2\text{H}_4$	Zeises' salt	$\text{K}[\text{Pt}(\text{C}_2\text{H}_4)\text{Cl}_3]$
$\text{Co}(\text{NO}_2)_3 \cdot \text{KNO}_2 \cdot 2\text{NH}_3$	Erdman's salt	$\text{K}[\text{Co}(\text{NH}_3)_2(\text{NO}_2)_4]$

Since many of the compounds are colored the next scheme was to name compounds on the basis of colour.

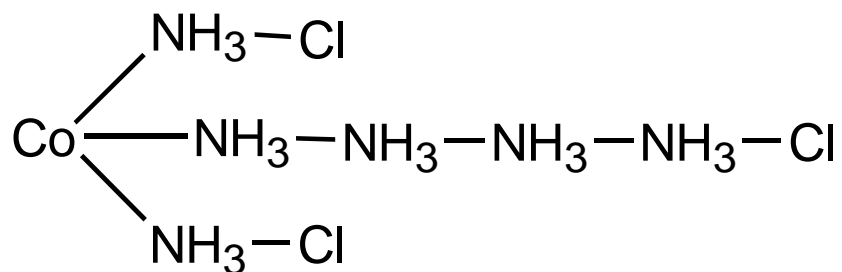
<u>Compound</u>	<u>Colour</u>	<u>Name</u>
$\text{CoCl}_3 \cdot 6\text{NH}_3$ *	Yellow	Luteocobaltic chloride
$\text{CoCl}_3 \cdot 5\text{NH}_3$	purple	Purpureocobaltic chloride
$\text{CoCl}_3 \cdot 4\text{NH}_3$	Green	Praseocobaltic chloride
$\text{CoCl}_3 \cdot 4\text{NH}_3$	Violet	Violeocobaltic chloride
$\text{IrCl}_3 \cdot 6\text{NH}_3$ *	White	luteoirridic chloride

*This compound called **luteo** because it contains six NH_3

- The chloroammine complexes of Co^{3+} and those of Cr^{3+} not only exhibit a spectrum of colours but also differ in the reactivity of their chlorides.
- For ex: addition of AgNO_3 solution to a freshly prepared solution of $\text{CoCl}_3 \cdot 6\text{NH}_3$ results in the immediate pptn. of all three chloride ions. $\text{CoCl}_3 \cdot 6\text{NH}_3 + \text{AgNO}_3 \rightarrow 3\text{AgCl}$
- $\text{CoCl}_3 \cdot 5\text{NH}_3 + \text{AgNO}_3 \rightarrow 2 \text{AgCl}$ only two chlorides ppt.
- These observations suggest that in $\text{CoCl}_3 \cdot 5\text{NH}_3$ and $\text{CoCl}_3 \cdot 4\text{NH}_3$ there are two different kinds of chlorides.
- One type is perhaps similar to that in NaCl and is readily ppt. whereas the other types held more firmly and does not ppt.

- Another kind of experiment provides useful information about the number of ions present in solutions of different complexes.
- The greater the number of ions in a solution, the greater is the electrical conductivity of the solution.
- One other important early observation was that certain complexes exist in two different forms having the same chemical composition.
- Ex: green and violet form of $\text{CoCl}_3 \cdot 4\text{NH}_3$.
- Isomers: compounds having the same chemical formula but different structures.
- Several hypothesis and theories were proposed to account for all of these experimental facts among these are:

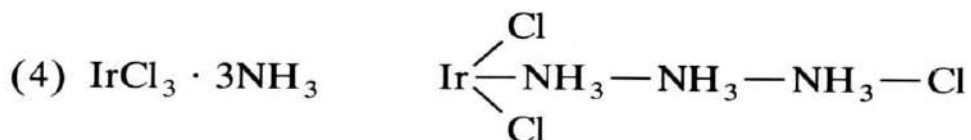
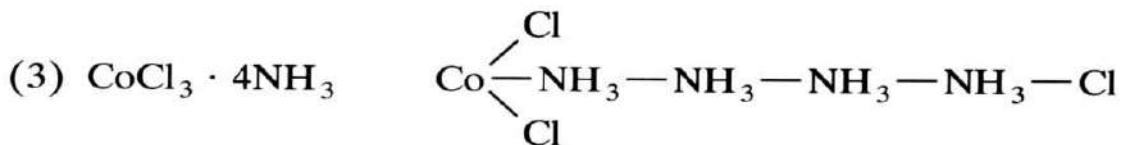
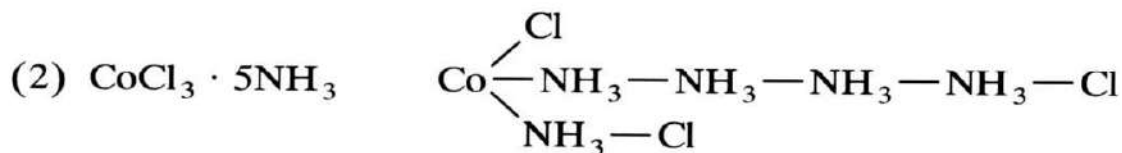
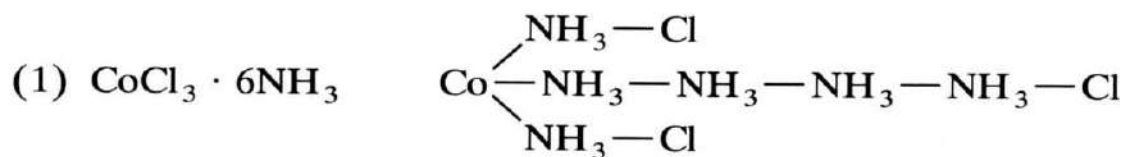
- **1-Blomstrand-Jorgensen Chain Theory(1869):**
- The concept of the tetra valency of carbon and the formation of carbon-carbon chains in organic compounds was already well recognized.
- Because it was felt that elements had only one type of valence,
- **Blomst.** And his student **Jorgensen** suggested ,there could be **only three bonds** to cobalt(III) in it's complexes, therefore a chain structure was used to account for the addition of six NH_3 molecules in **$\text{CoCl}_3 \cdot 6\text{NH}_3$ (I)**. The three chlorides are separated by some distance from cobalt therefore believed to precipitate readily as AgCl on addition of Ag^+
- **Cl^- attached to NH_3 may be dissociated**



- The second compound $\text{CoCl}_3 \cdot 5\text{NH}_3$ (b) 2
- One chloride is attached directly to cobalt, so it was expected that this is the one that does not ionize and does not ppt. as
- AgCl .



(b)



The 3rd compound $\text{CoCl}_3 \cdot 4\text{NH}_3$ (b) 3 is also in accord with experiments that show two chlorides are held more firmly than the third, therefore it is expected that only one chloride will be ppt. upon addition of Ag^+ .

The 4th. Compound $\text{CoCl}_3 \cdot 3\text{NH}_3$ (b) 4 :

One would predict that the chlorides would behave as they do in $\text{CoCl}_3 \cdot 4\text{NH}_3$ (b) 3, Jorgensen did not succeed in preparing the last compound, but made instead the analogous

iridium complex $\text{IrCl}_3 \cdot 3\text{NH}_3$. The solution of this compound did not conduct current nor did give a pptn. upon addition of AgNO_3 . Thus Jorgensen had succeeded in showing that his chain theory could not be correct.

Werner Coordination Theory:

Alfred Werner (1866-1919)

1893, age 26: coordination theory

Nobel prize for Chemistry, 1913

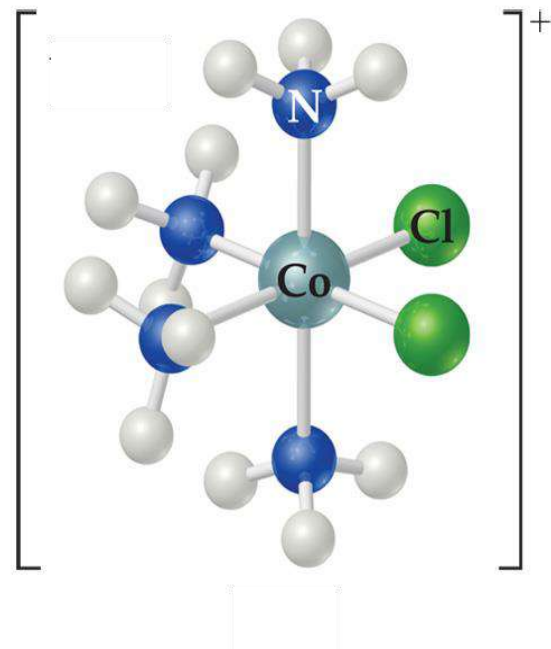
Addition of 6 mol NH_3 to $\text{CoCl}_{3(\text{aq})}$

Conductivity studies

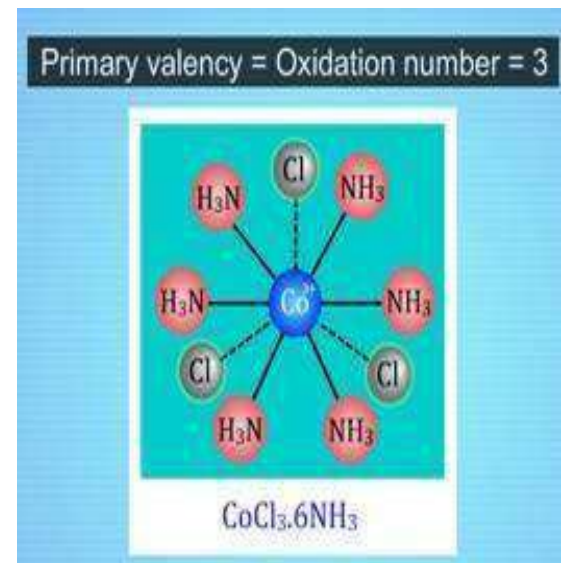
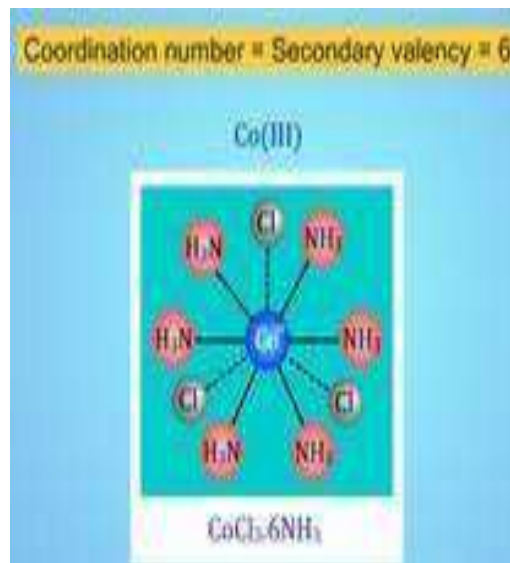
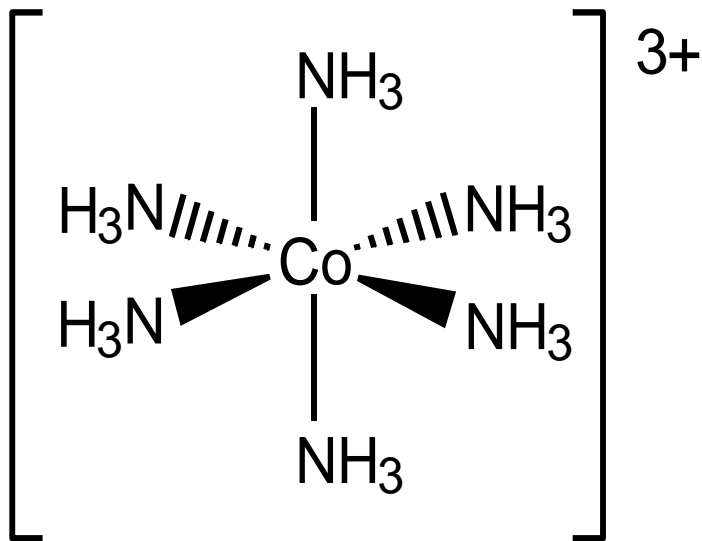
Precipitation with AgNO_3

Werner's Theory

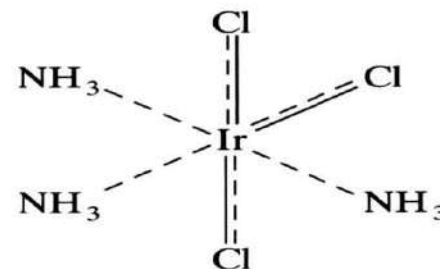
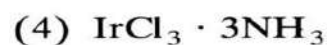
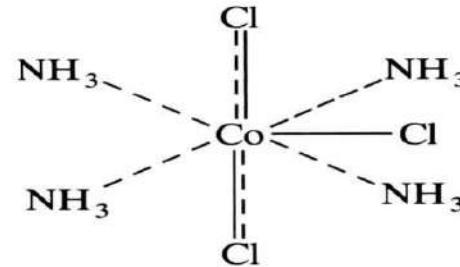
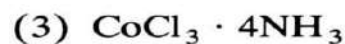
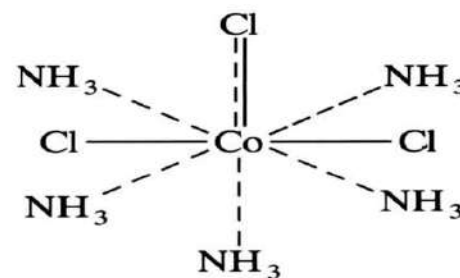
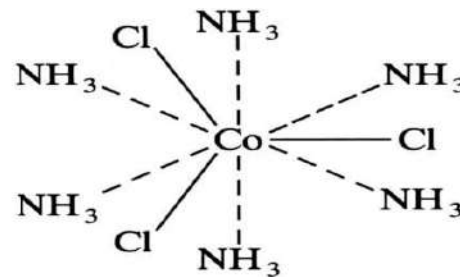
- Alfred Werner suggested in 1893 that metal ions exhibit what he called *primary* and *secondary* valences.
 - Primary valences were the oxidation number for the metal (+3 on the cobalt at the right).
 - Secondary valences were the coordination number, the number of atoms directly bonded to the metal (6 in the complex at the right).
 - Primary valences always satisfied by negative ions while secondary valence satisfy by either negative ions or neutral molecules.



- The central metal and the ligands directly bonded to it make up the **coordination sphere** of the complex.
- In $\text{CoCl}_3 \cdot 6 \text{NH}_3$, all six of the ligands are NH_3 and the 3 chloride ions are outside the coordination sphere.



Some chloride ions must do *double duty* and help satisfy the both of primary valence and secondary valence.



Werner Coordination Theory

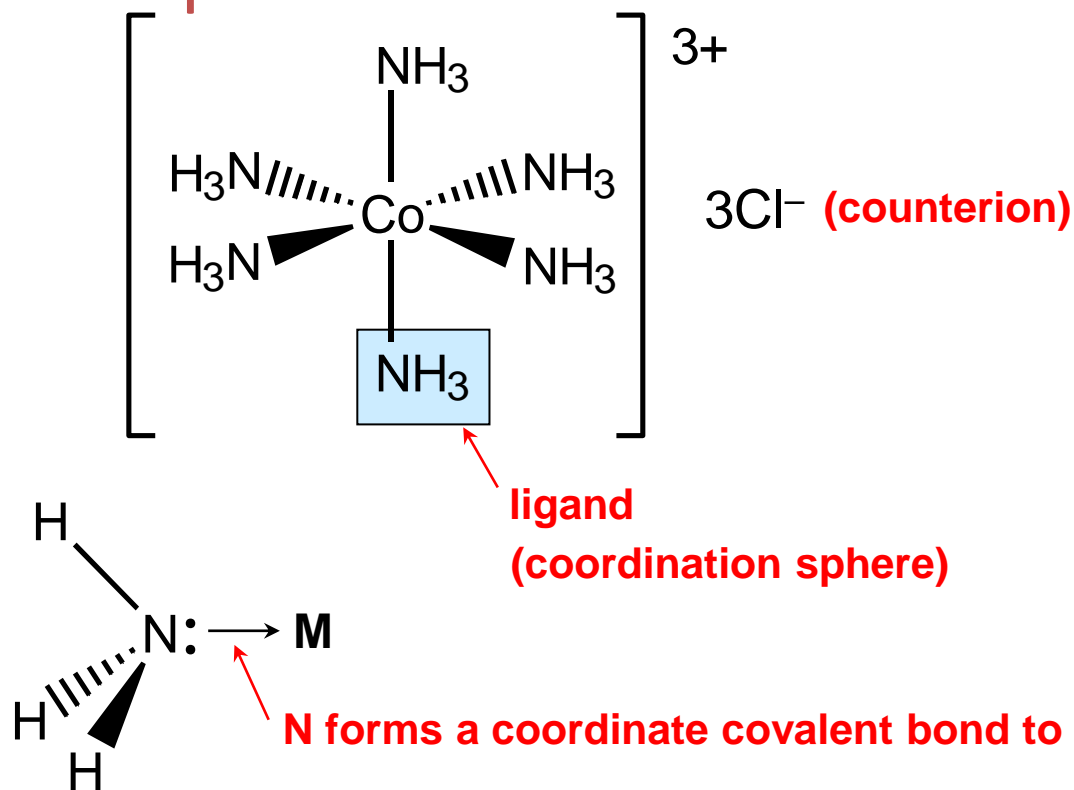
Upon addition of AgNO_3 the chlorides which lie outside of the coordination sphere would precipitated.

Compound	Moles of ions	Moles of AgCl(s)
" $\text{CoCl}_3 \cdot 6\text{NH}_3$ "	4	3
" $\text{CoCl}_3 \cdot 5\text{NH}_3$ "	3	2
" $\text{CoCl}_3 \cdot 4\text{NH}_3$ "	2	1
" $\text{CoCl}_3 \cdot 3\text{NH}_3$ "	0	0

Coordination Chemistry

Definitions

- Coordination compounds



In $\text{CoCl}_3 \cdot 5 \text{NH}_3$ the five NH_3 groups and one chlorine are bonded to the cobalt, and the other two chloride ions are outside the sphere.

Thus one chloride ion must serve the dual function of satisfying both primary and secondary valence.

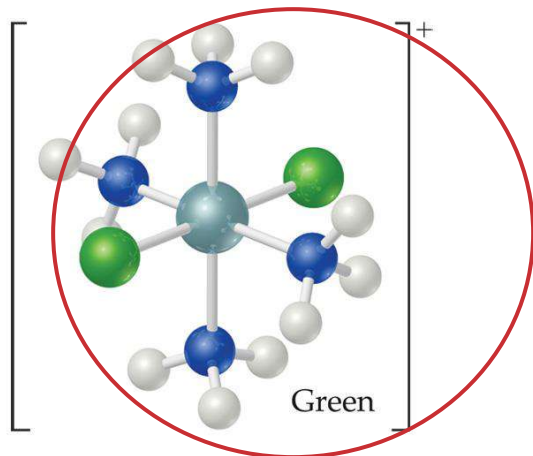
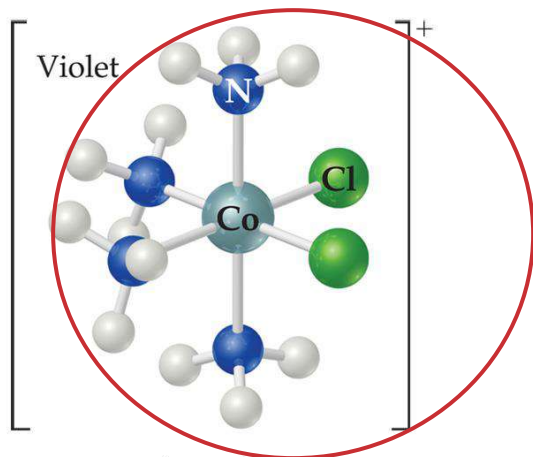
Such a chloride is not readily precipitate from solution by Ag^+ ion. The other two chlorides which lie outside of coordination sphere readily ppt. upon addition of Ag^+ ion. The formula is $[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$.

Werner proposed putting all molecules and ions within the sphere in brackets and those “free” anions (that dissociate from the complex ion when dissolved in water) outside the brackets.

TABLE 24.1 Properties of Some Ammonia Complexes of Cobalt(III)

Original Formulation	Color	Ions per Formula Unit	"Free" Cl ⁻ Ions per Formula Unit	Modern Formulation
CoCl ₃ ·6 NH ₃	Orange	4	3	[Co(NH ₃) ₆]Cl ₃
CoCl ₃ ·5 NH ₃	Purple	3	2	[Co(NH ₃) ₅ Cl]Cl ₂
CoCl ₃ ·4 NH ₃	Green	2	1	<i>trans</i> -[Co(NH ₃) ₄ Cl ₂]Cl
CoCl ₃ ·4 NH ₃	Violet	2	1	<i>cis</i> -[Co(NH ₃) ₄ Cl ₂]Cl

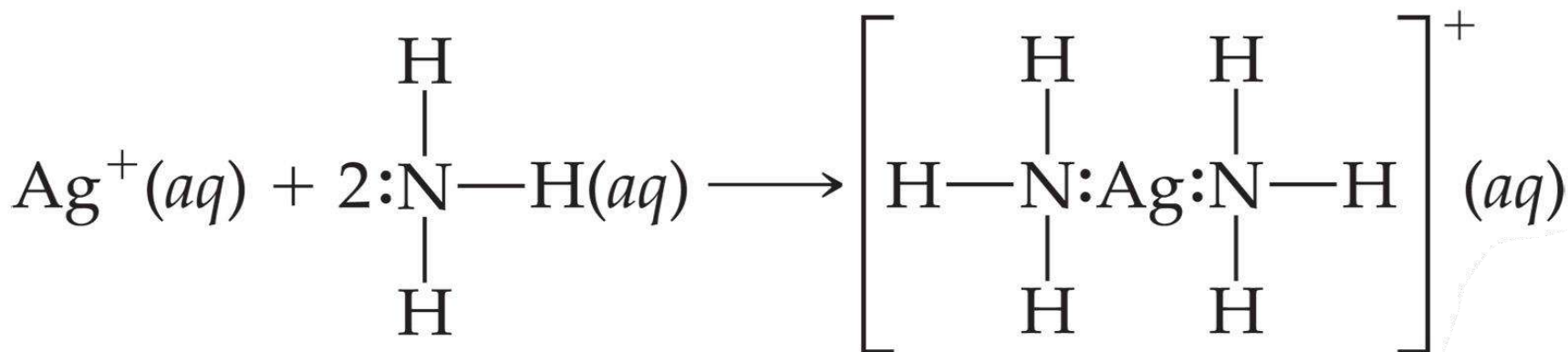
Werner's Theory



- This approach correctly predicts there would be two forms of $\text{CoCl}_3 \cdot 4 \text{NH}_3$.
 - The formula would be written $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$.
 - One of the two forms has the two chlorines next to each other.
 - The other has the chlorines opposite each other.

Metal-Ligand Bond

- This bond is formed between a Lewis acid and a Lewis base.
 - The ligands (Lewis bases) have nonbonding electrons.
 - The metal (Lewis acid) has empty orbitals.



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Ligands

- The molecule or ions which are coordinated to the metal atom or ion.
- Eg. $K_4[Fe(CN)_6]$, the 6 cyanide group coordinated by Fe^{2+} and are the ligands.
- Ligand can be negative ions, positive ions or neutral molecules.
- Ligand are lewis base.
- Central metal atom or ion is lewis acid.

- **Common Ligands:**

1-Monodentate ligands:

Contains only one donar atom

Examples: H_2O , NH_3 , CN^- , SCN^- , X^- (halide ions),
 CO , O^{2-}

2-Bidentate ligands:

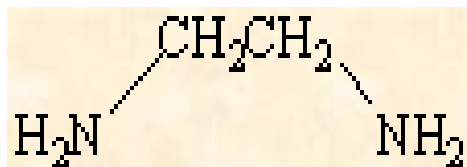
Contains two donar atoms

Examples: Oxalate ion (ox) $\text{C}_2\text{O}_4^{2-}$, etylenediamine (en)
 $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$

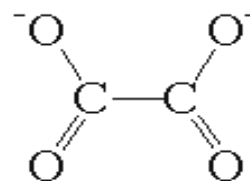
3-Polydentate ligands:

Contains more than two donar atoms

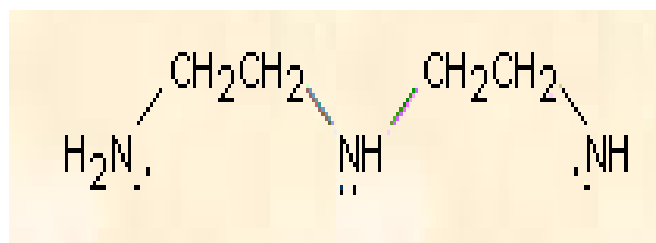
Example: ethylenediaminetetra acetateion (EDTA^{4-})



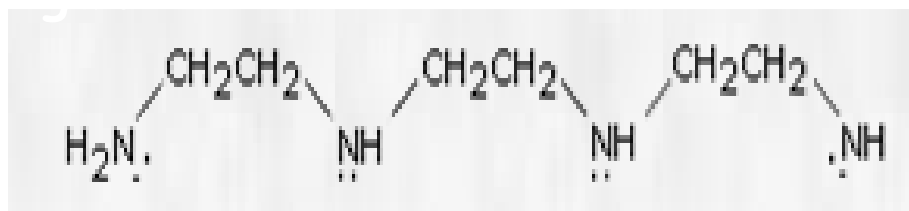
ethylenediamine(en)



oxalate (ox)

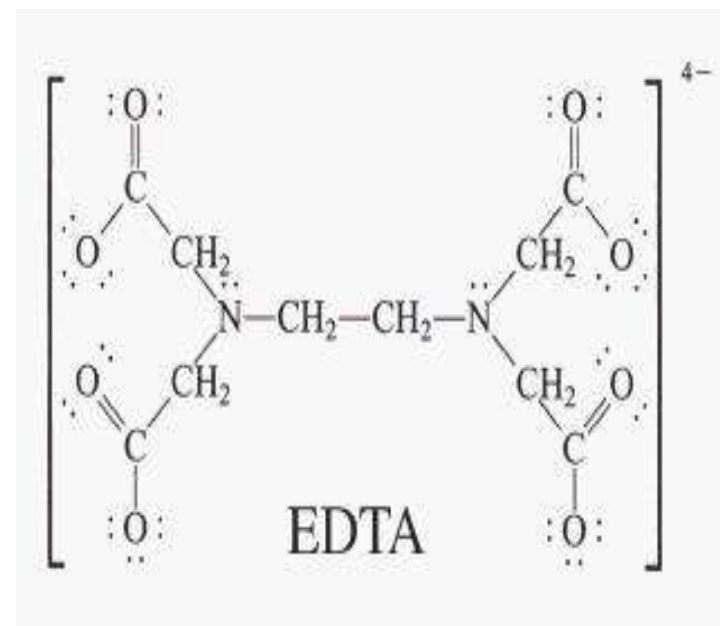
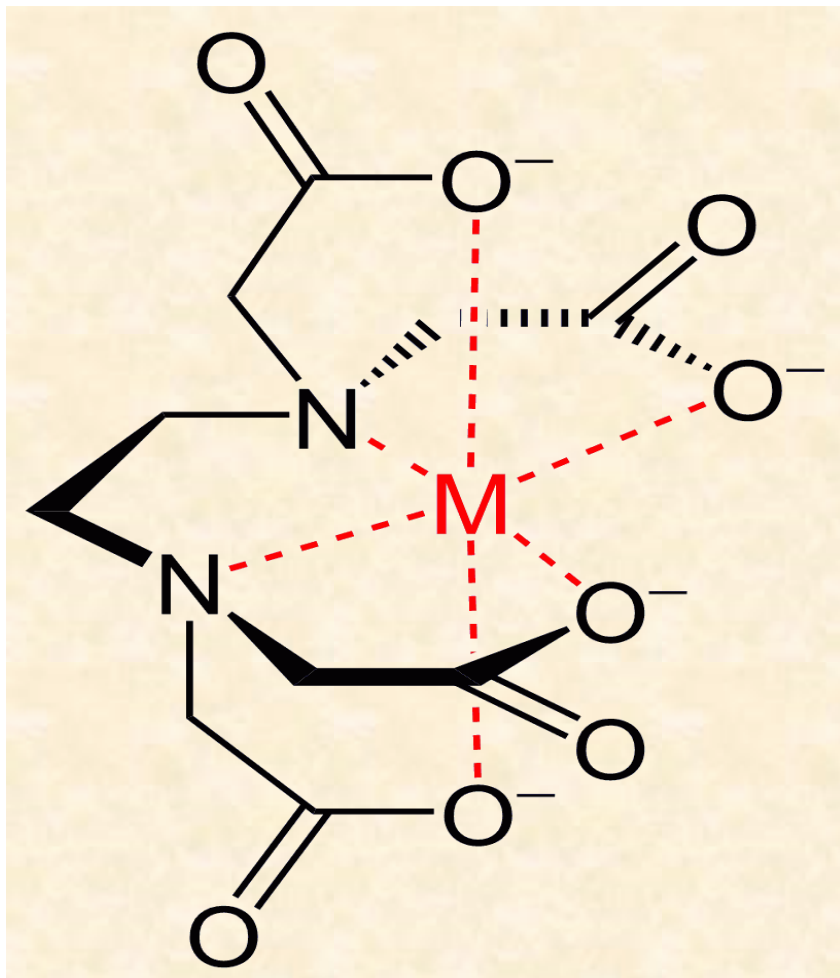


diethylenetriamine(dien)



triethylenetetraamine(trien)

Polydentate ligand (EDTA)



Coordination number : 6

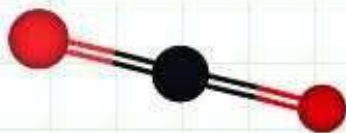
Coordination Number

CN - Number of ligand atoms bonded directly to the central metal ion.
Specific for given metal ion in particular Oxidation #.

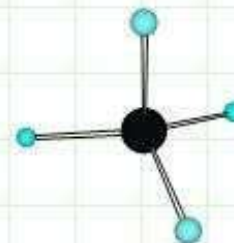
i.e., $[\text{Co}(\text{NH}_3)_6]^+$	CN = 6	Ligand # = 6
$[\text{Ag}(\text{NH}_3)_2]^+$	CN = 2	Ligand # = 2
$[\text{Co}(\text{en})_3]^+$	CN = 6	Ligand # = 3

Geometry of Complex is related to CN.

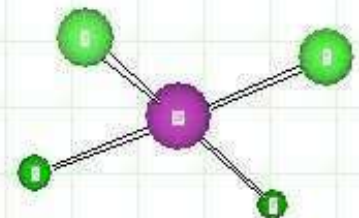
CN = 2 Linear



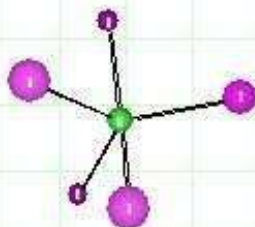
CN = 4 Tetrahedral (d^{10})



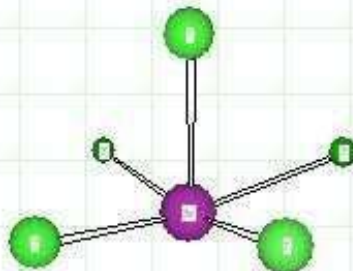
Sq Planar (d^8)



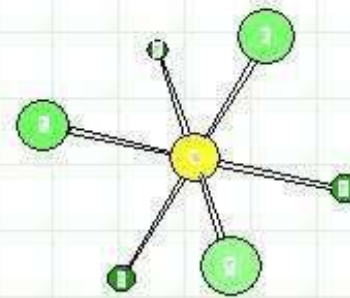
CN = 5 Trigonal bipyramidal



Square Pyramide

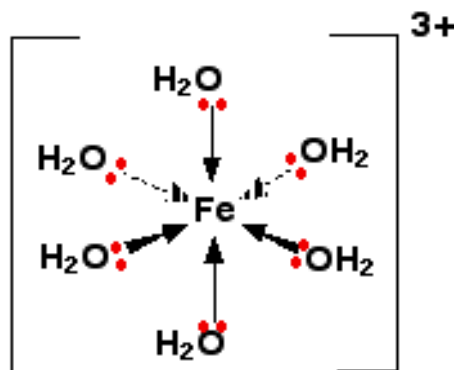


CN = 6 Octahedral

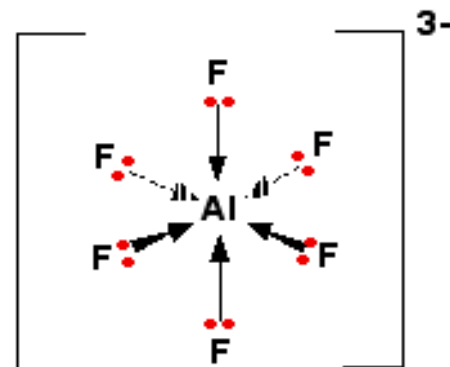


Complex ion

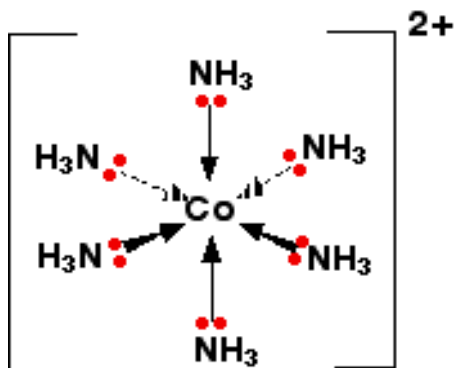
A complex ion has a metal ion at its Centre with a number of other molecules or ions surrounding it.



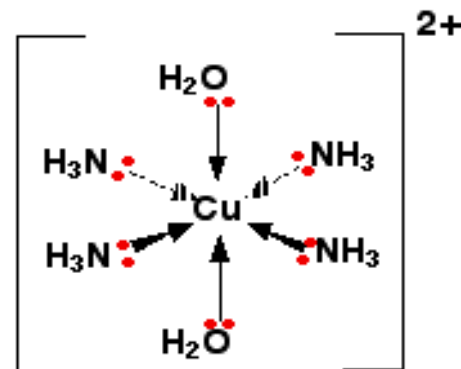
[Fe(H₂O)₆]³⁺



[AlF₆]³⁻

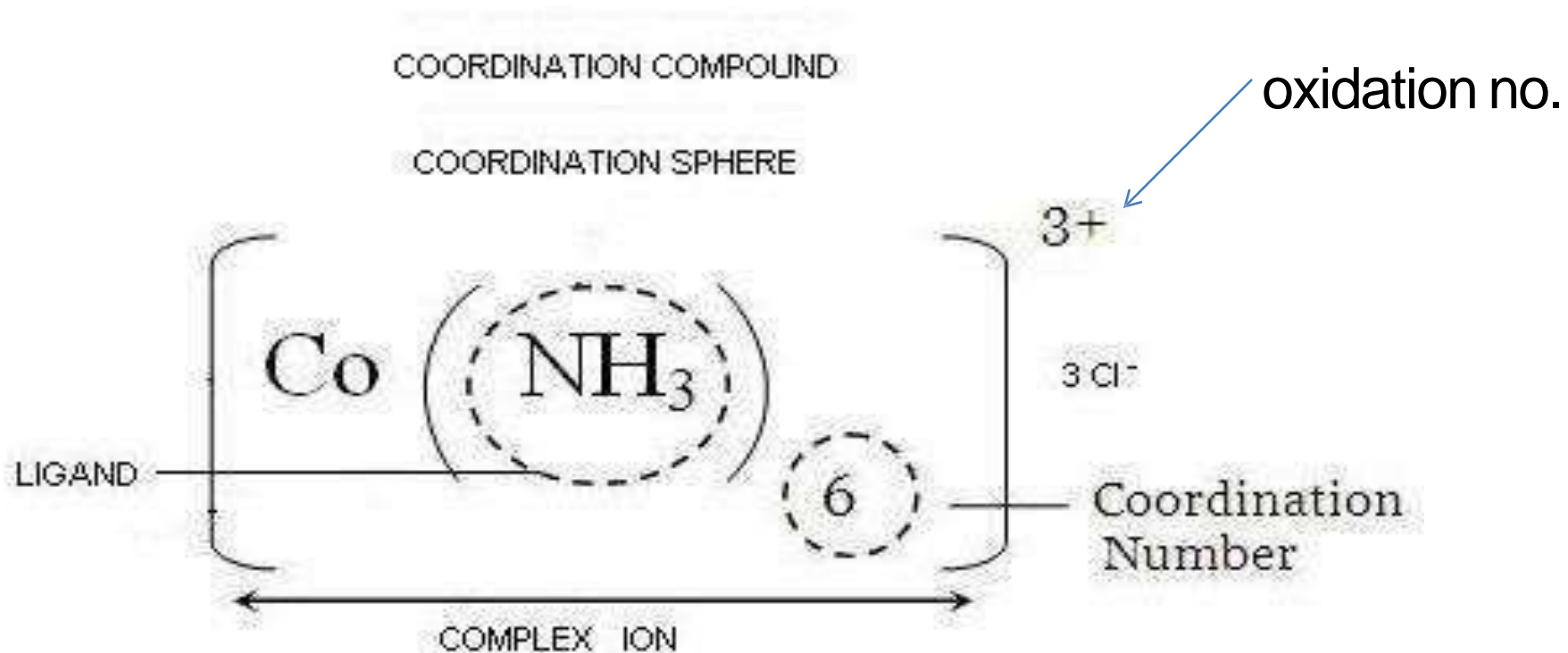


[Co(NH₃)₆]²⁺



[Cu(NH₃)₄(H₂O)₂]²⁺

Coordination sphere ion



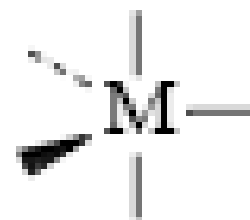
The spatial arrangement of ligand atoms,
directly attached to the central atom/ion.



Square planar



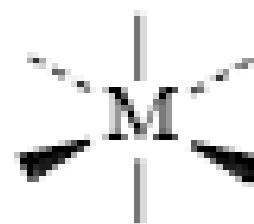
Tetrahedral



Trigonal
bipyramidal



Square
pyramidal



Octahedral

Nomenclature of coordination compounds : IUPAC rules

1. The cation is named first in ionic compounds, then the anion.
2. Nonionic compounds are given a one-word name.
3. The following rules pertain to the names of ligands.
 - a. The ligands are named first and the central atom last.
 - b. Ligands are named in alphabetical order by their root name.
 - c. Neutral ligands are named the same as the molecule, except for a few such as H_2O (aqua) and NH_3 (ammine), which have special names.
 - d. Anionic ligands are named by adding $-o$ to the stem of the usual name, such as chloro for Cl^- and sulfato for SO_4^{2-} .
 - e. The name of each ligand is preceded by a Latin prefix (di-, tri-, tetra-, penta, hexa- etc.) if more than one of that ligand is bonded to the central atom. For example, the ligands in $[\text{PtCl}_4]^{2-}$ are named tetrachloro, and the ligands in $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]^+$ are named tetraamminedichloro.

- If the ligand is polydentate, as in ethylenediamine, the number of ligands bonded to the central atom is indicated by the corresponding Greek prefixes (bis-, tris-, tetrakis-, pentakis-, hexakis-, etc.). For example, the ligands in $[\text{Co}(\text{en})_3]^{3+}$ are named trisethylenediamine. A Greek prefix is also used when a Latin prefix forms a part of the name of the ligand, as in triethylamine, $[\text{N}(\text{CH}_3)_3]$. In this case, the ligand name is enclosed in parentheses. For example, the ligands in $[\text{Co}(\text{N}(\text{CH}_3)_3)_4]^{2+}$ are named tetrakis(triethylamine).
- For a cationic complex ion or a nonionic compound, the central atom is given its ordinary name followed by its oxidation number Roman numerals, enclosed in parentheses. For example, $[\text{Cr}(\text{H}_2\text{O})_5\text{Cl}]^{2+}$ is named pentaquachlorochromium(III) ion, and $[\text{Cr}(\text{NH}_3)_3\text{Cl}_3]$ is named triamminetrichlorochromium(III).
- 5. For anionic complex ions, the suffix -ate is added to the name of the central atom, followed by the oxidation number in Roman numerals, enclosed in parentheses. For example, $[\text{Cr}(\text{CN})_6]^{3-}$ is named hexacyanochromate(III) ion.

Examples for anionic ligands

- ❖ Bromide (Br^-) becomes bromo
- ❖ Chloride (Cl^-) becomes chloro
- ❖ Hydroxide (OH^-) becomes hydroxo
- ❖ Oxide (O^{2-}) becomes oxo
- ❖ Nitrite (NO_2^-) becomes nitrito (M-O bond) or nitro (M-N bond)
- ❖ Carbonate (CO_3^{2-}) becomes carbonato
- ❖ Thiosulfate ($\text{S}_2\text{O}_3^{2-}$) becomes thiosulfato

*Nomenclature of coordination
compounds : IUPAC rules*

Cation named before anion for ionic compounds;

**When naming
complexes:**

- ✓ **Ligands are named first alphabetically**
- ✓ **Metal atom ion is named last**
- ✓ **Coordination state given in Roman numerals follows in parentheses**

Name of anionic ligands end with suffix -o

Change -ide to -o

Change -ite to -ito

Change -ate to -ato

Neutral ligands referred to by their usual names

Example: ethylenediamine

Exceptions

Water, H_2O = aqua

Ammonia, NH_3 = ammine

Carbon monoxide, CO = carbonyl

Number of each type of ligand in a complex is indicated by prefix

di-.2, tri-. 3, tetra-. 4, penta-.5,

If the name of the ligand begins with/ contains a prefix,

bis-.2, tris-. 3, tetrakis-.4, pentakis-.5, hexakis-.6

When there is more than one of a particular ligand, number is specified by di, tri, tetra, penta, hexa, and so forth. when confusion might result, the prefixes bis, tris and tetrakis are employed e.g. bis(ethylenediamine) negative (anionic) complex ions always end in the suffix -ate

aluminum -----> aluminate

chromium -----> chromate

manganese -----> manganate

cobalt -----> cobaltate

For some metals the -ate is appended to the Latin system always appears with

the common English name for the element

iron ----> ferr -----> ferrate

copper ---> cupra -----> cuprate

lead ----> plumb -----> plumbate

silver ---> argent ----> argentate

gold ---> aur ----> aurate

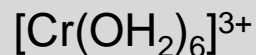
tin ----> stann -----> stannate

the oxidation number of the metal in the complex is written in roman numerals within parentheses following the name of the metal

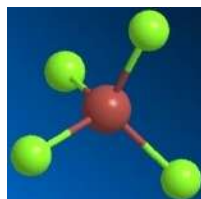
Examples of complexes derived from common ligands



Water



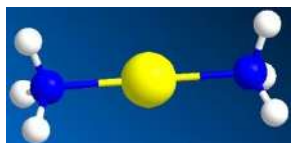
Hexaaquachromium(III) ion



Halide



Potassium tetrachloroferrate(III)



Ammonia



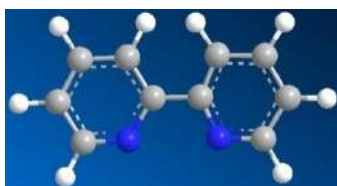
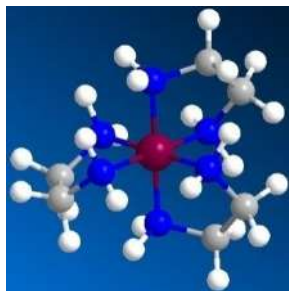
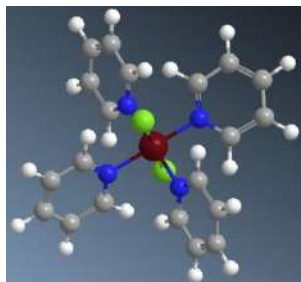
Diamminesilver(I) ion

Cyanide



Tetracyanonickelate(II)

Examples of complexes derived from common ligands



Ligand	Complex	IUPAC name
pyridine	$[\text{Ru}(\text{py})_4\text{Cl}_2]$	dichlorotetrapyridineruthenium(II).
Ethylene diamine	$[\text{Co}(\text{en})_3]^{3+}$	Tris(ethylenediamine)cobalt(III)ion
Bipyridine (bipy)	$[\text{Ru}(\text{bipy})_3]^{3+}$ -	Tris(bipyridyl)ruthenium(III)ion

Formula of coordination compound



Name of coordination compound

Pentaamminechlorocobalt(III)chloride

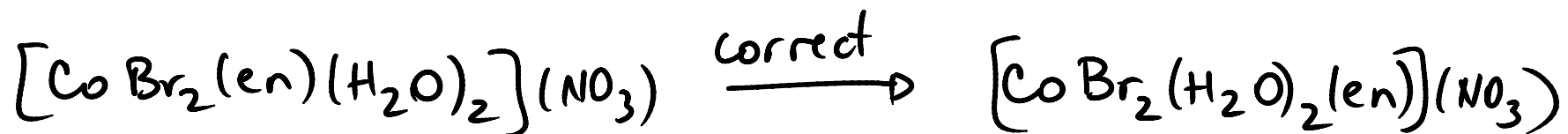
Sodium amminebromochloronitro-N-platinate(II)

Potassium tetracyanonickelate(II)

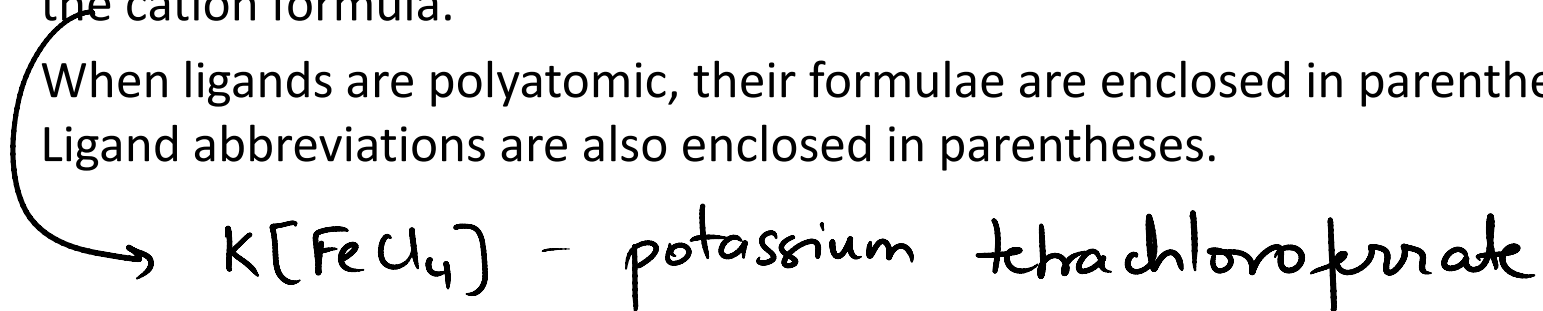
Ammonium hexacyanoferrate(III)

Diamminesilver(I)diaquadioxalatomanganate(III)

Nomenclature rules: Formulae



- In a coordination formula, the central atom is listed first.
- The formally anionic ligands appear next, listed in alphabetical order according to the first symbols of their formula. The neutral ligands follow, also in alphabetical order, according to the same principle. The formula of the entire coordination entity, whether charged or not, is enclosed in square brackets.
- If the coordination entity is negatively charged, the formula is preceded by the cation formula.
- When ligands are polyatomic, their formulae are enclosed in parentheses. Ligand abbreviations are also enclosed in parentheses.



- 1. In naming the entire complex, the name of the cation is given first and the anion second (just as for sodium chloride), no matter whether the cation or the anion is the complex species.
- 2. In the complex ion, the name of the ligand or ligands precedes that of the central metal atom. (This procedure is reversed from writing formulae.)

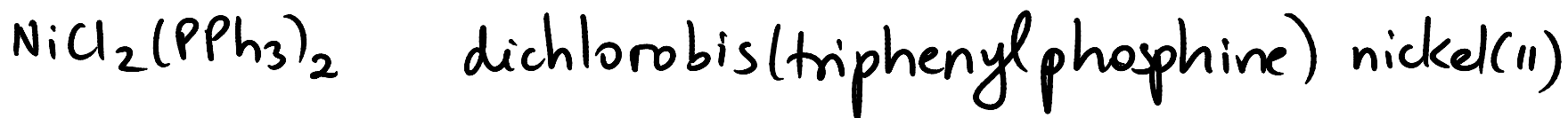
$[\text{Co}(\text{en})_3]\text{Cl}_3$ - tris(ethylenediamine) cobalt(III) chloride

- 3. Ligand names generally end with 'o' if the ligand is negative ('chloro' for Cl^- , 'cyano' for CN^- , 'hydro' for H^-) and unmodified if the ligand is neutral ('methanamine' for MeNH_2).

Special ligand names are 'aqua' for water, 'ammine' for ammonia, 'carbonyl' for CO , 'nitrosyl' for NO .

$\text{Fe}(\text{CO})_5$ - pentacarbonyl iron(0)

- 4. A Greek prefix (mono, di, tri, tetra, penta, hexa, etc.) indicates the number of each ligand (mono is usually omitted for a single ligand of a given type). If the name of the ligand itself contains the terms mono, di, tri, eg triphenylphosphine, then the ligand name is enclosed in parentheses and its number is given with the alternate prefixes bis, tris, tetrakis instead.



- Again, one would use diamine, for $(\text{NH}_3)_2$, but bis(methylamine), for $(\text{NH}_2\text{Me})_2$, to make a distinction from dimethylamine. (Note that this ambiguity does not arise if the preferred IUPAC name, methenamine, is used instead of methylamine).

There is no elision of vowels or use of a hyphen, e.g. in tetraamine and similar names. Some texts suggest that if a ligand is "complicated" then use the bis, tris multipliers. What constitutes "complicated" is not spelled out however, so a simpler approach is to use them if the name of the ligand is three or more syllables long!

- 5. A Roman numeral or a zero in parentheses is used to indicate the oxidation state of the central metal atom.
- 6. If the complex ion is negative, the name of the metal ends in 'ATE' for example, ferrate, cuprate, nickelate, cobaltate, etc.
- 7. If more than one ligand is present in the species, then the ligands are named in **alphabetical order** regardless of the number of each. For example, NH_3 (ammine) would be considered an 'a' ligand and come before Cl^- (chloro).

Some additional notes

- *Some metals in anions have special names*

B - Borate Au - Aurate Ag - Argentate Fe - Ferrate

Pb - Plumbate Sn - Stannate Cu - Cuprate

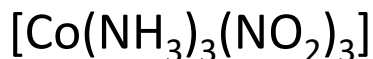
- *Use of brackets or enclosing marks*

Square brackets are used to enclose a complex ion or neutral coordination species.

Examples:



note that it is not necessary to enclose the halogens in brackets.



Note that in 2004 it was recommended that anionic ligands will end with -*ido* so that chloro would become chlorido, etc.