Chapter 20

Electron Configurations

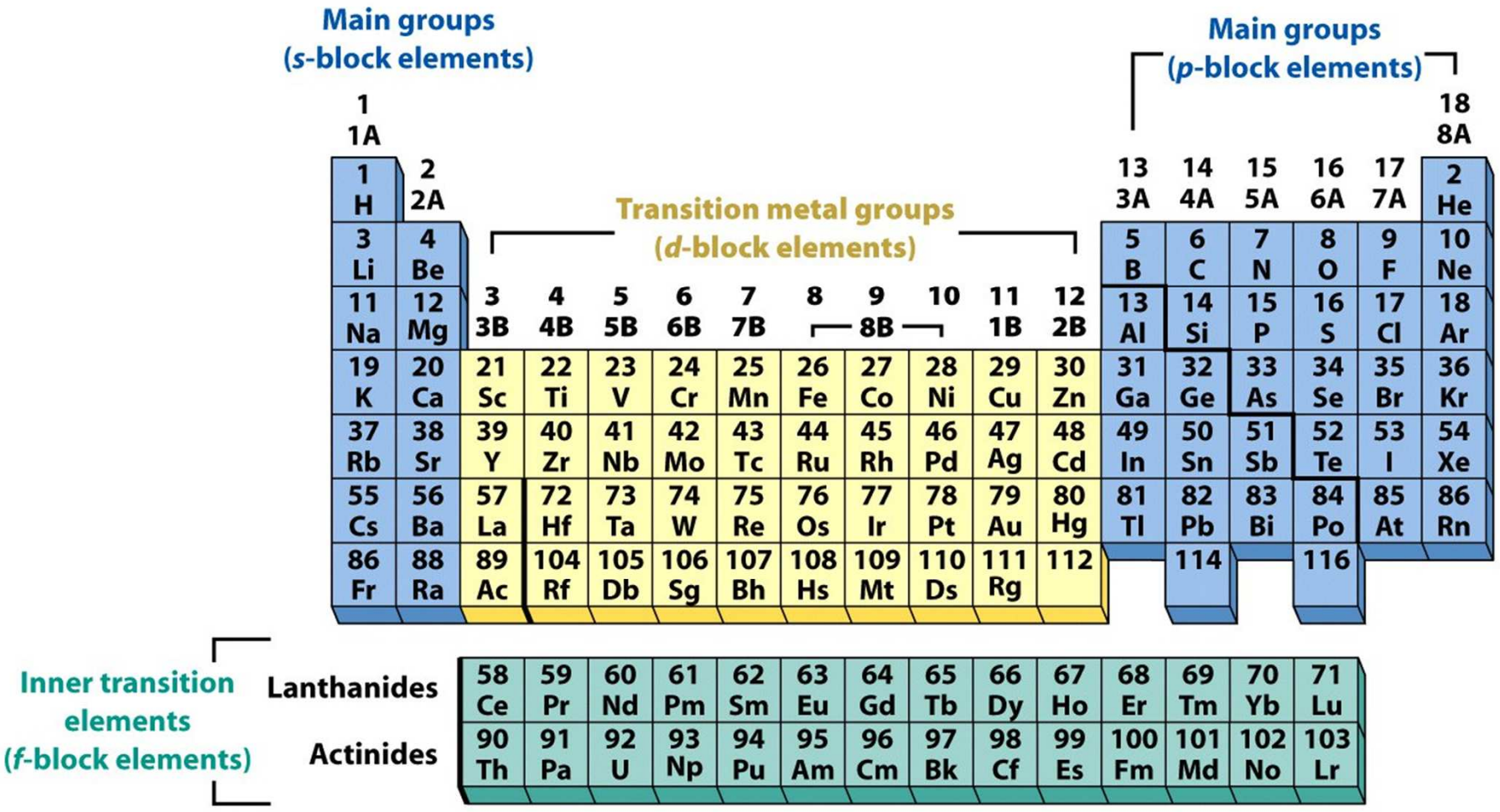
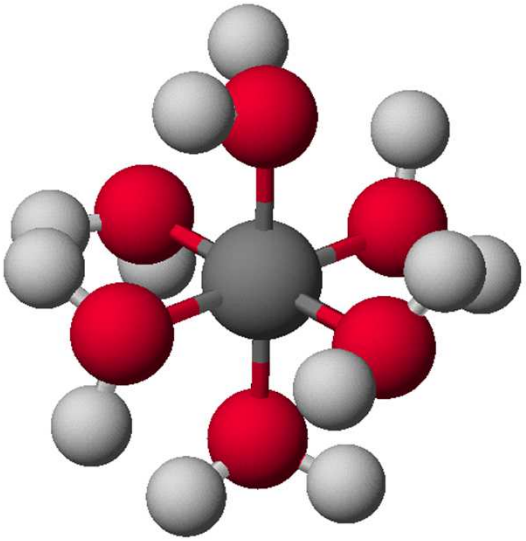


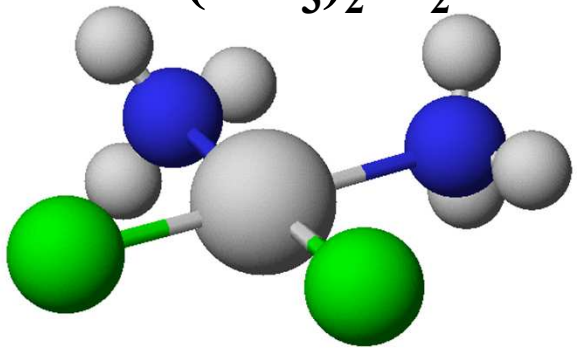
Figure 20-1 Chemistry, 5/e

Coordination Compounds

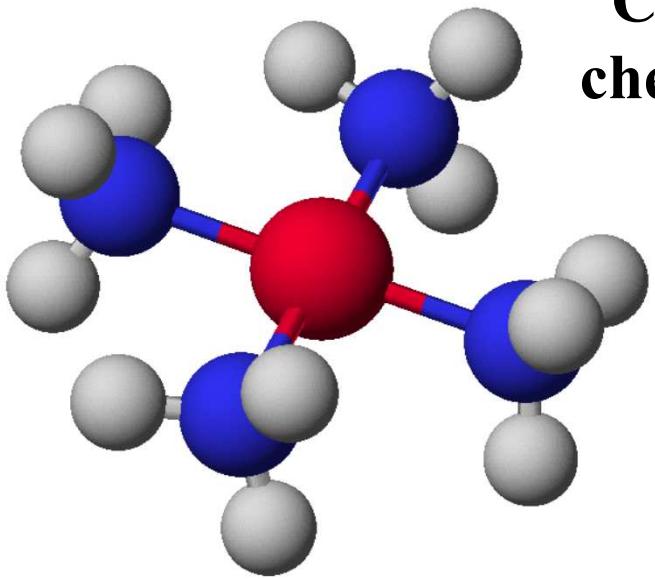


$Co(H_2O)_6^{2+}$

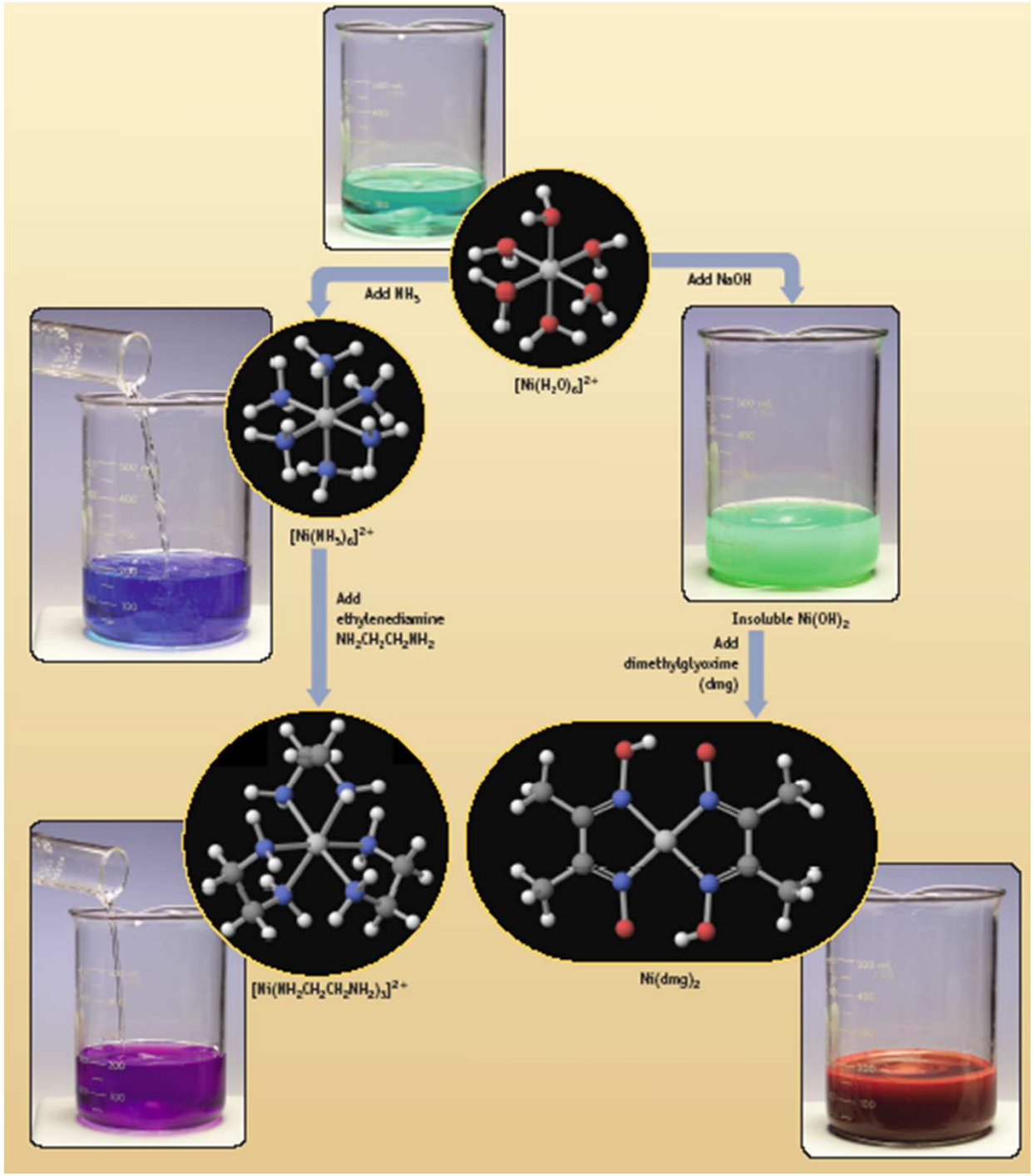
$Pt(NH_3)_2Cl_2$



"Cisplatin" - a cancer chemotherapy agent



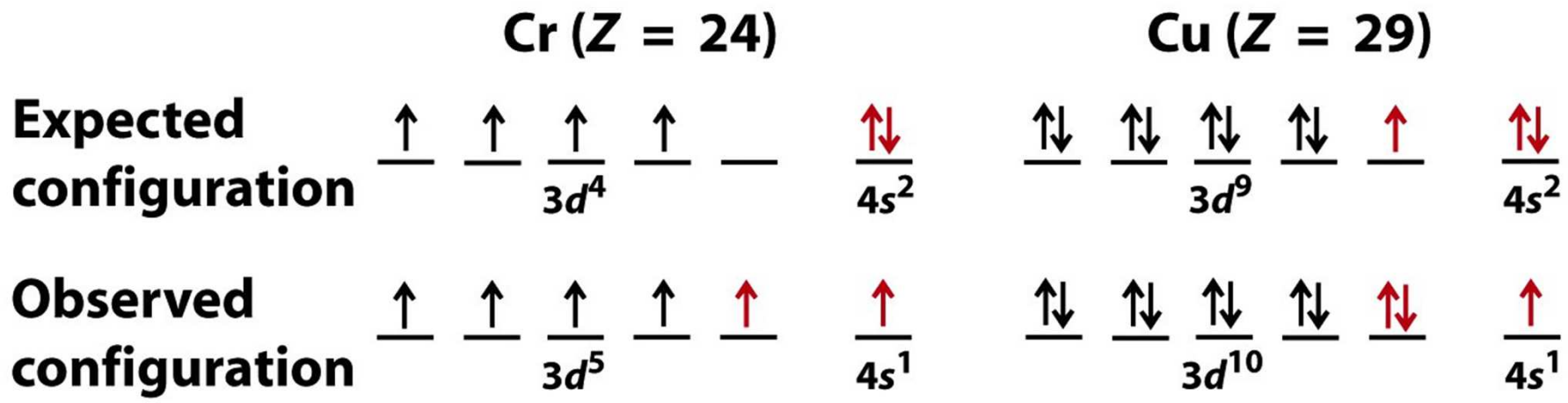
$Cu(NH_3)_4^{2+}$



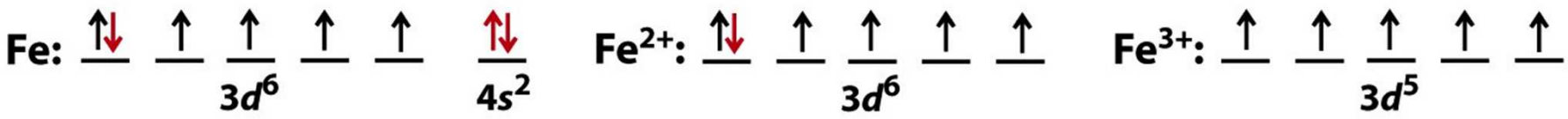
Coordination Compounds of Ni^{2+}

Electron Configurations

Sc (Z = 21): [Ar] $3d^1\ 4s^2$ **Zn** (Z = 30): [Ar] $3d^{10}\ 4s^2$



Unnumbered 20 p815a Chemistry, 5/e



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Omit 20.2 - 20.4

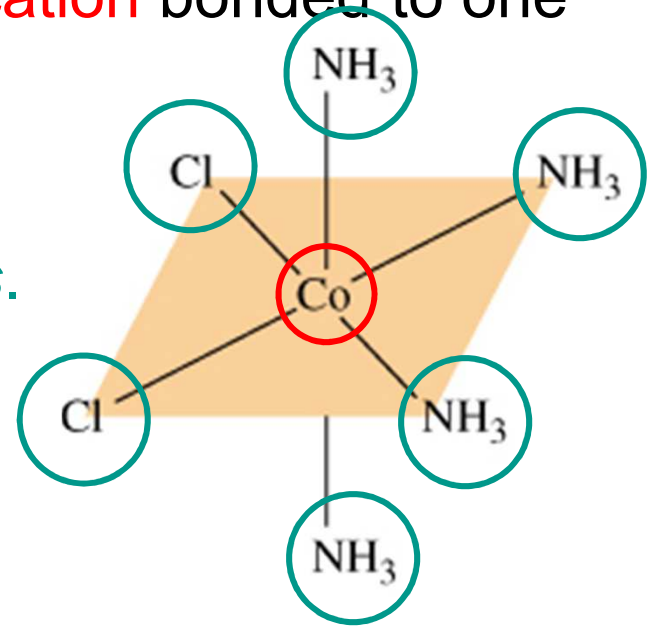
Coordination Compounds

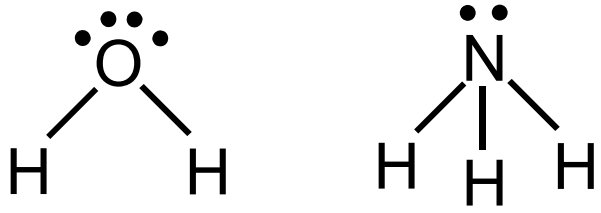
Many ***coordination compound*** consists of a complex ion.

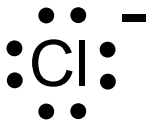
A ***complex ion*** contains a central metal cation bonded to one or more molecules or ions.

The molecules or ions that surround the metal in a complex ion are called ***ligands***.

A ligand has **at least one** unshared pair of valence electrons

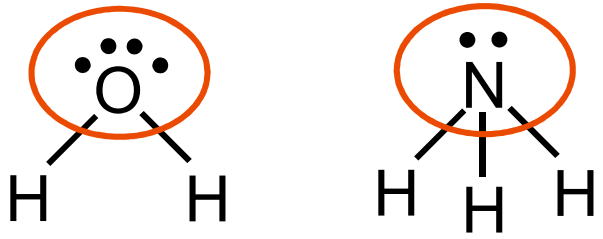






Coordination Compounds

The atom in a ligand that is bound directly to the metal atom is the ***donor atom***.



Ligands with:

one donor atom	monodentate	H_2O, NH_3, Cl^-
two donor atoms	bidentate	ethylenediamine
three or more donor atoms	polydentate	EDTA

The number of donor atoms surrounding the central metal atom in a complex ion is the ***coordination number***.

Coordination Compounds

Coordination Number: The number of ligand donor atoms that surround a central metal ion or atom.

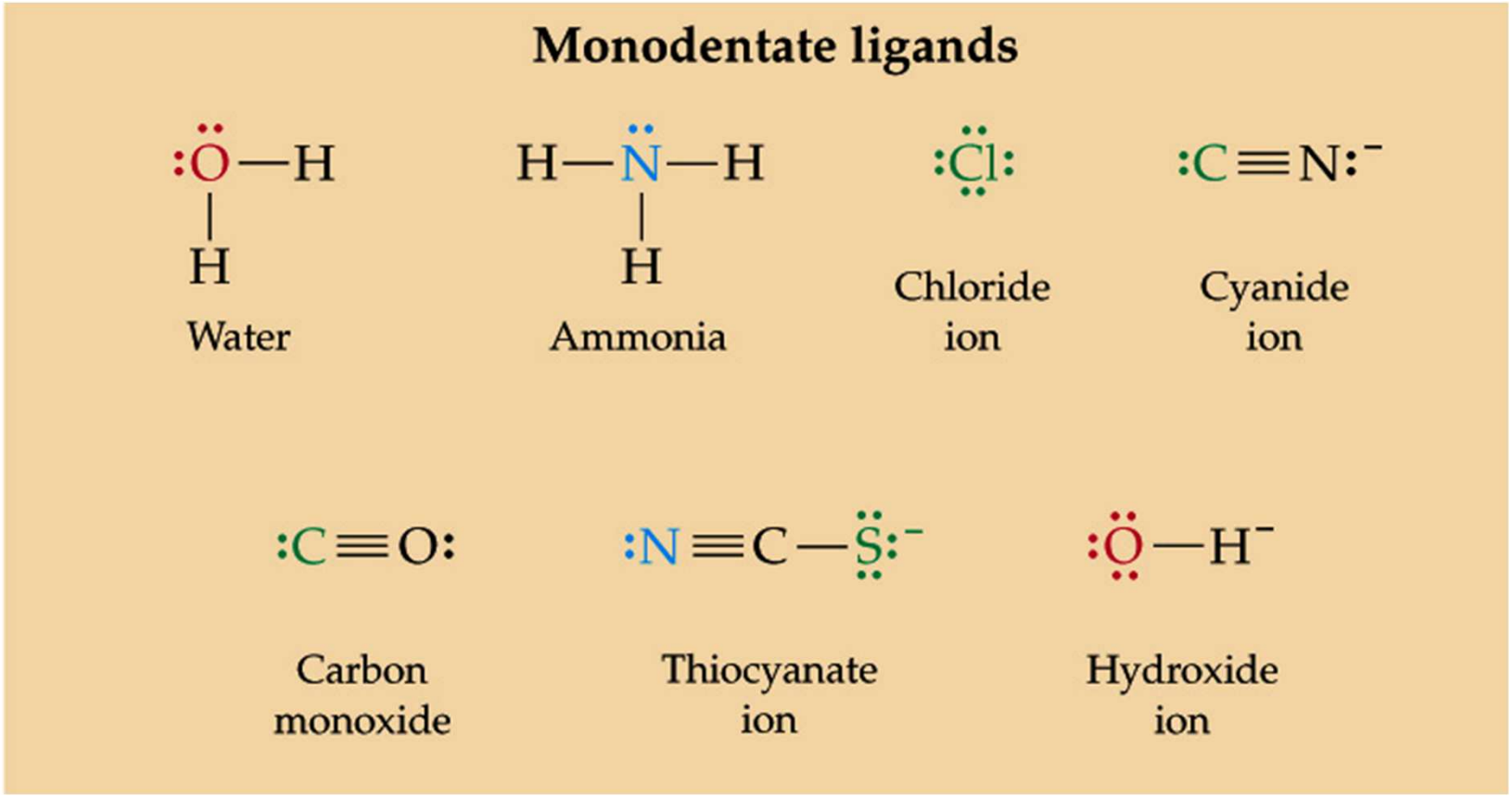
TABLE 20.4 Examples of Complexes with Various Coordination Numbers

Coordination Number	Complex
2	$[Ag(NH_3)_2]^+$, $[CuCl_2]^-$
3	$[HgI_3]^-$
4	$[Zn(NH_3)_4]^{2+}$, $[Ni(CN)_4]^{2-}$
5	$[Ni(CN)_5]^{3-}$, $Fe(CO)_5$
6	$[Cr(H_2O)_6]^{3+}$, $[Fe(CN)_6]^{3-}$
7	$[ZrF_7]^{3-}$
8	$[Mo(CN)_8]^{4-}$

Table 20-4 Chemistry, 5/e

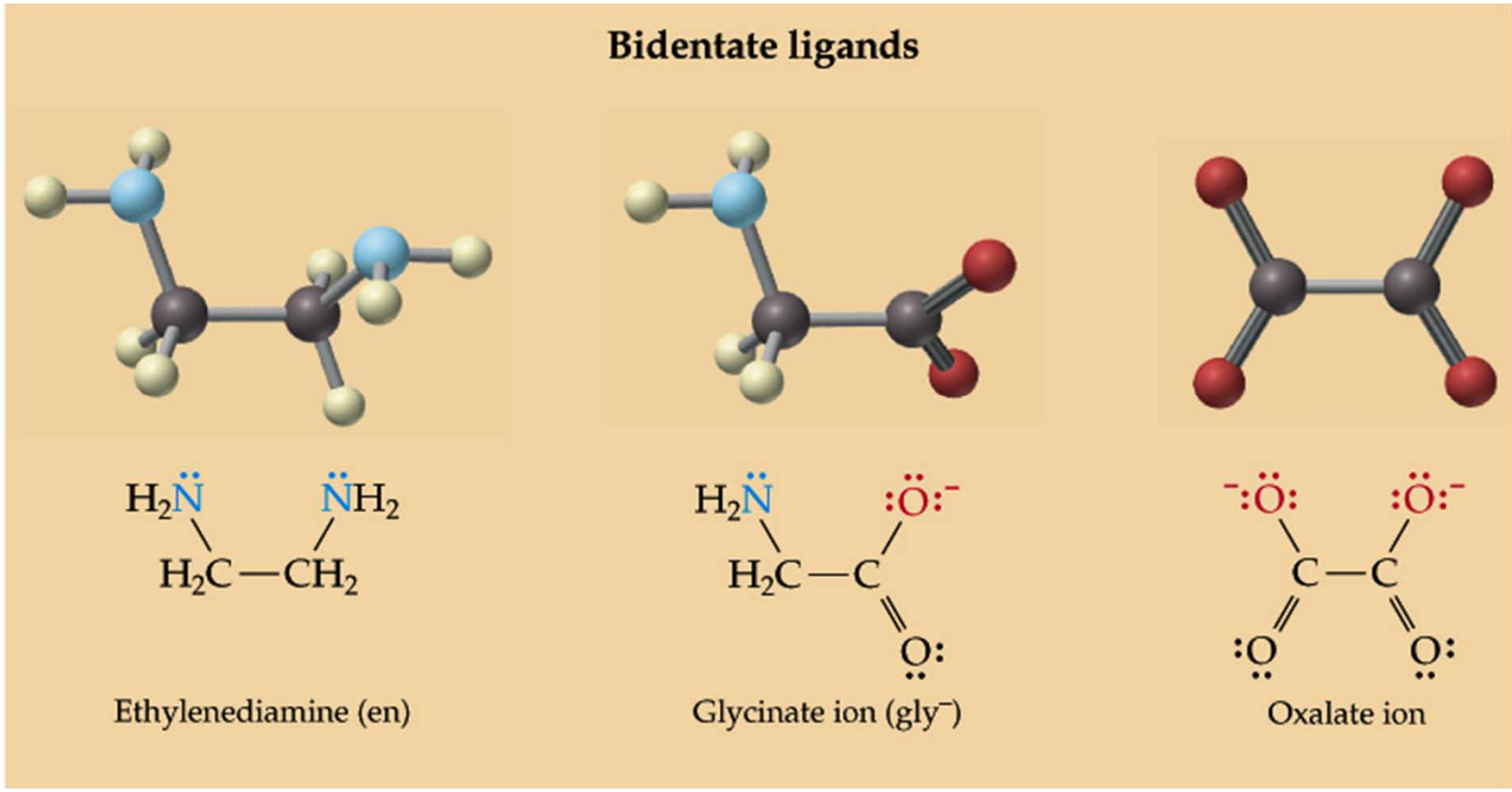
Ligands

02


Monodentate ligands
Water
Ammonia
Chloride ion
Cyanide ion
Carbon monoxide
Thiocyanate ion
Hydroxide ion

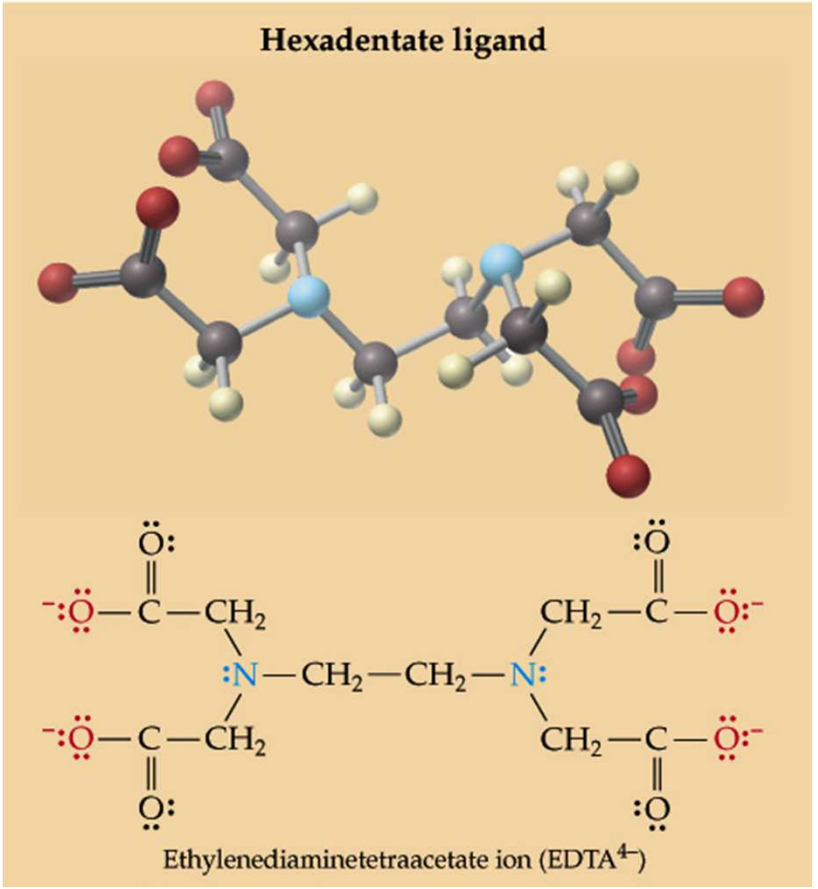
Ligands

03


Bidentate ligands
Ethylenediamine (en)
Glycinate ion (gly⁻)
Oxalate ion

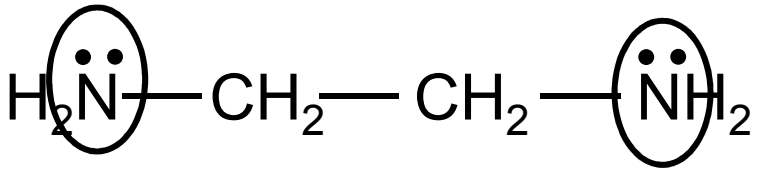
Poly DentateLigands

- **$EDTA^{4-}$** is often used to treat heavy metal poisoning such as Hg^{2+}, Pb^{2+}, and Cd^{2+}.
- **$EDTA^{4-}$** bonds to Pb^{2+}, which is excreted by the kidneys as $[Pb(EDTA)]^{2-}$.

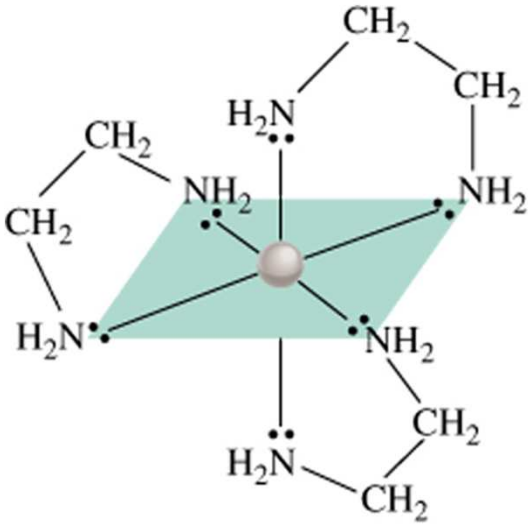


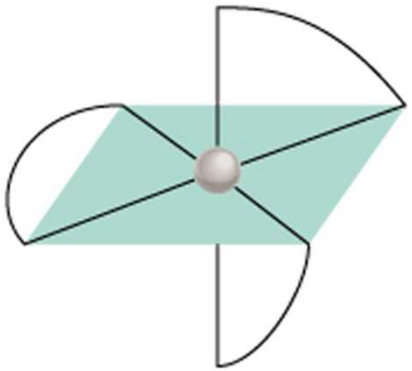
Coordination Compounds

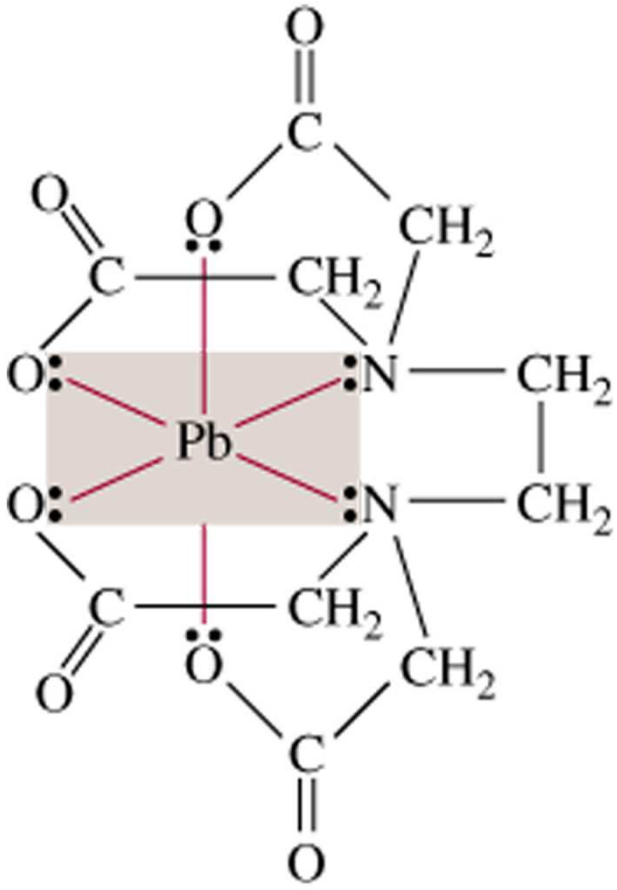
bidentate ligand



polydentate ligand (EDTA)

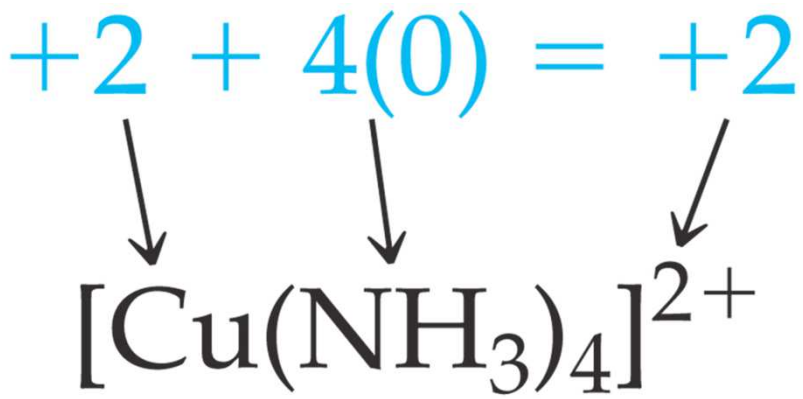






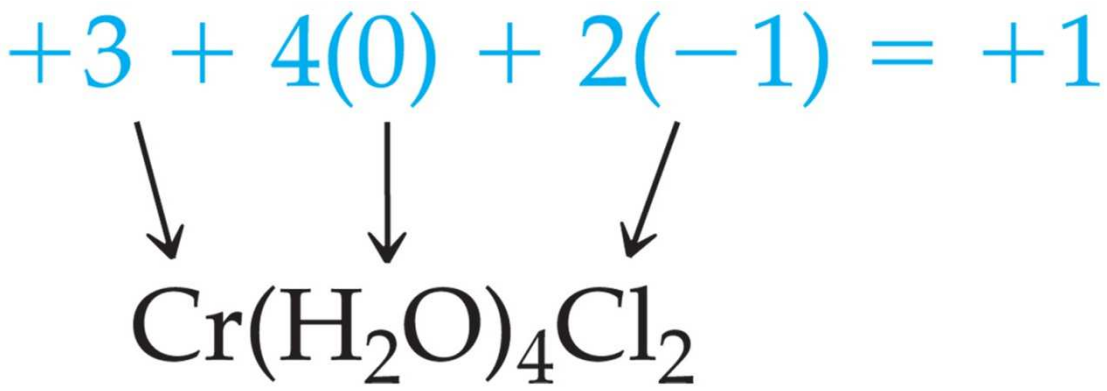
Bidentate and polydentate ligands are called ***chelating agents***

What is the Oxidation Numbers of Cu?



Knowing the charge on a complex ion and the charge on each ligand, one can determine the oxidation number for the metal.

What is the charge on the following Complex, If the Oxidation number of Cr is +3?



Or, knowing the oxidation number on the metal and the charges on the ligands, one can calculate the charge on the complex ion.

What are the oxidation numbers of the metals in $K[Au(OH)_4]$ and $[Cr(NH_3)_6](NO_3)_3$?

OH^- has charge of -1

K^+ has charge of +1

? Au + 1 + 4x(-1) = 0

Au = +3

NO_3^- has charge of -1

NH_3 has no charge

? Cr + 6x(0) + 3x(-1) = 0

Cr = +3

Oxidation States of the 1st Row Transition Metals

(most stable oxidation numbers are shown in red)

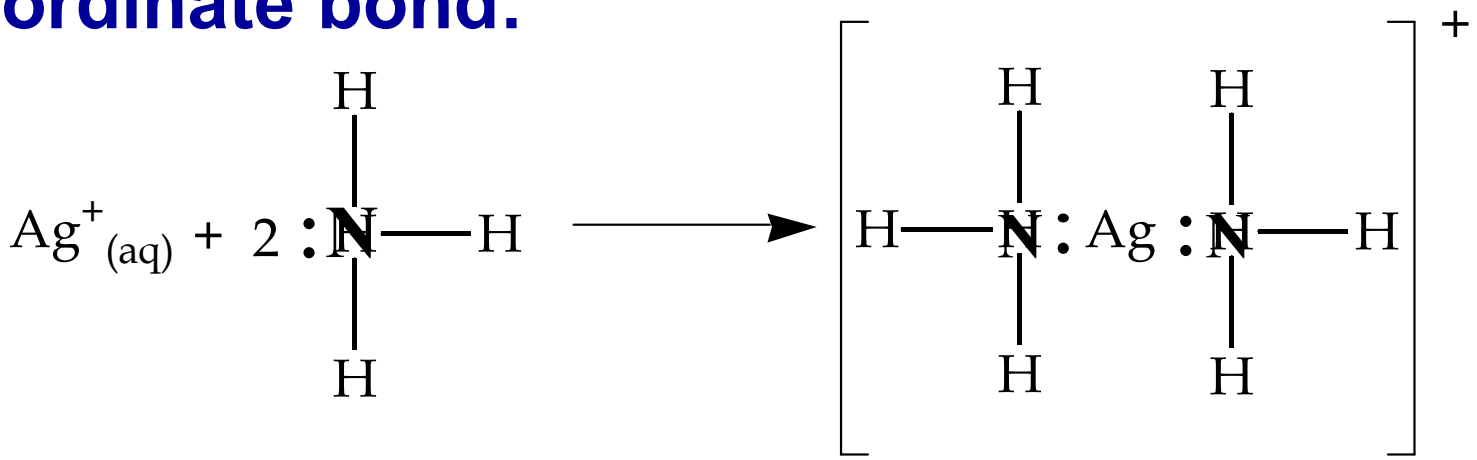
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu
				+7				
			+6	+6	+6			
		+5	+5	+5	+5			
	+4	+4	+4	+4	+4	+4		
+3	+3	+3	+3	+3	+3	+3	+3	+3
	+2	+2	+2	+2	+2	+2	+2	+2
								+1

Learning Check

A complex ion contains a Cr^{3+} bound to four H_2O molecules and two Cl^- ions. Write its formula.

Writing Formula for Coordinated Complex

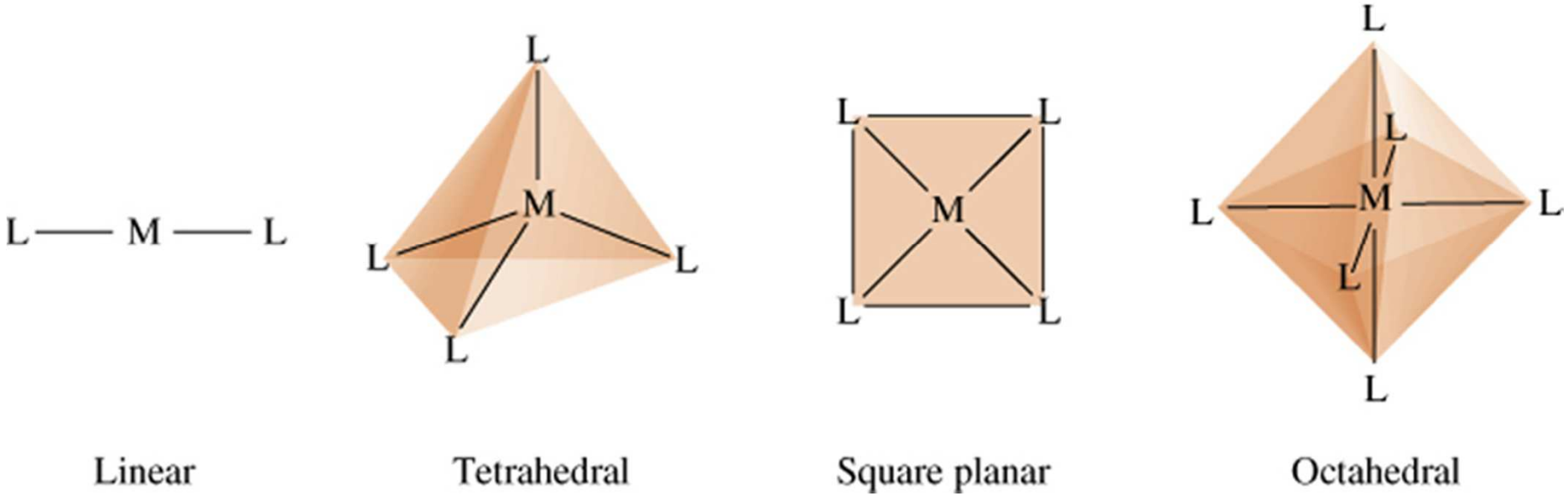
- **Coordinate bond:**



- **Coordination Sphere:** is the central metal and surrounding ligands. The square brackets separate the complex from counter ions such as SO_4^{2-}.

$$[Ag(NH_3)_2]_2\,SO_4$$

Geometry of Coordination Compounds

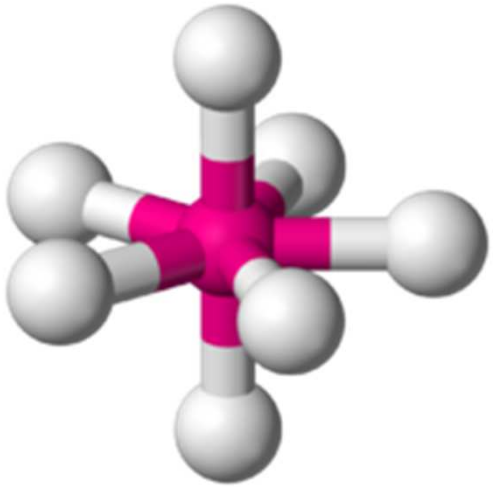


Linear Tetrahedral Square planar Octahedral

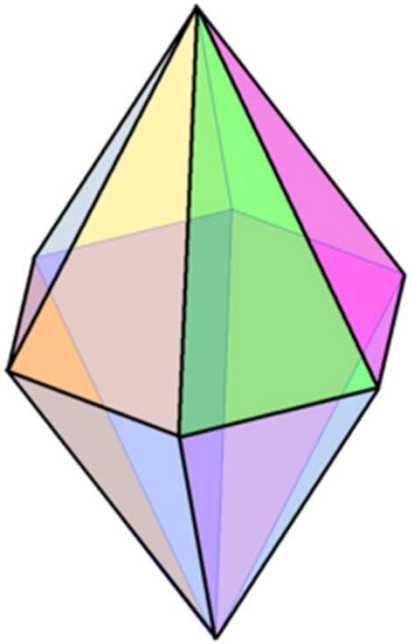
Coordination number	Structure
2	Linear
4	**Tetrahedral (mostly d^{10})or Square planar (mostly d^8)**
6	Octahedral

Coordination Number of 7&8

- Geometry



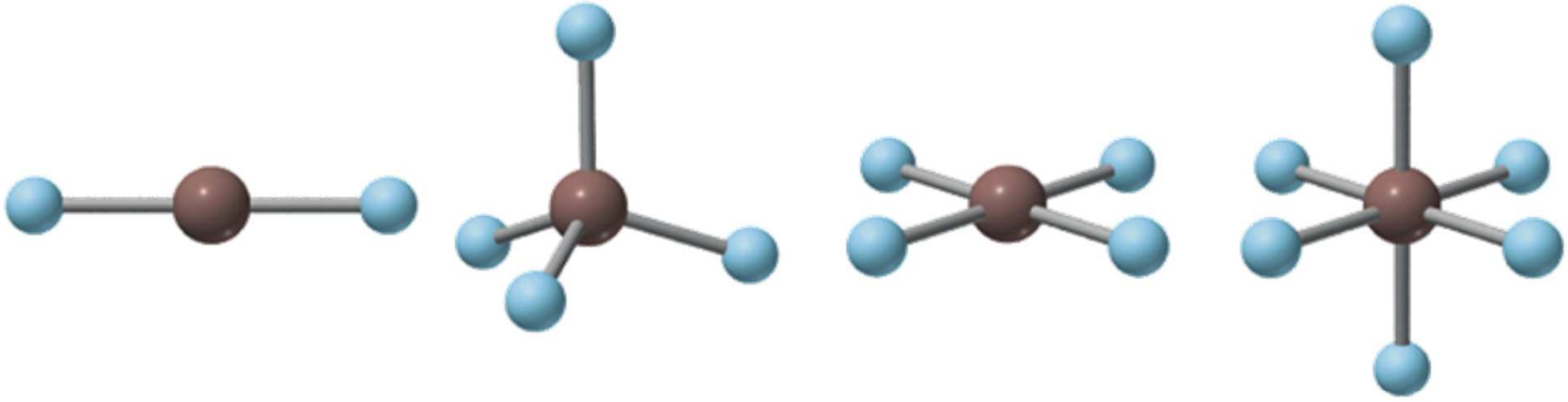
Pentagonal bipyramid

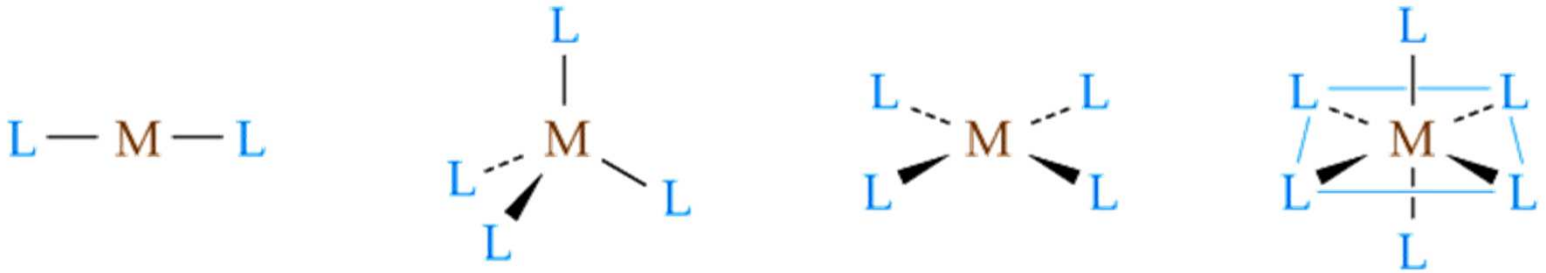


Hexagonal bipyramid

Coordination Compounds

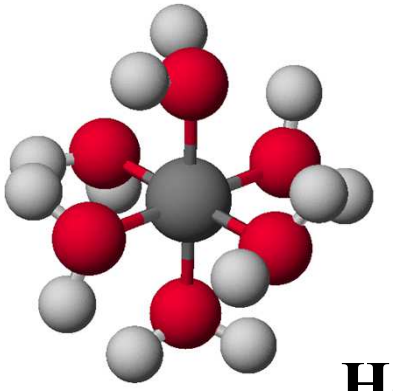
- **Geometries:**





Linear Tetrahedral Square planar Octahedral

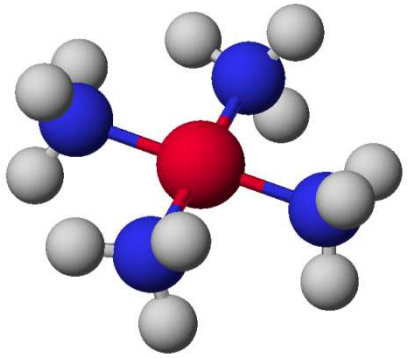
Nomenclature



$Co(H_2O)_6^{2+}$

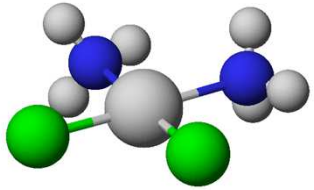
Hexaaquacobalt(II)

H_2O as a ligand is aqua



$Cu(NH_3)_4^{2+}$

Tetraamminecopper(II)



$Pt(NH_3)_2Cl_2$ **diamminedichloroplatinum(II)**

NH_3 as a ligand is ammine

Systematic naming specifies the type and number of ligands, the metal, and its oxidation state.

Ligand's Names 01

TABLE 20.5 Names of Some Common Ligands

Anionic Ligand	Ligand Name	Neutral Ligand	Ligand Name
Bromide, Br^-	Bromo	Ammonia, NH_3	Ammine
Carbonate, CO_3^{2-}	Carbonato	Water, H_2O	Aqua
Chloride, Cl^-	Chloro	Carbon monoxide, CO	Carbonyl
Cyanide, CN^-	Cyano	Ethylenediamine, en	Ethylenediamine
Fluoride, F^-	Fluoro		
Glycinate, gly^-	Glycinato		
Hydroxide, OH^-	Hydroxo		
Oxalate, $C_2O_4^{2-}$	Oxalato		
Thiocyanate, SCN^-	Thiocyanato*		
	Isothiocyanato†		

* Ligand donor atom is S. † Ligand donor atom is N.

Nomenclature

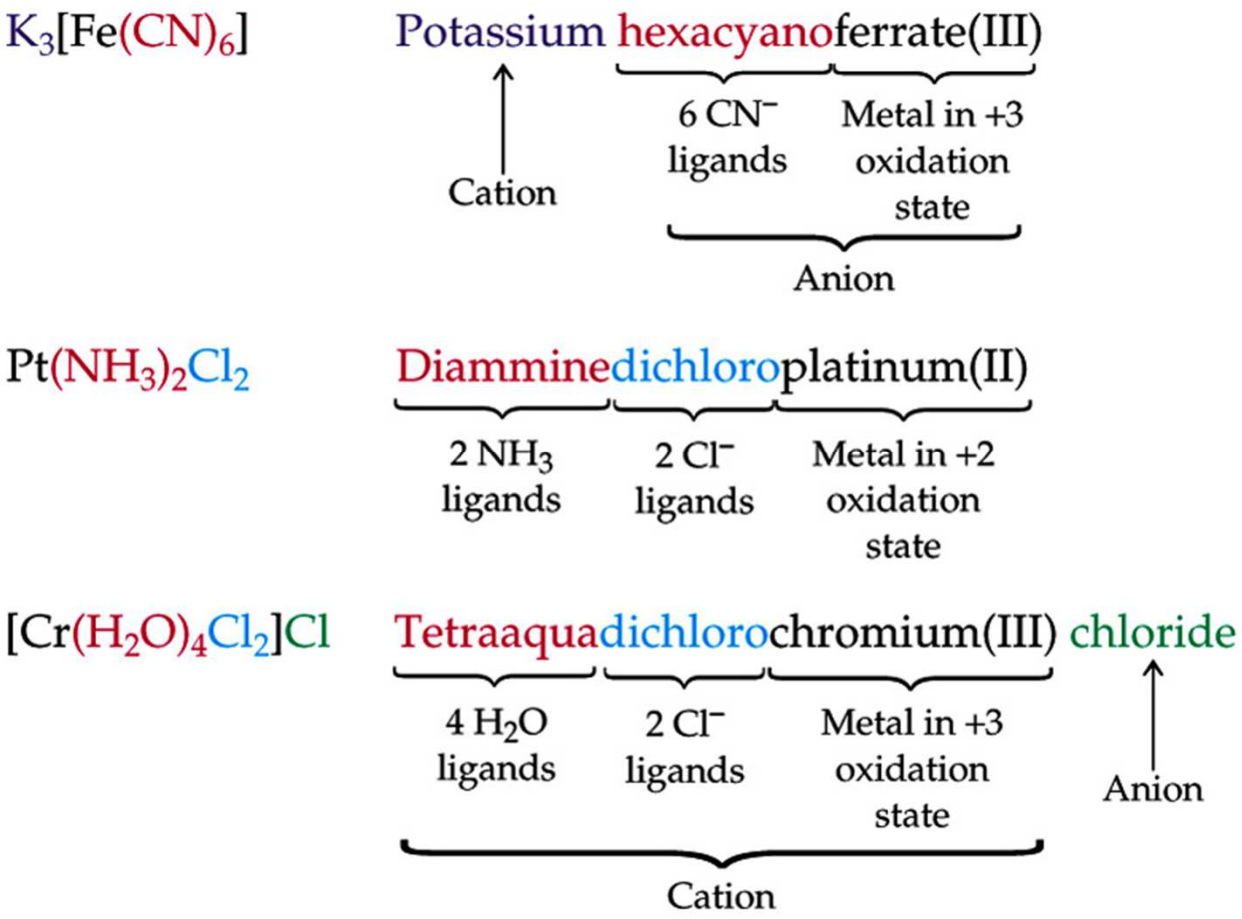


Table 22.5 Names of Anions Containing Metal Atoms

Metal	Name of Metal in Anionic Complex
Aluminum	Aluminate
Chromium	Chromate
Cobalt	Cobaltate
Copper	Cuprate
Gold	Aurate
Iron	Ferrate
Lead	Plumbate
Manganese	Manganate
Molybdenum	Molybdate
Nickel	Nickelate
Silver	Argentate
Tin	Stannate
Tungsten	Tungstate
Zinc	Zincate

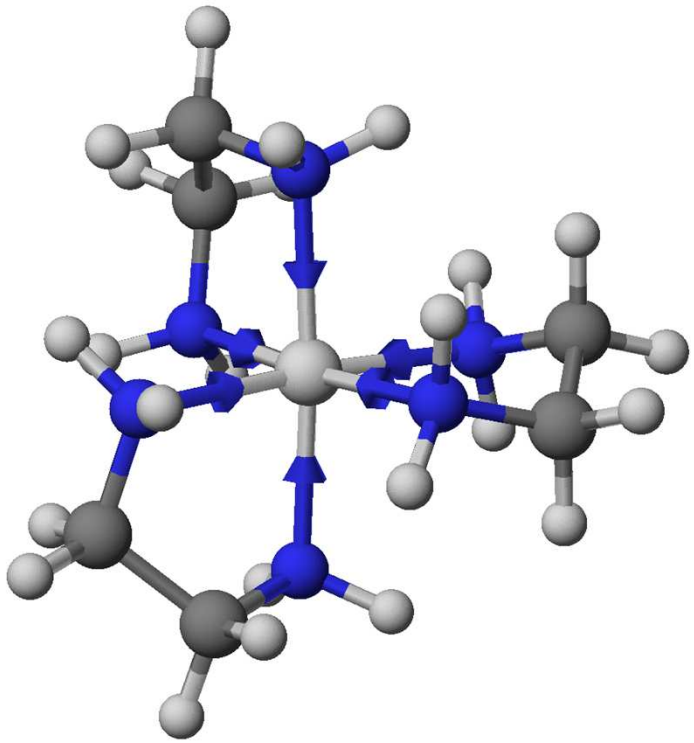
Nomenclature

- **Systematic naming follows IUPAC rules:**
  - If compound is a salt, name cation first and then the anion, just as in naming simple salts.
  - In naming a complex ion or neutral complex, name ligands first and then the metal.
  - If the complex contains more than one ligand of a particular type, indicate the number with the appropriate Greek prefix: *di–, tri–, tetra–, penta–, hexa–*.

Nomenclature

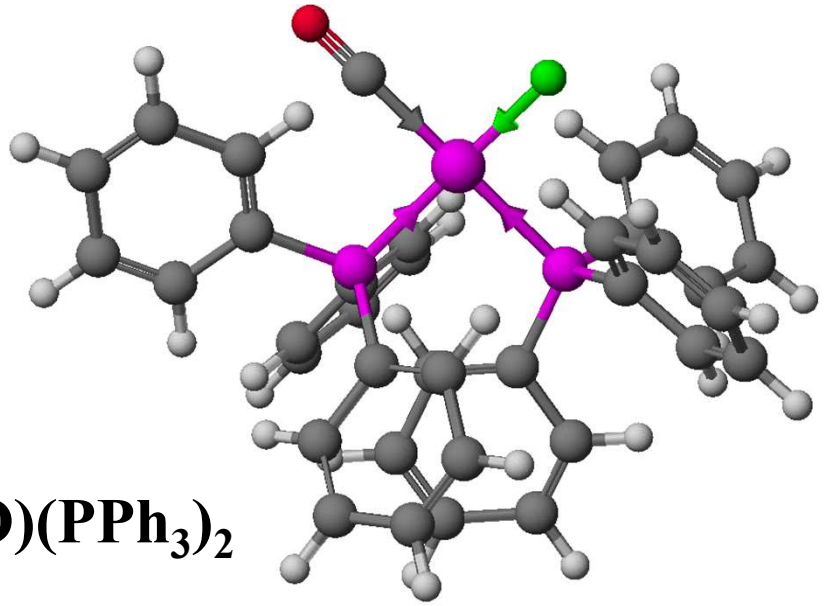
- If the name of a ligand itself contains a Greek prefix, (ethylenediamine or **triphenylphosphine**) put the ligand name in parentheses and use: *bis (2), tris (3), or tetrakis (4)*.
- Use a Roman numeral in parentheses, immediately following the name of the metal, to indicate the metal's oxidation state.
- In naming the metal, use the ending *–ate* if metal is in an anionic complex.

Nomenclature



$[Ni(NH_2C_2H_4NH_2)_3]^{2+}$

Tris(ethylenediamine)nickel(II)



$IrCl(CO)(PPh_3)_2$

Carbonylchlorobis(triphenylphosphine)iridium(I)

Table 22.5 Names of Anions Containing Metal Atoms

Metal	Name of Metal in Anionic Complex
Aluminum	Aluminate
Chromium	Chromate
Cobalt	Cobaltate
Copper	Cuprate
Gold	Aurate
Iron	Ferrate
Lead	Plumbate
Manganese	Manganate
Molybdenum	Molybdate
Nickel	Nickelate
Silver	Argentate
Tin	Stannate
Tungsten	Tungstate
Zinc	Zincate

What is the systematic name of $[Cr(H_2O)_4Cl_2]Cl$?

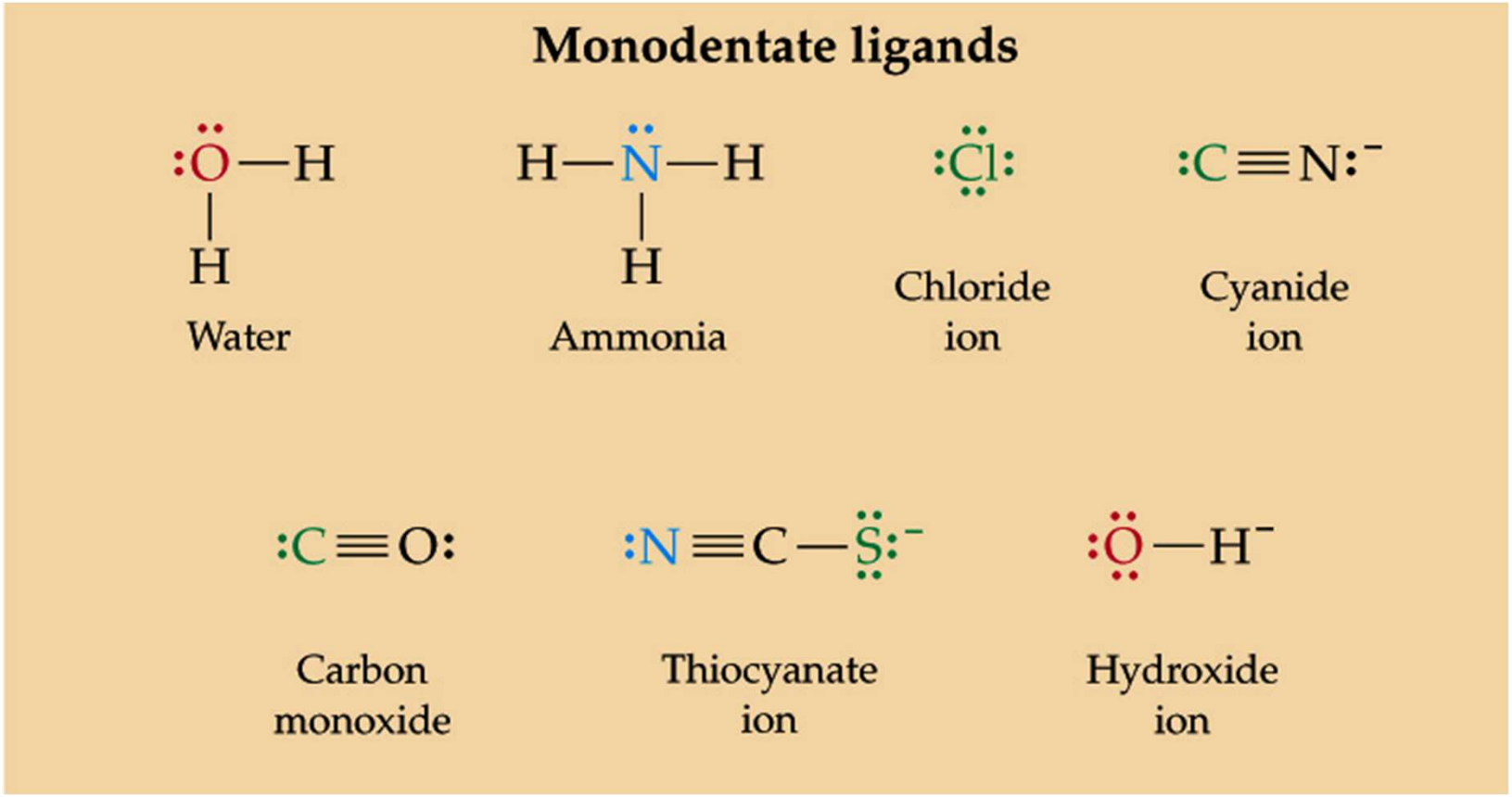
tetraaquadichlorochromium(III) chloride

Write the formula of tris(ethylenediamine)cobalt(II) sulfate

$[Co(en)_3]SO_4$

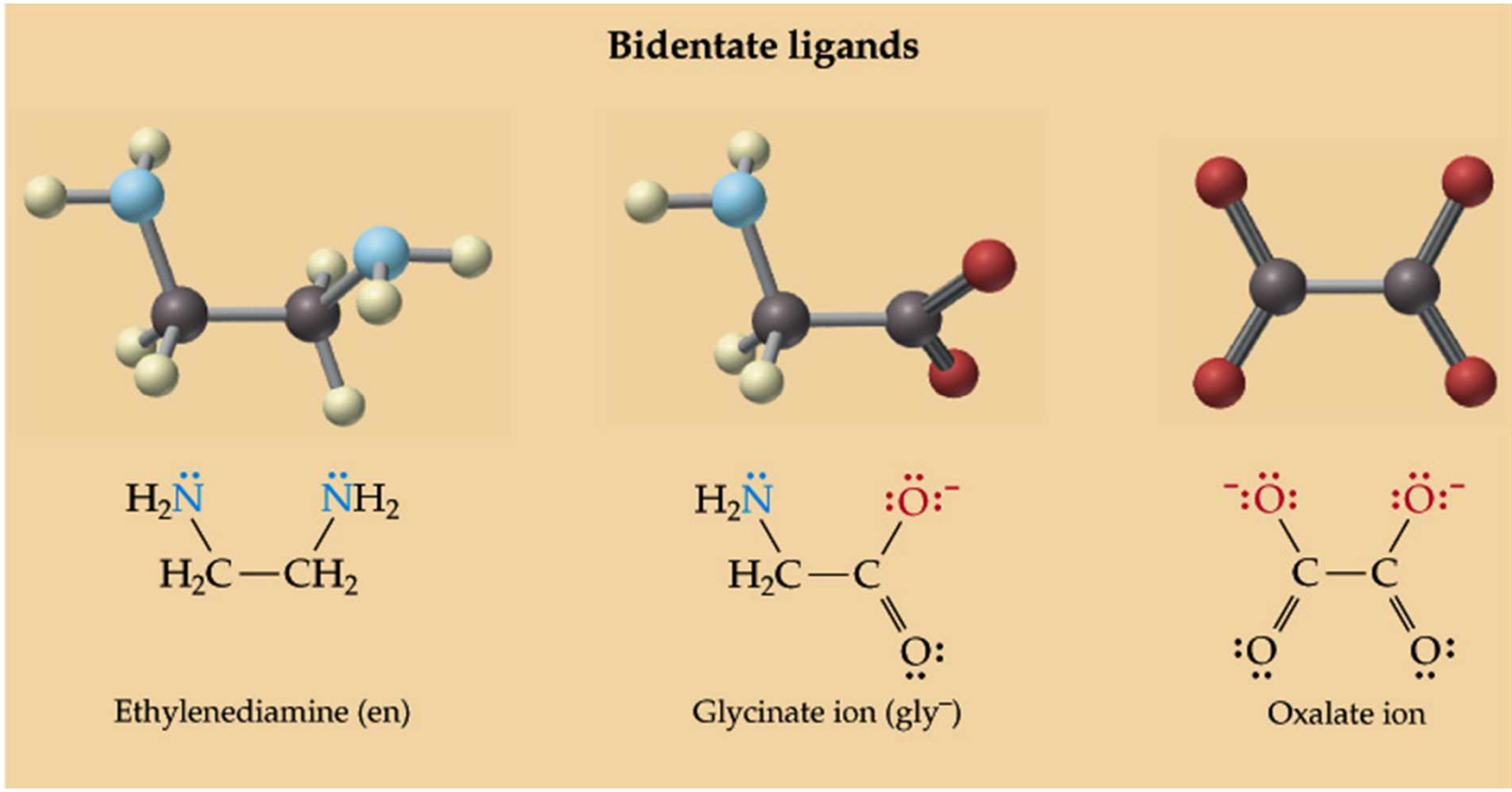
Ligands

02


Monodentate ligands
Water
Ammonia
Chloride ion
Cyanide ion
Carbon monoxide
Thiocyanate ion
Hydroxide ion

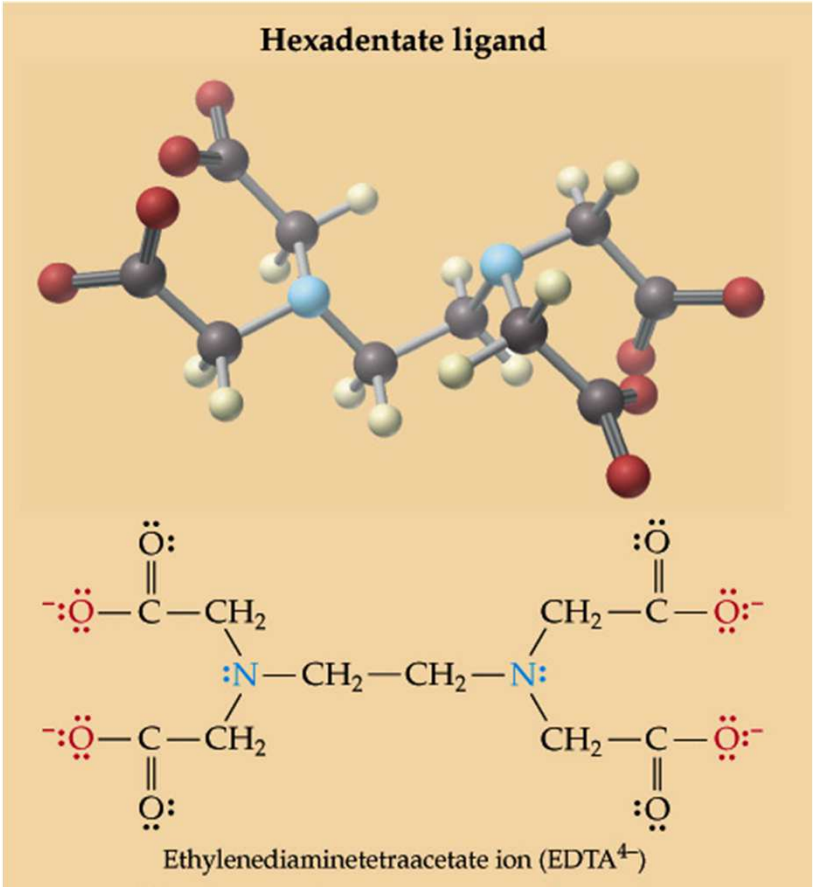
Ligands

03


Bidentate ligands
Ethylenediamine (en)
Glycinate ion (gly⁻)
Oxalate ion

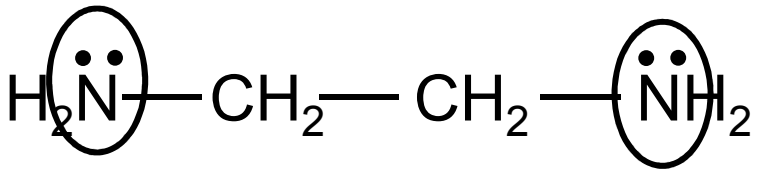
Poly DentateLigands

- **$EDTA^{4-}$** is often used to treat heavy metal poisoning such as Hg^{2+}, Pb^{2+}, and Cd^{2+}.
- **$EDTA^{4-}$** bonds to Pb^{2+}, which is excreted by the kidneys as $[Pb(EDTA)]^{2-}$.

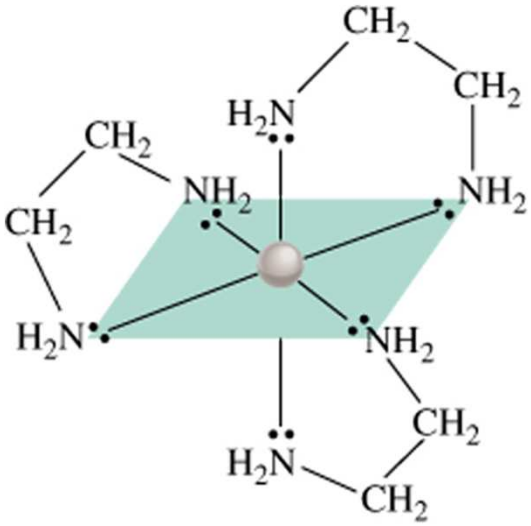


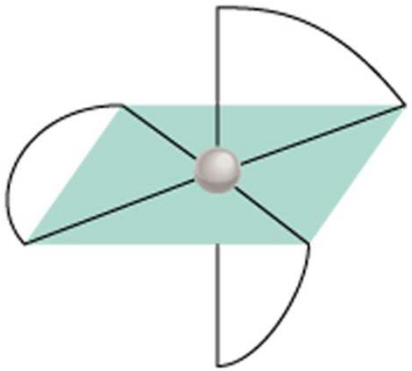
Coordination Compounds

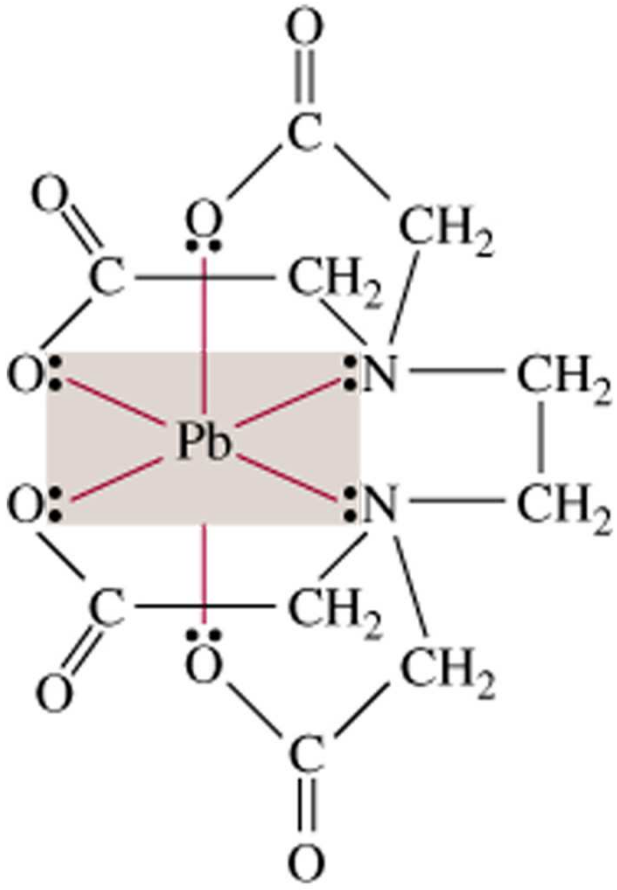
bidentate ligand



polydentate ligand (EDTA)

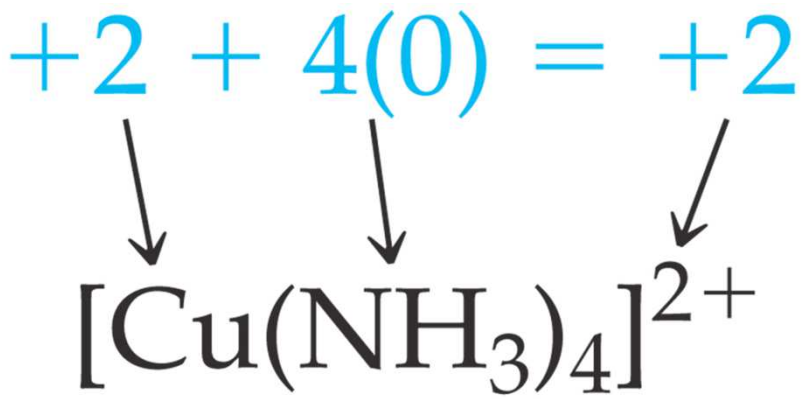






Bidentate and polydentate ligands are called ***chelating agents***

What is the Oxidation Numbers of Cu?



Knowing the charge on a complex ion and the charge on each ligand, one can determine the oxidation number for the metal.

Oxidation Number Rules

Rule	Applies to	Statement
1	Elements	The oxidation number of an atom in an element is zero.
2	Monatomic ions	The oxidation number of an atom in a monatomic ion equals the charge of the ion.
3	Oxygen	The oxidation number of oxygen is –2 in most of its compounds. (An exception is O in H_2O_2 and other peroxides, where the oxidation number is –1.)

Oxidation Number Rules

Rule	Applies to	Statement
4	Hydrogen	+1, it will be -1 when hydrogen comes with metal. NaH
5	Halogens	Fluorine is –1 in all its compounds. Each of the other halogens is –1 in binary compounds unless the other element is oxygen.
6	Compounds and ions	The sum of the oxidation numbers of the atoms in a compound is zero. The sum in a polyatomic ion equals the charge on the ion.

What is the charge on the following Complex, If the Oxidation number of Cr is +3?

$$+3 + 4(0) + 2(-1) = +1$$

$$\downarrow \quad \downarrow \quad \downarrow$$

$$Cr(H_2O)_4Cl_2$$

Or, knowing the oxidation number on the metal and the charges on the ligands, one can calculate the charge on the complex ion.

What are the oxidation numbers of the metals in $K[Au(OH)_4]$ and $[Cr(NH_3)_6](NO_3)_3$?

OH^- has charge of -1

K^+ has charge of +1

? Au + 1 + 4x(-1) = 0

Au = +3

NO_3^- has charge of -1

NH_3 has no charge

? Cr + 6x(0) + 3x(-1) = 0

Cr = +3

Oxidation States of the 1st Row Transition Metals

(most stable oxidation numbers are shown in red)

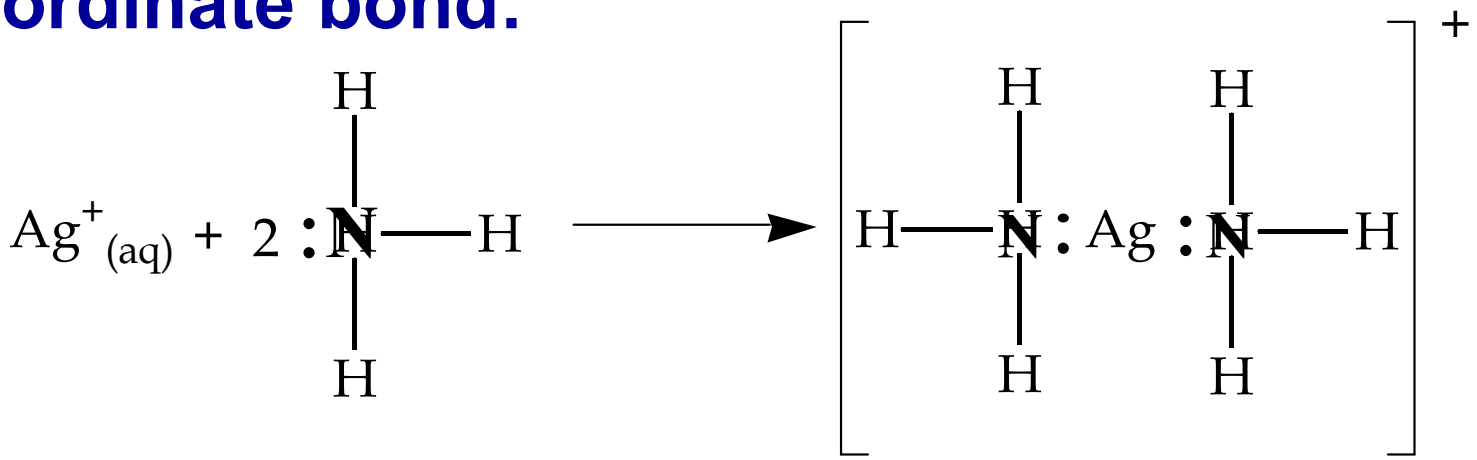
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu
				+7				
			+6	+6	+6			
		+5	+5	+5	+5			
	+4	+4	+4	+4	+4	+4		
+3	+3	+3	+3	+3	+3	+3	+3	+3
	+2	+2	+2	+2	+2	+2	+2	+2
								+1

Learning Check

A complex ion contains a Cr^{3+} bound to four H_2O molecules and two Cl^- ions. Write its formula.

Writing Formula for Coordinated Complex

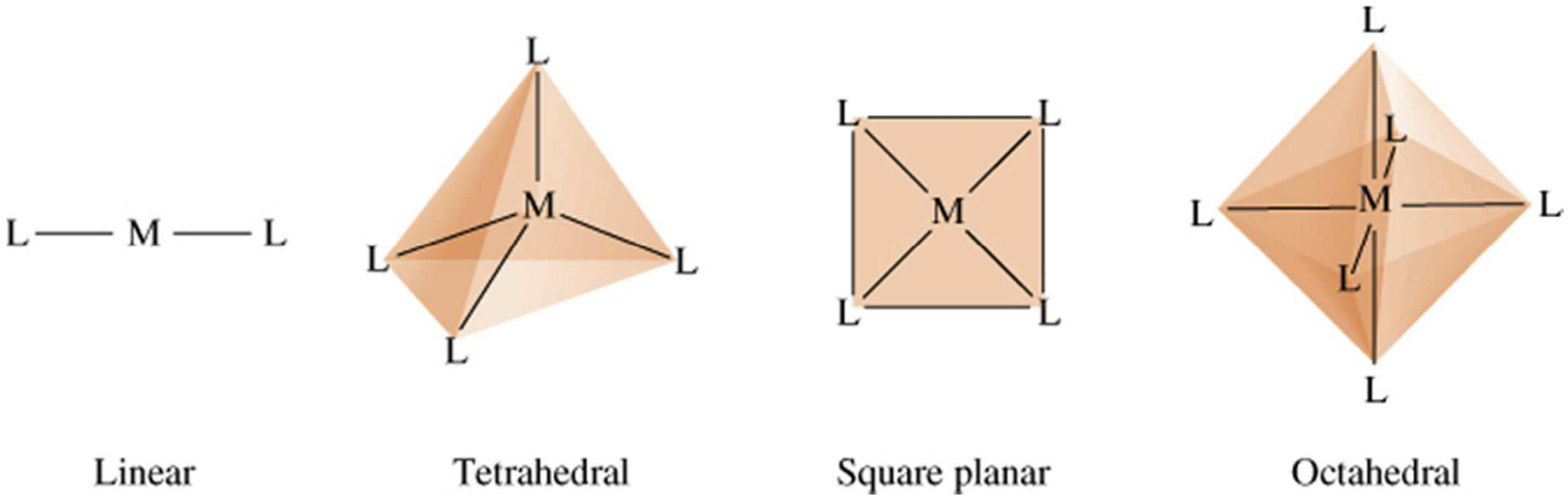
- **Coordinate bond:**



- **Coordination Sphere:** is the central metal and surrounding ligands. The square brackets separate the complex from counter ions such as SO_4^{2-}.

$$[Ag(NH_3)_2]_2\,SO_4$$

Geometry of Coordination Compounds

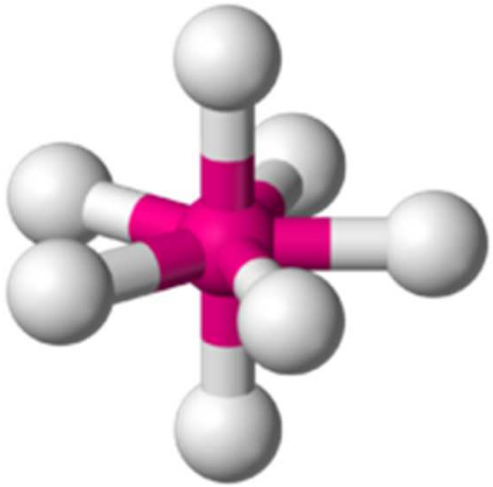


Linear Tetrahedral Square planar Octahedral

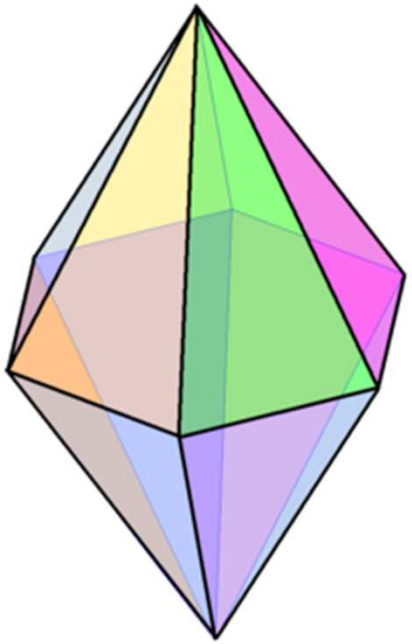
Coordination number	Structure
2	Linear
4	**Tetrahedral (mostly d^{10})or Square planar (mostly d^8)**
6	Octahedral

Coordination Number of 7&8

- Geometry



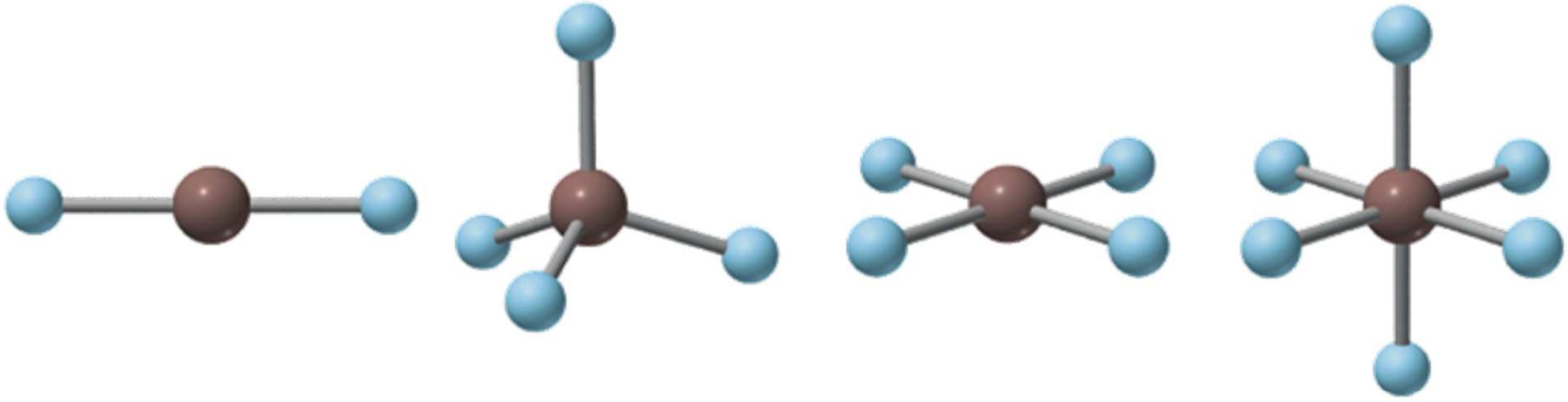
Pentagonal bipyramid

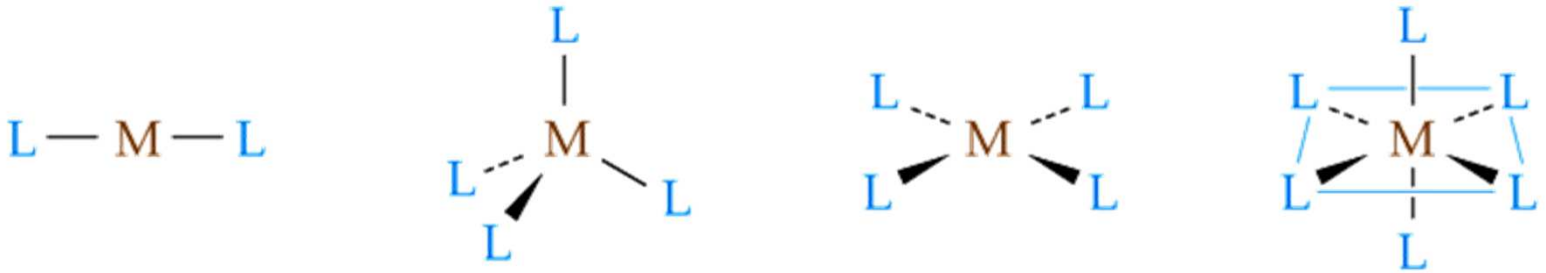


Hexagonal bipyramid

Coordination Compounds

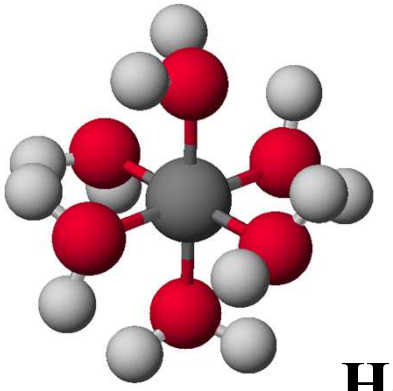
- **Geometries:**





Linear Tetrahedral Square planar Octahedral

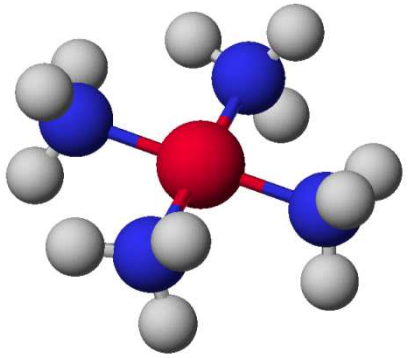
Nomenclature



$Co(H_2O)_6^{2+}$

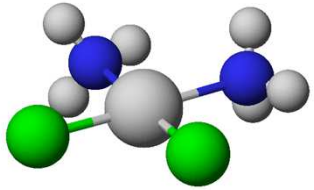
Hexaaquacobalt(II)

H_2O as a ligand is aqua



$Cu(NH_3)_4^{2+}$

Tetraamminecopper(II)



$Pt(NH_3)_2Cl_2$ **diamminedichloroplatinum(II)**

NH_3 as a ligand is ammine

Systematic naming specifies the type and number of ligands, the metal, and its oxidation state.

Ligand's Names 01

TABLE 20.5 Names of Some Common Ligands

Anionic Ligand	Ligand Name	Neutral Ligand	Ligand Name
Bromide, Br^-	Bromo	Ammonia, NH_3	Ammine
Carbonate, CO_3^{2-}	Carbonato	Water, H_2O	Aqua
Chloride, Cl^-	Chloro	Carbon monoxide, CO	Carbonyl
Cyanide, CN^-	Cyano	Ethylenediamine, en	Ethylenediamine
Fluoride, F^-	Fluoro		
Glycinate, gly^-	Glycinato		
Hydroxide, OH^-	Hydroxo		
Oxalate, $C_2O_4^{2-}$	Oxalato		
Thiocyanate, SCN^-	Thiocyanato*		
	Isothiocyanato†		

* Ligand donor atom is S. †Ligand donor atom is N.

Nomenclature

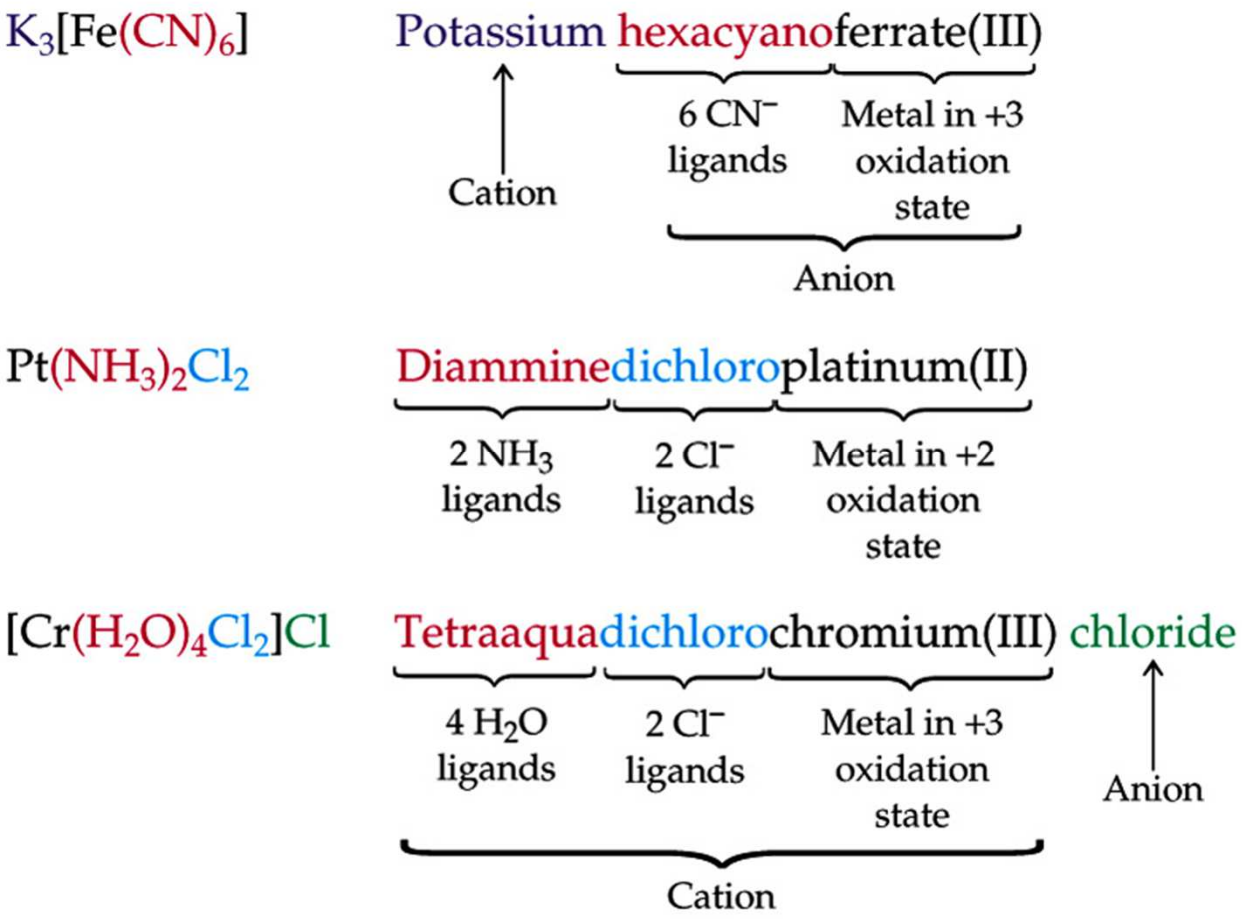


Table 22.5 Names of Anions Containing Metal Atoms

Metal	Name of Metal in Anionic Complex
Aluminum	Aluminate
Chromium	Chromate
Cobalt	Cobaltate
Copper	Cuprate
Gold	Aurate
Iron	Ferrate
Lead	Plumbate
Manganese	Manganate
Molybdenum	Molybdate
Nickel	Nickelate
Silver	Argentate
Tin	Stannate
Tungsten	Tungstate
Zinc	Zincate

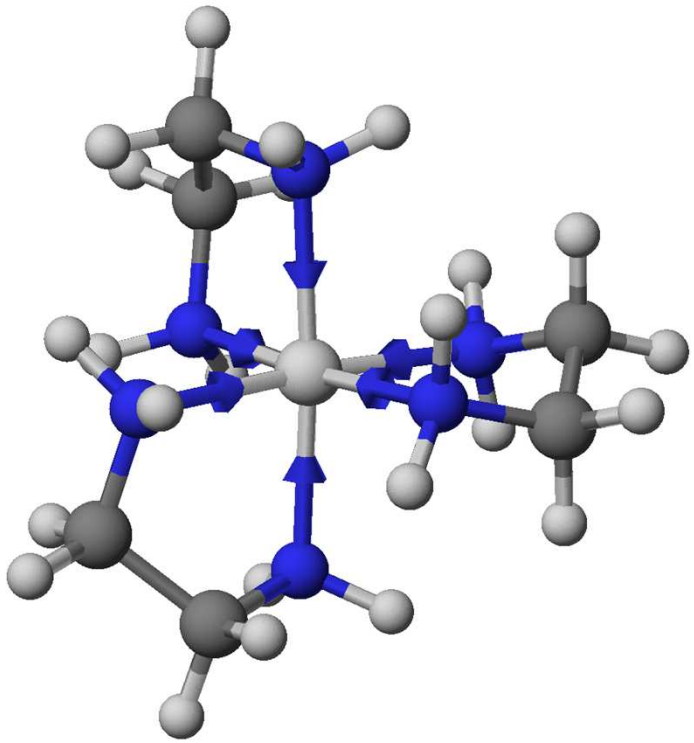
Nomenclature

- **Systematic naming follows IUPAC rules:**
  - If compound is a salt, name cation first and then the anion, just as in naming simple salts.
  - In naming a complex ion or neutral complex, name ligands first and then the metal.
  - If the complex contains more than one ligand of a particular type, indicate the number with the appropriate Greek prefix: *di–, tri–, tetra–, penta–, hexa–*.

Nomenclature

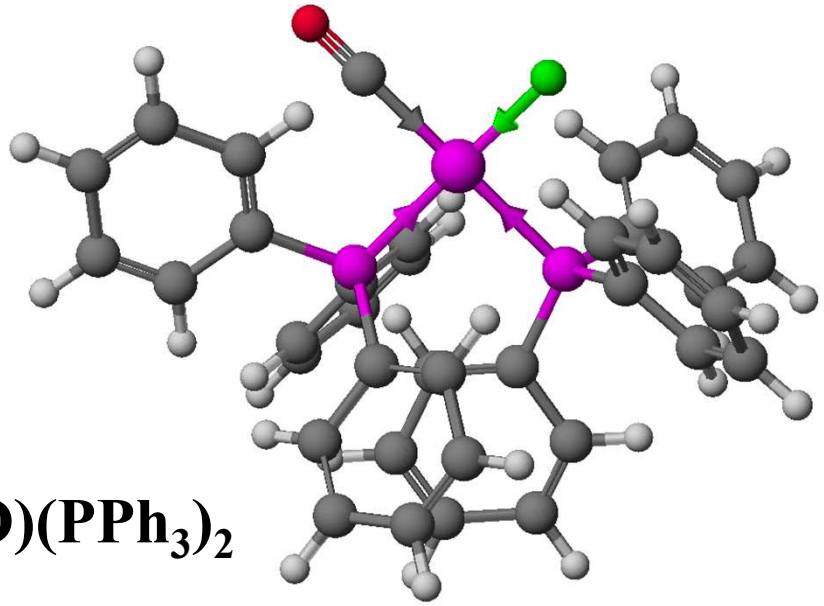
- If the name of a ligand itself contains a Greek prefix, (ethylenediamine or **triphenylphosphine**) put the ligand name in parentheses and use: *bis (2), tris (3), or tetrakis (4)*.
- Use a Roman numeral in parentheses, immediately following the name of the metal, to indicate the metal's oxidation state.
- In naming the metal, use the ending *–ate* if metal is in an anionic complex.

Nomenclature



$[Ni(NH_2C_2H_4NH_2)_3]^{2+}$

Tris(ethylenediamine)nickel(II)



$IrCl(CO)(PPh_3)_2$

Carbonylchlorobis(triphenylphosphine)iridium(I)

Table 22.5 Names of Anions Containing Metal Atoms

Metal	Name of Metal in Anionic Complex
Aluminum	Aluminate
Chromium	Chromate
Cobalt	Cobaltate
Copper	Cuprate
Gold	Aurate
Iron	Ferrate
Lead	Plumbate
Manganese	Manganate
Molybdenum	Molybdate
Nickel	Nickelate
Silver	Argentate
Tin	Stannate
Tungsten	Tungstate
Zinc	Zincate

What is the systematic name of $[Cr(H_2O)_4Cl_2]Cl$?

tetraaquadichlorochromium(III) chloride

Write the formula of tris(ethylenediamine)cobalt(II) sulfate

$[Co(en)_3]SO_4$

Constitutional Isomerism

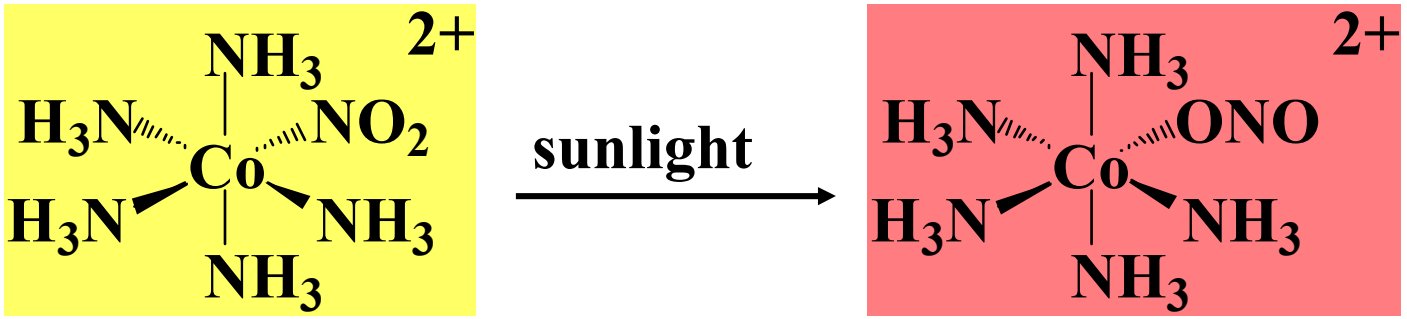
1. Constitutional Isomers: Have different connections among their constituent atoms.

- **Ionization Isomers :**

  $[Co(NH_3)_5Br]SO_4$ (violet compound with Co–Br bond), $[Co(NH_3)_5\,SO_4]Br$ (red compound with Co–SO_4 bond).

- **Linkage Isomers** form when a ligand can bond through two different donor atoms. Consider $[Co(NH_3)_5NO_2]^{2+}$ which is yellow with the Co–NO_2 bond and red with the Co–ONO bond.

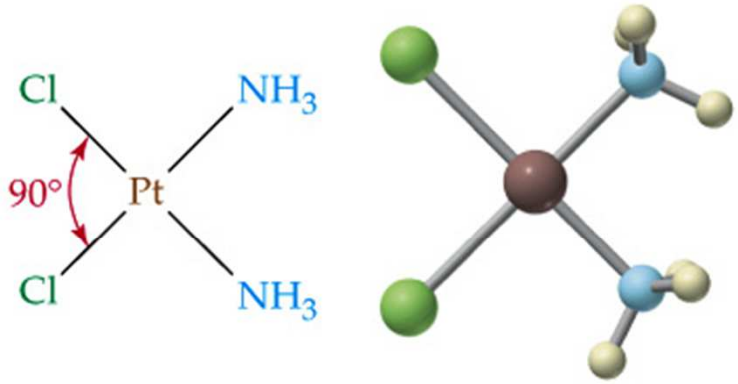
Linkage Isomerism



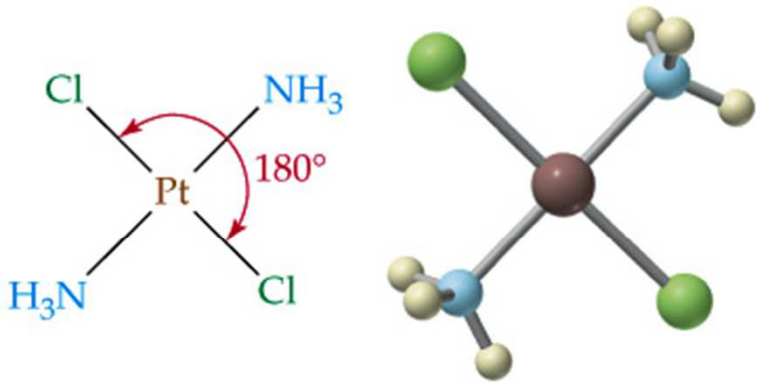
Such a transformation could be used as an energy storage device.

Stereoisomers 05

- **Geometric Isomers of $Pt(NH_3)_2Cl_2$:** In the *cis isomer,* atoms are on the *same* side. In the *trans isomer,* atoms are on *opposite* sides.



(a) cis



(b) trans

2.Stereoisomers

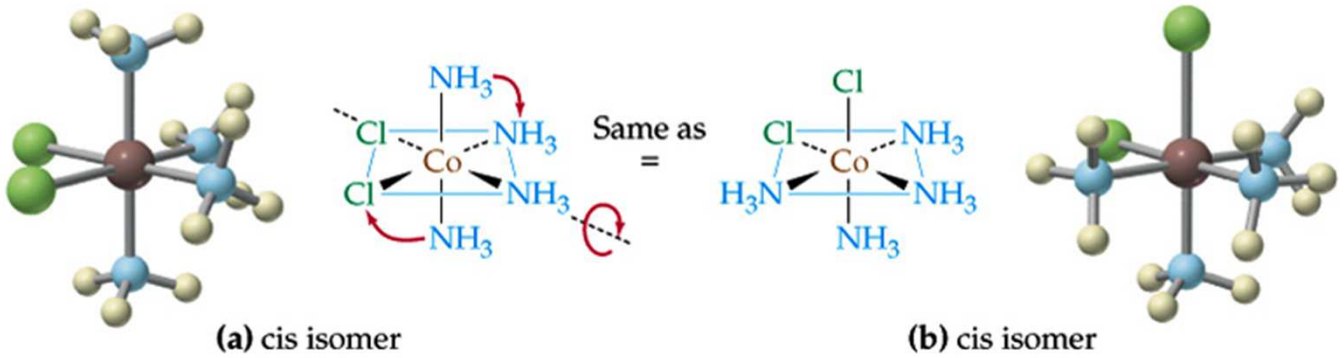
i. **Diastereoisomers (geometric)** have the same connections among atoms but different spatial orientations of the metal–ligand bonds.

a) **cis isomers** have identical ligands in *adjacent corners* of a square.

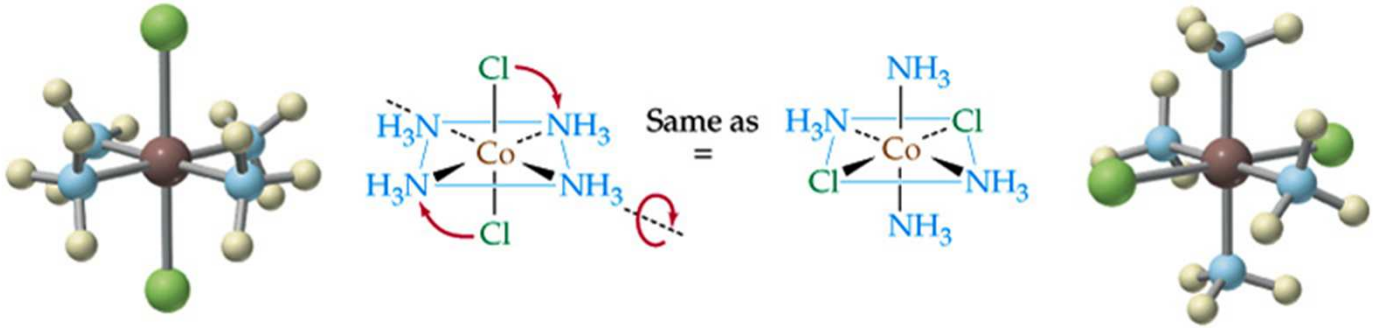
b) **trans isomers** have identical ligands *across the corners* from each other.

Isomers

- **Geometric Isomers of $[Co(NH_3)_4Cl_2]Cl$:**



(a) cis isomer **(b)** cis isomer

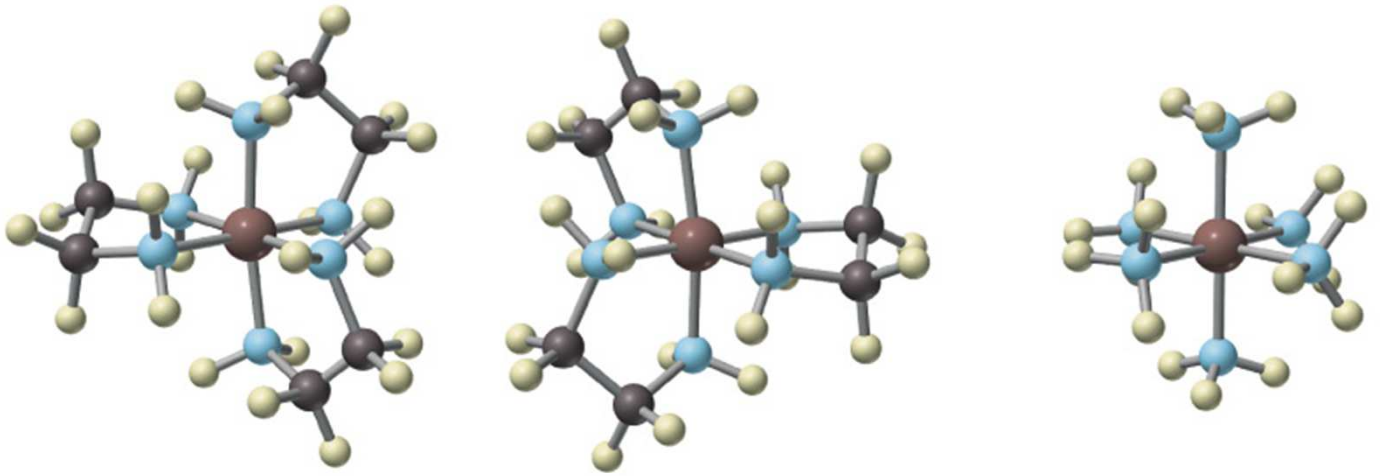


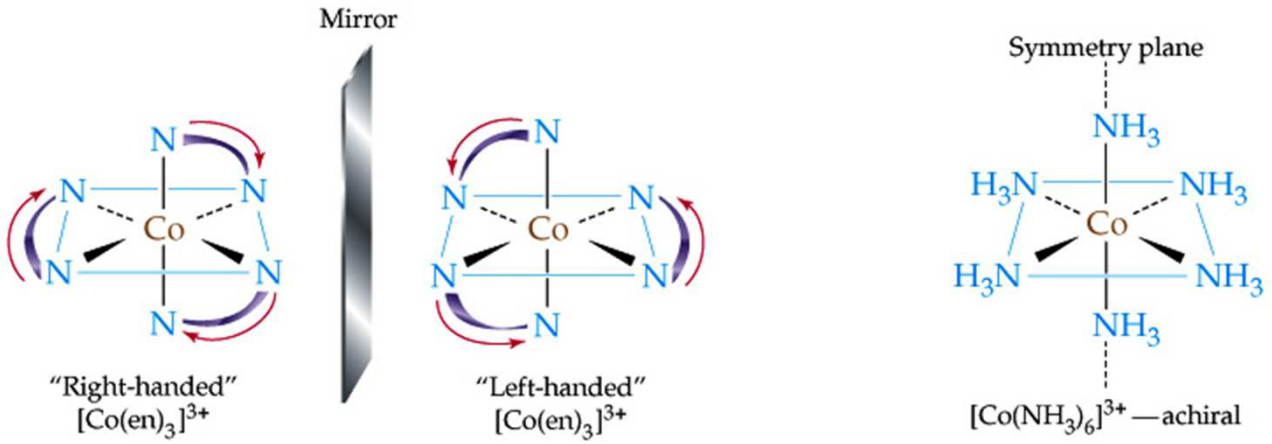
(c) trans isomer **(d)** trans isomer

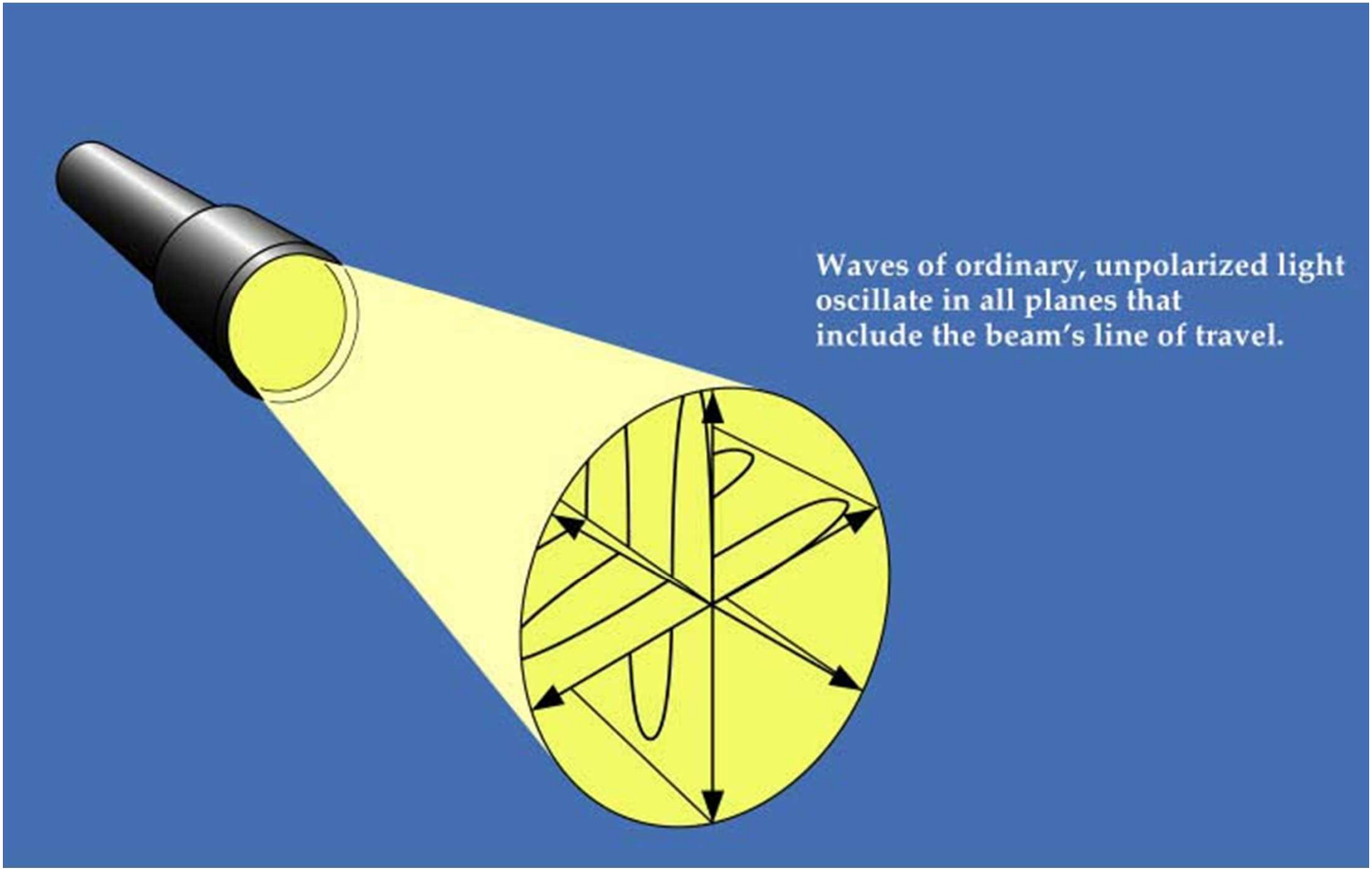
Enantiomers

- **Enantiomers** are stereoisomers of molecules or ions that are *nonidentical mirror images* of each other.
- Objects that have “handedness” are said to be *chiral*, and objects that lack “handedness” are said to be *achiral*.
- An object or compound is *achiral* if it has a *symmetry plane* cutting through the middle.

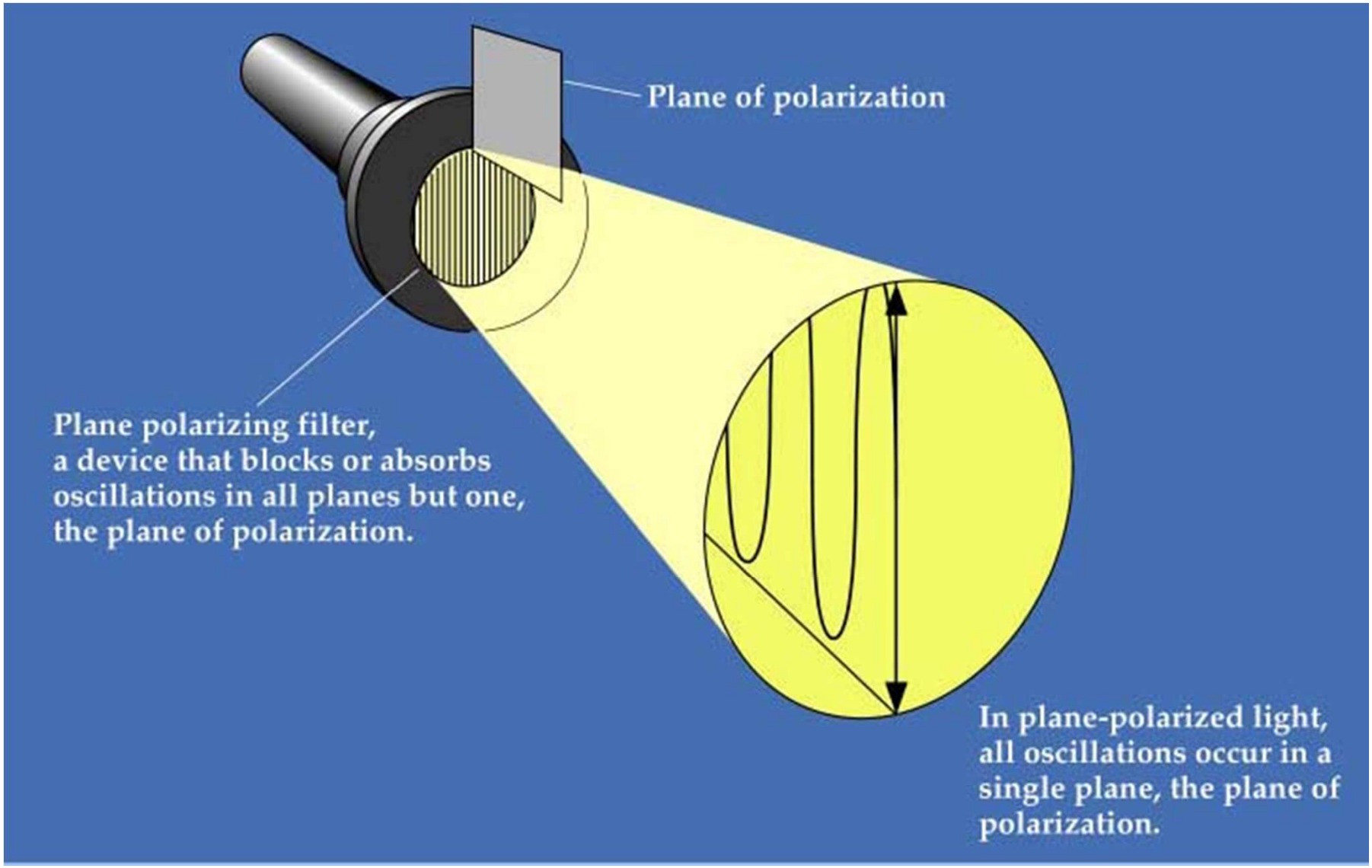
Enantiomers



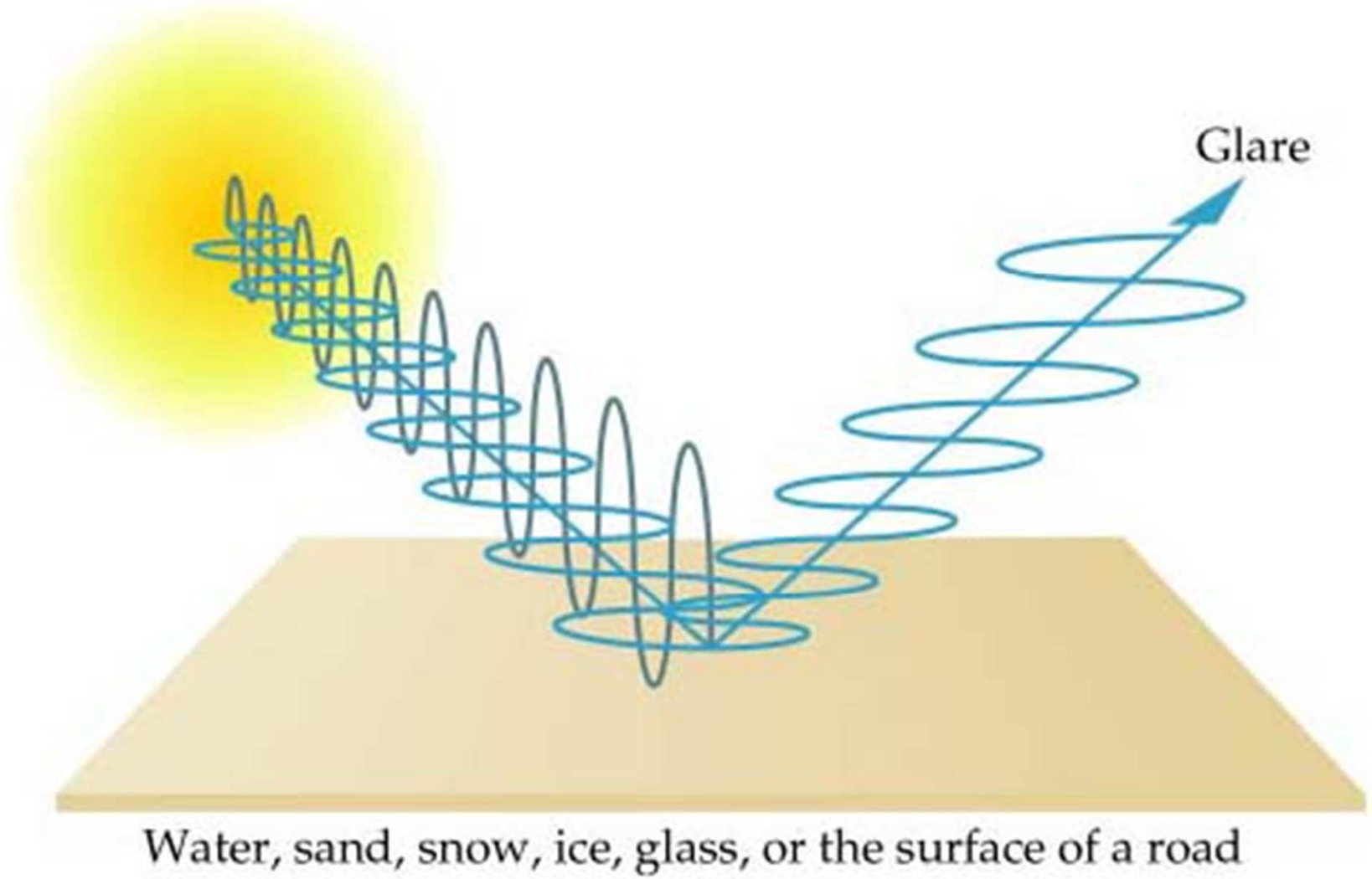




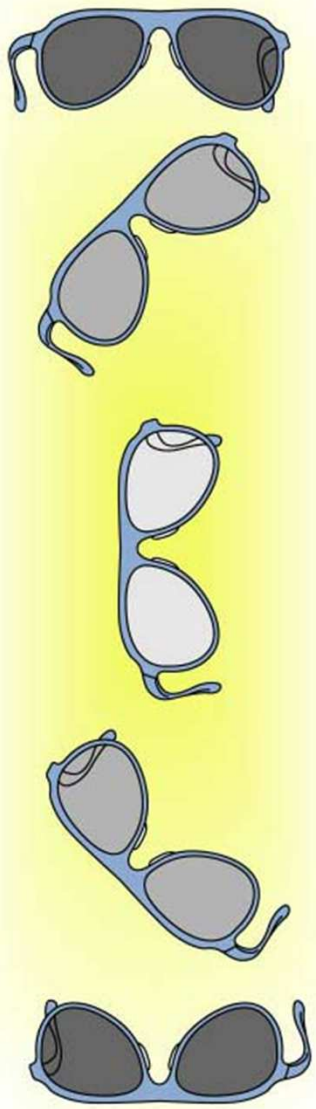
Unpolarized light.



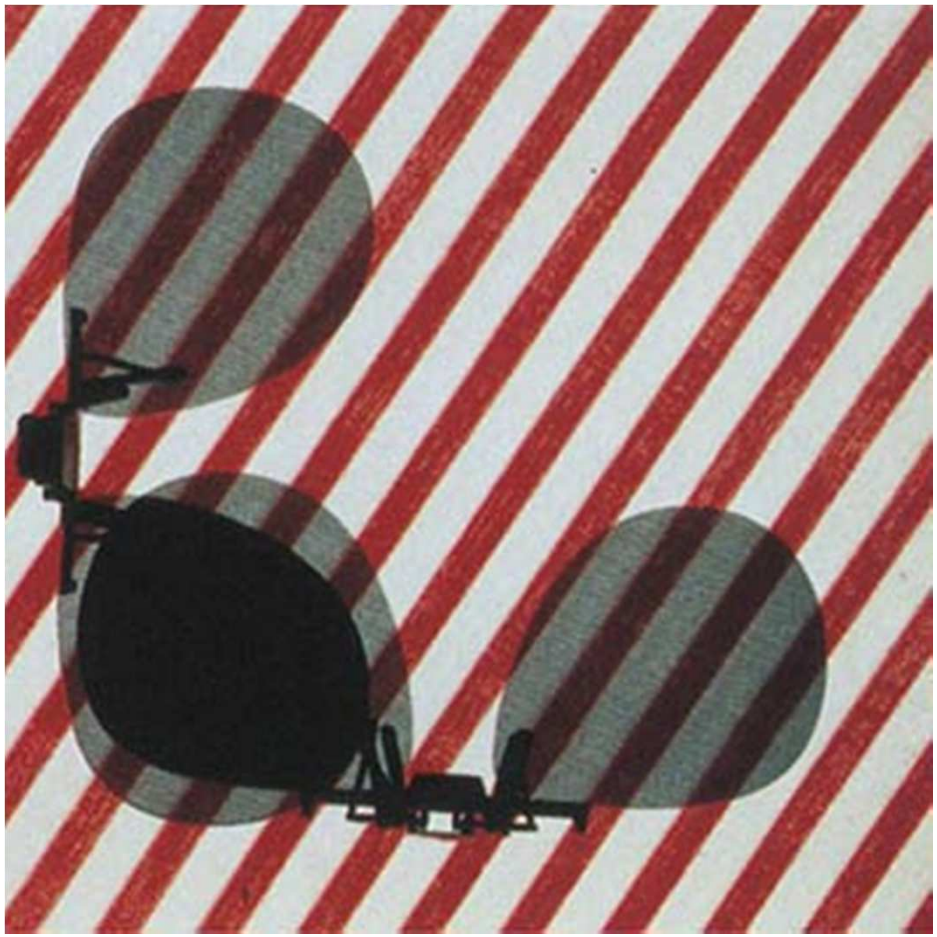
Plane-polarized light.



Reflected glare is plane-polarized light.

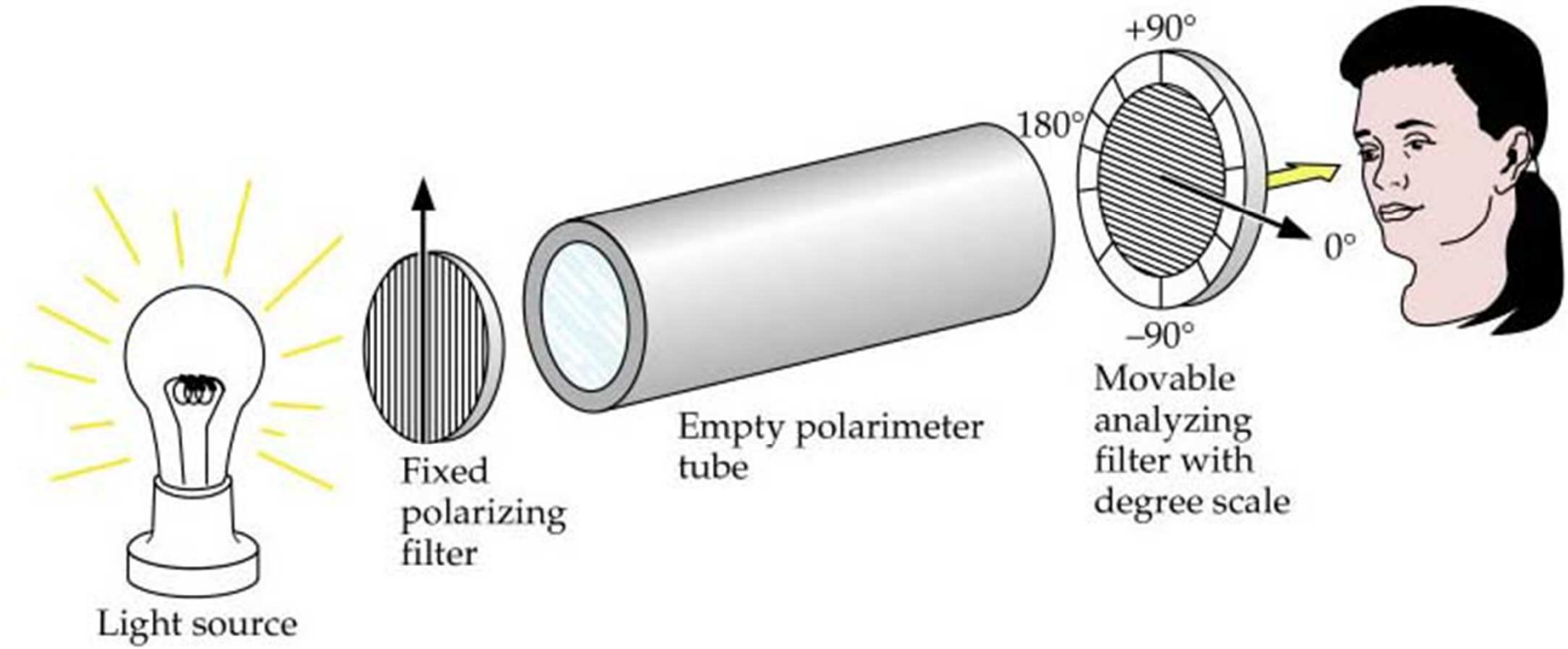


Polarizing sunglasses versus glare.



Courtesy Andy Washnik

The effect of polarizing lenses on unpolarized light.



The essentials of a polarimeter.

Enantiomers

- **Enantiomers** have identical properties except for their reaction with other chiral substances and their effect on *plane-polarized light*.

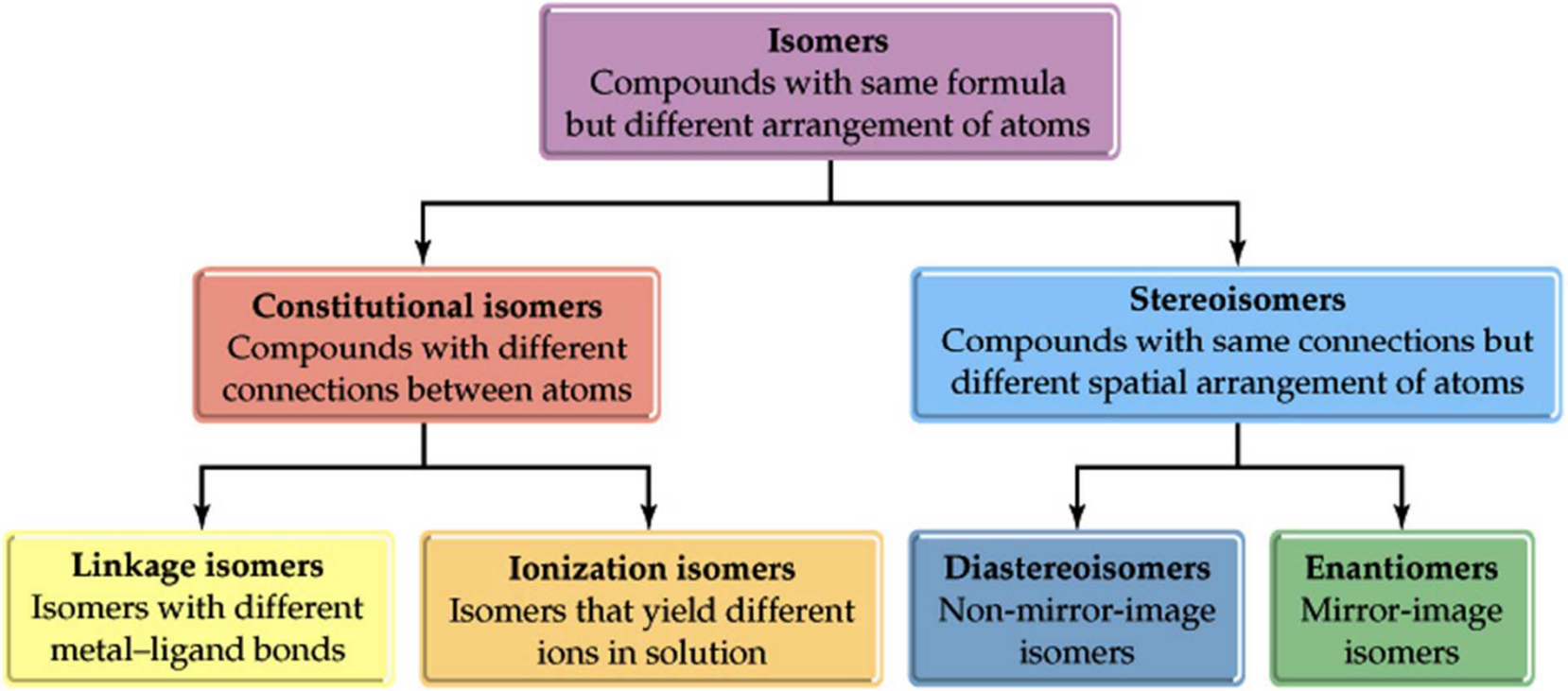
- Enantiomers are often called *optical isomers*; their effect on plane-polarized light can be measured with a *polarimeter*.

Enantiomers

- **Plane-polarized light** is obtained by passing ordinary light through a polarizing filter.
- In a polarimeter the plane-polarized light is passed though a chiral solution and the polarization plane measured with an analyzing filter.
  - If the plane rotates to the right it is *dextrorotatory*.
  - If the plane rotates to the left it is *levorotatory*.
  - Equal amounts of each are *racemic*.

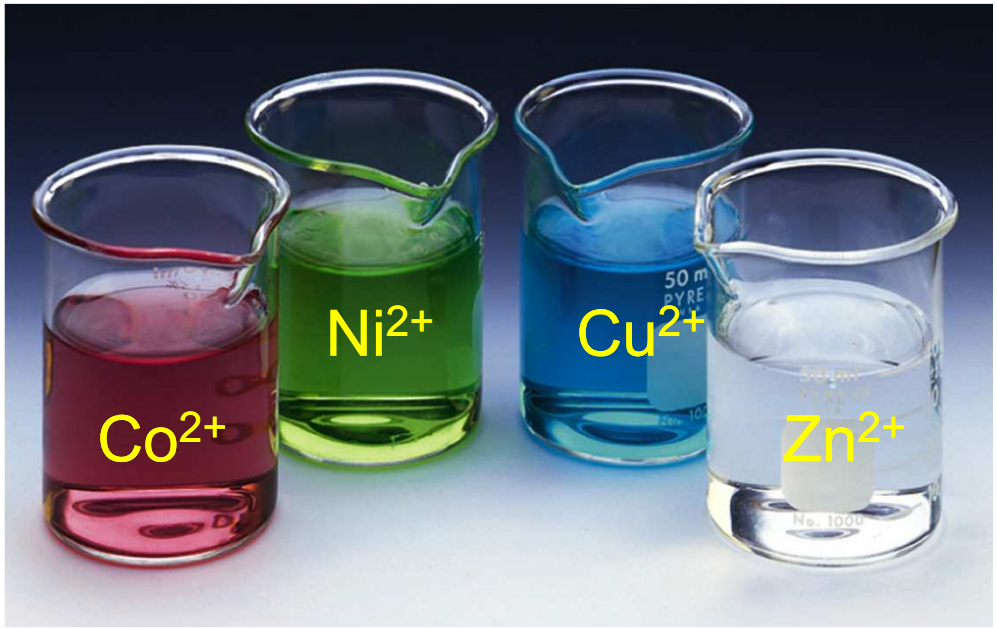
Isomers 01

- **Isomers** are compounds that have the same formula but a different atomic arrangement.



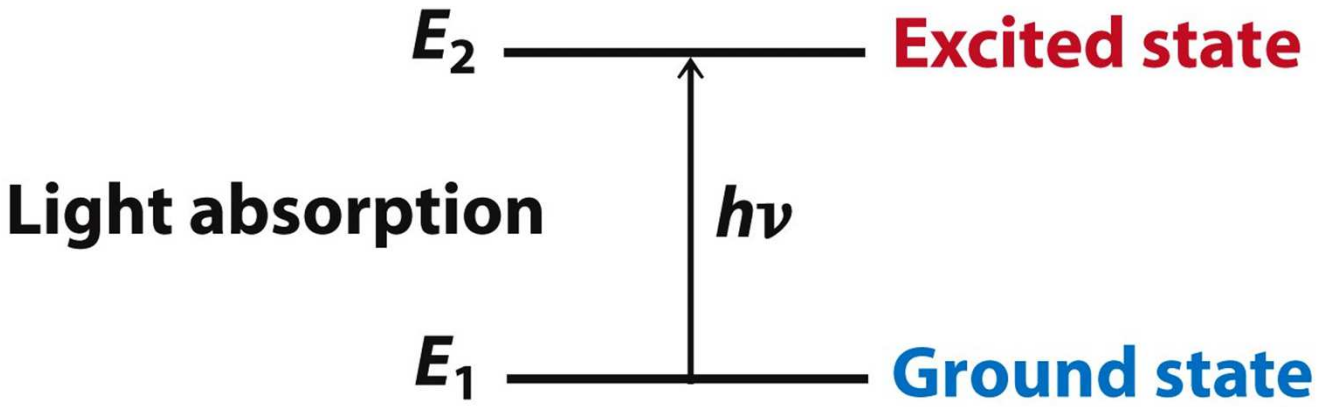
Bonding in Complexes 01

- **Bonding Theories** attempt to account for the color and magnetic properties of transition metal complexes.



- Solutions of $[Ni(H_2O)_6]^{2+}$, $[Ni(NH_3)_6]^{2+}$, & $[Ni(en)_3]^{2+}$

Color of Transition Metal Complexes



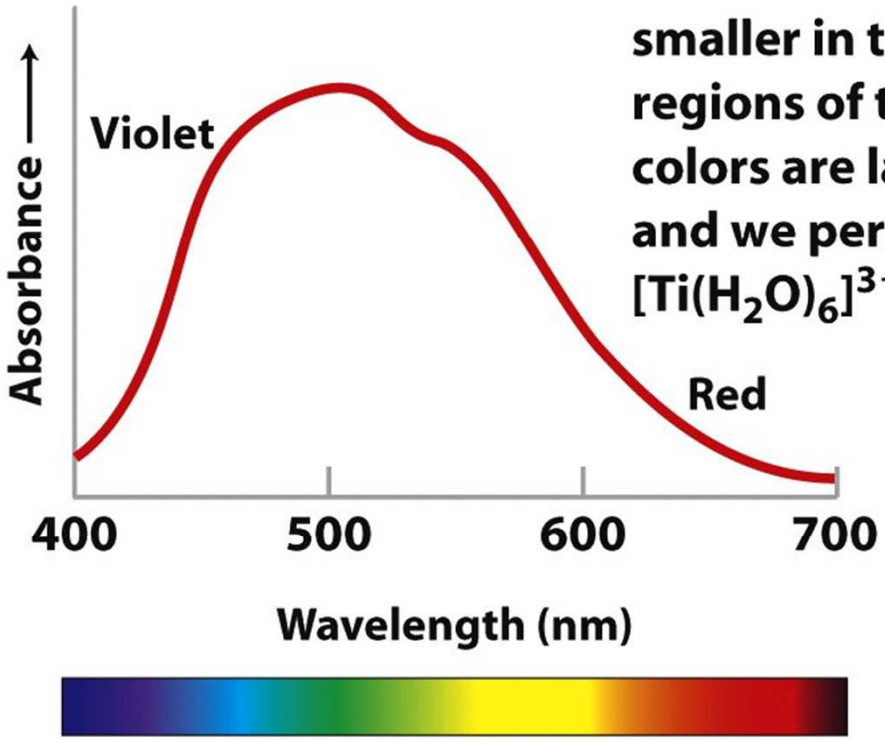
Unnumbered 20 p845 Chemistry, 5/e

$$\Delta E = E_2 - E_1 = h\nu = \frac{hc}{\lambda}$$

or

$$\lambda = \frac{hc}{\Delta E}$$

Color of Transition Metal Complexes



Because the absorbance is smaller in the red and violet regions of the spectrum, these colors are largely transmitted and we perceive the color of $[Ti(H_2O)_6]^{3+}$ to be red-violet.

Figure 20-25 Chemistry, 5/e

Color of Transition Metal Complexes

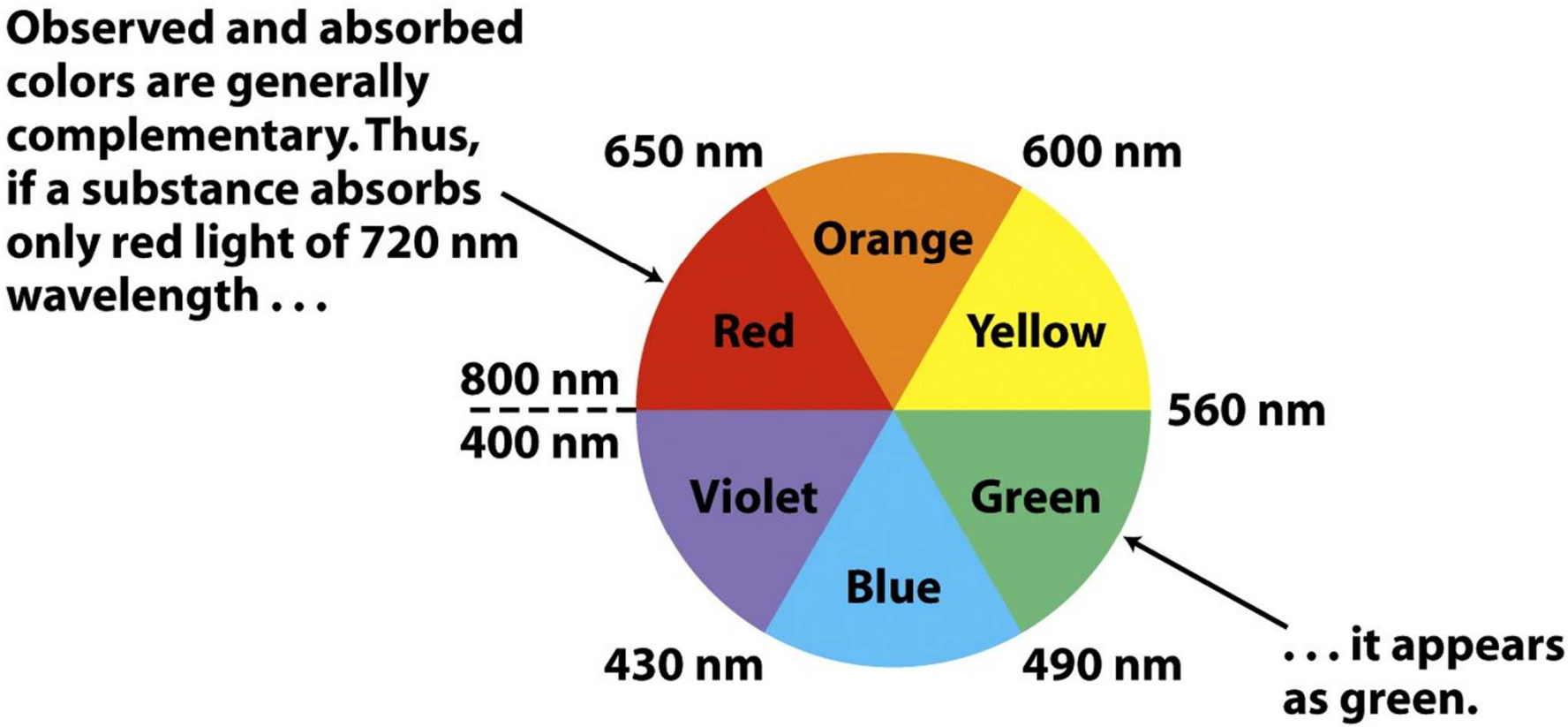


Figure 20-26 Chemistry, 5/e

Bonding in Complexes: Valence Bond Theory

Unnumbered 20 p846 Chemistry, 5/e

The octahedral d^2sp^3 and sp^3d^2

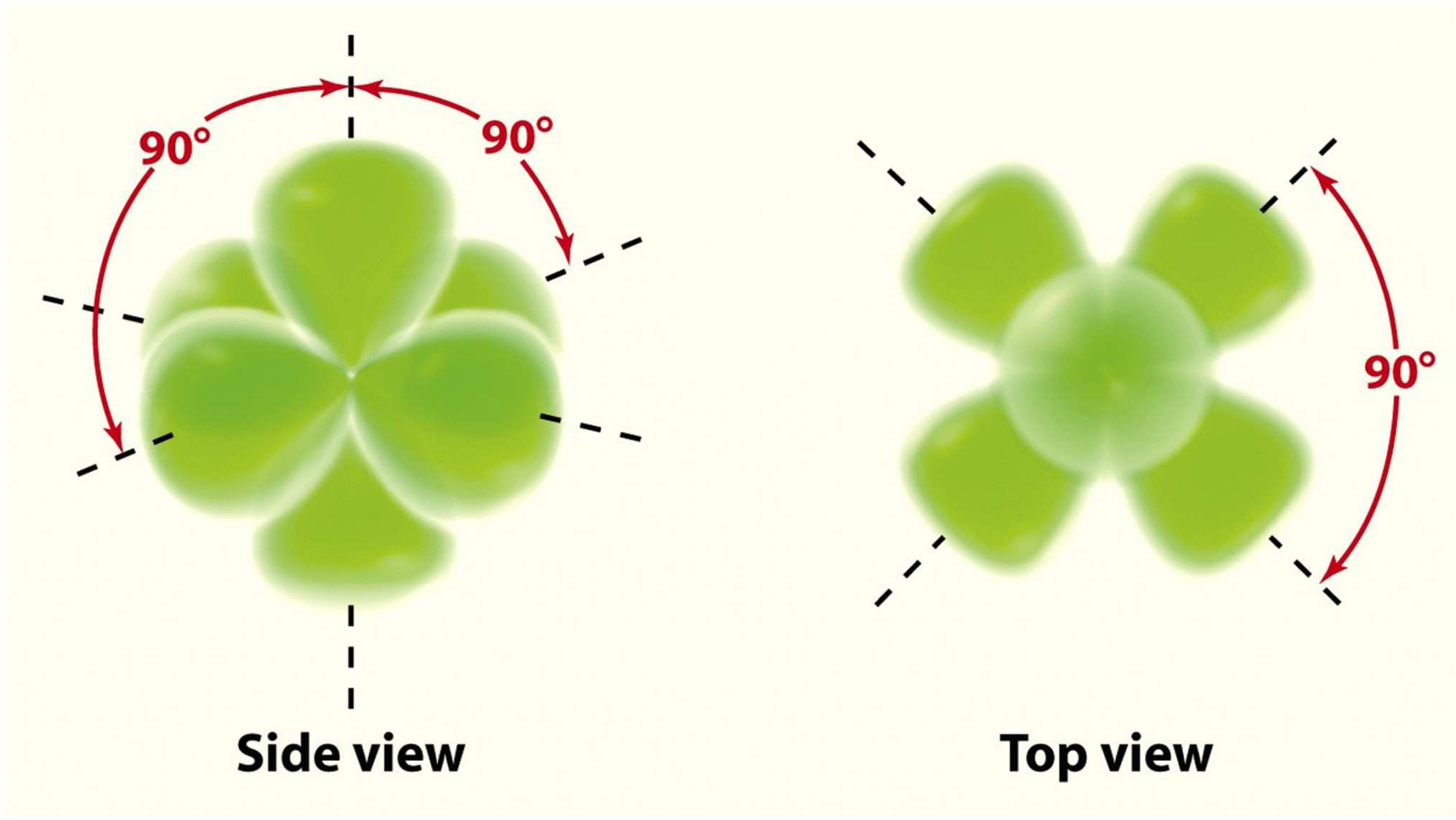


Figure 20-27 Chemistry, 5/e

Square Planar geometry of four dsp^2

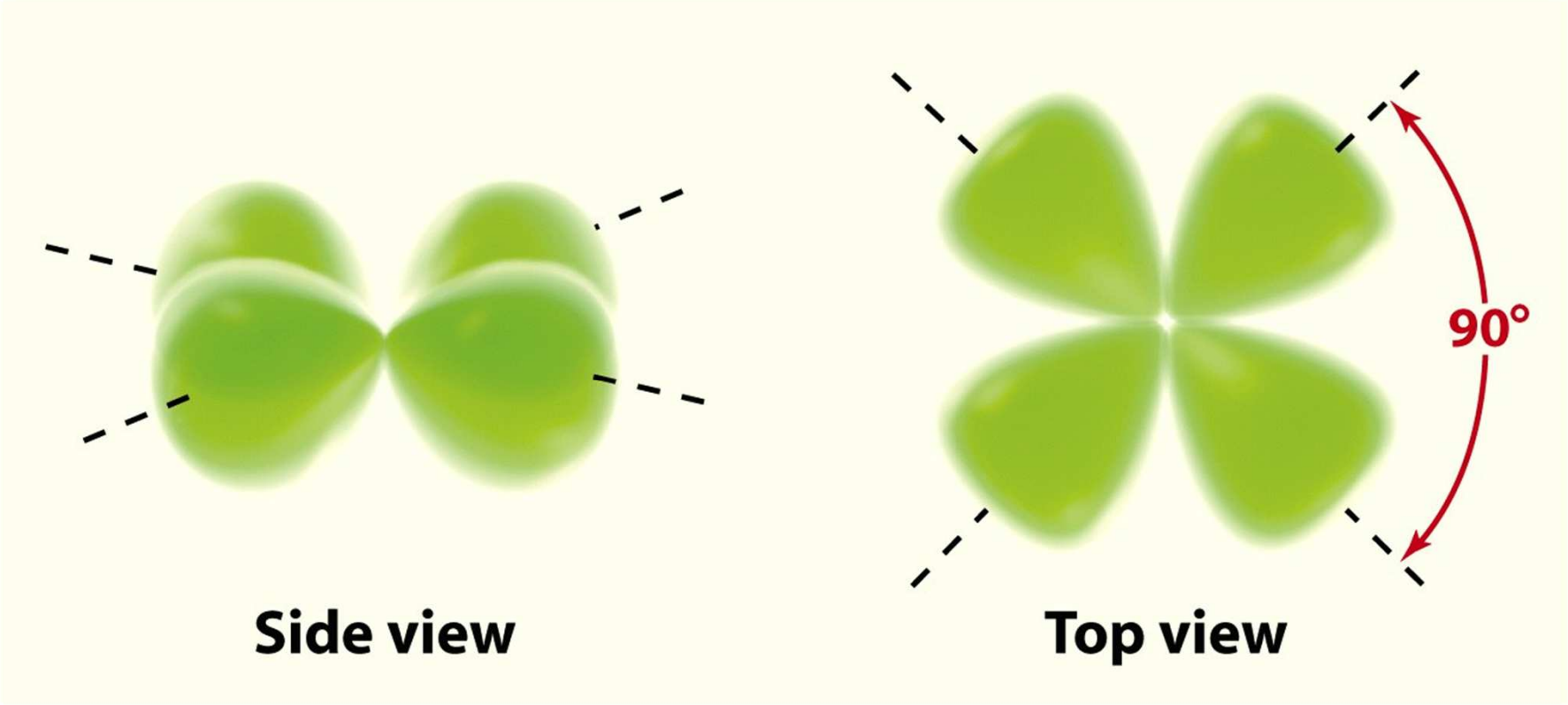


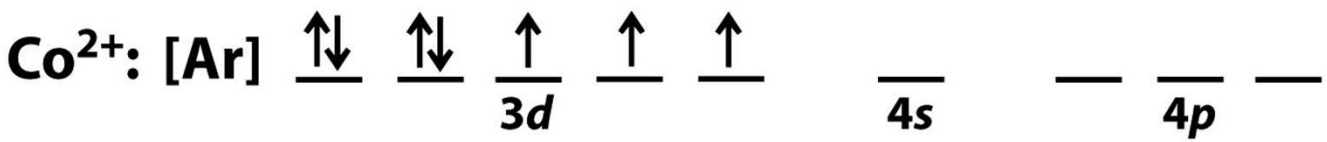
Figure 20-28 Chemistry, 5/e

Bonding in Complexes: Valence Bond Theory

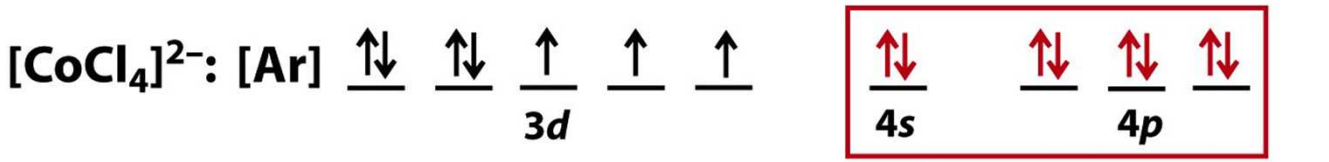
TABLE 20.7 Hybrid Orbitals for Common Coordination Geometries

Coordination Number	Geometry	Hybrid Orbitals	Example
2	Linear	*sp*	$[Ag(NH_3)_2]^+$
4	Tetrahedral	sp^3	$[CoCl_4]^{2-}$
4	Square planar	dsp^2	$[Ni(CN)_4]^{2-}$
6	Octahedral	d^2sp^3 or sp^3d^2	$[Cr(H_2O)_6]^{3+}$, $[Co(H_2O)_6]^{2+}$

Table 20-7 Chemistry, 5/e



Unnumbered 20 p847a Chemistry, 5/e



Four sp^3 bonds to the ligands

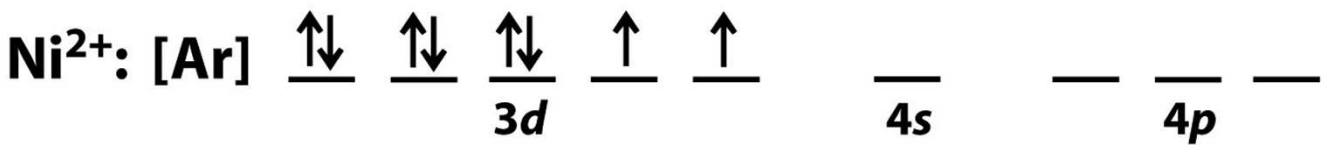
Unnumbered 20 p847b Chemistry, 5/e

Bonding in Complexes: Valence Bond Theory

TABLE 20.7 Hybrid Orbitals for Common Coordination Geometries

Coordination Number	Geometry	Hybrid Orbitals	Example
2	Linear	*sp*	$[Ag(NH_3)_2]^+$
4	Tetrahedral	sp^3	$[CoCl_4]^{2-}$
4	Square planar	dsp^2	$[Ni(CN)_4]^{2-}$
6	Octahedral	d^2sp^3 or sp^3d^2	$[Cr(H_2O)_6]^{3+}$, $[Co(H_2O)_6]^{2+}$

Table 20-7 Chemistry, 5/e



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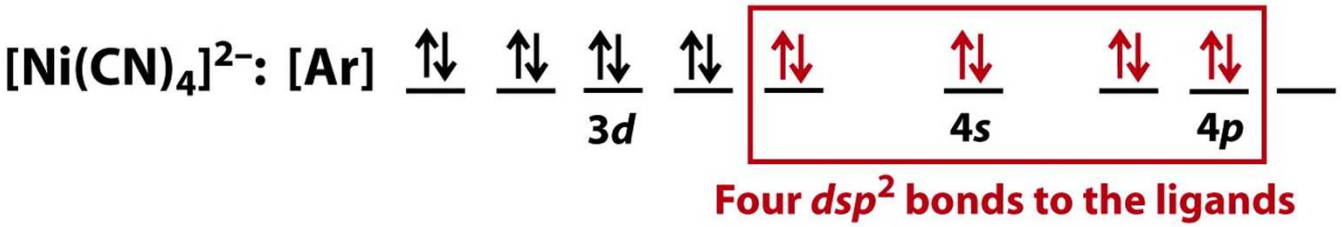

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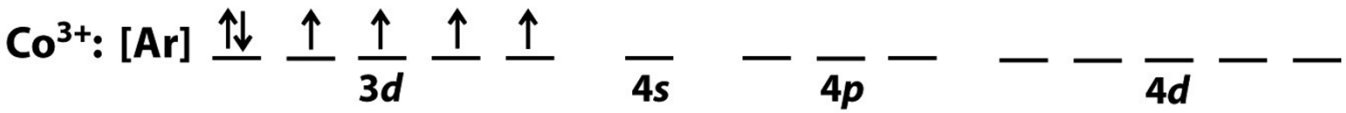
High- and Low-Spin Complexes



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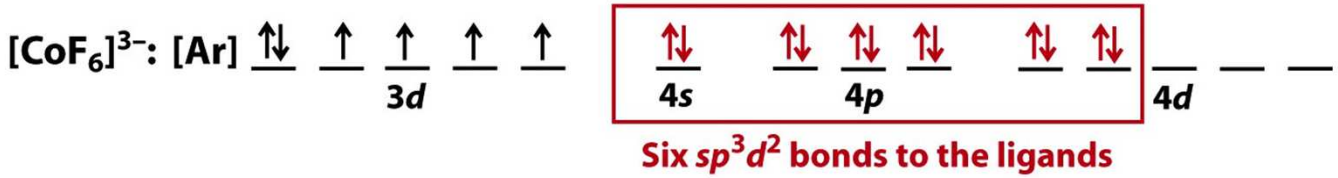

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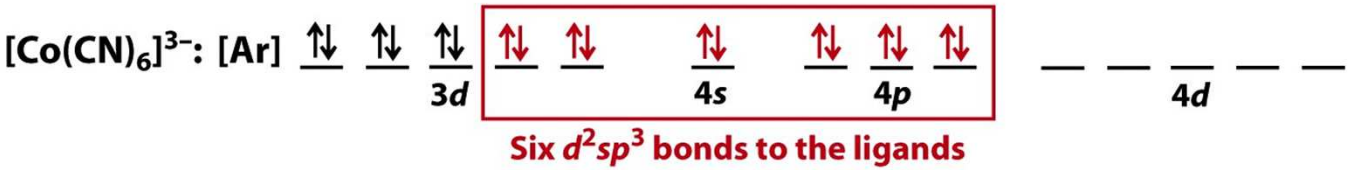
High spin: **Maxium numer of unpaired electron, Paramagnetic**



Unnumbered 20 p848d Chemistry, 5/e

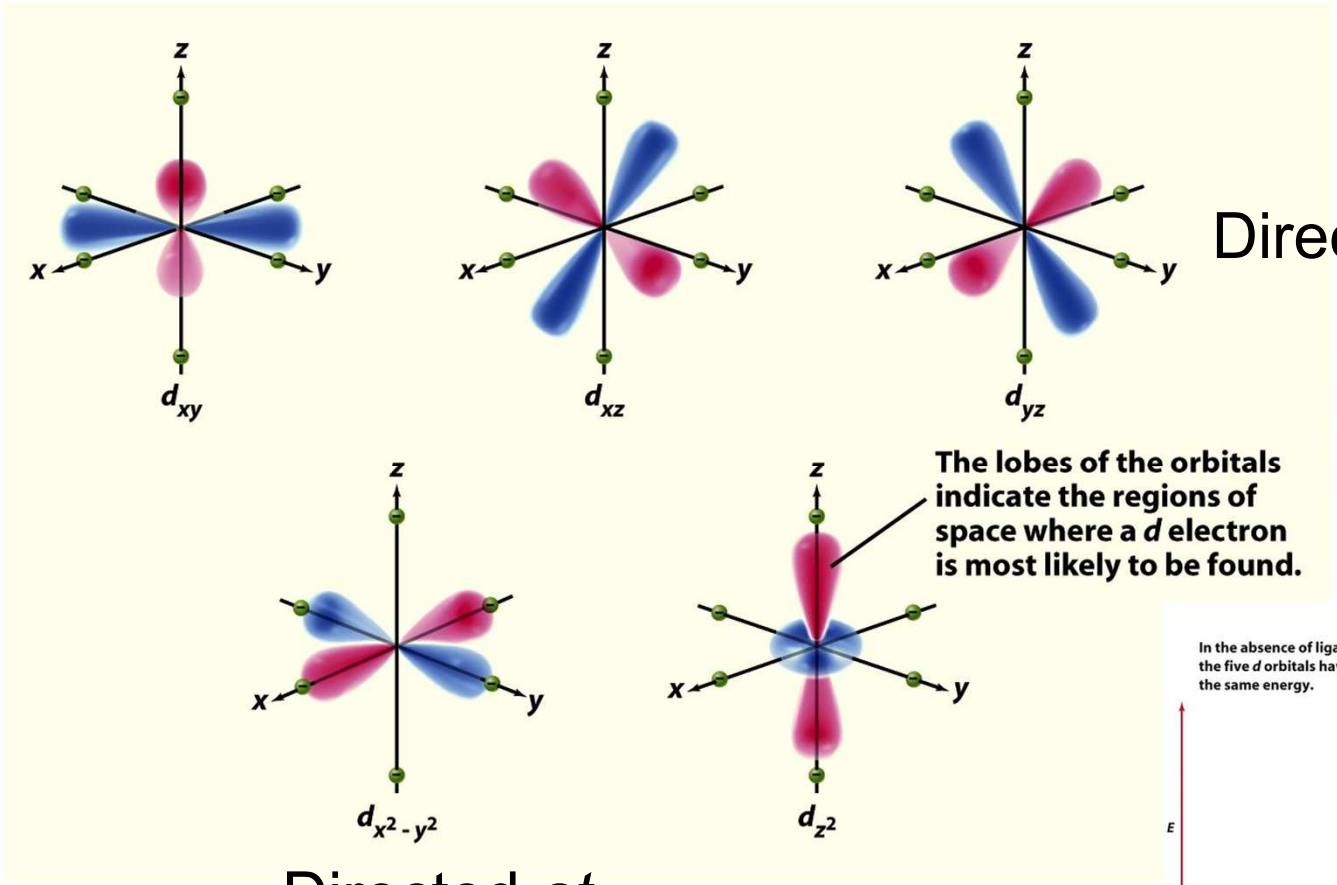
Low spin: **Minimum numer of unpaired electron**

Crystal Field Theory

Crystal Field Theory: A model that views the bonding in complexes as arising from electrostatic interactions and considers the effect of the ligand charges on the energies of the metal ion *d* orbitals.

Crystal Field Theory

Octahedral Complexes



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Directed *between* ligands

Directed *at* ligands

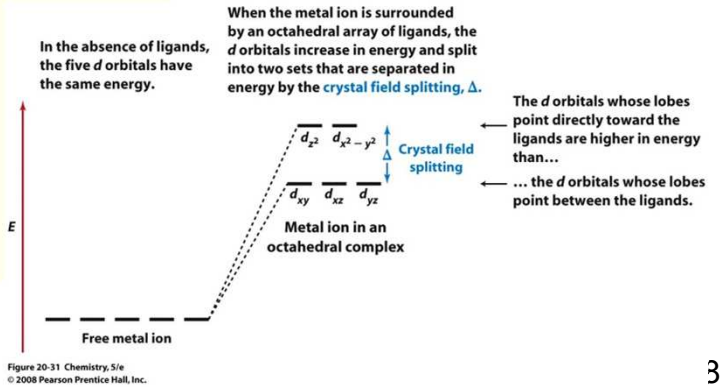

Figure 20-31 Chemistry, 5/e
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Crystal Field Theory

Octahedral Complexes

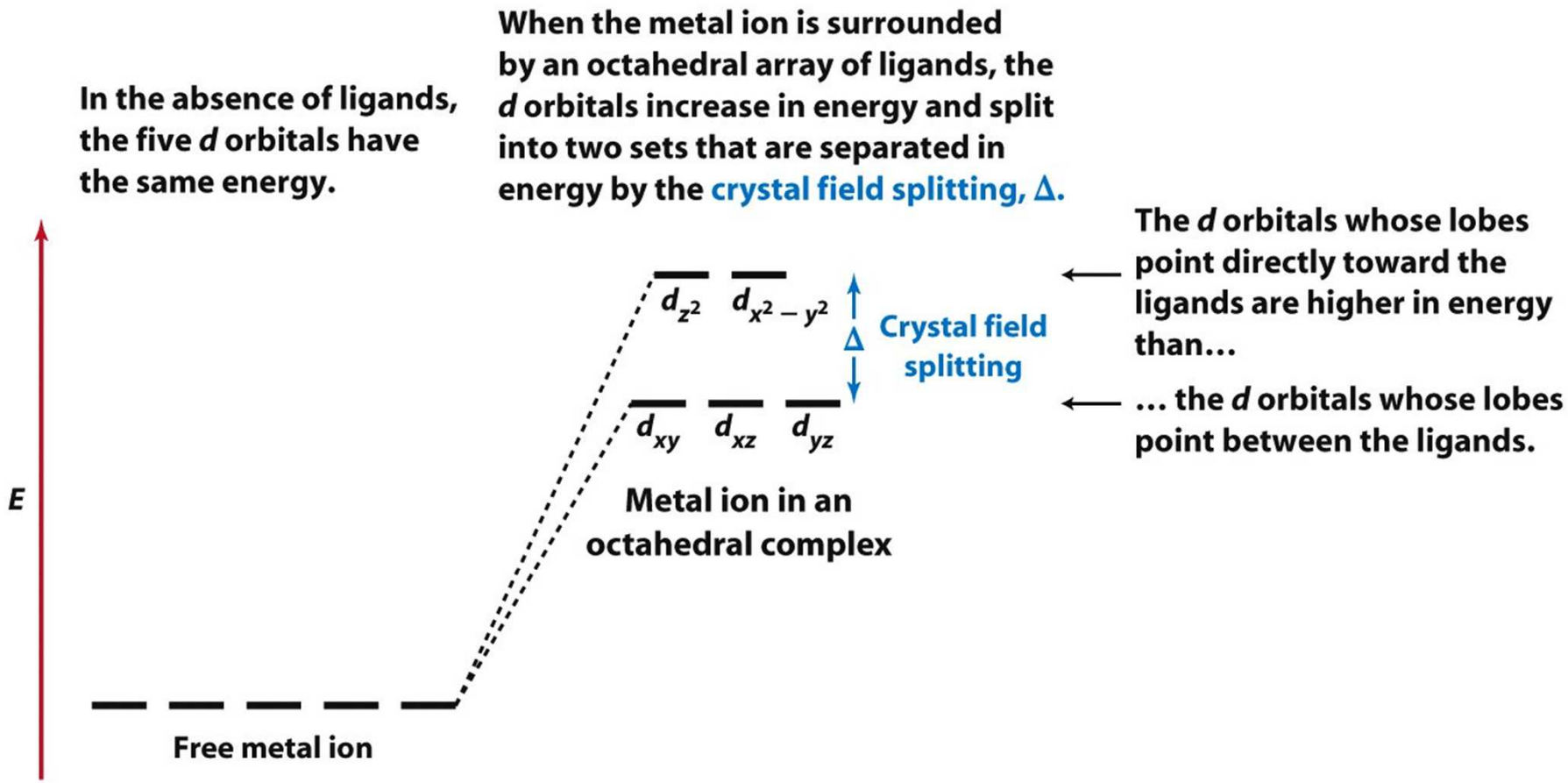
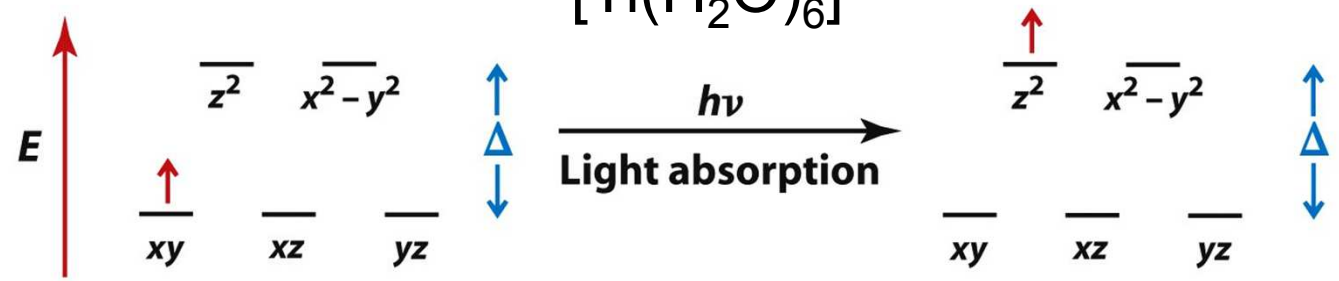


Figure 20-31 Chemistry, 5/e

Crystal Field Theory

Octahedral Complexes

$[Ti(H_2O)_6]^{3+}$



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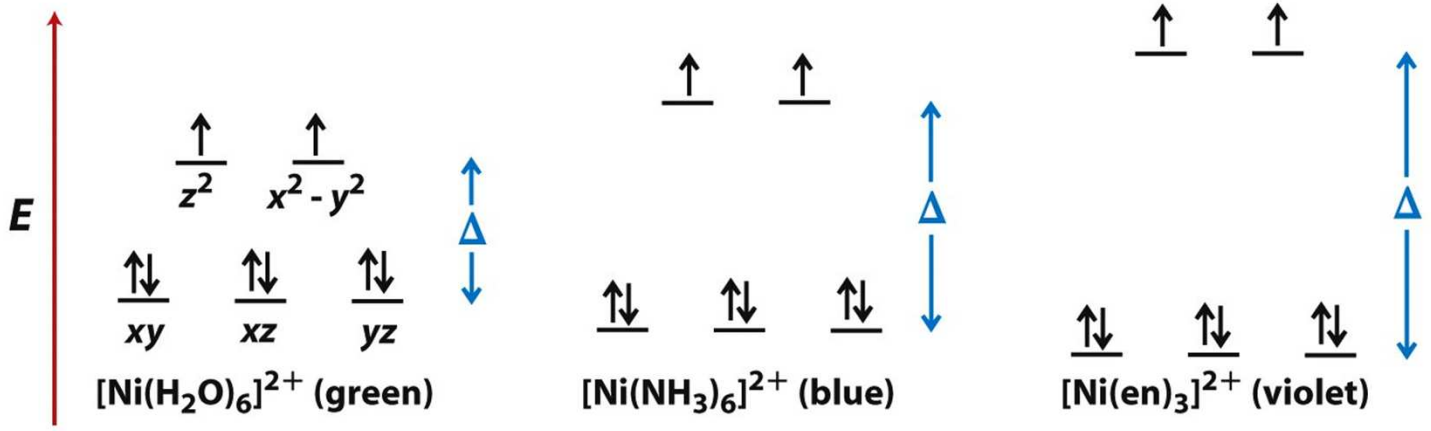
(red-violet)

$[Ni(X)_6]^{2+}$ X=H_2O, NH_3, and ethylenediamine (en)



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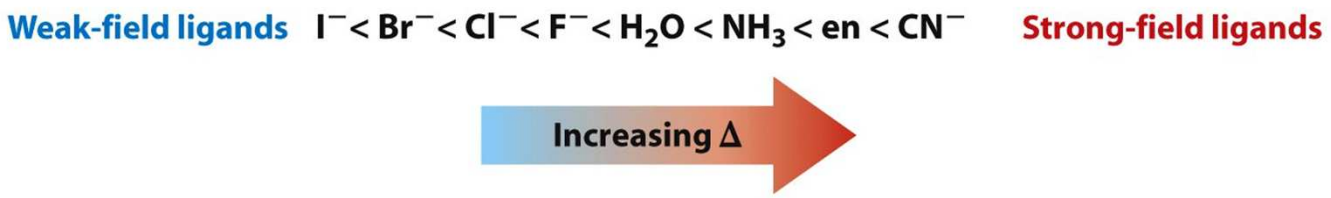
Crystal Field Theory

Octahedral Complexes

The crystal field splitting changes according to the spectrochemical series.



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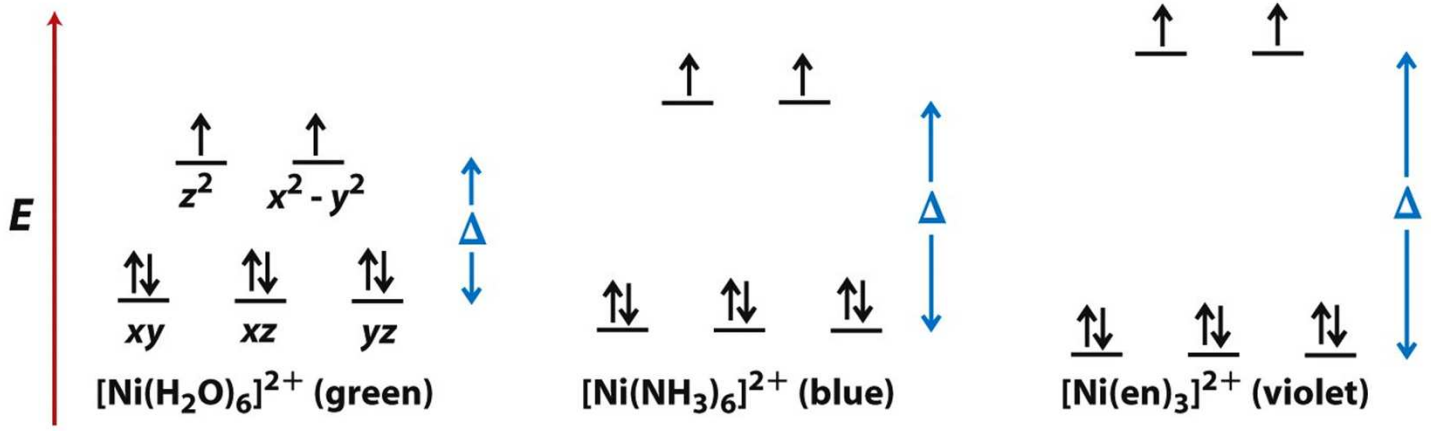
$[Ni(X)_6]^{2+}$ X=H_2O, NH_3, and ethylenediamine (en)



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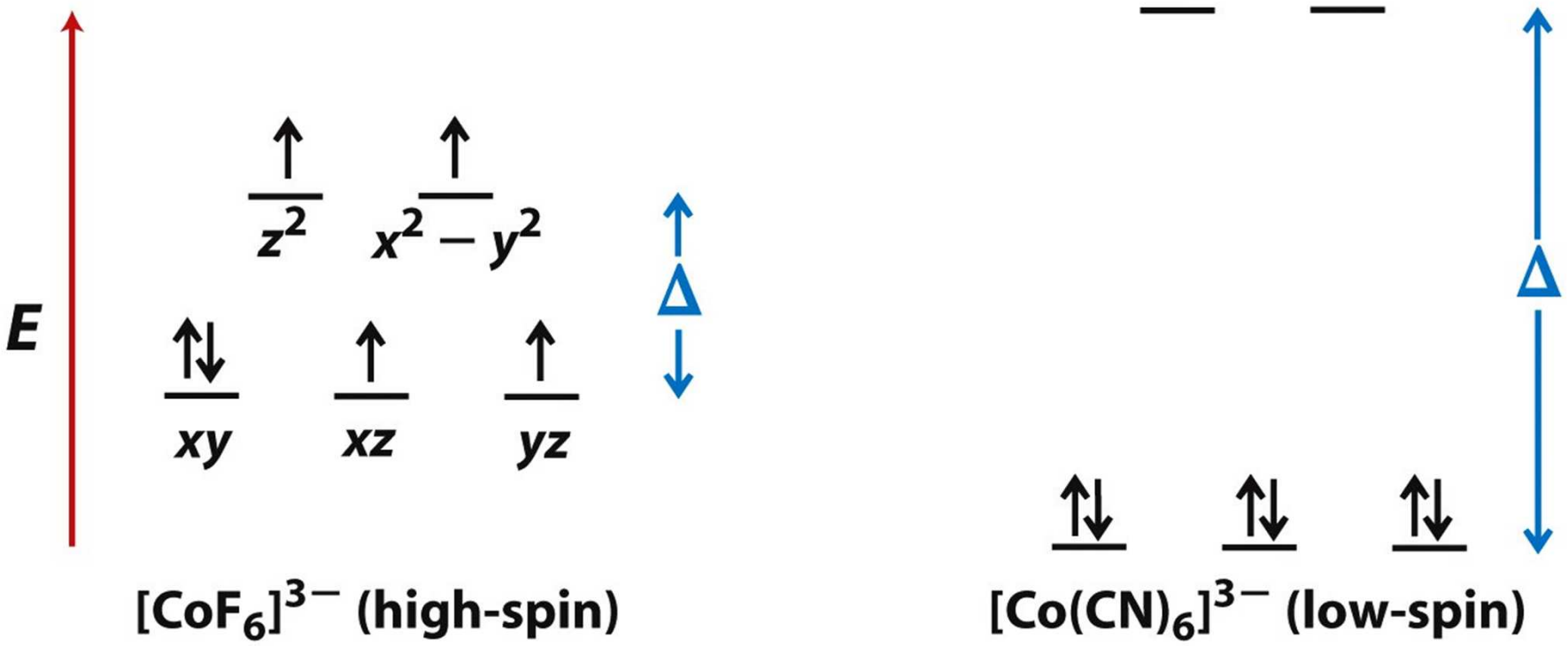
Crystal Field Theory

Octahedral Complexes

This accounts for the magnetic properties of complexes.



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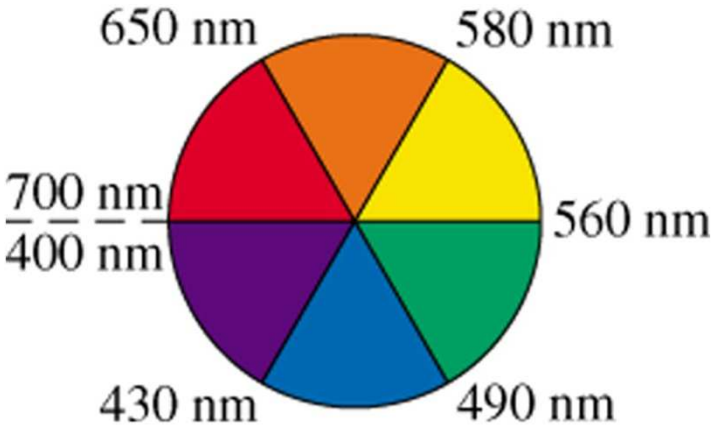
The absorption maximum for the complex ion $[Co(NH_3)_6]^{3+}$ occurs at 470 nm. What is the color of the complex and what is the crystal field splitting in kJ/mol?



Absorbs blue, will appear orange.

$$\Delta E = h\nu = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}\ \text{J s}) \times (3.00 \times 10^{8}\ \text{m s}^{-1})}{470 \times 10^{-9}\ \text{m}} = 4.23 \times 10^{-19}\ \text{J}$$

ΔE (kJ/mol) ?

$$4.23 \times 10^{-19}\ \text{J/atom} \times 6.022 \times 10^{23}\ \text{atoms/mol}$$

$$= 255\ \text{kJ/mol}$$