Chemistry 1B

Fall 2016

Topics ~~Lectures~~ 17-18

Coordination Chemistry

LISTEN UP!!!

- WE WILL ONLY COVER LIMITED PARTS OF CHAPTER 19

(940-944;952-954;963-970)

good reasons for studying coordination chemistry

- a 4th type of bonding (coordinate covalent)
- experimental verification of the shape of atomic orbitals (crystal field theory)
- important in biological chemistry
- they are pretty !!!! (glazes) ➡

remembering

- Lewis structures
- atomic d-orbitals
- electron configurations
- paramagnetism and diamagnetism

what is coordination complex?

a central metal atom or ion to which ligands are bound by coordinate covalent bonds

more

- coordinate covalent bond:

  covalent bond where one atom contributes both electrons (in olden times called ‘dative’ bond)

- ligand:

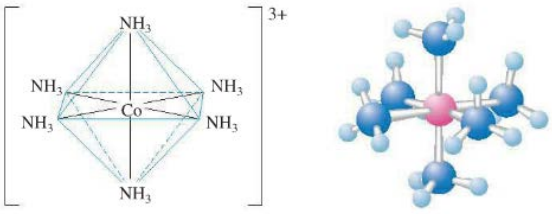
  ion or molecule which binds to central atom, contributing both electrons to a covalent bond

- coordination number:

  how many coordinate covalent bonds around central atom/ion

simple example (figure on p. 942)

$[Co(NH_3)_6]\ Cl_3$ (s)   salt of complex ion



The $Co(NH_3)_6^{3+}$ ion

$[Co(NH_3)_6]Cl_3$ (s) + $H_2O \rightarrow$

$[Co(NH_3)_6]^{3+}$ (aq) + $3Cl^-$(aq)

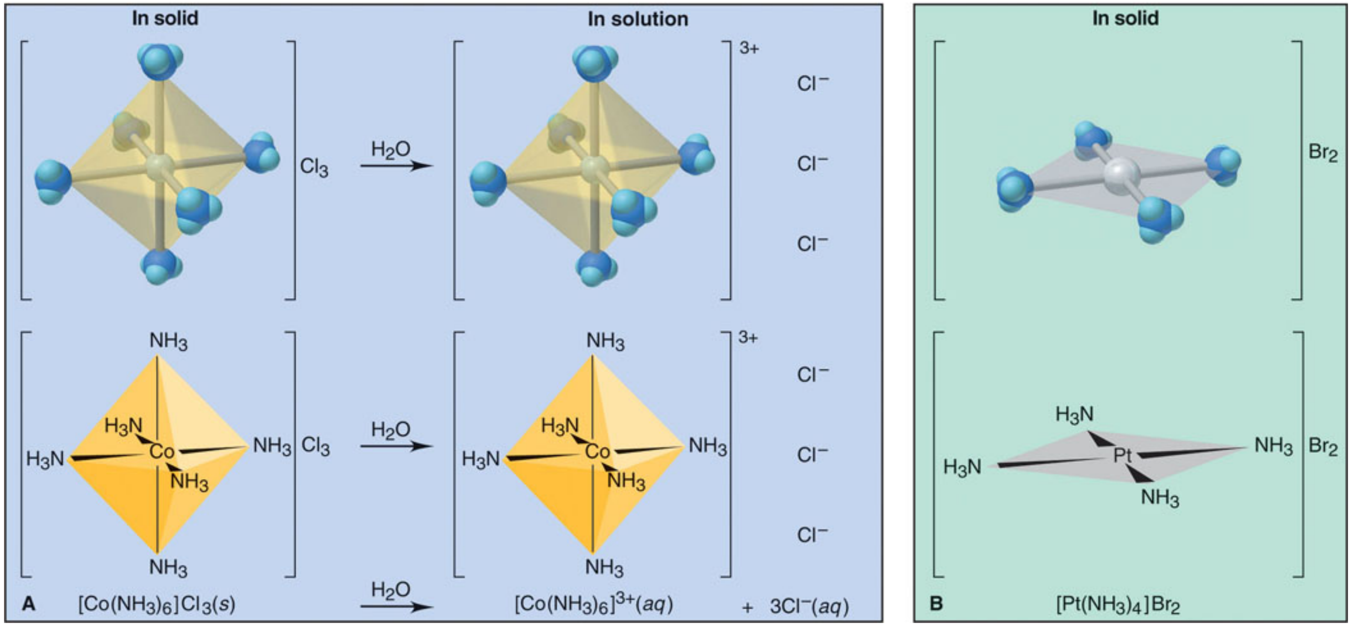
$[Co(NH_3)_6]^{3+}$ complex ion denoted by [ ]'s

6 NH_3 ligands

metal ion

$3Cl^-$ counter ions

figure 23.9 (Silberberg)



$[Co(NH_3)_6]^{3+}$ ⇒

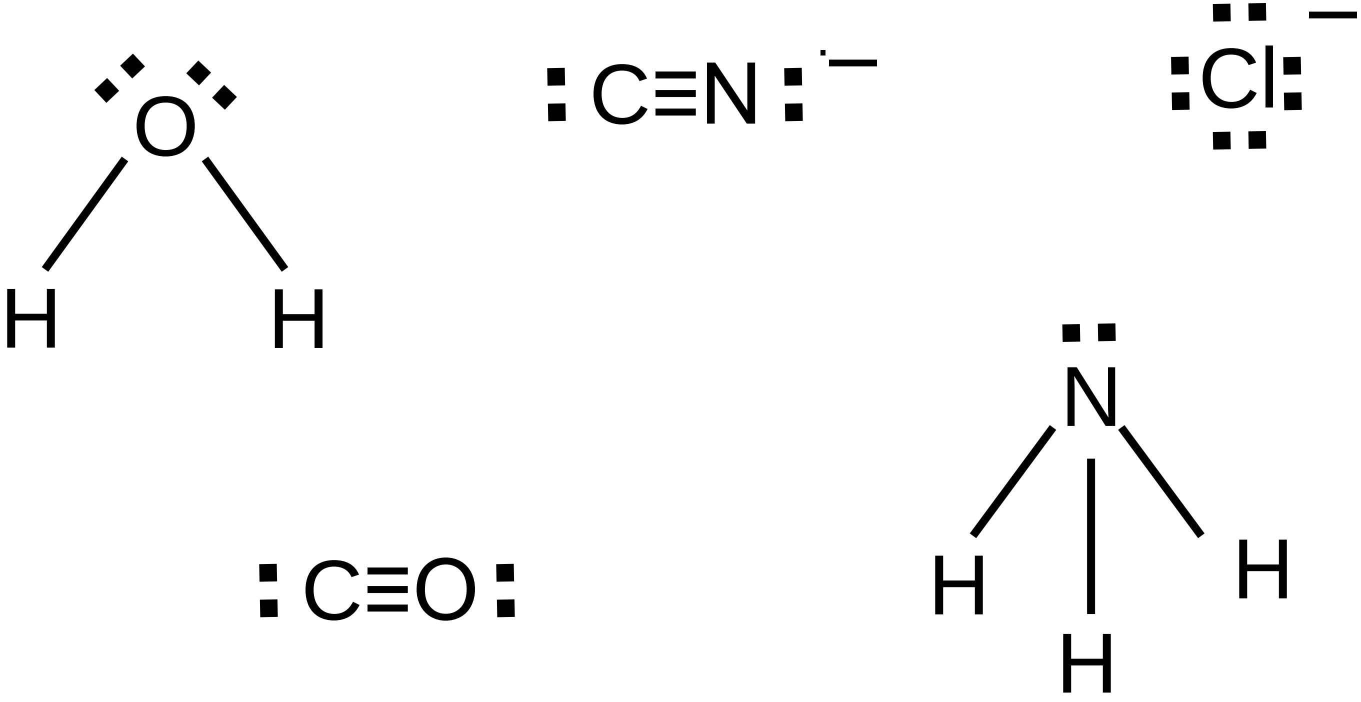
octahedral

$[Ni(CN)_4]^{2-}$ ⇒

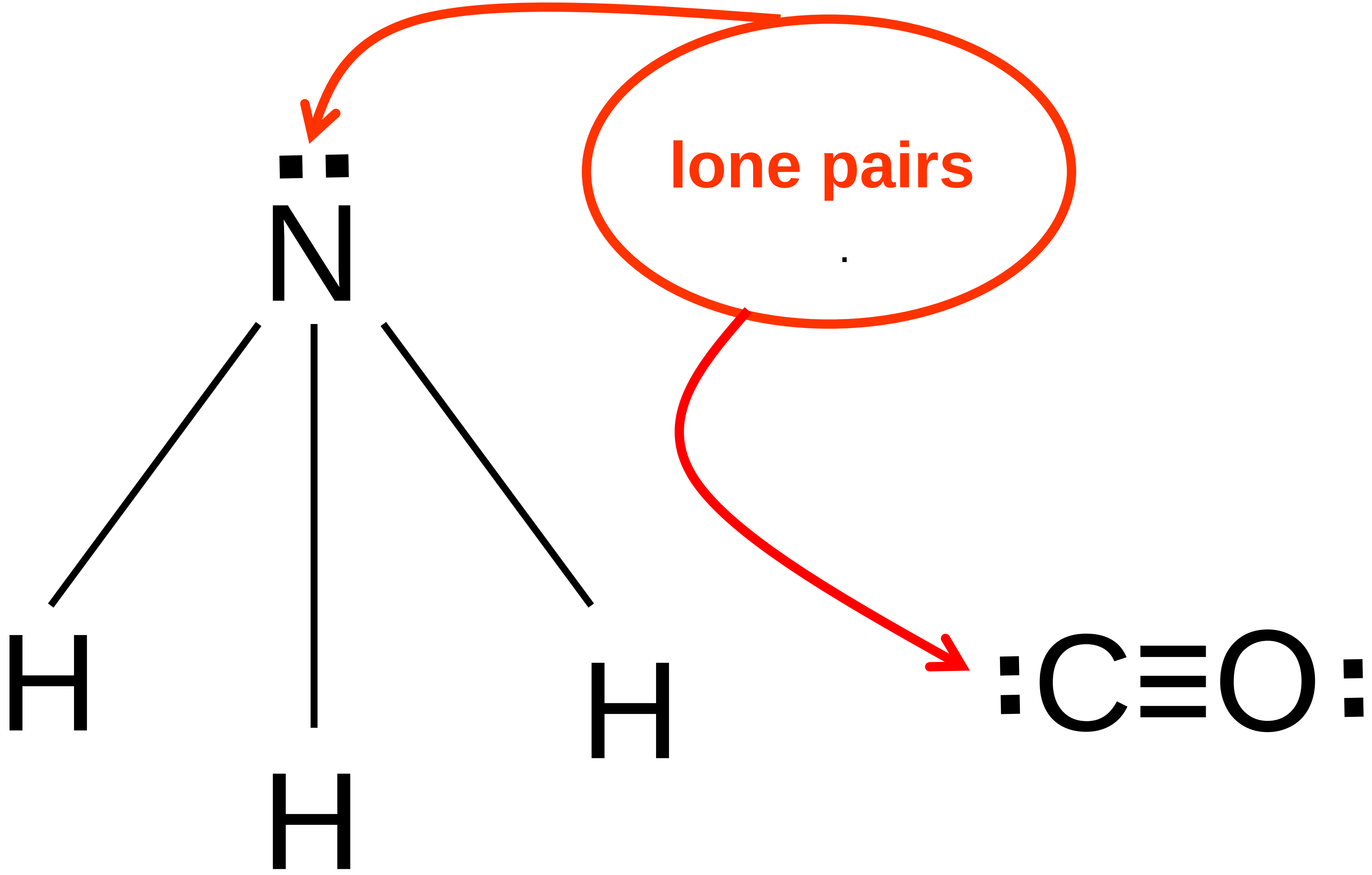
square planar

examples of common ‘simple’ ligands

H_2O, NH_3, Cl^-, CO, CN^-



what is common structural feature of ligands



lone pairs

Lewis acid

Lewis base

ligand

metal

L:

M^{+n}

Coordinate covalent bond: Lewis acid-Lewis base **CHEM 1A nr**

Lewis base

ligand

Lewis acid

metal

$$L\!:\!M^{+n}$$

coordinate covalent bonding

$[Co(NH_3)_6]^{3+}$

Octahedral complex

↓

coordination number =6

possible geometries of coordination complexes (table 23.6 Silberberg) [see figure 19.6 Zumdahl]

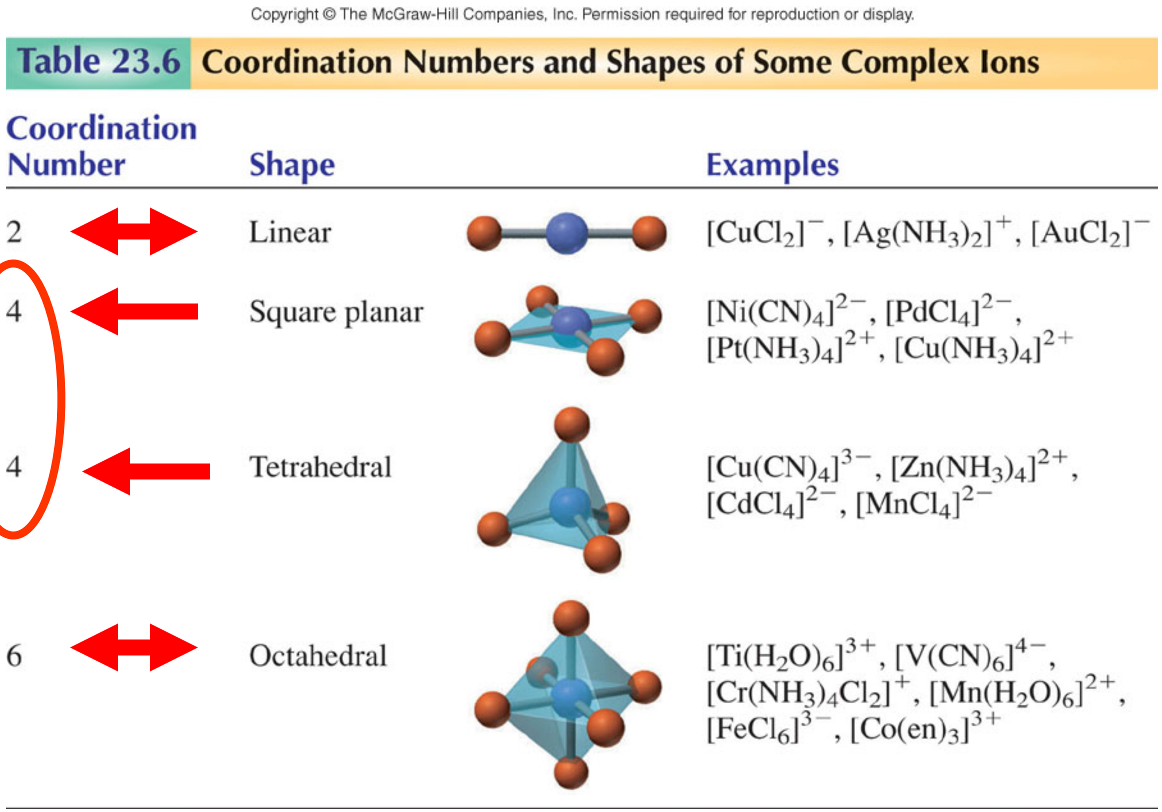


Table 23.6 Coordination Numbers and Shapes of Some Complex Ions

Coordination Number	Shape	Examples
2	Linear	$[CuCl_2]^-$, $[Ag(NH_3)_2]^+$, $[AuCl_2]^-$
4	Square planar	$[Ni(CN)_4]^{2-}$, $[PdCl_4]^{2-}$, $[Pt(NH_3)_4]^{2+}$, $[Cu(NH_3)_4]^{2+}$
4	Tetrahedral	$[Cu(CN)_4]^{3-}$, $[Zn(NH_3)_4]^{2+}$, $[CdCl_4]^{2-}$, $[MnCl_4]^{2-}$
6	Octahedral	$[Ti(H_2O)_6]^{3+}$, $[V(CN)_6]^{4-}$, $[Cr(NH_3)_4Cl_2]^+$, $[Mn(H_2O)_6]^{2+}$, $[FeCl_6]^{3-}$, $[Co(en)_3]^{3+}$

ligands (Table 23.7 Silberberg) [Table 19.13 Zumdahl]

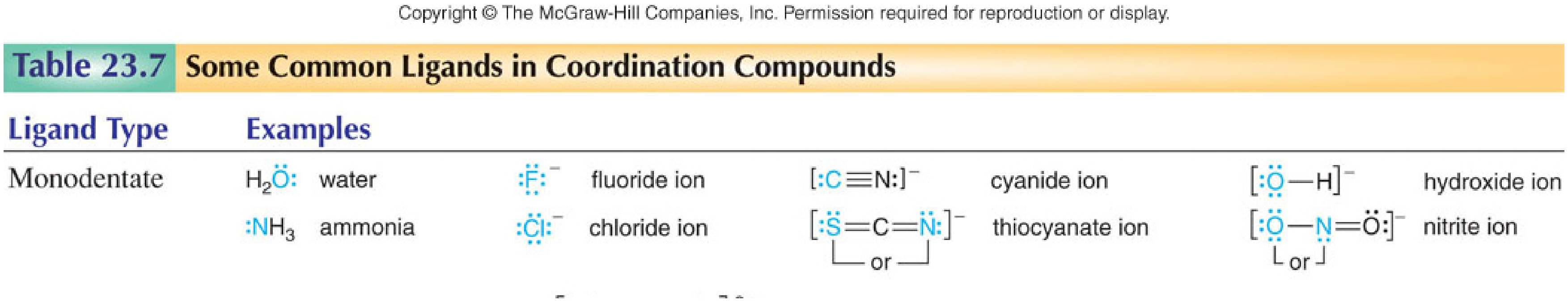


Table 23.7 Some Common Ligands in Coordination Compounds

Ligand Type	Examples							
Monodentate	$H_2\ddot{O}:$	water	$:\ddot{F}:^-$	fluoride ion	$[:C\equiv N:]^-$	cyanide ion	$[:\ddot{O}-H]^-$	hydroxide ion
	$:NH_3$	ammonia	$:\ddot{Cl}:^-$	chloride ion	$[:\ddot{S}=C=\ddot{N}:]^-$ or	thiocyanate ion	$[:\ddot{O}-\ddot{N}=\ddot{O}:]^-$ or	nitrite ion

monodentate

atom forming coordinate covalent bond indicated in **BLUE**

ligands (Table 23.7 Silberberg) [see Table 19.13 Zumdahl]

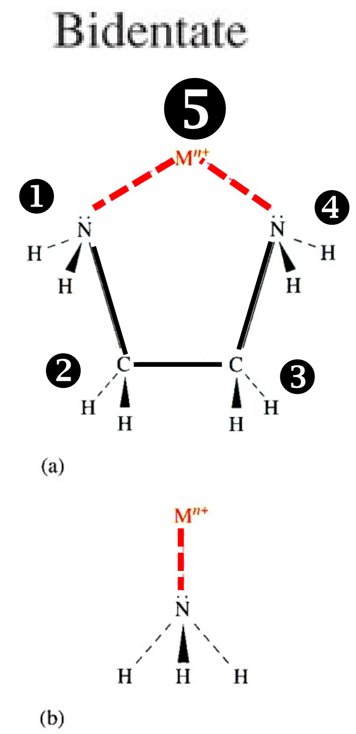
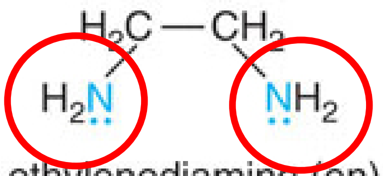
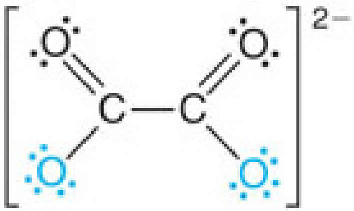


Figure 20.7
(a) The bidentate ligand ethylenediamine can bond to the metal ion through the lone pair on each nitrogen atom, thus forming two coordinate covalent bonds.
(b) Ammonia is a monodentate ligand.



ethylenediamine (en)

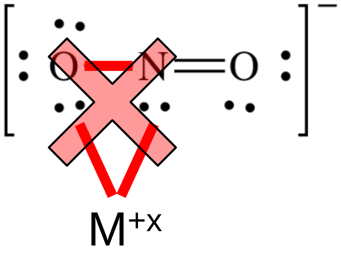


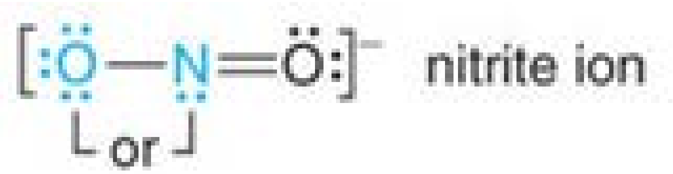
oxalate ion

bidentate

atoms forming coordinate covalent bonds indicated in **BLUE**

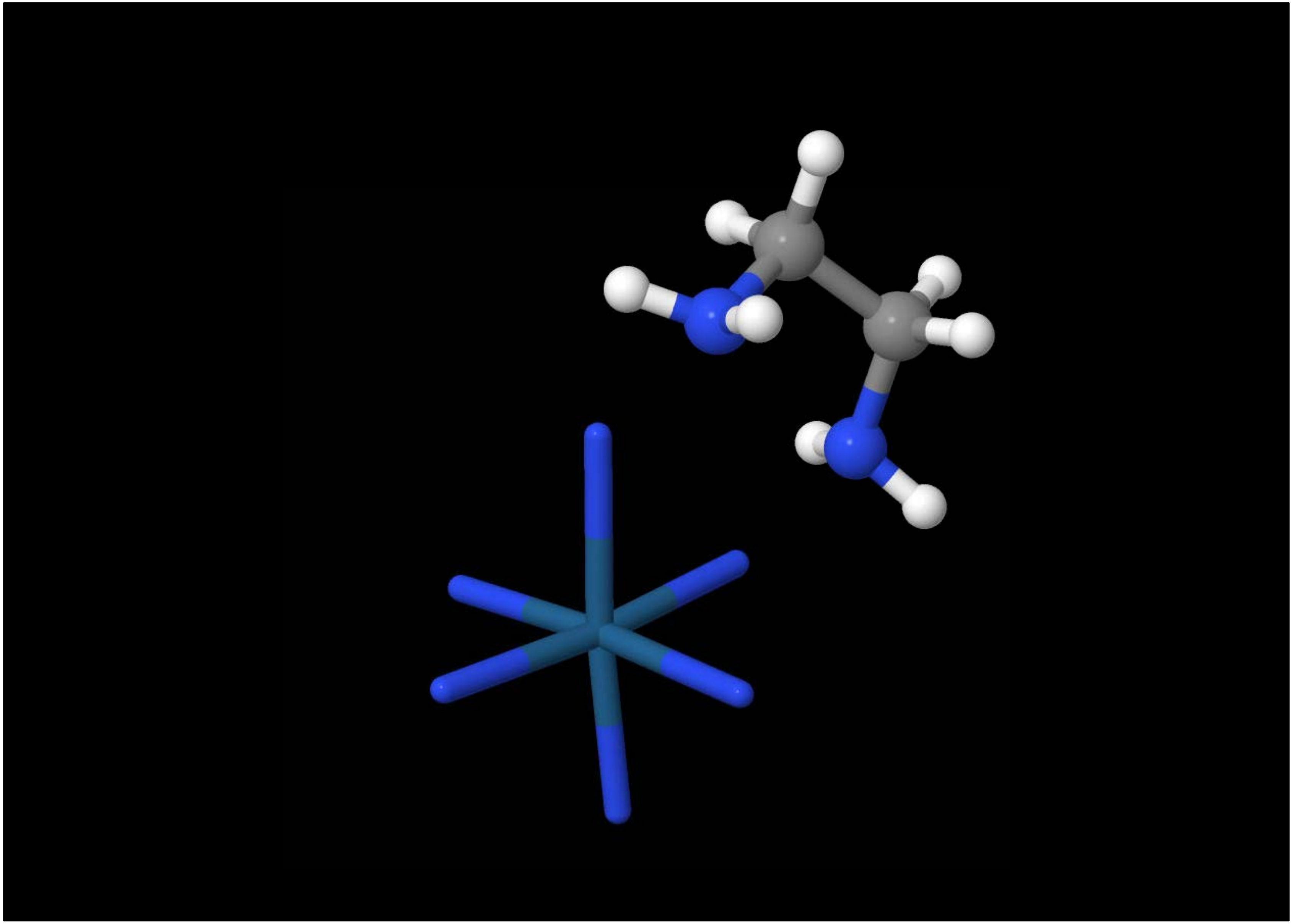
multi-dentate 5 or six membered ring with M$^+$



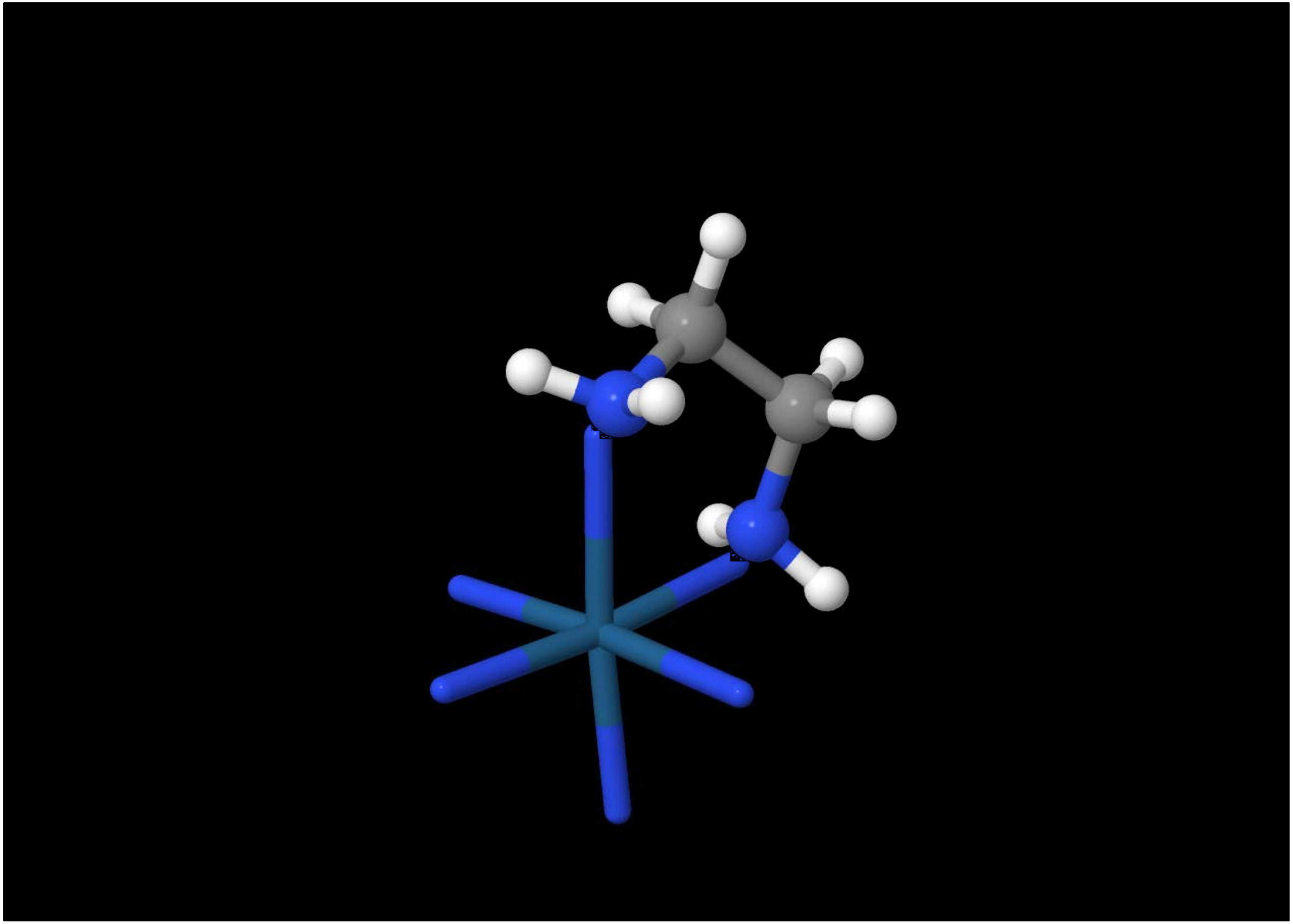


nitrite ion

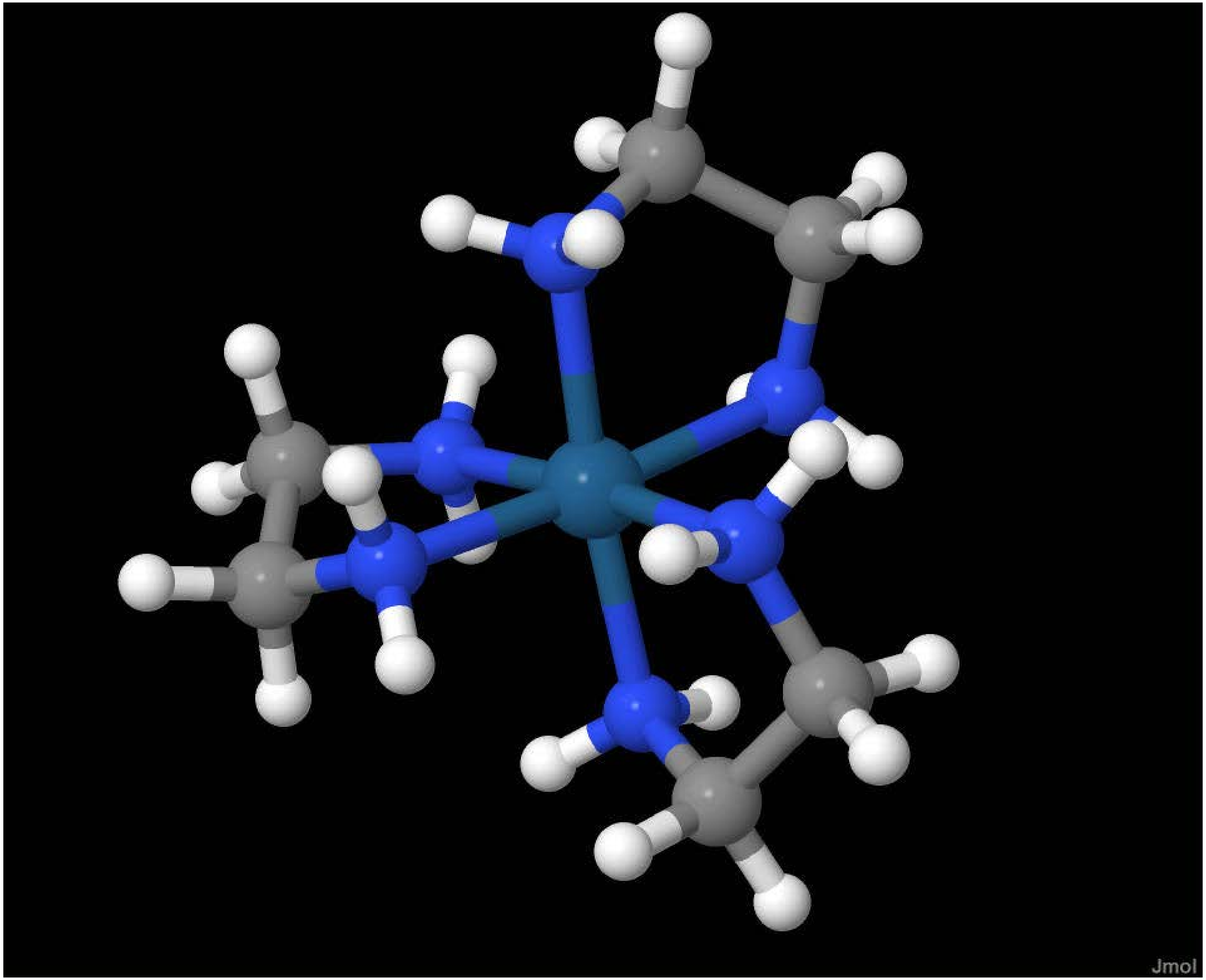
ethylene diamine ***bidentate*** *ligand*



*ethylene diamine **bidentate** ligand*



$[Cr(en)_3]^{3+}$ octahedral complex



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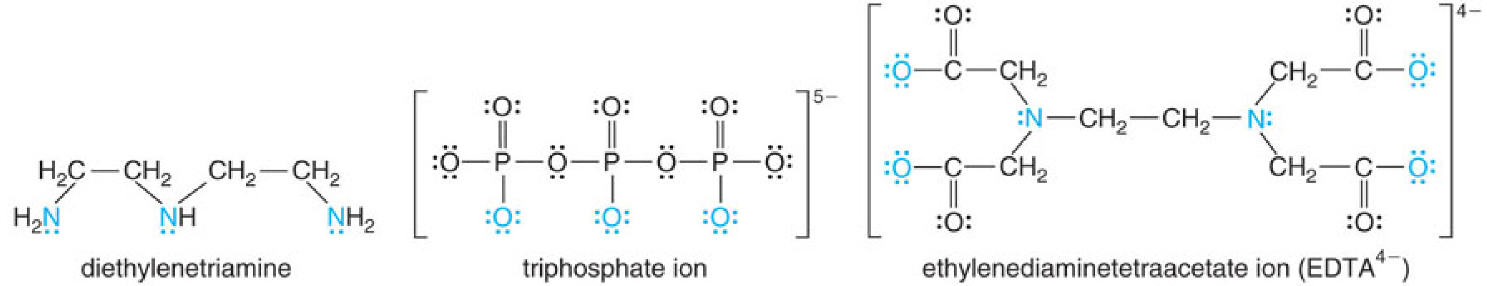
ligands (Table 23.7 Silberberg) [see Table 19.13 Zumdahl]

Polydentate

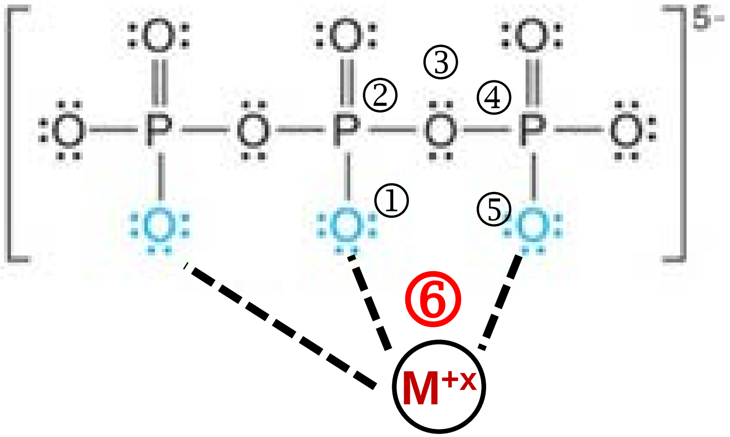


diethylenetriamine

triphosphate ion

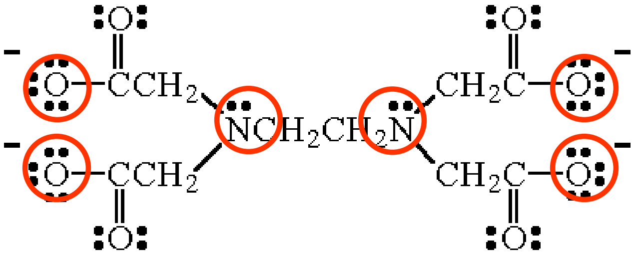
ethylenediaminetetraacetate ion ($EDTA^{4-}$)

polydentate

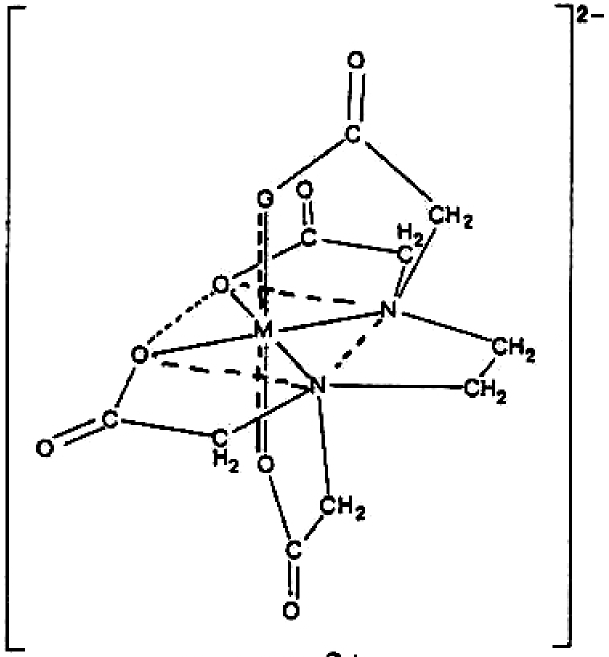


atoms forming coordinate
covalent bonds indicated in **BLUE**

EDTA a chelate (claw!!)

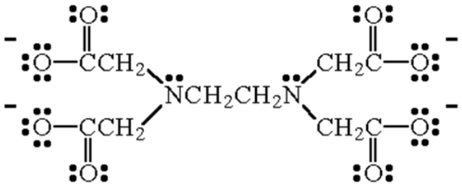


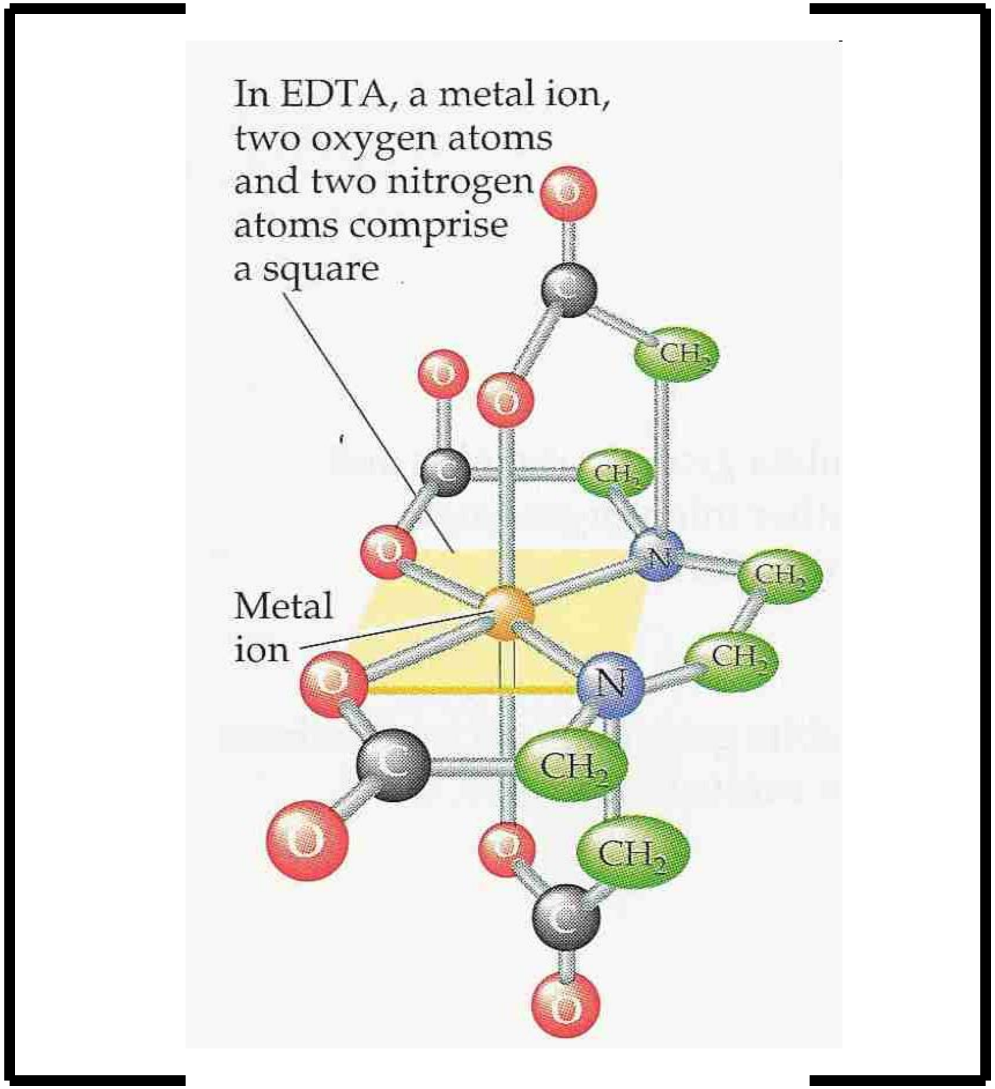
hexadentate



M=Pb^{2+}

more EDTA^{4-}




In EDTA, a metal ion, two oxygen atoms and two nitrogen atoms comprise a square

2-

for Fe^{2+}

Table 19.13 , Figure 19.7

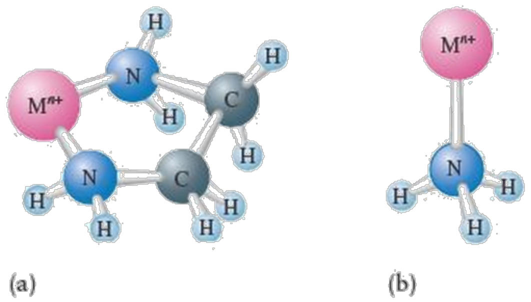


FIGURE 19.7

(a) The bidentate ligand ethylenediamine can bond to the metal ion through the lone pair on each nitrogen atom, thus forming two coordinate covalent bonds. (b) Ammonia is a monodentate ligand.

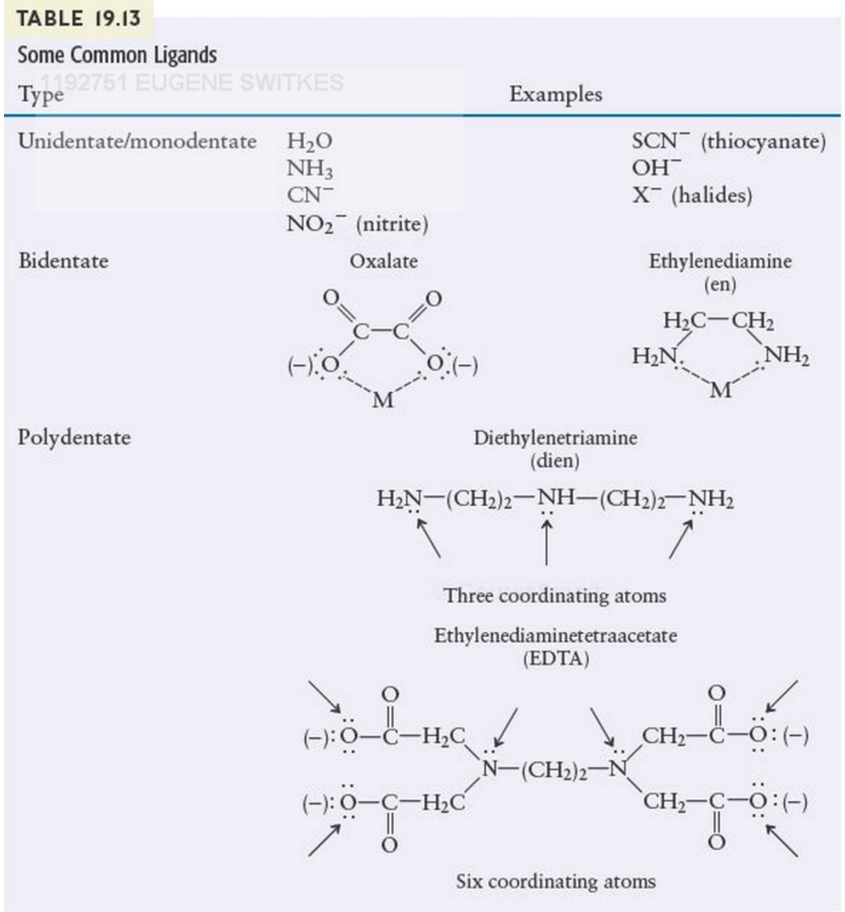


TABLE 19.13

Some Common Ligands

Type	Examples	
Unidentate/monodentate	H_2O NH_3 CN^- NO_2^- (nitrite)	SCN^- (thiocyanate) OH^- X^- (halides)
Bidentate	Oxalate	Ethylenediamine (en)
Polydentate	Diethylenetriamine (dien) $H_2\ddot{N}-(CH_2)_2-\ddot{N}H-(CH_2)_2-\ddot{N}H_2$ Three coordinating atoms	
	Ethylenediaminetetraacetate (EDTA) Six coordinating atoms	

determining: num ligands charge oxidation state d-electrons

given $[Co(NH_3)_n]\,Cl_3$ is salt of octahedral complex

- **coordination number=6 since octahedral**
- **n=6** since NH_3 is monodentate ligand
- **3^+** charge on complex from counterion: 3 Cl^-
- **Co^{3+}** oxidation state of metal from charge on complex and zero charge on NH_3 ligands
- **d^6** d-electrons from aufbau principle FOR CATIONS

other examples

$K_3[Fe(CN)_{\mathbf{n}}]$ octahedral

$[Co(en)_{\mathbf{n}}]Cl_3$ octahedral

$Na_2[Ni(CN)_{\mathbf{n}}]$ square planar

~~Sections 19.1-19.2, 19.4 (pp 940-951;956- 963)~~ **(don’t fret)**

- General factoids about transition metals
- Nomenclature
- Isomerism

FIGURE 19.4

A bicycle with a titanium frame.

Manganese nodules on the sea floor.

FIGURE 19.15

~~Section 19.5 Localized Electron model (pp 963-964)~~ ***(don’t fret)***

hybridization involving d-orbitals:

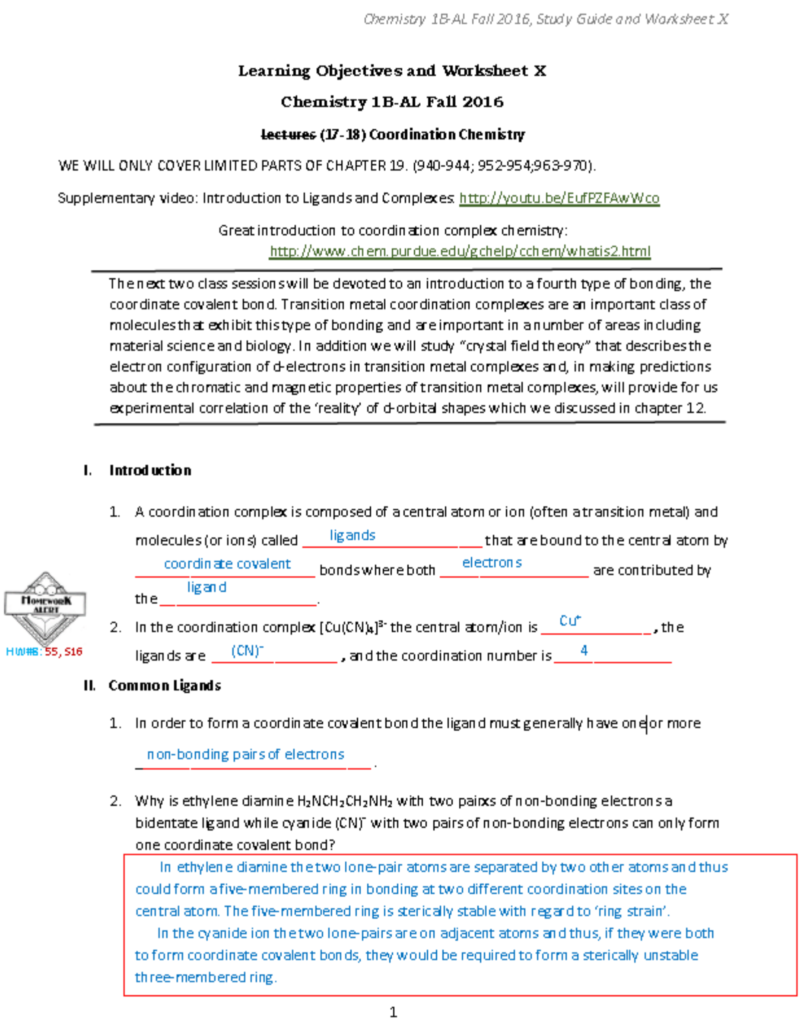
d^2sp^3 six octahedrally oriented hybrids
dsp^3 four square planar hybrids

Crystal Field Theory of Coordination Complexes

magnetic properties
and
pretty colors

(Pp 964-970)

have covered worksheet 10 I-III



Learning Objectives and Worksheet X

Chemistry 1B-AL Fall 2016

~~Lectures~~ (17-18) Coordination Chemistry

WE WILL ONLY COVER LIMITED PARTS OF CHAPTER 19. (940-944; 952-954;963-970).

Supplementary video: Introduction to Ligands and Complexes: http://youtu.be/EufPZFAwWco

Great introduction to coordination complex chemistry: http://www.chem.purdue.edu/gchelp/cchem/whatis2.html

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The next two class sessions will be devoted to an introduction to a fourth type of bonding, the coordinate covalent bond. Transition metal coordination complexes are an important class of molecules that exhibit this type of bonding and are important in a number of areas including material science and biology. In addition we will study "crystal field theory" that describes the electron configuration of d-electrons in transition metal complexes and, in making predictions about the chromatic and magnetic properties of transition metal complexes, will provide for us experimental correlation of the 'reality' of d-orbital shapes which we discussed in chapter 12.

I. Introduction

1. A coordination complex is composed of a central atom or ion (often a transition metal) and molecules (or ions) called ___ligands___ that are bound to the central atom by ___coordinate covalent___ bonds where both ___electrons___ are contributed by the ___ligand___.

HW#8: 55, S16

2. In the coordination complex $[Cu(CN)_4]^{3-}$ the central atom/ion is ___Cu^+___, the ligands are ___$(CN)^-$___, and the coordination number is ___4___

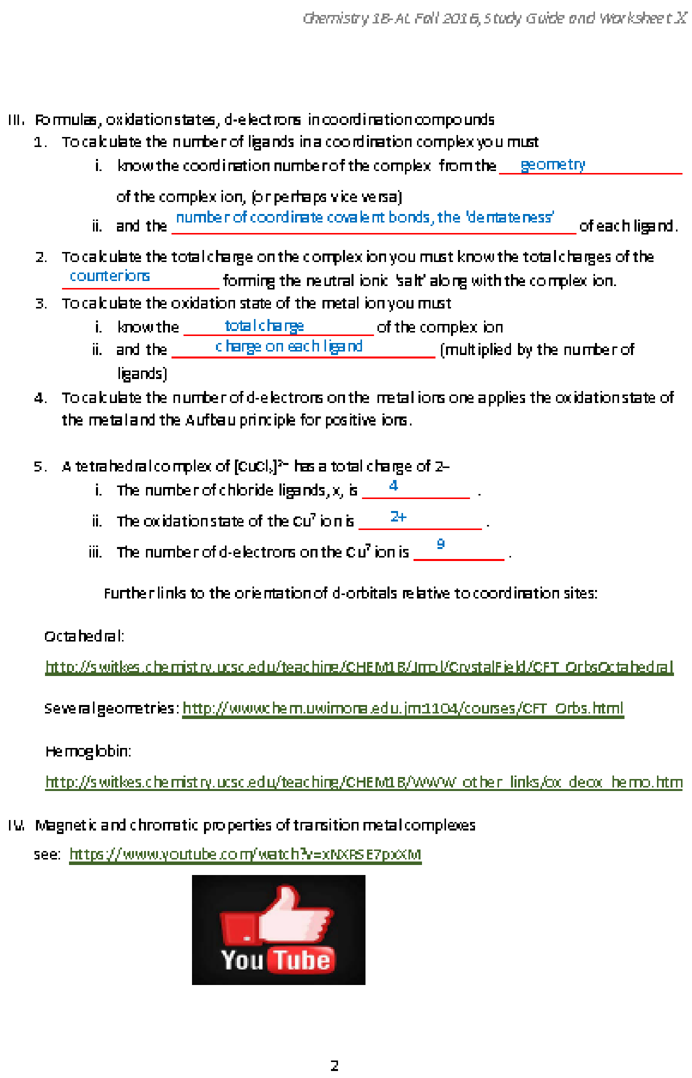
II. Common Ligands

1. In order to form a coordinate covalent bond the ligand must generally have one or more ___non-bonding pairs of electrons___.

2. Why is ethylene diamine $H_2NCH_2CH_2NH_2$ with two pairxs of non-bonding electrons a bidentate ligand while cyanide $(CN)^-$ with two pairs of non-bonding electrons can only form one coordinate covalent bond?

In ethylene diamine the two lone-pair atoms are separated by two other atoms and thus could form a five-membered ring in bonding at two different coordination sites on the central atom. The five-membered ring is sterically stable with regard to 'ring strain'.

In the cyanide ion the two lone-pairs are on adjacent atoms and thus, if they were both to form coordinate covalent bonds, they would be required to form a sterically unstable three-membered ring.



III. Formulas, oxidation states, d-electrons in coordination compounds

1. To calculate the number of ligands in a coordination complex you must
   i. know the coordination number of the complex from the ___geometry___ of the complex ion, (or perhaps vice versa)
   ii. and the ___number of coordinate covalent bonds, the 'dentateness'___ of each ligand.
2. To calculate the total charge on the complex ion you must know the total charges of the ___counterions___ forming the neutral ionic 'salt' along with the complex ion.
3. To calculate the oxidation state of the metal ion you must
   i. know the ___total charge___ of the complex ion
   ii. and the ___charge on each ligand___ (multiplied by the number of ligands)
4. To calculate the number of d-electrons on the metal ions one applies the oxidation state of the metal and the Aufbau principle for positive ions.

5. A tetrahedral complex of $[CuCl_x]^{2-}$ has a total charge of 2–
   i. The number of chloride ligands, x, is ___4___ .
   ii. The oxidation state of the $Cu^?$ ion is ___2+___ .
   iii. The number of d-electrons on the $Cu^?$ ion is ___9___ .

Further links to the orientation of d-orbitals relative to coordination sites:

Octahedral:

http://switkes.chemistry.ucsc.edu/teaching/CHEM1B/Jmol/CrystalField/CFT_OrbsOctahedral

Several geometries: http://wwwchem.uwimona.edu.jm1104/courses/CFT_Orbs.html

Hemoglobin:

http://switkes.chemistry.ucsc.edu/teaching/CHEM1B/WWW_other_links/ox_deox_hemo.htm

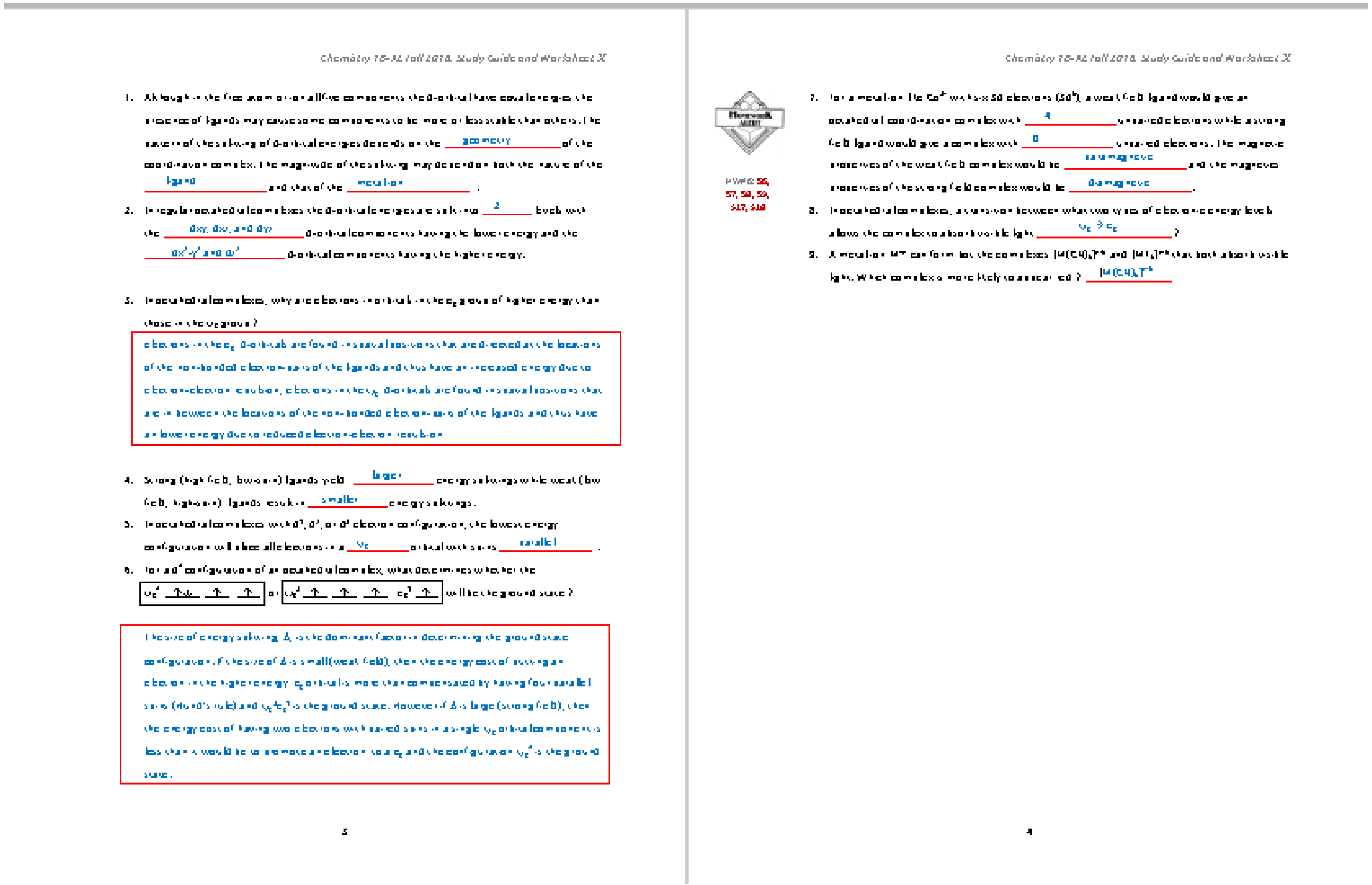
IV. Magnetic and chromatic properties of transition metal complexes

see: https://www.youtube.com/watch?v=xNXRSE7pXXM

this video (clickers Q's next class) cover: worksheet 10 IV

IV. Magnetic and chromatic properties of transition metal complexes

see: https://www.youtube.com/watch?v=xNXRSE7pxXM



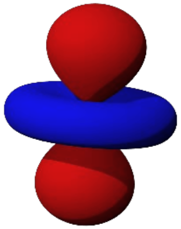
recommended !!!!

IV. Magnetic and chromatic properties of transition metal complexes

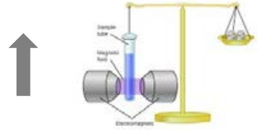
see: https://www.youtube.com/watch?v=xNXRSE7pxXM

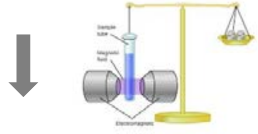
crystal-field theory of transition metal coordination complexes

"reality" of the shapes of d-orbitals



- why are 'free' transition metal ions colorless ?
  but
  transition metal ions in coordination complexes are often colored ?

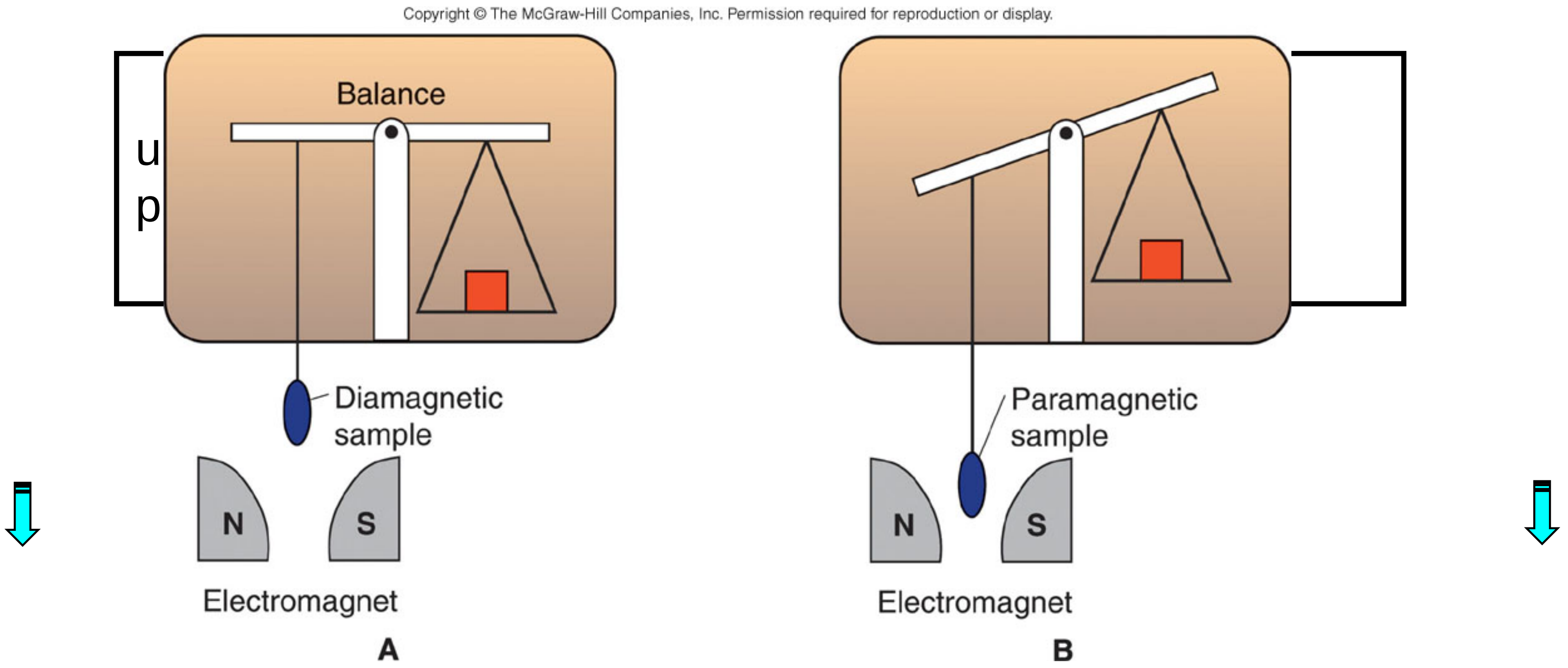




- why are some transition metal complexes diamagnetic?
- and others are paramagnetic?

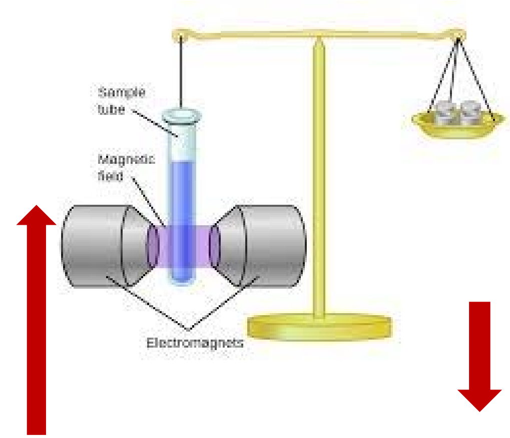
paramagnetism vs diamagnetism (Gouy balance)

diamagnetic paramagnetic



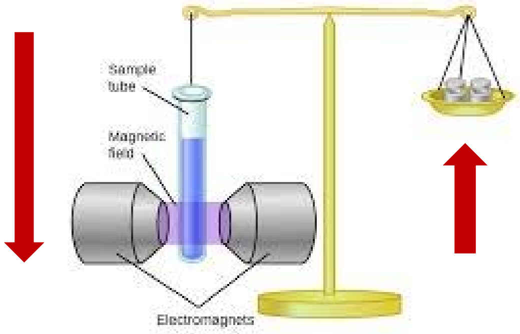
strength of paramagnetism depends on number of unpaired electrons

crystal field theory and magnetic properties $[Co(NH_3)_6]^{3+}$ vs $[Co(F)_6]^{3-}$



$[Co(NH_3)_6]^{3+}$ is diamagnetic

but



$[Co(F)_6]^{3-}$ is paramagnetic

crystal field theory and color

- most electronic excitations in UV
  (H 1s → H 2p λ=121 nm)

- Co^{3+} [Ar]$3d^6$ → Co^{3+} [Ar]$3d^5 4s^1$ (λ=75.3 nm) **UV**
  NH_3 → NH_3* (excited state) (λ=216 nm) **UV**

Co^{3+} and NH_3 are colorless !!!

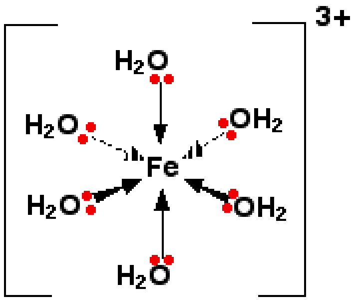
but in coordination complex

- $[Co(NH_3)_6]^{3+}$ → excited state* (λ=430 nm,
  absorbs ‘indigo’)

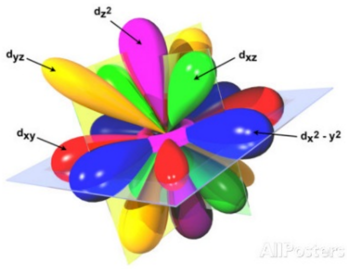
$[NH_3)_6]^{3+}$ appears yellow-orange !!

crystal field theory

1. the ligands form coordinate covalent electron pair σ-bonds with the metal ion/atom, the ligand contributing both electrons



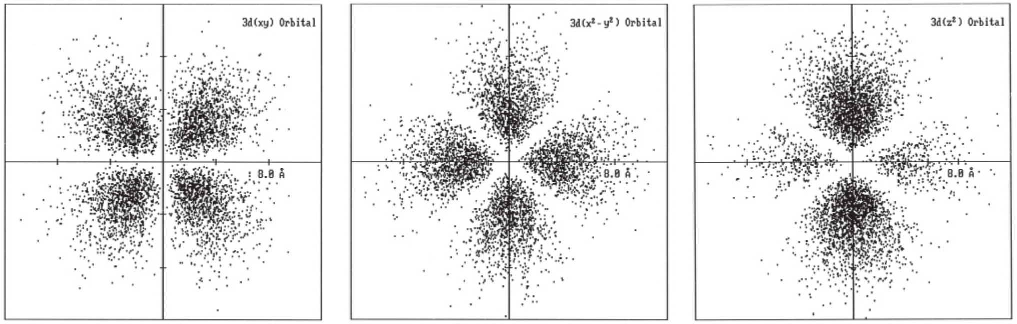
2. crystal field theory addresses the effects of the presence of these ligands on the d-electrons of the metal ion by considering the electrostatic (repulsive) interaction of the ligand non-bonding pairs with the d-electrons.

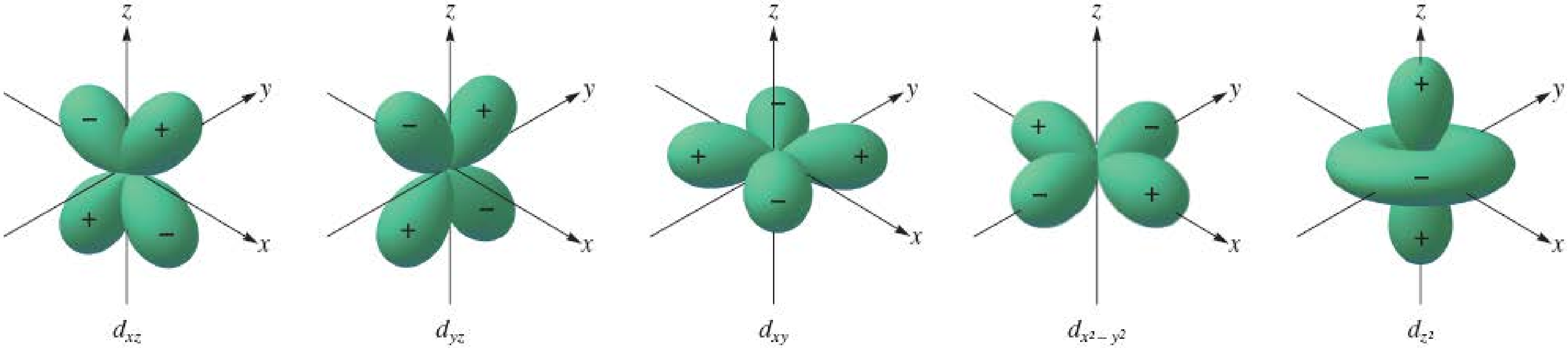


limiting the playing field

- Crystal field theory- an electrostatic approach to ligand-metal d-orbital interactions
  (more complicated ligand-field and m.o. approaches lead to similar predictions)
- Only responsible for octahedral complexes
  (other geometries follow similar considerations)

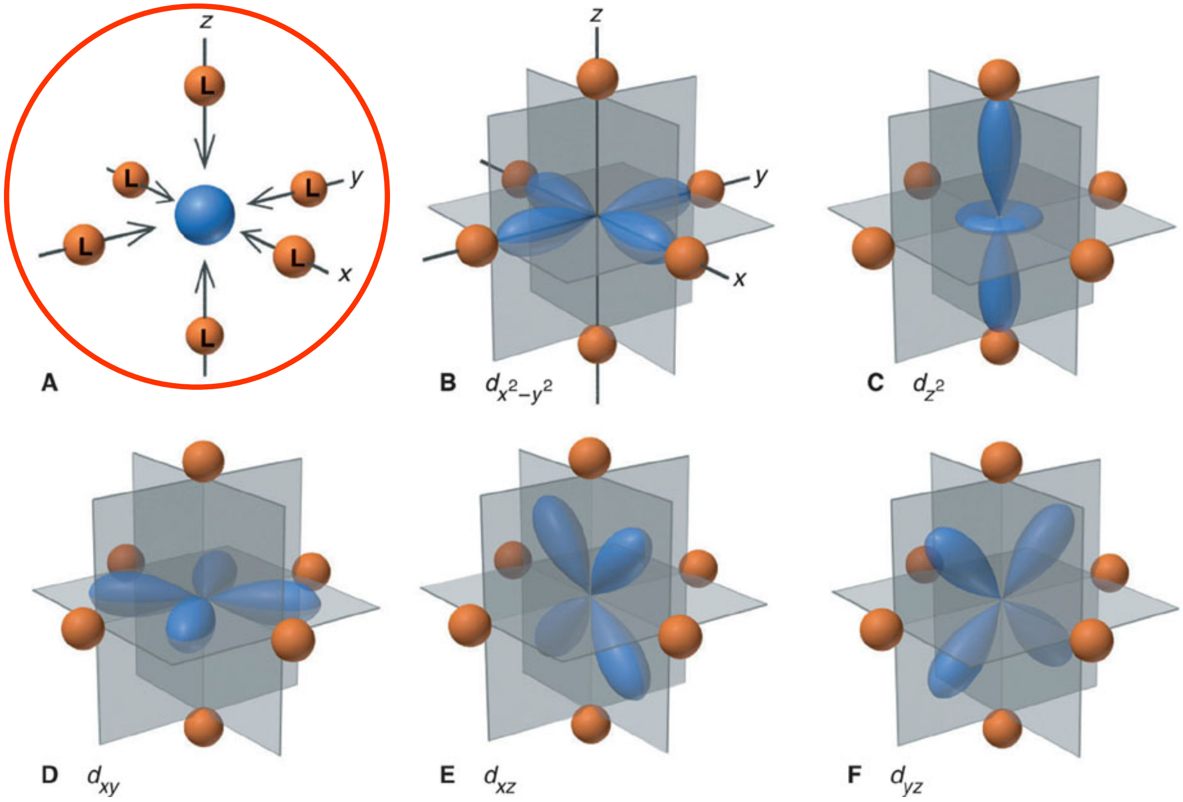
remember atomic d-orbitals (figure 12.21)



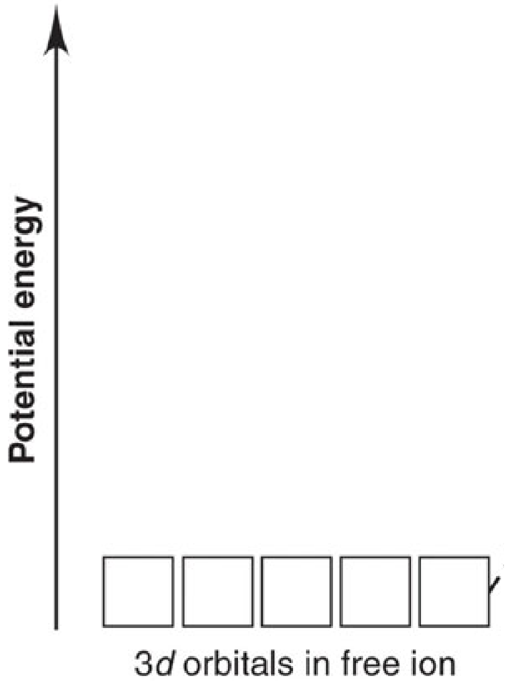


dxz **dyz** **dxy** **dx^2-y^2** **dz^2**

*metal ion d-obitals in **octahedral** complex (Silberberg fig. 23.17; Zumdahl fig. 19.21)*



what happens to energies of d-orbitals when ligands bind to metal ion? (fig 23.18)

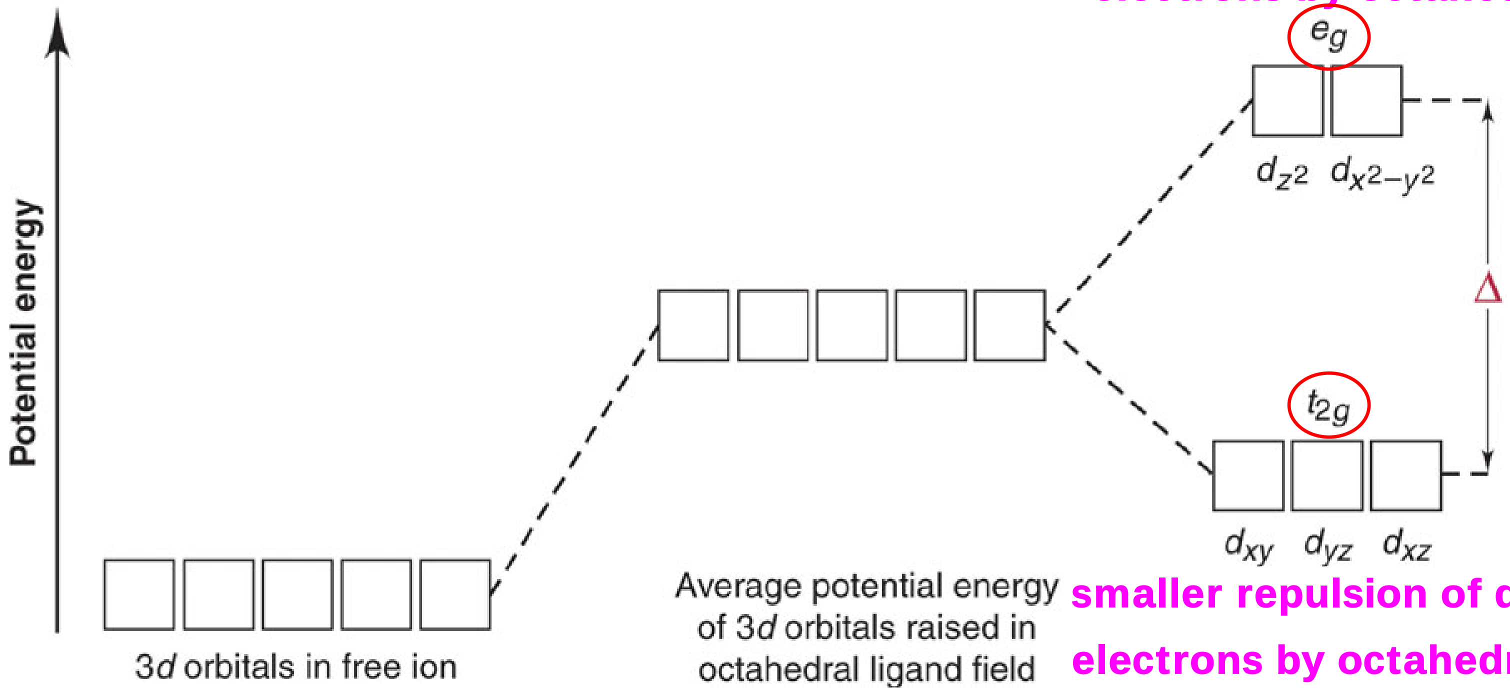


average ligand repulsion
for metal d-electrons

would each d-electron
be repelled the same?

what happens to energies of d-orbitals when ligands bind to metal ion? (fig 23.18)

greater repulsion of $d_{x^2-y^2}$ and d_{z^2} electrons by octahedral ligands



smaller repulsion of d_{xy}, d_{xz}, and d_{yz} electrons by octahedral ligands

average ligand repulsion for metal d-electrons

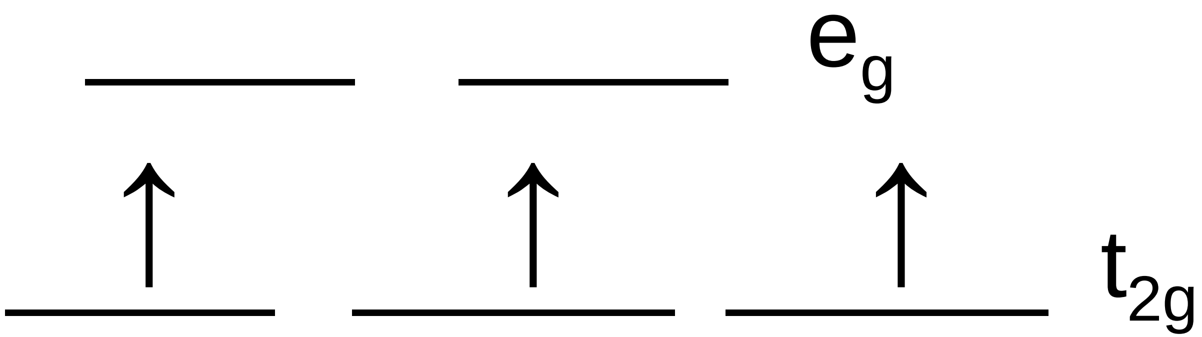
would each d-electron be repelled the same?

filling of d-orbitals in octahedral complex: d^1 → d^3 ground state

$[V(CN)_6]^{4-}$

V^{2+}

d^3



configuration: $(t_{2g})^3$ $\underline{\uparrow}\,\underline{\uparrow}\,\underline{\uparrow}$

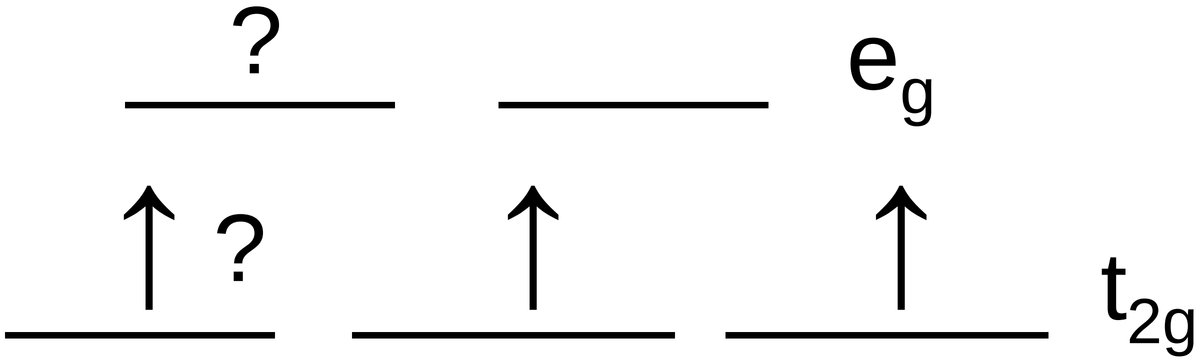
paramagnetic: three unpaired electrons

filling of d-orbitals in octahedral complex: $d^4 \rightarrow d^{10}$ ground state

$[Cr(H_2O)_6]^{2+}$ vs $[Cr(CN)_6]^{4-}$

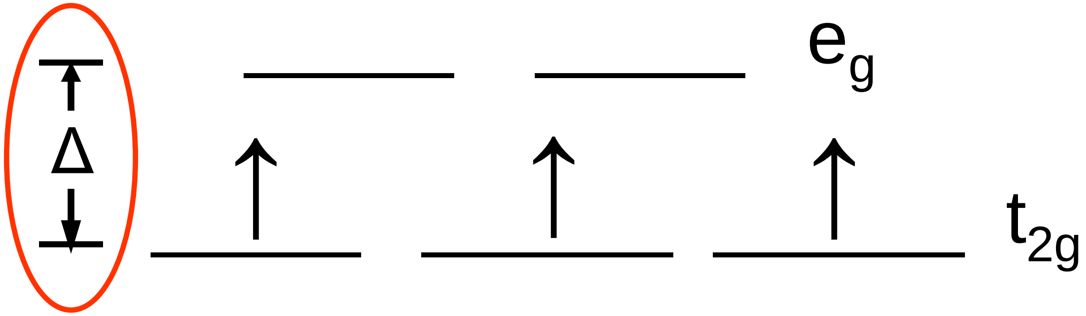
Cr^{2+} Cr^{2+}

d^4 d^4



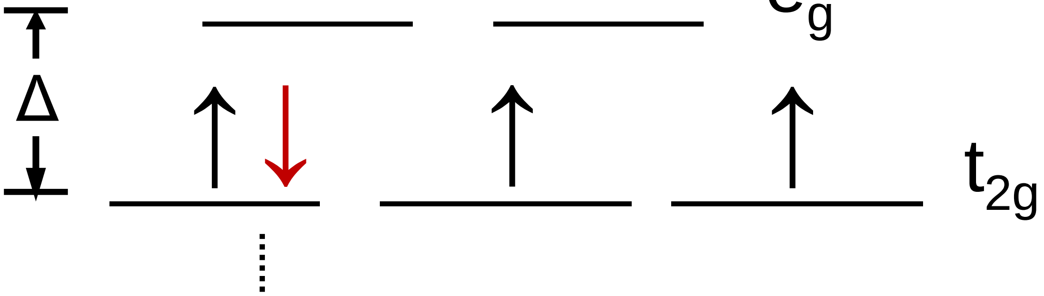
where does electron 4th go ?

Δ vs ($E_{pairing}$) : two possibilities for d^4



$t_{2g}^{3}\, e_g$

costs Δ *(in energy)*
but e’s
remain unpaired



t_{2g}^{4} ▯↓ ▯ ▯

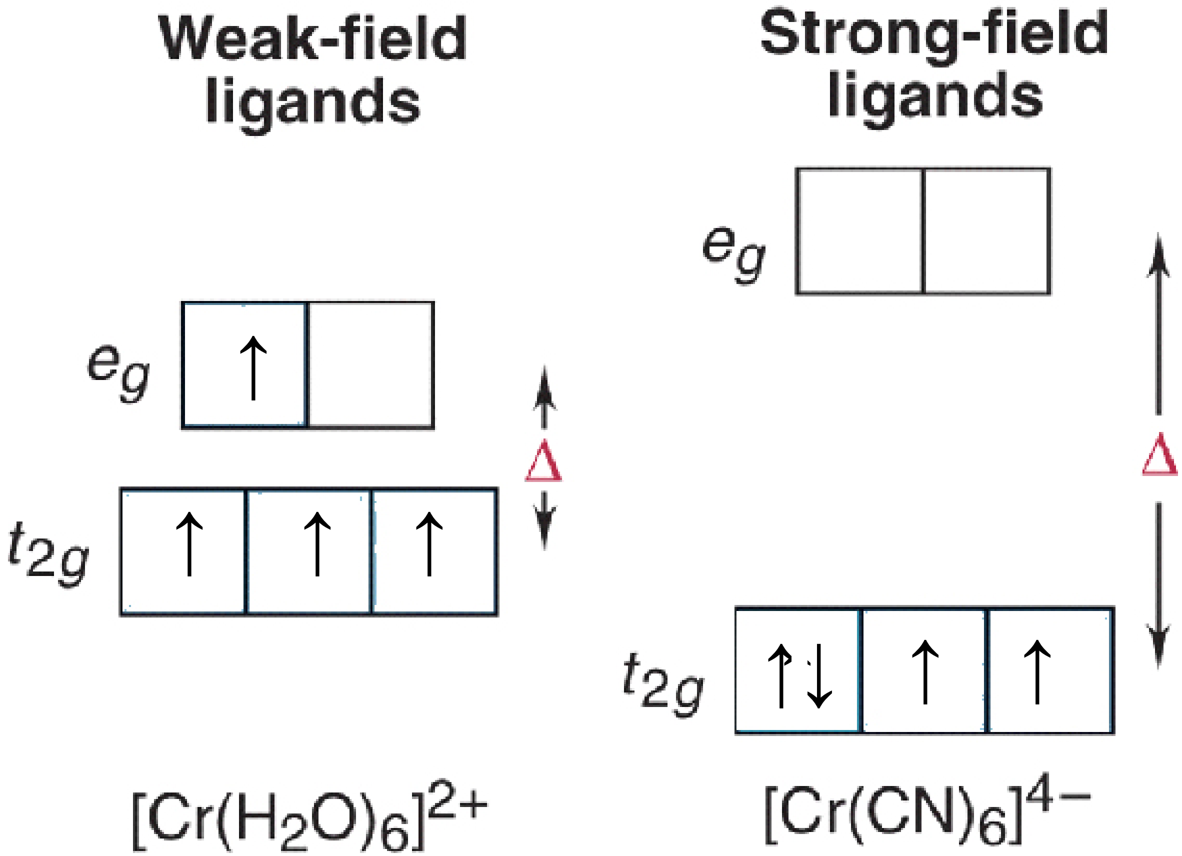
costs $E_{pairing}$
but
not Δ

$E_{pairing}$= higher energy for paired vs unpaired electrons

strong and weak field ligands: lowest orbitals vs unpaired spins
Δ vs ($E_{pairing}$) (Silberberg fig 23.18)

d^4

d^4



($E_{pairing}$) > Δ
small Δ favors filling
maximum unpaired spins

Δ > ($E_{pairing}$)
large Δ favors filling
lowest orbitals first

$[Cr(H_2O)_6]^{2+}$ vs $[Cr(CN)_6]^{4-}$

- $[Cr(H_2O)_6]^{2+}$, d^4, weak-field ≡ high spin,

  ↑ _
  ↑ ↑ ↑ $t_{2g}^3e_g^1$
  4 unpaired electrons, paramagnetic

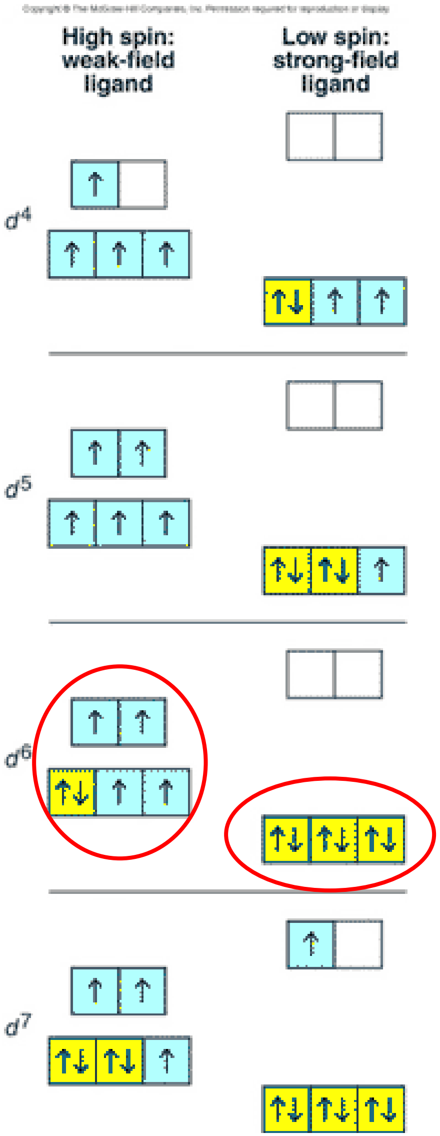
- $[Cr(CN)_6]^{4-}$, d^4, strong-field ≡ low spin,

  _ _
  ↑↓ ↑ ↑ t_{2g}^4
  2 unpaired electrons, paramagnetic

high-spin vs low-spin complexes: $d^4 \rightarrow d^7$ (Silberberg fig. 23.24)

small □

large □

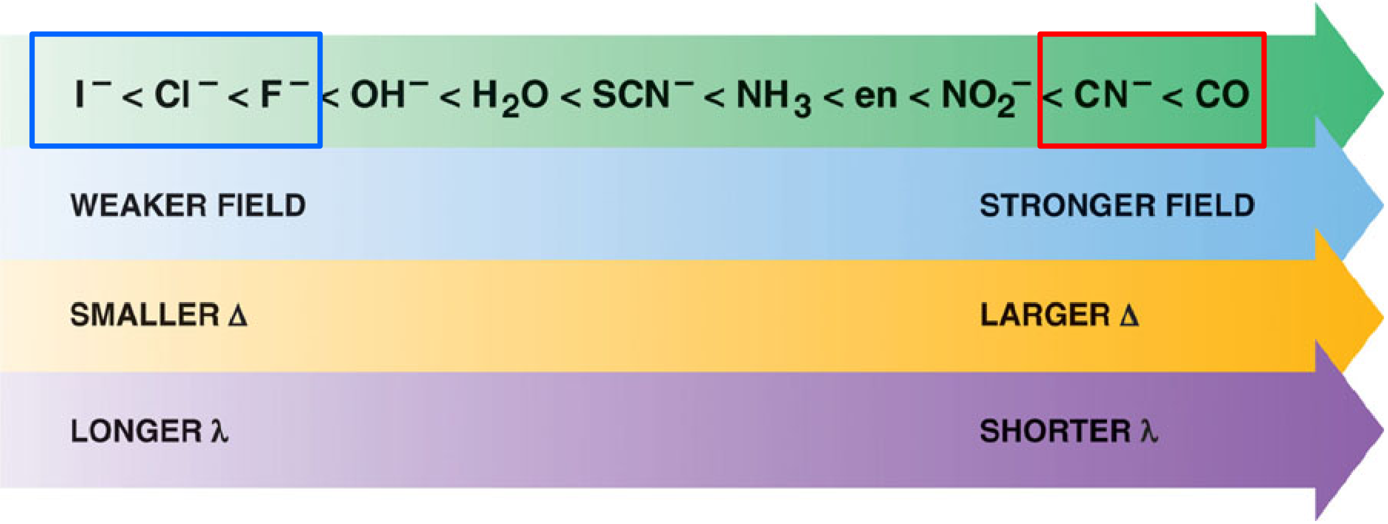


d^6

paramagnetic

diamagnetic

spectrochemical series (fig. 23.22 Silberberg; Zumdahl p. 961)



$I^- < Cl^- < F^- < OH^- < H_2O < SCN^- < NH_3 < en < NO_2^- < CN^- < CO$

WEAKER FIELD — STRONGER FIELD

SMALLER Δ — LARGER Δ

LONGER λ — SHORTER λ

know: CN^-, CO strong (high) field

F^-, Cl^-, I^- (halogen anions) weak (low) field

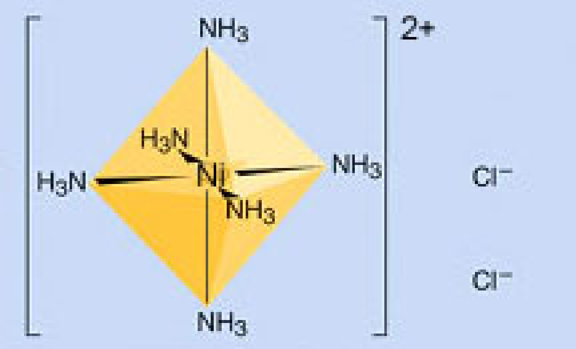
if using others you would be told which

crystal field theory (pp 959-955)

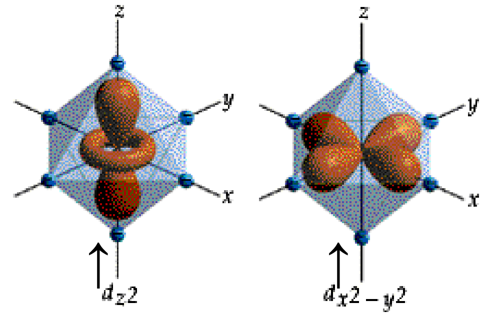
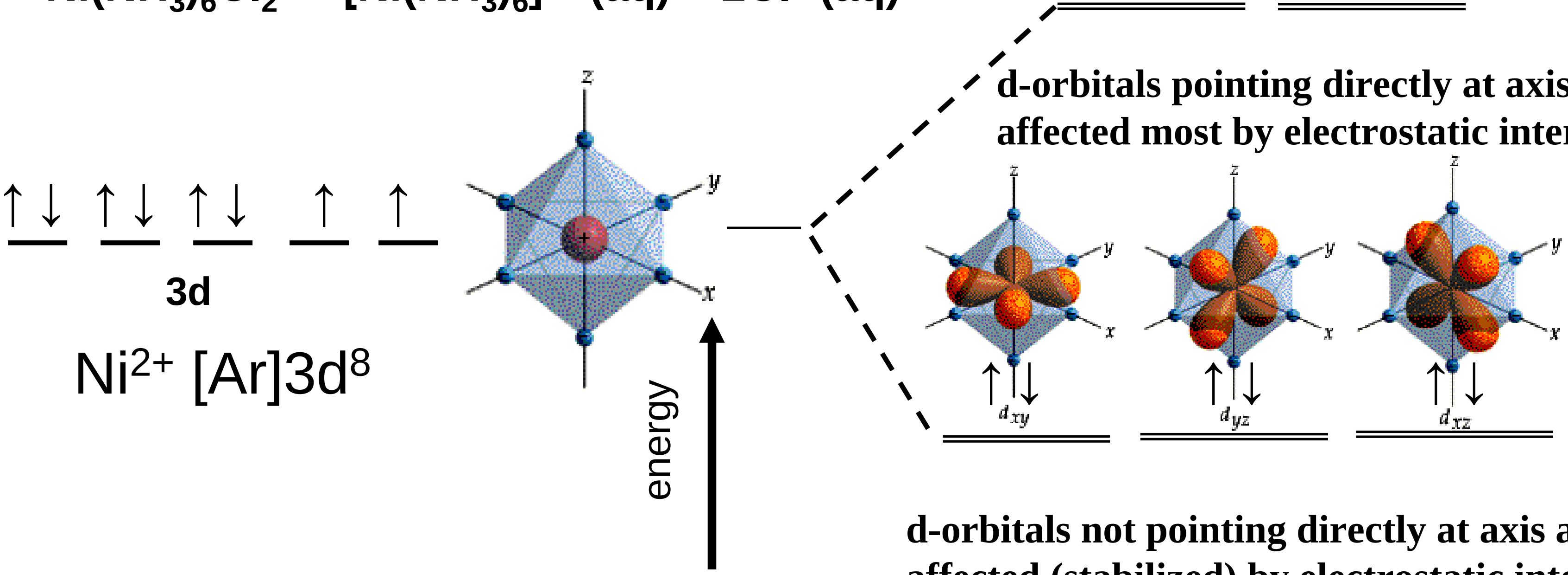
- How are the magnetic properties of transition metal complexes related to the shape of d-orbitals?
- Why are transition metal complexes colored?

Color in octahedral complex ions arises from $t_{2g} \rightarrow e_g$ electronic transitions (excitations) that have energies corresponding to photons in the visible wavelengths.

d-Orbitals and ligand Interaction (octahedral field)



$\text{Ni(NH}_3)_6\text{Cl}_2 \xrightarrow{\text{H}_2\text{O}} [\text{Ni(NH}_3)_6]^{2+}$ (aq) + 2Cl^{-} (aq)

3d

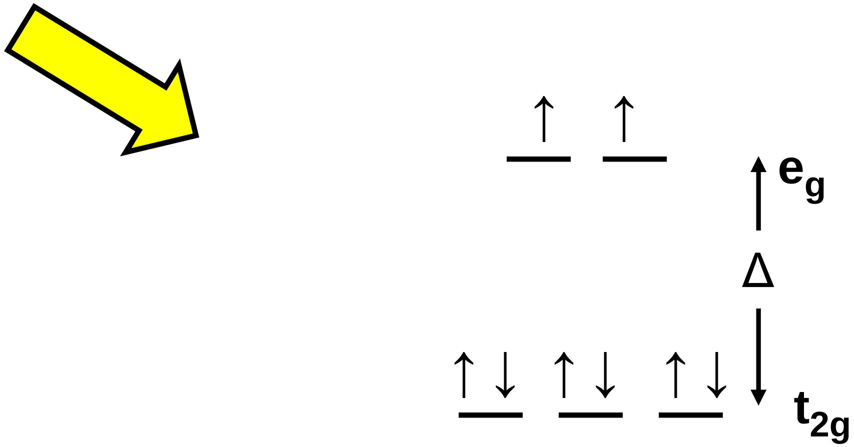
Ni^{2+} [Ar]3d^8

d-orbitals pointing directly at axis are affected most by electrostatic interaction

d-orbitals not pointing directly at axis are least affected (stabilized) by electrostatic interaction

ibchem.com/IB/ibfiles/periodicity/per_ppt/**Crystal_field_theory**.ppt

absorption of visible light in octahedral transition metal complexes

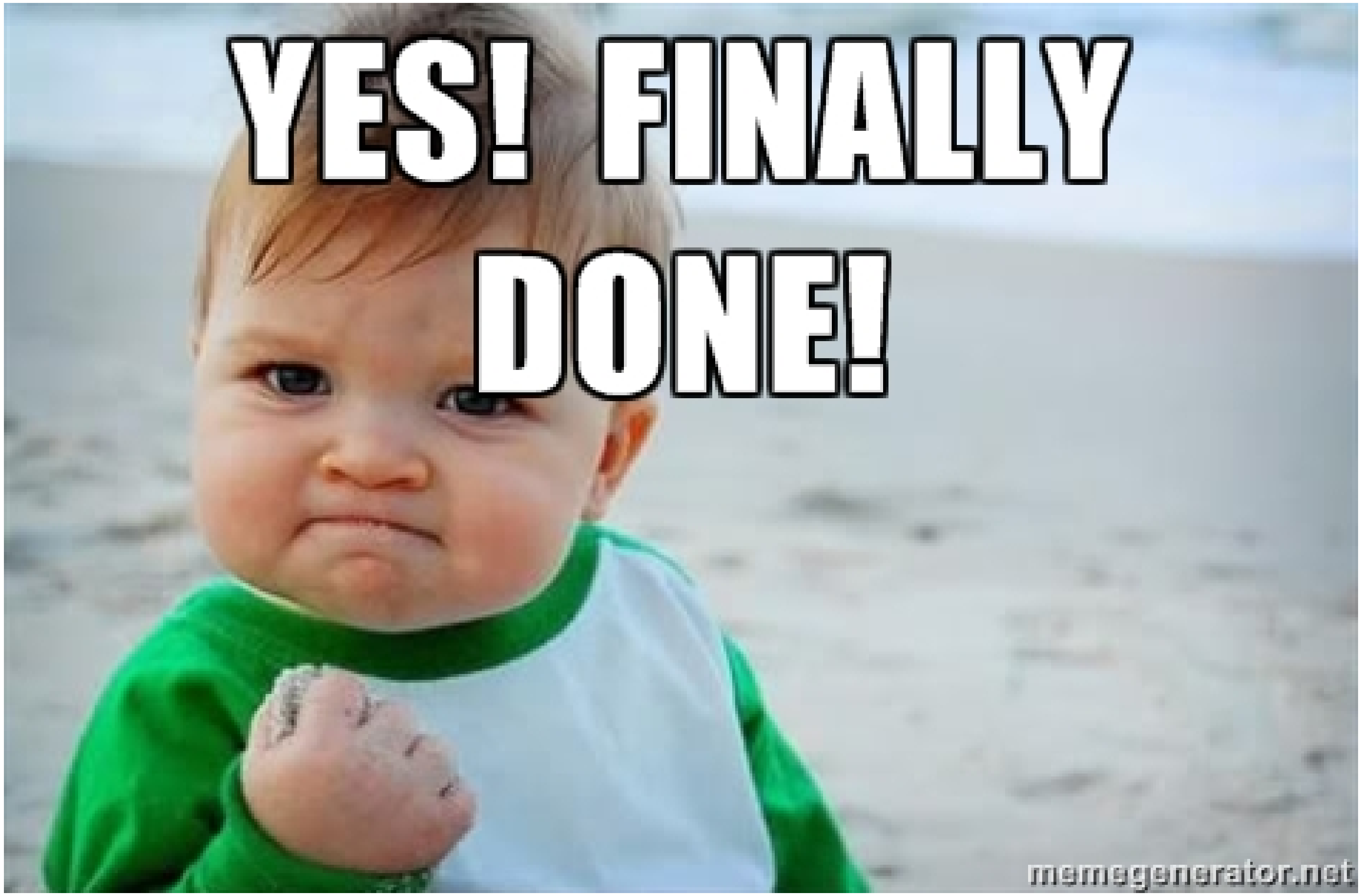


excited: $\mathbf{t_{2g}^{5}\,e_g^{3}}$

ground: $\mathbf{t_{2g}^{6}\,e_g^{2}}$

$[Ni(NH_3)_6]^{2+}$

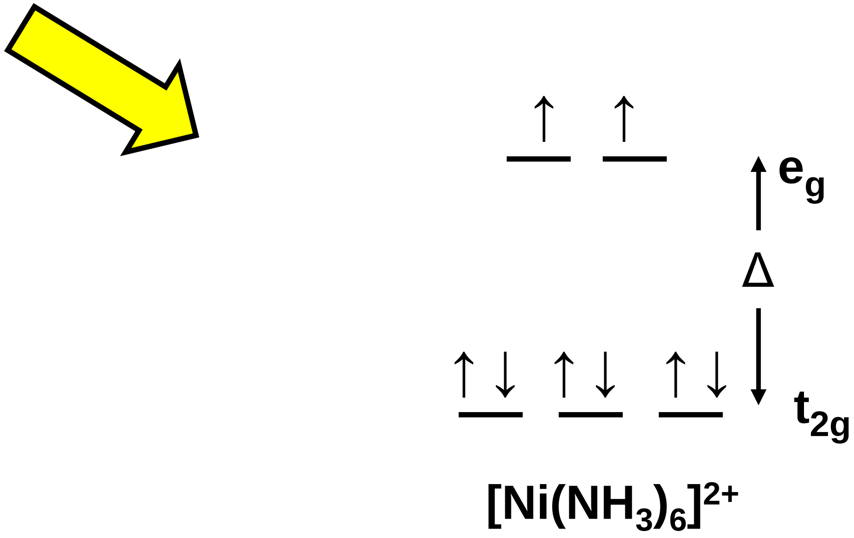
- larger Δ's correspond to absorbing shorter wavelengths
- how does the wavelength absorbed relate to the color perceived for various transition metal complex ions ?
  [next class !!]


YES! FINALLY
DONE!
memegenerator.net

Perception of the Color of Objects

an addendum to Crystal Field Theory

absorption of visible light in octahedral transition metal complexes



excited: $\mathbf{t_{2g}^5\, e_g^3}$

ground: $\mathbf{t_{2g}^6\, e_g^2}$

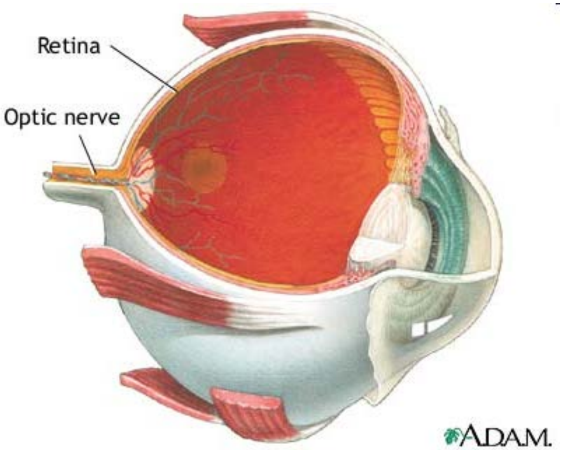
- larger Δ's correspond to absorbing shorter wavelengths
- how does the wavelength absorbed relate to the color perceived for various transition metal complex ions ?

why are some molecules colored ? (spectroscopy lectures later)

human vision and chemistry LATER in spectroscopy

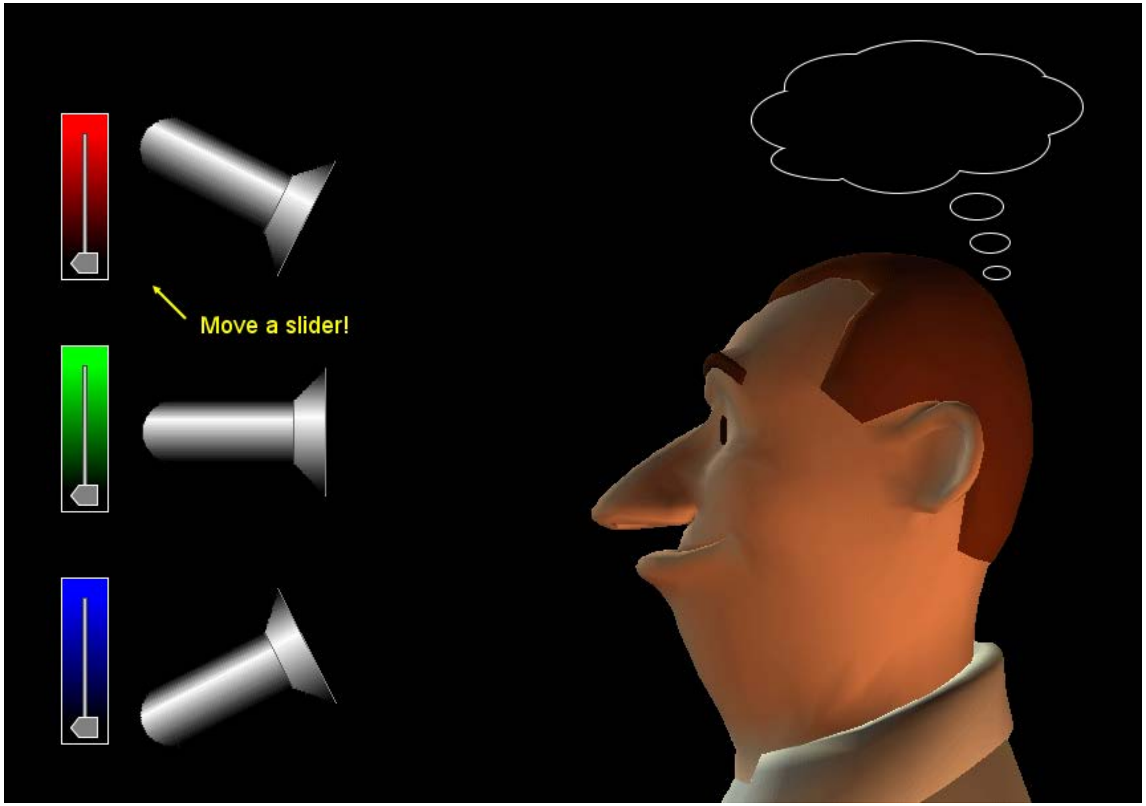
➡ ***not now***

- light in 400-700 nm range interacts with a molecule (rhodopsin) in the rods and cones at the back of the eye (the retina)



- substances that absorb light in this region will appear colored

the perception of color depends on the wavelengths of light reaching the eye

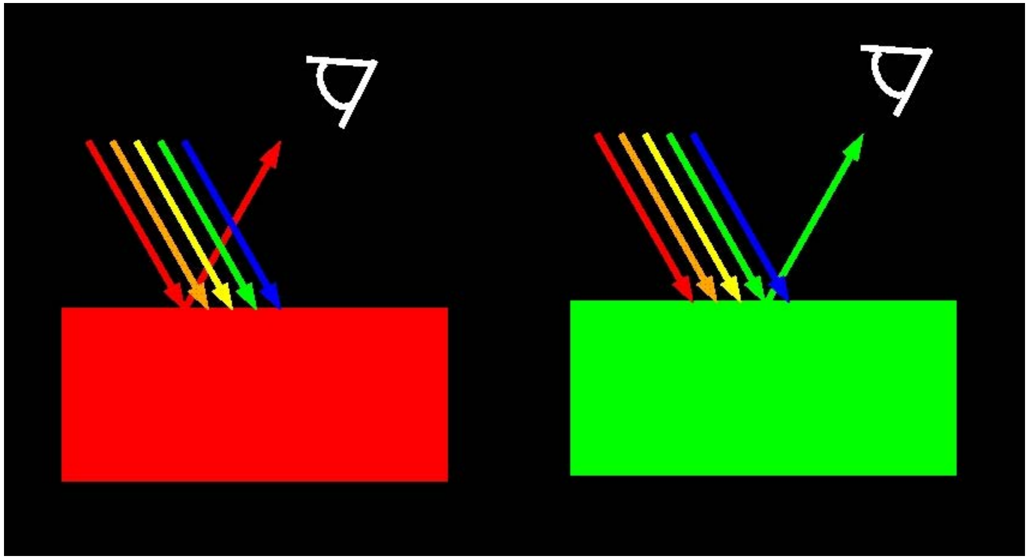


http://phet.colorado.edu/sims/color-vision/color-vision_en.jnlp

color and absorption of light

- The color of an object arises from the wavelengths **reflected** by the object and entering the eye

- If the object is viewed in white light (as is usual) the color seen is the **complement of the wavelengths absorbed**



color and absorption of light, white light (R+G+B) incident (table 19.16) (complementary colors)

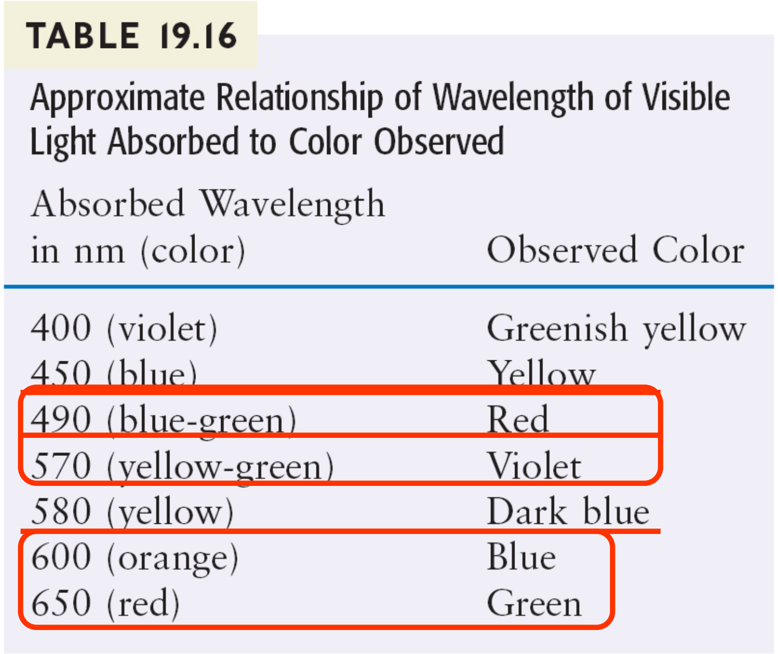


TABLE 19.16

Approximate Relationship of Wavelength of Visible Light Absorbed to Color Observed

Absorbed Wavelength in nm (color)	Observed Color
400 (violet)	Greenish yellow
450 (blue)	Yellow
490 (blue-green)	Red
570 (yellow-green)	Violet
580 (yellow)	Dark blue
600 (orange)	Blue
650 (red)	Green

reflects

~~R~~ + ~~G~~ + ~~B~~

(R,G,B) primaries

white=R+G+B

Y (yellow)=R+G

Cyan=G+B (blue-green)

Purple=R+B

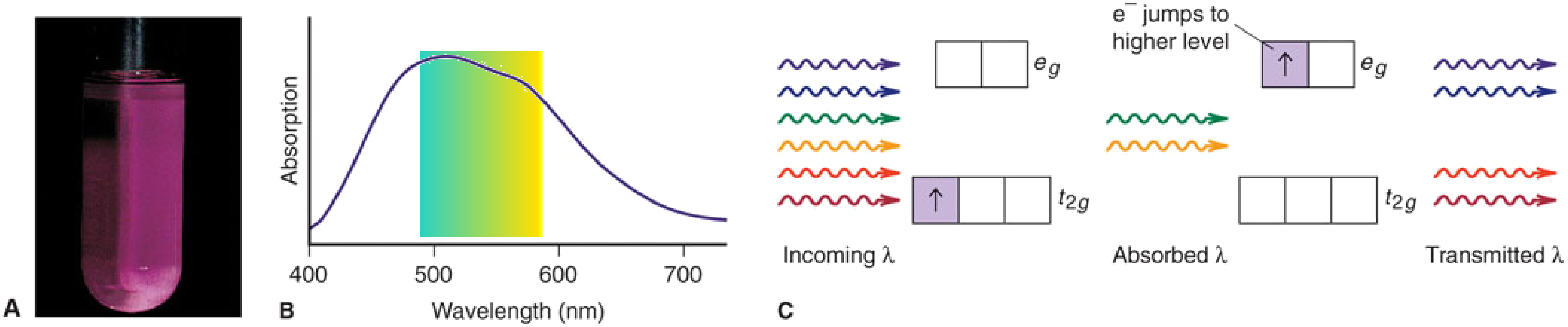
know:

absorbs	**appears**
no visible	**White**
B	**Yellow (R+G)**
Cyan (G+B)	**Red**
G	**Purple (R+B)**
Y (R+G)	**Blue**
R	**Green-Blue (cyan)**
R+G+B	**Black**

additive color mixing demo

subtractive color mixing demo

$[Ti(H_2O)_6]^{3+}$ d^1



absorbs green-yellow appears purple

Hold your hands up and twist them, like you're brushing everything away.
All done or finished. Let's see you sign it!

colored transition metal complexes- glazes

$Ni(NH_3)_6Br_2$

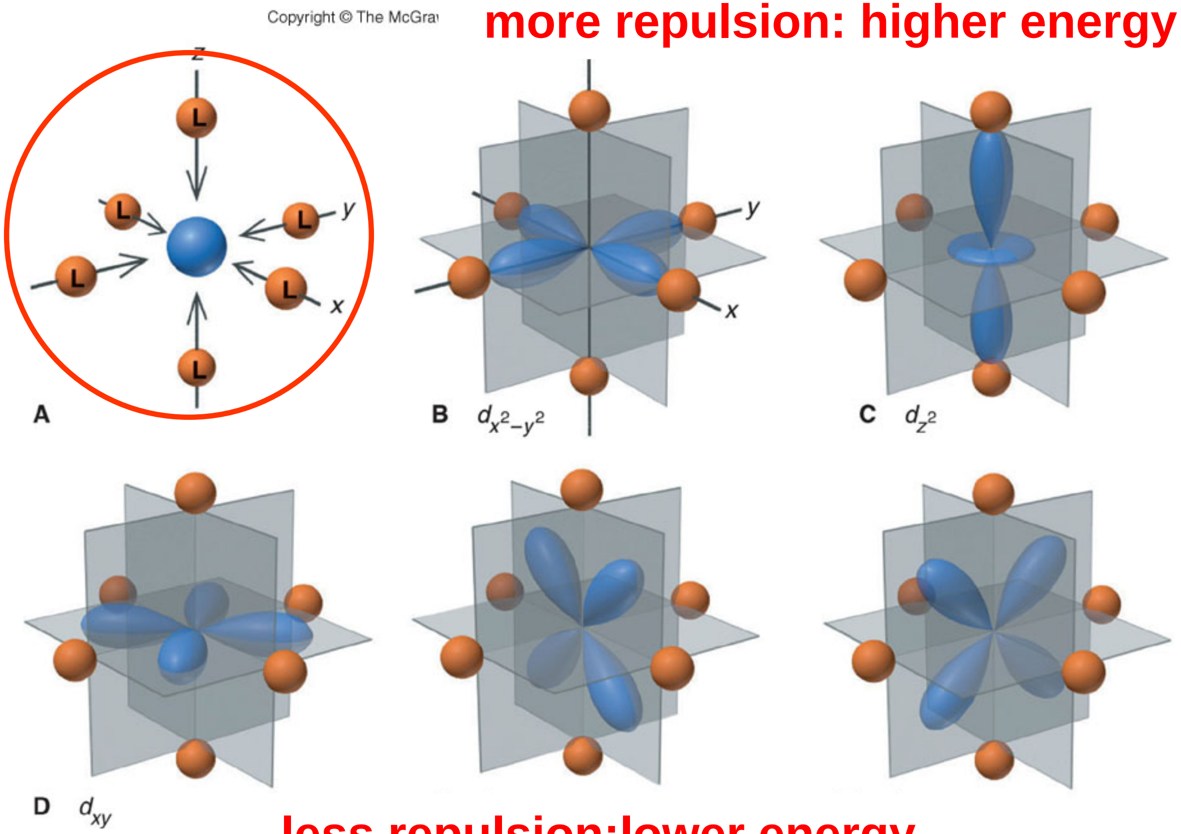
$CoCl_2{\cdot}6H_2O$

$NiSO_4{\cdot}6H_2O$

http://woelen.scheikunde.net/science/chem/elem/metalsalts.jpg

metal ion d-obitals in **octahedral** complex (Silberberg fig. 23.17; Zumdahl fig. 19.21)

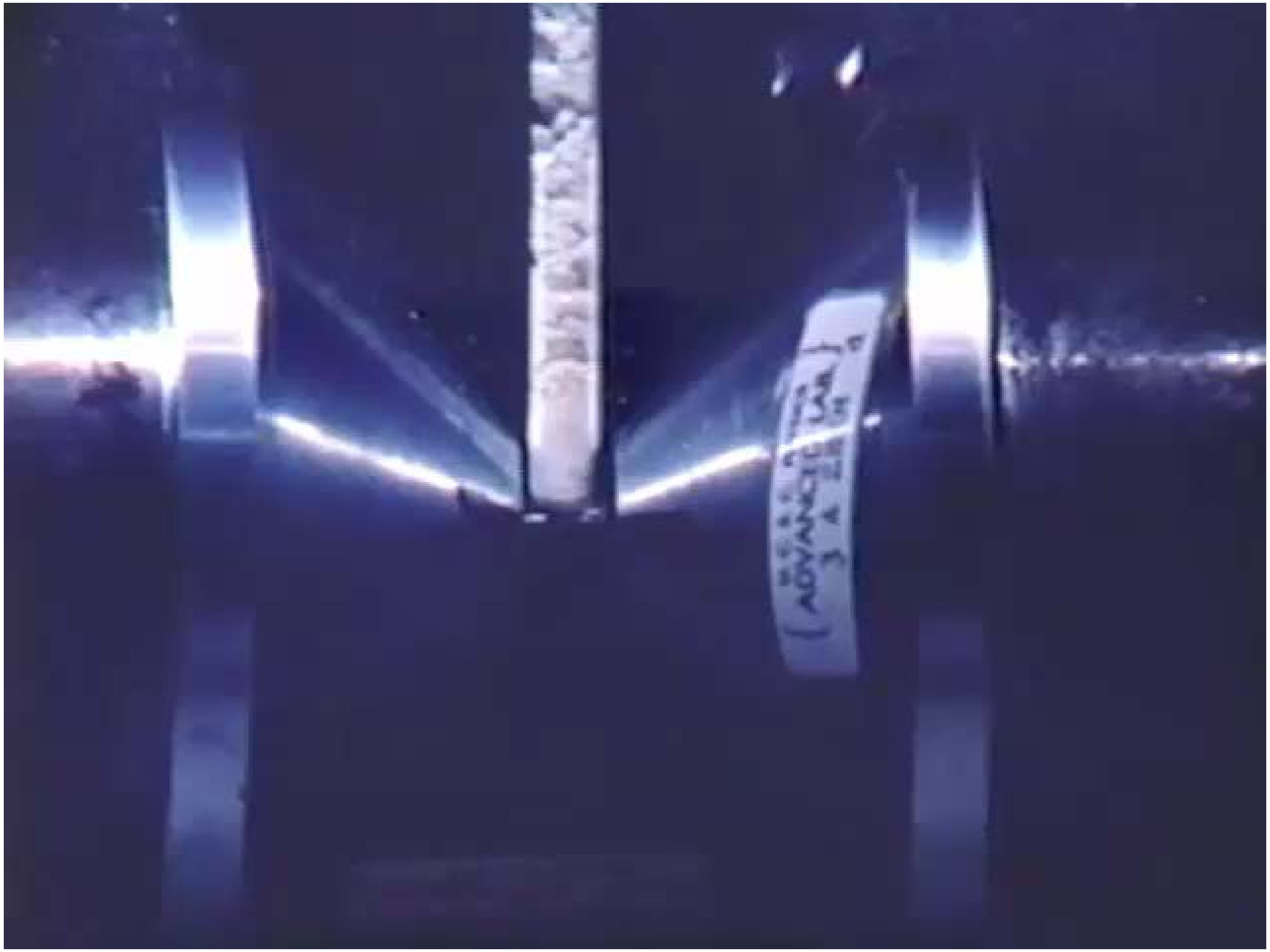
more repulsion: higher energy



less repulsion:lower energy

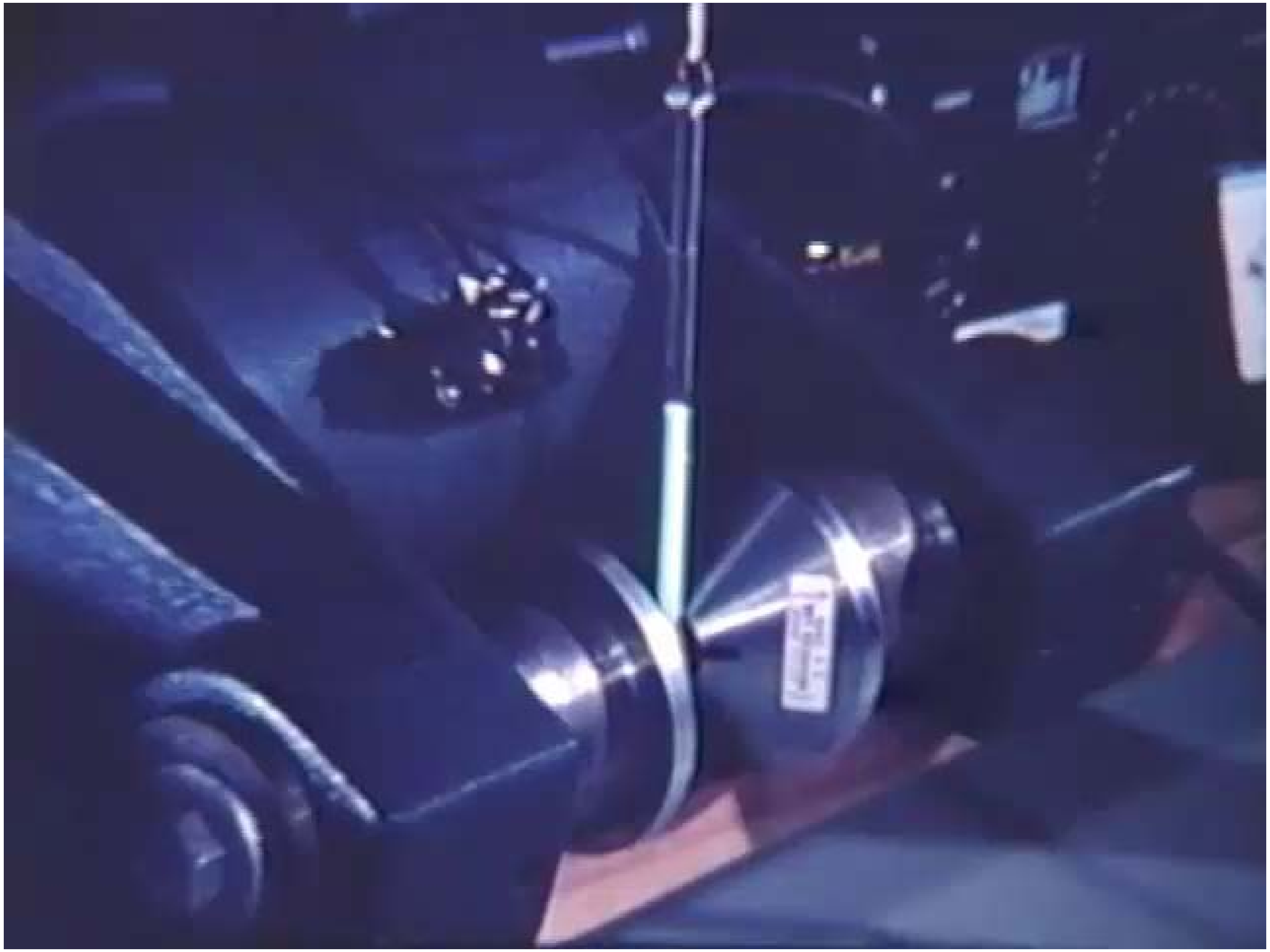
http://switkes.chemistry.ucsc.edu/teaching/CHEM1B/Jmol/CrystalField/CFT_OrbsOctahedral_java.html(java)

diamagnetism



open video in browser

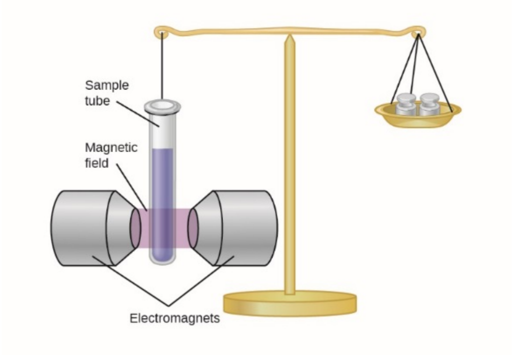
paramagnetism



open video in browser

Gouy balance to measure magnetic properties

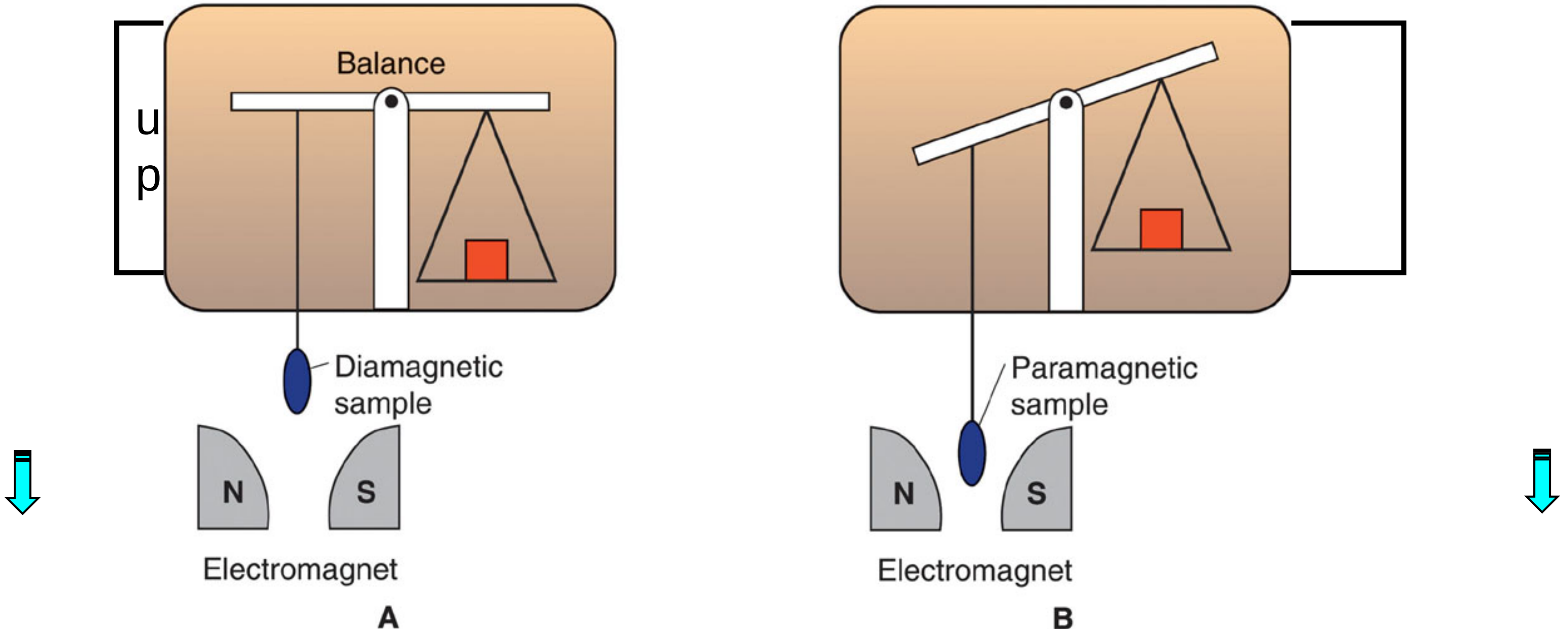
the Gouy (not the gooey !!) Balance



**Louis Georges Gouy
(1854-1926)**

paramagnetism vs diamagnetism (Gouy balance)

diamagnetic paramagnetic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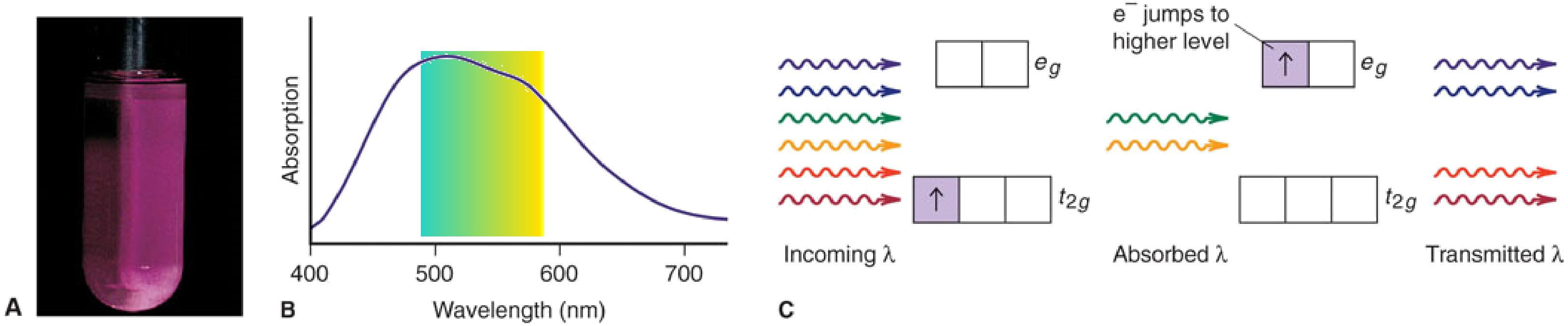
strength of paramagnetism depends on number of unpaired electrons

color

Color in octahedral complex ions arises from $t_{2g} \rightarrow e_g$ electronic transitions (excitations) that have energies corresponding to photons in the visible wavelengths.

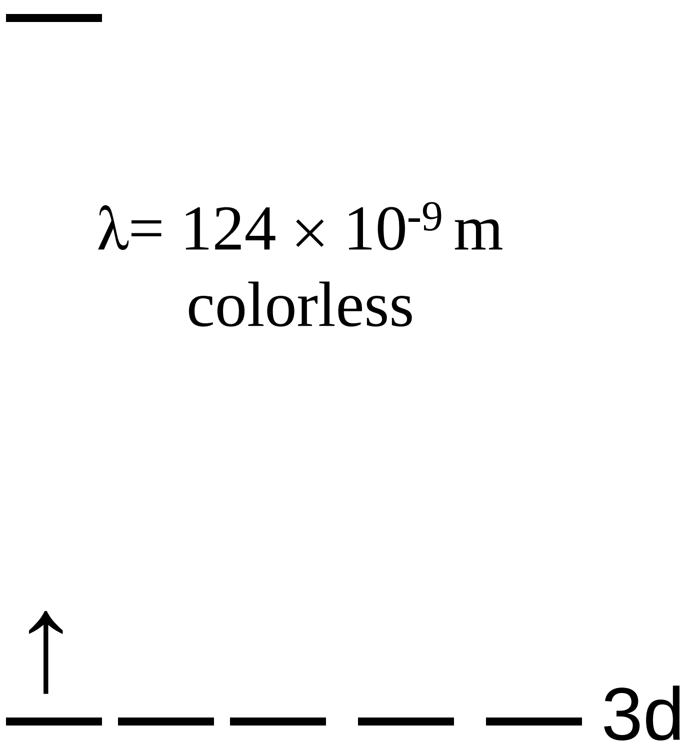
color and absorption of light (Zumdahl fig 19.25, Silberberg fig. 23.20)

$[Ti(H_2O)_6]^{3+}$ d^1



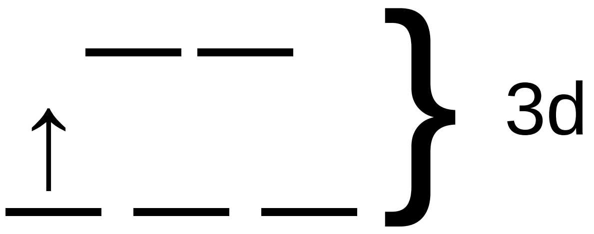
absorbs green-yellow   appears purple

so ......



$\lambda = 124 \times 10^{-9}$ m
colorless

Ti^{3+} (g) d^1



$\lambda \approx 510 \times 10^{-9}$ m
appears purple

$[Ti(H_2O)_6]^{3+}$ d^1

~~d orbital energies for tetrahedral and square planar geometries (fig. 19.28,19.29)~~ (don't fret)

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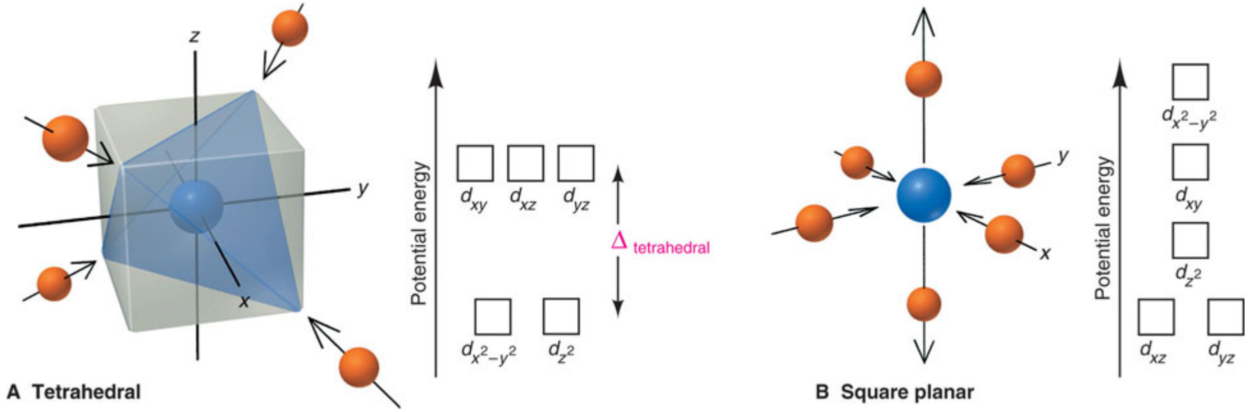


A Tetrahedral

B Square planar

will not be on exams

~~transition metals in biology~~ ~~(Zumdahl table 19.8, silberberg Table B23.1~~) (don't fret)

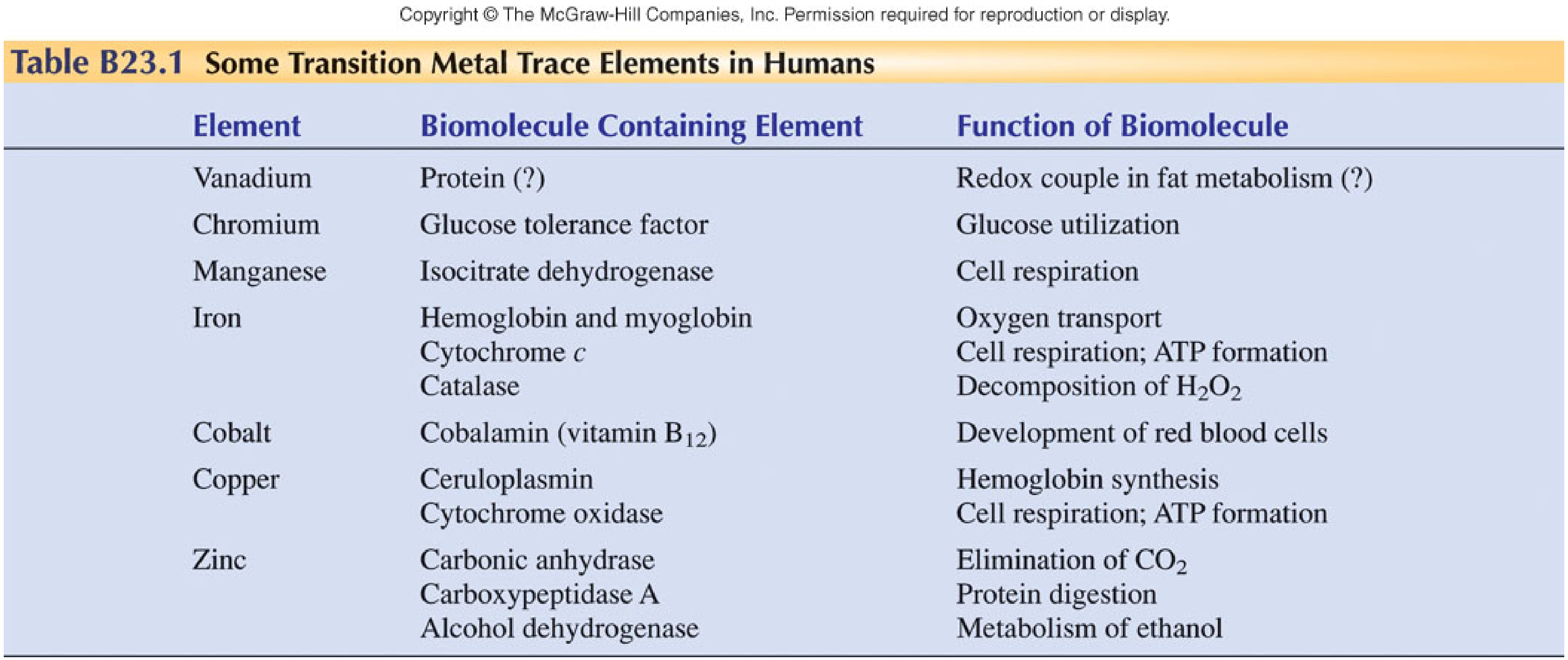
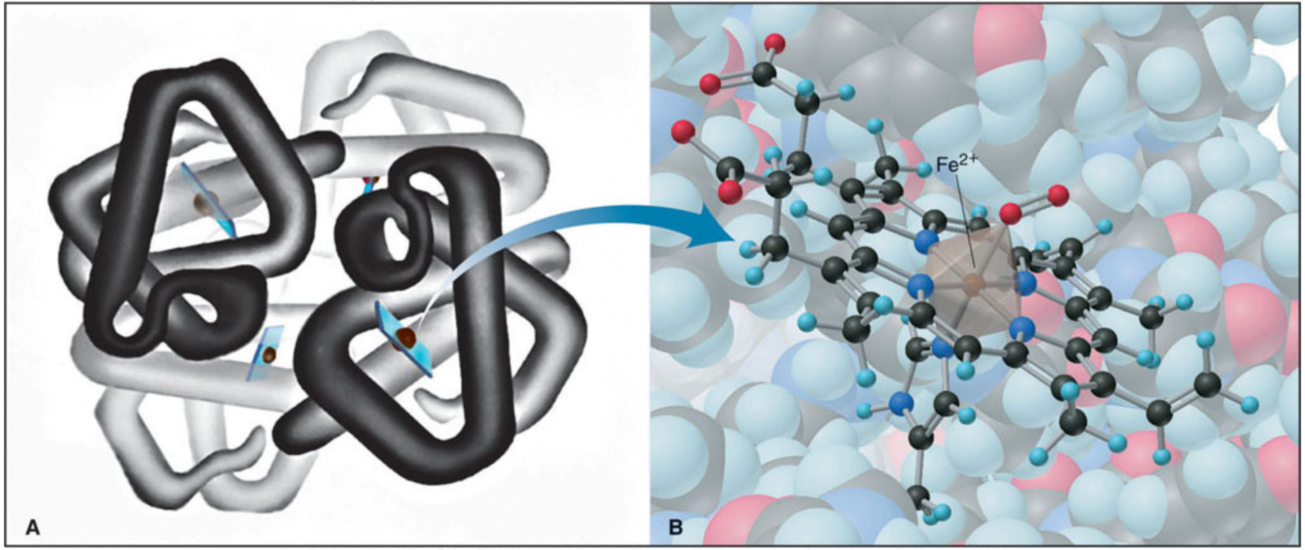


Table B23.1 Some Transition Metal Trace Elements in Humans

Element	Biomolecule Containing Element	Function of Biomolecule
Vanadium	Protein (?)	Redox couple in fat metabolism (?)
Chromium	Glucose tolerance factor	Glucose utilization
Manganese	Isocitrate dehydrogenase	Cell respiration
Iron	Hemoglobin and myoglobin Cytochrome *c* Catalase	Oxygen transport Cell respiration; ATP formation Decomposition of H_2O_2
Cobalt	Cobalamin (vitamin B_{12})	Development of red blood cells
Copper	Ceruloplasmin Cytochrome oxidase	Hemoglobin synthesis Cell respiration; ATP formation
Zinc	Carbonic anhydrase Carboxypeptidase A Alcohol dehydrogenase	Elimination of CO_2 Protein digestion Metabolism of ethanol



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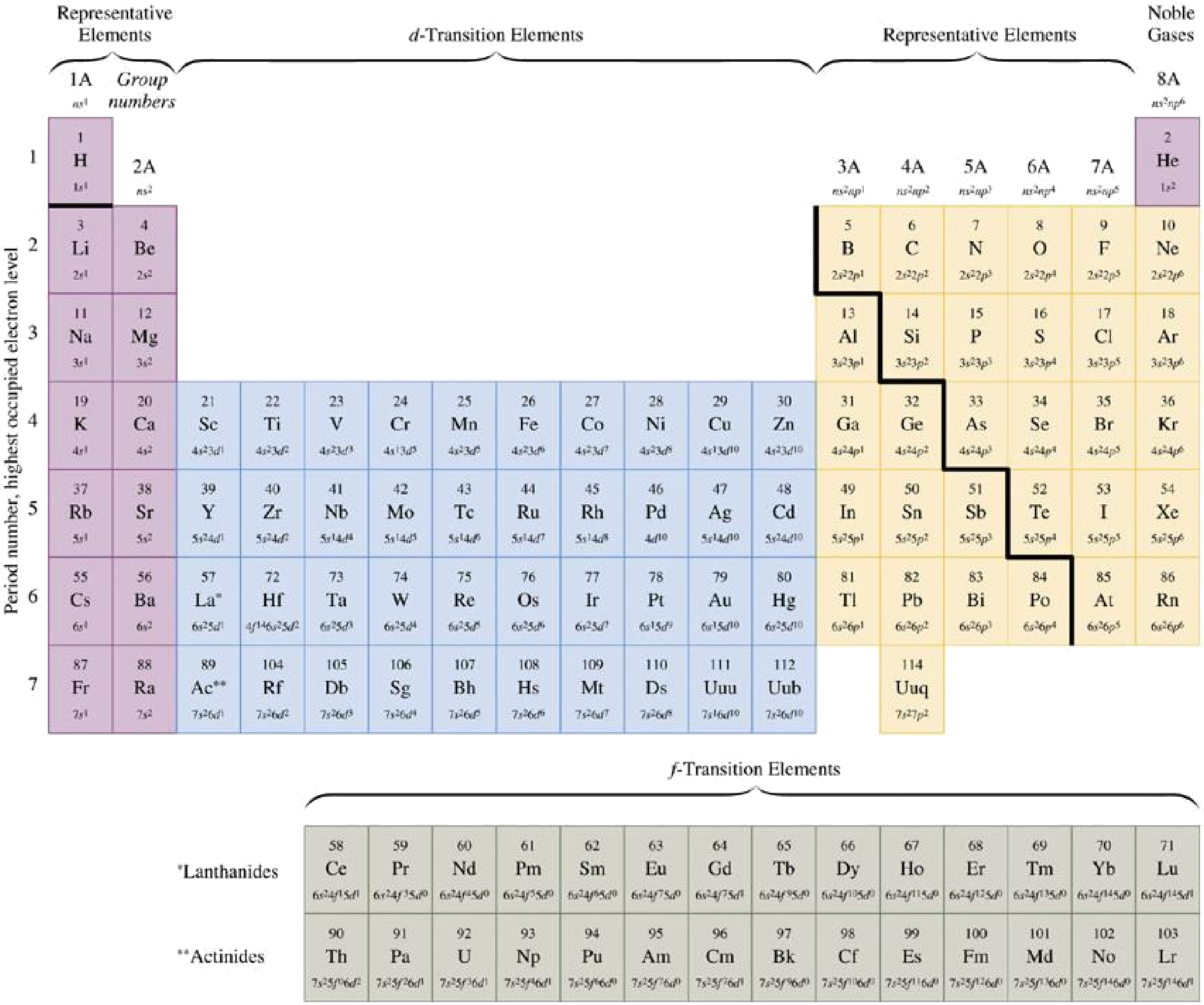
oxyheme deoxyheme

END

Zumdahl figure 12.29



Representative Elements | *d*-Transition Elements | Representative Elements | Noble Gases

Group numbers

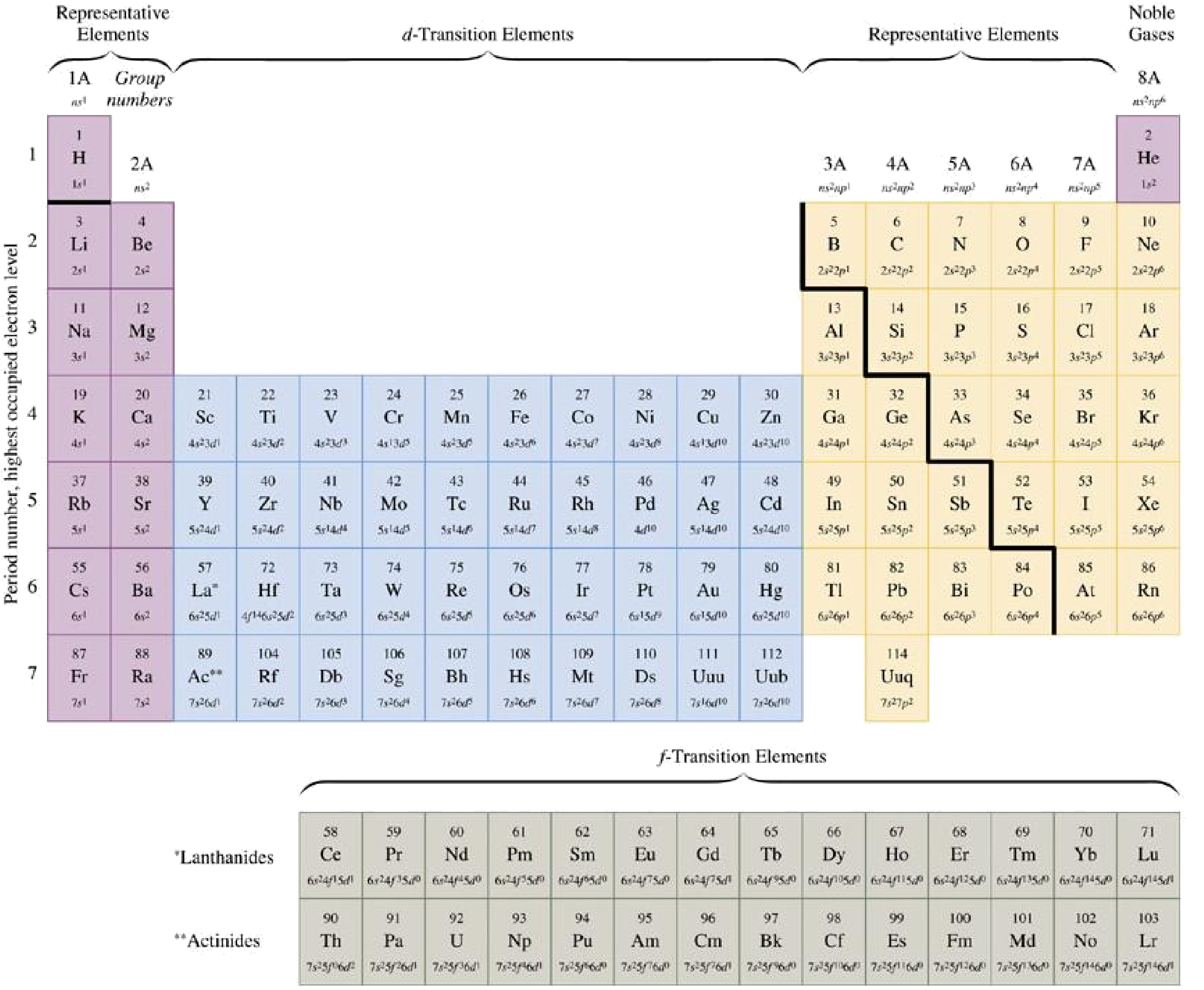
Period number, highest occupied electron level

	1A ns^1	2A ns^2											3A ns^2np^1	4A ns^2np^2	5A ns^2np^3	6A ns^2np^4	7A ns^2np^5	8A ns^2np^6
1	1 H $1s^1$																	2 He $1s^2$
2	3 Li $2s^1$	4 Be $2s^2$											5 B $2s^22p^1$	6 C $2s^22p^2$	7 N $2s^22p^3$	8 O $2s^22p^4$	9 F $2s^22p^5$	10 Ne $2s^22p^6$
3	11 Na $3s^1$	12 Mg $3s^2$											13 Al $3s^23p^1$	14 Si $3s^23p^2$	15 P $3s^23p^3$	16 S $3s^23p^4$	17 Cl $3s^23p^5$	18 Ar $3s^23p^6$
4	19 K $4s^1$	20 Ca $4s^2$	21 Sc $4s^23d^1$	22 Ti $4s^23d^2$	23 V $4s^23d^3$	24 Cr $4s^13d^5$	25 Mn $4s^23d^5$	26 Fe $4s^23d^6$	27 Co $4s^23d^7$	28 Ni $4s^23d^8$	29 Cu $4s^13d^{10}$	30 Zn $4s^23d^{10}$	31 Ga $4s^24p^1$	32 Ge $4s^24p^2$	33 As $4s^24p^3$	34 Se $4s^24p^4$	35 Br $4s^24p^5$	36 Kr $4s^24p^6$
5	37 Rb $5s^1$	38 Sr $5s^2$	39 Y $5s^24d^1$	40 Zr $5s^24d^2$	41 Nb $5s^14d^4$	42 Mo $5s^14d^5$	43 Tc $5s^14d^6$	44 Ru $5s^14d^7$	45 Rh $5s^14d^8$	46 Pd $4d^{10}$	47 Ag $5s^14d^{10}$	48 Cd $5s^24d^{10}$	49 In $5s^25p^1$	50 Sn $5s^25p^2$	51 Sb $5s^25p^3$	52 Te $5s^25p^4$	53 I $5s^25p^5$	54 Xe $5s^25p^6$
6	55 Cs $6s^1$	56 Ba $6s^2$	57 La* $6s^25d^1$	72 Hf $4f^{14}6s^25d^2$	73 Ta $6s^25d^3$	74 W $6s^25d^4$	75 Re $6s^25d^5$	76 Os $6s^25d^6$	77 Ir $6s^25d^7$	78 Pt $6s^15d^9$	79 Au $6s^15d^{10}$	80 Hg $6s^25d^{10}$	81 Tl $6s^26p^1$	82 Pb $6s^26p^2$	83 Bi $6s^26p^3$	84 Po $6s^26p^4$	85 At $6s^26p^5$	86 Rn $6s^26p^6$
7	87 Fr $7s^1$	88 Ra $7s^2$	89 Ac** $7s^26d^1$	104 Rf $7s^26d^2$	105 Db $7s^26d^3$	106 Sg $7s^26d^4$	107 Bh $7s^26d^5$	108 Hs $7s^26d^6$	109 Mt $7s^26d^7$	110 Ds $7s^26d^8$	111 Uuu $7s^16d^{10}$	112 Uub $7s^26d^{10}$		114 Uuq $7s^27p^2$				

f-Transition Elements

*Lanthanides	58 Ce $6s^24f^15d^1$	59 Pr $6s^24f^35d^0$	60 Nd $6s^24f^45d^0$	61 Pm $6s^24f^55d^0$	62 Sm $6s^24f^65d^0$	63 Eu $6s^24f^75d^0$	64 Gd $6s^24f^75d^1$	65 Tb $6s^24f^95d^0$	66 Dy $6s^24f^{10}5d^0$	67 Ho $6s^24f^{11}5d^0$	68 Er $6s^24f^{12}5d^0$	69 Tm $6s^24f^{13}5d^0$	70 Yb $6s^24f^{14}5d^0$	71 Lu $6s^24f^{14}5d^1$
**Actinides	90 Th $7s^25f^06d^2$	91 Pa $7s^25f^26d^1$	92 U $7s^25f^36d^1$	93 Np $7s^25f^46d^1$	94 Pu $7s^25f^66d^0$	95 Am $7s^25f^76d^0$	96 Cm $7s^25f^76d^1$	97 Bk $7s^25f^96d^0$	98 Cf $7s^25f^{10}6d^0$	99 Es $7s^25f^{11}6d^0$	100 Fm $7s^25f^{12}6d^0$	101 Md $7s^25f^{13}6d^0$	102 No $7s^25f^{14}6d^0$	103 Lr $7s^25f^{14}6d^1$

Zumdahl figure 12.29



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3	11 Na $3s^1$	12 Mg $3s^2$											13 Al $3s^23p^1$	14 Si $3s^23p^2$	15 P $3s^23p^3$	16 S $3s^23p^4$	17 Cl $3s^23p^5$	18 Ar $3s^23p^6$
4	19 K $4s^1$	20 Ca $4s^2$	21 Sc $4s^23d^1$	22 Ti $4s^23d^2$	23 V $4s^23d^3$	24 Cr $4s^13d^5$	25 Mn $4s^23d^5$	26 Fe $4s^23d^6$	27 Co $4s^23d^7$	28 Ni $4s^23d^8$	29 Cu $4s^13d^{10}$	30 Zn $4s^23d^{10}$	31 Ga $4s^24p^1$	32 Ge $4s^24p^2$	33 As $4s^24p^3$	34 Se $4s^24p^4$	35 Br $4s^24p^5$	36 Kr $4s^24p^6$
5	37 Rb $5s^1$	38 Sr $5s^2$	39 Y $5s^24d^1$	40 Zr $5s^24d^2$	41 Nb $5s^14d^4$	42 Mo $5s^14d^5$	43 Tc $5s^14d^6$	44 Ru $5s^14d^7$	45 Rh $5s^14d^8$	46 Pd $4d^{10}$	47 Ag $5s^14d^{10}$	48 Cd $5s^24d^{10}$	49 In $5s^25p^1$	50 Sn $5s^25p^2$	51 Sb $5s^25p^3$	52 Te $5s^25p^4$	53 I $5s^25p^5$	54 Xe $5s^25p^6$
6	55 Cs $6s^1$	56 Ba $6s^2$	57 La* $6s^25d^1$	72 Hf $4f^{14}6s^25d^2$	73 Ta $6s^25d^3$	74 W $6s^25d^4$	75 Re $6s^25d^5$	76 Os $6s^25d^6$	77 Ir $6s^25d^7$	78 Pt $6s^15d^9$	79 Au $6s^15d^{10}$	80 Hg $6s^25d^{10}$	81 Tl $6s^26p^1$	82 Pb $6s^26p^2$	83 Bi $6s^26p^3$	84 Po $6s^26p^4$	85 At $6s^26p^5$	86 Rn $6s^26p^6$
7	87 Fr $7s^1$	88 Ra $7s^2$	89 Ac** $7s^26d^1$	104 Rf $7s^26d^2$	105 Db $7s^26d^3$	106 Sg $7s^26d^4$	107 Bh $7s^26d^5$	108 Hs $7s^26d^6$	109 Mt $7s^26d^7$	110 Ds $7s^26d^8$	111 Uuu $7s^16d^{10}$	112 Uub $7s^26d^{10}$		114 Uuq $7s^27p^2$				

f-Transition Elements

*Lanthanides	58 Ce $6s^24f^15d^1$	59 Pr $6s^24f^35d^0$	60 Nd $6s^24f^45d^0$	61 Pm $6s^24f^55d^0$	62 Sm $6s^24f^65d^0$	63 Eu $6s^24f^75d^0$	64 Gd $6s^24f^75d^1$	65 Tb $6s^24f^95d^0$	66 Dy $6s^24f^{10}5d^0$	67 Ho $6s^24f^{11}5d^0$	68 Er $6s^24f^{12}5d^0$	69 Tm $6s^24f^{13}5d^0$	70 Yb $6s^24f^{14}5d^0$	71 Lu $6s^24f^{14}5d^1$
**Actinides	90 Th $7s^25f^06d^2$	91 Pa $7s^25f^26d^1$	92 U $7s^25f^36d^1$	93 Np $7s^25f^46d^1$	94 Pu $7s^25f^66d^0$	95 Am $7s^25f^76d^0$	96 Cm $7s^25f^76d^1$	97 Bk $7s^25f^96d^0$	98 Cf $7s^25f^{10}6d^0$	99 Es $7s^25f^{11}6d^0$	100 Fm $7s^25f^{12}6d^0$	101 Md $7s^25f^{13}6d^0$	102 No $7s^25f^{14}6d^0$	103 Lr $7s^25f^{14}6d^1$

colored transition metal complexes- glazes

$Ni(NH_3)_6Br_2$

$CoCl_2{\cdot}6H_2O$

$NiSO_4{\cdot}6H_2O$

http://woelen.scheikunde.net/science/chem/elem/metalsalts.jpg