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# CEE 680: Water Chemistry

Lecture #33  
Coordination Chemistry: Practice  
 (Stumm & Morgan, Chapt.6: pg.317-319)  
 Benjamin; Chapter 8.1-8.6

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## Which ligands for which metals?

- Benjamin 2<sup>nd</sup> ed., pg 532

Table 10.1 Some important inorganic ligands and some metals to which they bind.

Ligand	Metals	Environment/Application
H <sub>2</sub> O	All	Any aquatic system
OH <sup>-</sup>	Virtually all	Any aquatic system
F <sup>-</sup>	Fe <sup>3+</sup> , Al <sup>3+</sup>	Some natural systems; industrial systems where HF is used to treat metal surfaces
Cl <sup>-</sup>	Cu <sup>2+</sup> , Cu <sup>+</sup> , Pb <sup>2+</sup> , Cd <sup>2+</sup>	Estuaries, seawater; corrosion of metals
CN <sup>-</sup>	Fe <sup>3+</sup> , Fe <sup>2+</sup> , Cu <sup>+</sup> , Cu <sup>2+</sup> , Ni <sup>2+</sup> , Ag <sup>+</sup>	Metal plating
NH <sub>3</sub>	Cu <sup>+</sup> , Cu <sup>2+</sup> , Cd <sup>2+</sup> , Ni <sup>2+</sup>	Metal finishing
S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	Ag <sup>+</sup>	Photofinishing
P <sub>2</sub> O <sub>7</sub> <sup>4-</sup> , P <sub>3</sub> O <sub>10</sub> <sup>5-</sup>	Ca <sup>2+</sup> , Mn <sup>2+</sup> , Fe <sup>3+</sup>	Detergents, corrosion inhibitors

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## Classification of Metals

- A and B type cations

A-Type Metal Cations	Transition-Metal Cations	B-Type Metal Cations
Electron configuration of inert gas; low polarizability; "hard spheres"; $(H^+)$ , $Li^+$ , $Na^+$ , $K^+$ , $Be^{2+}$ , $Mg^{2+}$ , $Ca^{2+}$ , $Sr^{2+}$ , $Al^{3+}$ , $Sc^{3+}$ , $La^{3+}$ , $Si^{4+}$ , $Ti^{4+}$ , $Zr^{4+}$ , $Th^{4+}$	One to nine outer shell electrons; not spherically symmetric; $V^{2+}$ , $Cr^{2+}$ , $Mn^{2+}$ , $Fe^{2+}$ , $Co^{2+}$ , $Ni^{2+}$ , $Cu^{2+}$ , $Ti^{3+}$ , $V^{3+}$ , $Cr^{3+}$ , $Mn^{3+}$ , $Fe^{3+}$ , $Co^{3+}$	Electron number corresponds to $Ni^0$ , $Pd^0$ , and $Pt^0$ (10 or 12 outer shell electrons); low electronegativity; high polarizability; "soft spheres"; $Cu^+$ , $Ag^+$ , $Au^+$ , $Tl^+$ , $Ga^+$ , $Zn^{2+}$ , $Cd^{2+}$ , $Hg^{2+}$ , $Pb^{2+}$ , $Sn^{2+}$ , $Tl^{3+}$ , $Au^{3+}$ , $In^{3+}$ , $Bi^{3+}$

From: Stumm & Morgan,  
Table 6.3, pg 284

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## Pearson's Hard & Soft Acids

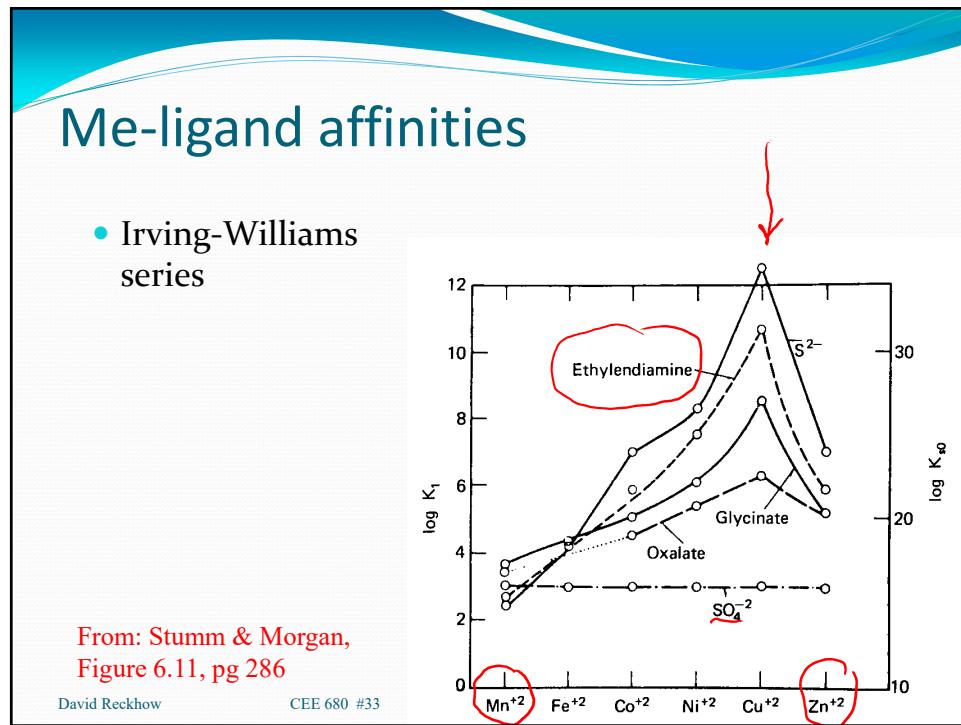
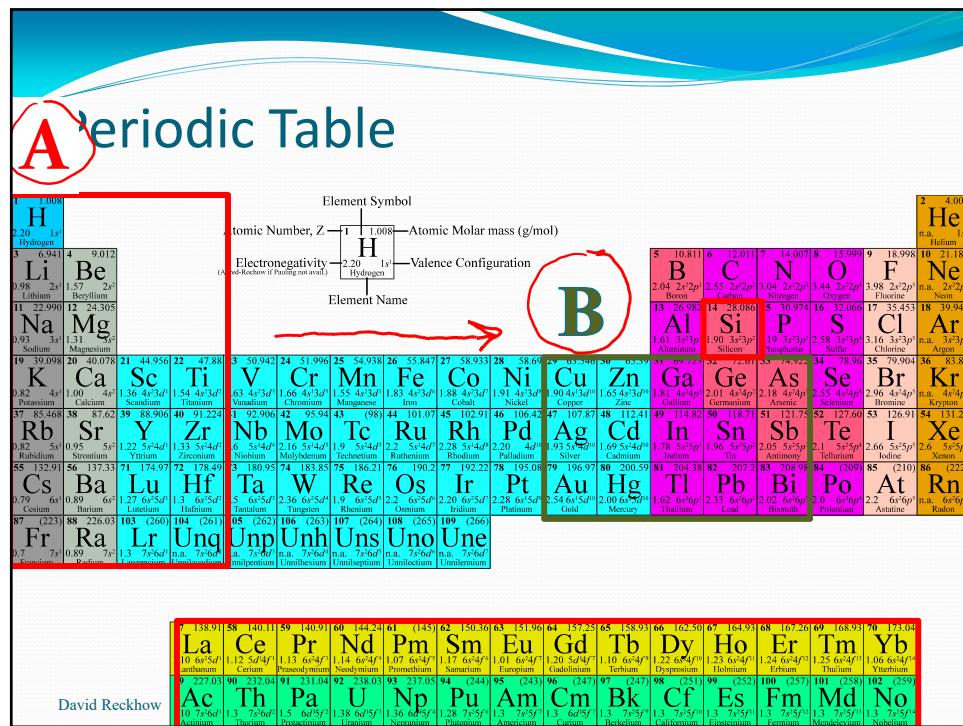
From: Stumm & Morgan,  
Table 6.3, pg 284

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Hard Acids	Borderline	Soft Acids
All A-type metal cations plus $Cr^{3+}$ , $Mn^{3+}$ , $Fe^{3+}$ , $Co^{3+}$ , $UO^{2+}$ , $VO^{2+}$ Also species such as $BF_3$ , $BCl_3$ , $SO_3$ , $RSO_2^+$ , $RPO_4^+$ , $CO_2$ , $RCO^+$ , $R_3C^+$	All bivalent transition-metal cations plus $Zn^{2+}$ , $Pb^{2+}$ , $Bi^{3+}$ , $SO_2$ , $NO^+$ , $B(CH_3)_3$	All B-type metal cations minus $Zn^{2+}$ , $Pb^{2+}$ , $Bi^{3+}$
<b>Preference for ligand atom:</b> $N \gg P$ $O \gg S$ $F \gg Cl$	<b>Qualitative generalizations on stability sequence:</b> Cations: Stability $\propto$ (charge/radius) Irving-Williams order: $Mn^{2+} < Fe^{2+} < Co^{2+} < Ni^{2+} < Cu^{2+} > Zn^{2+}$	$P \gg N$ $S \gg O$ $I \gg F$

Ligands:  
 $F > O > N = Cl > Br > I > S$   
 $OH^- > RO^- > RCO_2^-$   
 $CO_3^{2-} \gg NO_3^-$   
 $PO_4^{3-} \gg SO_4^{2-} \gg ClO_4^-$

Ligands:  
 $S > I > Br > Cl = N > O > F$



**Periodic Table**

The chart includes the following key features:

- Element Symbol**: Located at the top right.
- Atomic Number, Z**: Numerical value for each element.
- Atomic Molar mass (g/mol)**: Numerical value for each element.
- Electronegativity**: A color-coded scale from 0.8 to 4.0.
- Valence Configuration**: Electron shell notation (e.g., 1s<sup>1</sup>, 2s<sup>2</sup>).
- Element Name**: Full name of each element.
- Alfred-Kochow's Pilling-Strandawit**: A note indicating where data is available.

Element	Symbol	Atomic Number, Z	Atomic Molar mass (g/mol)	Electronegativity	Valence Configuration	Element Name
H	H	1	1.008	0.82	1s <sup>1</sup>	Hydrogen
He	He	2	4.00	n.a.	1s <sup>2</sup>	Helium
Li	Li	3	6.941	0.98	2s <sup>1</sup>	Lithium
Be	Be	4	9.012	1.57	2s <sup>2</sup>	Beryllium
B	B	5	10.811	2.04	2s <sup>2</sup> 2p <sup>1</sup>	Boron
C	C	6	12.011	2.53	2s <sup>2</sup> 2p <sup>2</sup>	Carbon
N	N	7	14.007	3.04	2s <sup>2</sup> 2p <sup>3</sup>	Nitrogen
O	O	8	15.999	3.44	2s <sup>2</sup> 2p <sup>4</sup>	Oxygen
F	F	9	18.998	3.98	2s <sup>2</sup> p <sup>5</sup>	Fluorine
Ne	Ne	10	21.180	n.a.	2s <sup>2</sup> p <sup>6</sup>	Neon
K	K	19	39.098	0.82	4s <sup>1</sup>	Potassium
Ca	Ca	20	40.078	1.00	4s <sup>2</sup>	Calcium
Sc	Sc	21	44.956	1.36	4s <sup>2</sup> 3d <sup>1</sup>	Scandium
Ti	Ti	22	47.88	1.54	4s <sup>2</sup> 3d <sup>1</sup>	Titanium
V	V	23	50.942	1.63	4s <sup>2</sup> 3d <sup>3</sup>	Vanadium
Cr	Cr	24	51.99	1.66	4s <sup>2</sup> 3d <sup>5</sup>	Chromium
Mn	Mn	25	54.938	1.55	4s <sup>2</sup> 3d <sup>5</sup>	Manganese
Fe	Fe	26	55.847	1.83	4s <sup>2</sup> 3d <sup>6</sup>	Iron
Co	Co	27	58.933	1.88	4s <sup>2</sup> 3d <sup>7</sup>	Cobalt
Ni	Ni	28	58.69	1.91	4s <sup>2</sup> 3d <sup>8</sup>	Nickel
Cu	Cu	29	63.546	1.90	4s <sup>2</sup> 3d <sup>10</sup>	Copper
Zn	Zn	30	65.45	1.65	4s <sup>2</sup> 3d <sup>10</sup>	Zinc
Ga	Ga	31	69.723	1.81	4s <sup>2</sup> 4p <sup>1</sup>	Gallium
Ge	Ge	32	72.61	1.61	3s <sup>2</sup> 3p <sup>2</sup>	Germanium
Al	Al	13	26.982	1.90	3s <sup>2</sup> 3p <sup>1</sup>	Aluminum
Si	Si	14	28.086	2.19	3s <sup>2</sup> 3p <sup>2</sup>	Silicon
P	P	15	30.974	2.58	3s <sup>2</sup> 3p <sup>3</sup>	Phosphorus
S	S	16	32.066	3.16	3s <sup>2</sup> 3p <sup>4</sup>	Sulfur
Cl	Cl	17	35.453	n.a.	3s <sup>2</sup> 3p <sup>5</sup>	Chlorine
Ar	Ar	18	39.948	n.a.	3s <sup>2</sup> 3p <sup>6</sup>	Argon
Rb	Rb	37	85.468	0.95	5s <sup>1</sup>	Rubidium
St	St	38	87.62	1.22	5s <sup>1</sup> 4d <sup>1</sup>	Samarium
Y	Y	39	89.906	1.33	5s <sup>2</sup> 4d <sup>1</sup>	Yttrium
Nb	Nb	40	90.906	2.16	5s <sup>2</sup> 4d <sup>2</sup>	Niobium
Mo	Mo	41	91.906	1.9	5s <sup>2</sup> 4d <sup>3</sup>	Molybdenum
Tc	Tc	42	95.906	2.2	5s <sup>2</sup> 4d <sup>4</sup>	Techne
Ru	Ru	43	96.906	2.28	5s <sup>2</sup> 4d <sup>5</sup>	Ruthenium
Rh	Rh	44	101.07	2.20	5s <sup>2</sup> 4d <sup>6</sup>	Rhenium
Pd	Pd	45	102.906	1.69	5s <sup>2</sup> 4d <sup>7</sup>	Palladium
Ag	Ag	46	106.906	1.96	5s <sup>2</sup> 4d <sup>8</sup>	Argentum
Cd	Cd	47	114.82	1.69	5s <sup>2</sup> 4d <sup>9</sup>	Cadmium
In	In	50	118.71	1.78	5s <sup>2</sup> 5p <sup>1</sup>	Inertium
Sh	Sh	51	121.75	1.96	5s <sup>2</sup> 5p <sup>2</sup>	Samarium
Sb	Sb	52	124.769	2.1	5s <sup>2</sup> 5p <sup>3</sup>	Antimony
Te	Te	53	125.97	2.66	5s <sup>2</sup> 5p <sup>4</sup>	Technetium
I	I	54	131.28	2.5	5s <sup>2</sup> 5p <sup>5</sup>	Xenon
Xe	Xe	55	131.28	2.5	5s <sup>2</sup> 5p <sup>6</sup>	Krypton
Rb	Rb	87	(223)	0.88	5s <sup>1</sup>	Rubidium
St	St	88	226.03	1.3	5s <sup>1</sup> 4d <sup>1</sup>	Samarium
Y	Y	89	(260)	1.03	5s <sup>1</sup> 4d <sup>1</sup>	Yttrium
La	La	57	138.91	1.10	6s <sup>2</sup> 5d <sup>1</sup>	La
Ce	Ce	58	140.11	1.2	5d <sup>1</sup> 4f <sup>1</sup>	Cerium
Pr	Pr	59	140.91	1.13	6s <sup>2</sup> 4f <sup>1</sup>	Praseodymium
Nd	Nd	60	144.24	1.14	6s <sup>2</sup> 4f <sup>1</sup>	Neodymium
Pm	Pm	61	(145)	0.07	6s <sup>2</sup> 4f <sup>1</sup>	Promethium
Sm	Sm	62	150.36	1.17	6s <sup>2</sup> 4f <sup>1</sup>	Samarium
Eu	Eu	63	151.96	1.01	6s <sup>2</sup> 4f <sup>1</sup>	Europium
Gd	Gd	64	157.25	1.20	6s <sup>2</sup> 4f <sup>1</sup>	Gadolinium
Tb	Tb	65	158.93	1.10	6s <sup>2</sup> 4f <sup>1</sup>	Terbium
Dy	Dy	66	162.50	1.23	6s <sup>2</sup> 4f <sup>1</sup>	Dysprosium
Ho	Ho	67	164.93	1.24	6s <sup>2</sup> 4f <sup>1</sup>	Holmium
Er	Er	68	167.26	1.25	6s <sup>2</sup> 4f <sup>1</sup>	Erbium
Tm	Tm	69	168.93	1.06	6s <sup>2</sup> 4f <sup>1</sup>	Thulium
Yb	Yb	70	173.04	n.a.	6s <sup>2</sup> 4f <sup>1</sup>	Ytterbium
Ac	Ac	89	227.03	1.10	7s <sup>2</sup> 6d <sup>1</sup>	Actinium
Th	Th	90	232.04	1.3	7s <sup>2</sup> 6d <sup>1</sup>	Thorium
Pa	Pa	91	231.04	1.6	7s <sup>2</sup> 6d <sup>1</sup>	Protactinium
U	U	92	238.03	1.36	7s <sup>2</sup> 6d <sup>1</sup>	Neptunium
Np	Np	93	237.05	1.28	7s <sup>2</sup> 5f <sup>1</sup>	Plutonium
Pm	Pm	94	(244)	0.95	7s <sup>2</sup> 5f <sup>1</sup>	Am
Am	Am	95	(245)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Curium
Cm	Cm	96	(247)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Berkelium
Bk	Bk	97	(247)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Californium
Cf	Cf	98	(257)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Lanthanum
Es	Es	99	(257)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Curium
Fm	Fm	100	(257)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Berkelium
Md	Md	101	(258)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Californium
No	No	102	(259)	1.3	7s <sup>2</sup> 5f <sup>1</sup>	Lanthanum

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