

THE PERIODIC TABLE

SYMBOL
1 ATOMIC NUMBER
2 ATOMIC WEIGHT
3 NAME

() = ESTIMATES

1 IA		18 VIIIA									
H	He	13 IIIA		14 IVA		15 VA		16 VIA		17 VIIA	
1 1.008 Hydrogen	2 4.01 Helium	B	C	N	O	F	Ne				
3 6.94 Lithium	4 9.01 Boron	5 12.01 Boron	6 12.01 Carbon	7 14.01 Nitrogen	8 16.00 Oxygen	9 19.00 Fluorine	10 20.18 Neon				
Na	Mg	Al	Si	P	S	Cl	Ar				
11 22.99 Sodium	12 24.31 Magnesium	13 28.08 Aluminum	14 28.09 Silicon	15 30.97 Phosphorus	16 32.07 Sulfur	17 35.45 Chlorine	18 39.95 Argon				
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
19 39.12 Potassium	20 40.08 Calcium	21 41.98 Scandium	22 47.88 Titanium	23 50.94 Vanadium	24 52.00 Chromium	25 54.94 Manganese	26 55.85 Iron	27 56.93 Cobalt	28 58.93 Nickel	29 60.55 Copper	30 65.39 Zinc
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd
37 85.47 Rubidium	38 87.62 Strontium	39 88.91 Yttrium	40 91.23 Zirconium	41 92.93 Niobium	42 95.94 Molybdenum	43 (97.9) Technetium	44 101.37 Ruthenium	45 102.91 Rhodium	46 106.42 Palladium	47 107.87 Silver	48 112.41 Cadmium
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg
55 132.91 Cesium	56 137.33 Barium	57 138.51 Lanthanum	72 178.48 Hafnium	73 180.95 Tantalum	74 183.85 Tungsten	75 186.21 Rhenium	76 190.2 Osmium	77 192.27 Iridium	78 195.98 Platinum	79 196.97 Gold	80 200.53 Mercury
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt		Tl	Pb
87 223.02 Francium	88 226.03 Radium	89 227.03 Actinium	93 (281) Rutherfordium	105 (265) Dubnium	106 (282) Sougat	107 (283) Bohrium	108 (285) Hassium	109 (266) Meitnerium		81 182.26 Thallium	82 207.2 Lead
										83 183.88 Bismuth	84 (289) Polonium
										85 (223) Astatine	86 (222) Radium
										87 186.00 Bromine	88 188.00 Krypton
										89 188.00 Chlorine	90 190.00 Fluorine
										91 192.00 Neon	92 194.00 Helium

HUMAN
METALSHUMAN
METALS

LANTHANIDES

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
58 140.12 Cerium	99 140.91 Praseodymium	60 144.24 Neodymium	61 (145) Promethium	62 150.38 Samarium	63 152.81 Europium	64 158.28 Gadolinium	65 162.91 Terbium	66 162.91 Dysprosium	67 164.90 Holmium	68 167.28 Erbium	69 168.13 Thulium	70 172.04 Ytterbium	71 174.97 Lutetium
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
90 228.04 Thorium	91 231.04 Protactinium	92 233.03 Uranium	93 237.06 Neptunium	94 (240) Plutonium	95 243.06 Americium	96 (247) Curium	97 (249) Berkelium	98 (251) Californium	99 (253) Espresso	100 254.04 Fermium	101 (257) Mendelevium	102 258.03 Neptunium	103 252.11 Lanthanum

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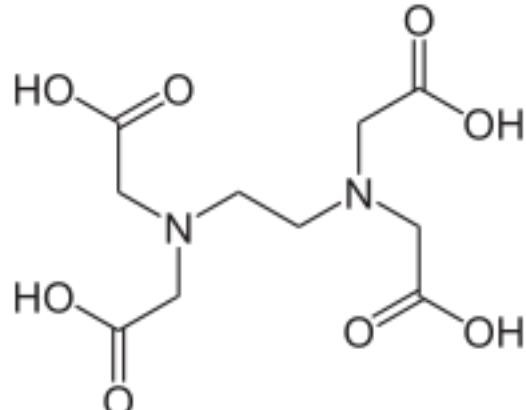
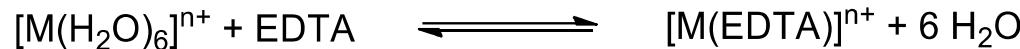
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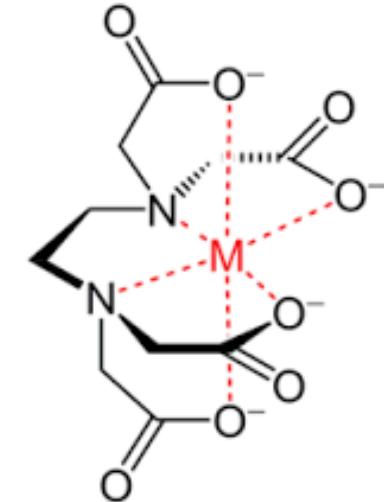
Formation constants of Ni^{2+} ammines, $[\text{Ni}(\text{NH}_3)_n(\text{OH}_2)_{6-n}]^{2+}$

n	p K_n	K_n	K_n/K_{n-1}
1	-2.72	524.8	
2	-2.17	147.9	0.28
3	-1.66	45.71	0.53
4	-1.12	13.18	0.56
5	-0.67	4.677	0.53
6	-0.03	1.07	0.42

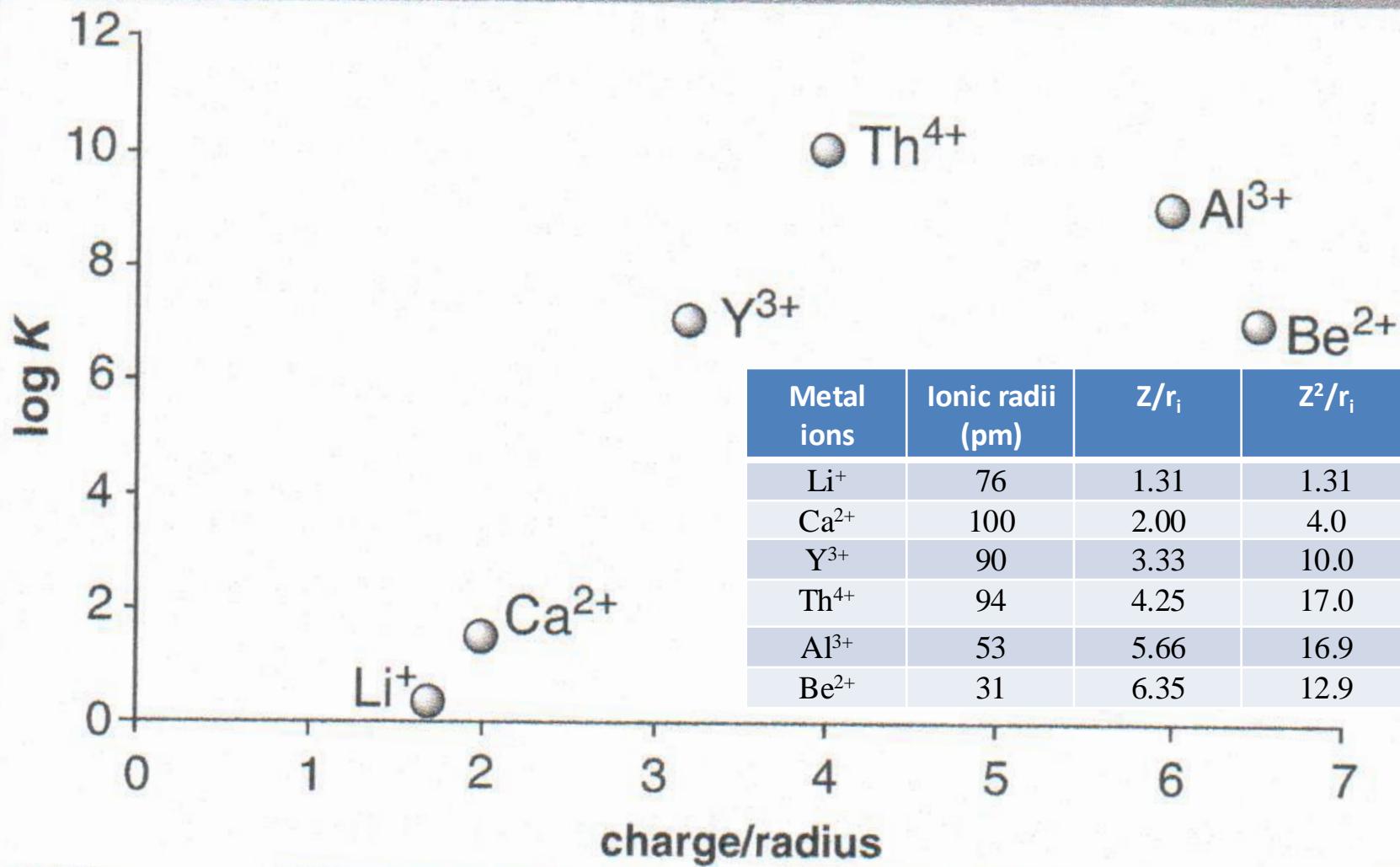
Formation constants of K_1^f for various metal-EDTA complexes



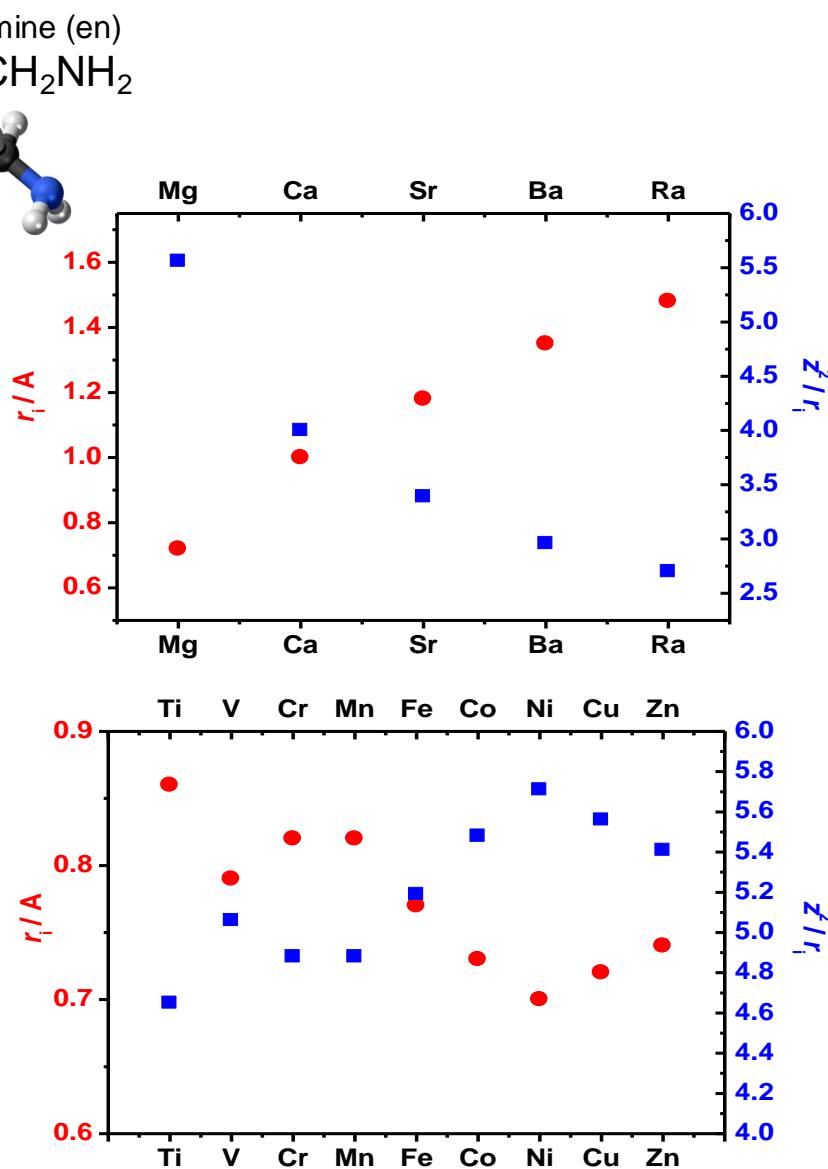
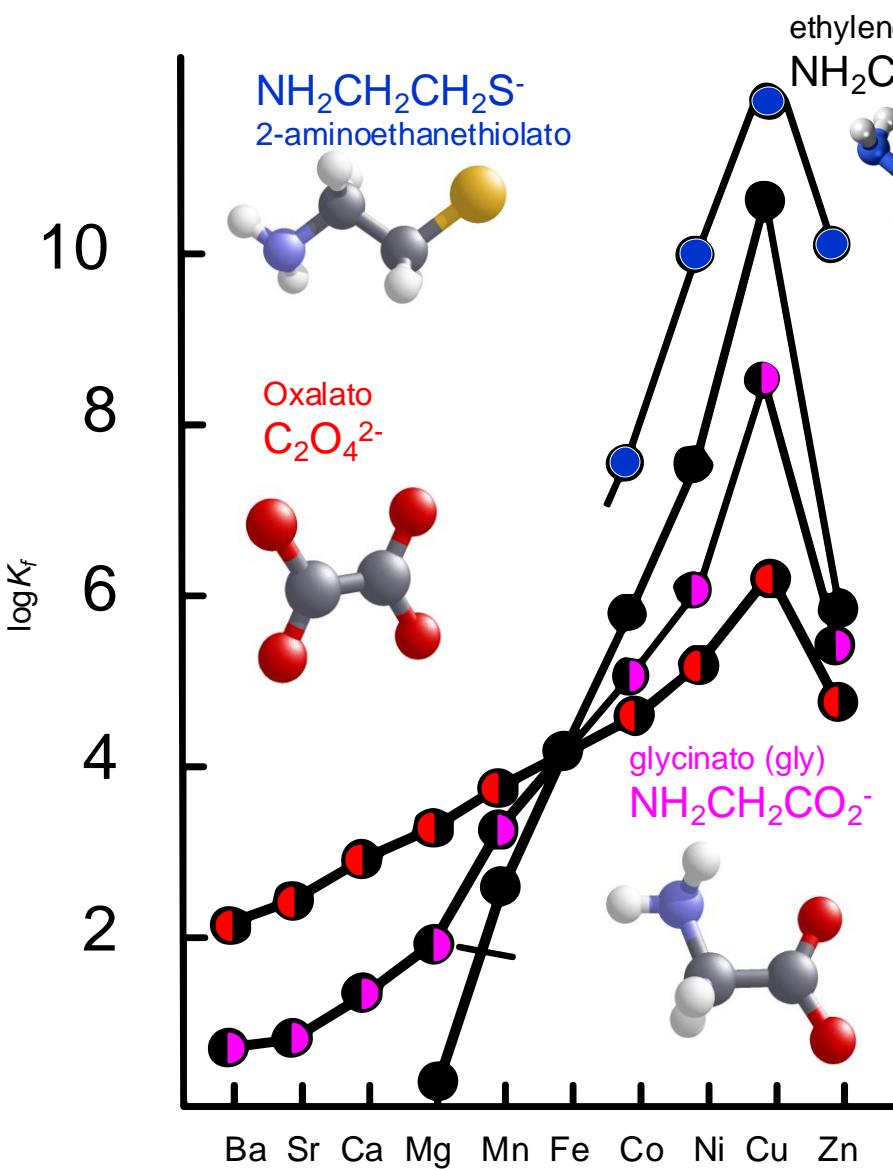
Metal ions	Log (K_1^f)
Ag^+	7.3
Ca^{2+}	10.8
Cu^{2+}	18.7
Ni^{2+}	18.6
Fe^{2+}	14.3
Fe^{3+}	25.1
Co^{2+}	16.1
Co^{3+}	36.0
V^{2+}	12.7
V^{3+}	25.9



Influence of the charge and ionic radii of metal on stability on a series of hydroxides.



Irving-William Series: stability of M^{2+} octahedral complexes with the different ligands follow the same trend, can it be explained with Z^2/r_i ?

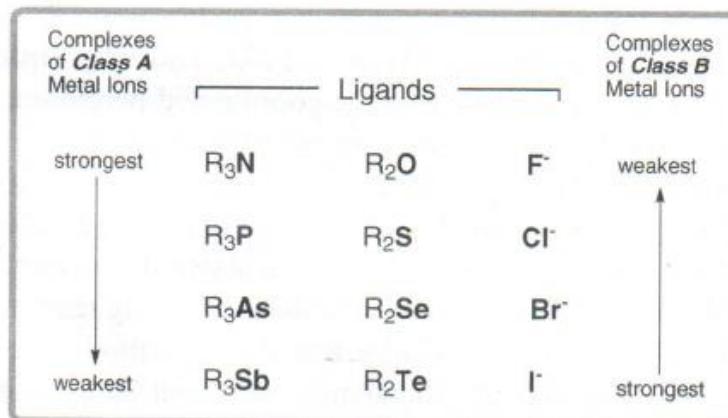


Ralph Pearson's Hard Soft Acid Base Theory

Table showing the nature of ligands and metals

Hard	Class A	Intermediate	Soft	Class B
<i>Ligands</i>				
	F^- , O^{2-} , OH , OH_2 , OHR , RCOO^- , NH_3 , NR_3 , RCN , Cl^- , NO_3^- , CO_3^{2-} , SO_4^{2-} , PO_4^{3-}	Br^- , SR , NO_2^- , N_3^- , SCN^- , $\text{H}_5\text{C}_5\text{N}$	PR_3 , SR_2 , SeR_2 , AsR_3 , CNR , CN^- , SCN^- , CO , I^- , H^- , R^-	
<i>Metal Ions</i>				
	Mo^{5+} , Ti^{4+} , V^{4+} , Sc^{3+} , Cr^{3+} , Fe^{3+} , Co^{3+} , Al^{3+} , Eu^{3+} , Cr^{2+} , Mn^{2+} , Ca^{2+} , Mg^{2+} , Be^{2+} , K^+ , Na^+ , Li^+ , H^+	Fe^{2+} , Co^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+} , Pb^{2+}	Cu^+ , Rh^+ , Ag^+ , Au^+ , Pd^{2+} , Pt^{2+} , Hg^{2+} , Cd^{2+}	

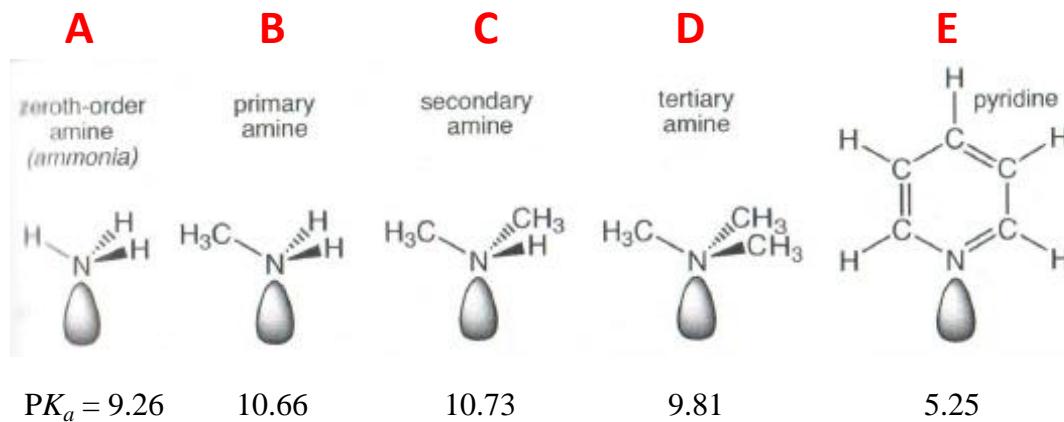
Table showing the nature of ligands as you go down the periodic chart.



Trends:

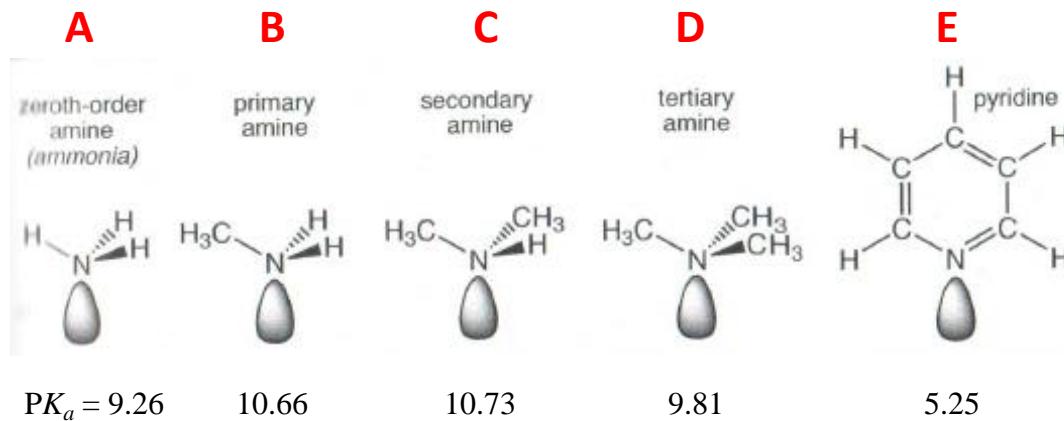
- Hard metals:** high oxidation states > 2 and early transition metals
- Soft metals:** late transition metals and low-oxidation states
- Intermediate metals:** first-row and $2+$ oxidation state
- Hard ligands:** ligands with donors that are N, O, or halides.
- Soft ligands:** are carbon donors or elements found in the second or later rows of the p-block
- Polarizability and hence softness increases going down the periodic chart.

Exercise: From the PK_a s of the conjugate acids, rank the following ligands in terms of their acid strength!



Exercise: Based on what we just learned, which ligand do you think will form the strongest complex with Co^{3+} ? Rank them.

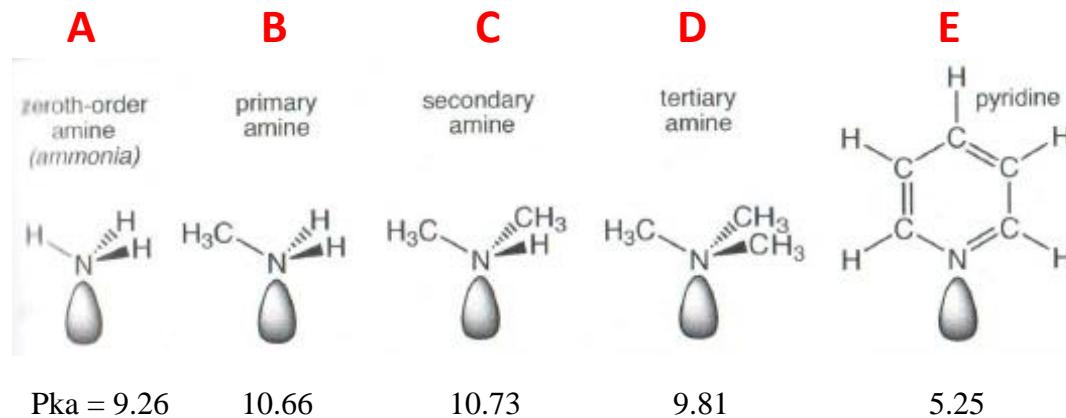
Exercise: From the PK_a s of the conjugate acids, rank the following ligands in terms of their acid strength!



Answer: E > A > D > B > C

Exercise: Based on what we just learned, which ligand do you think will form the strongest complex with Co^{3+} ? Rank them.

Exercise: From the Pk_as of the conjugate acids, rank the following ligands in terms of their acid strength!



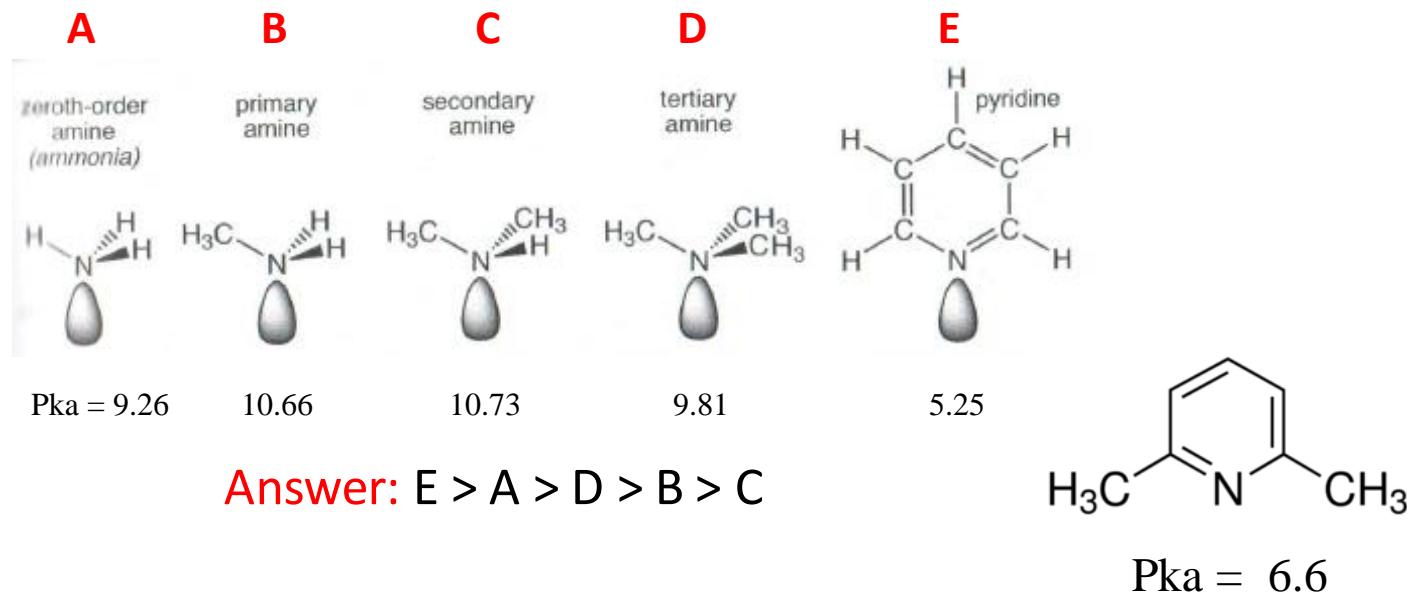
Answer: E > A > D > B > C

Exercise: Based on what we just learned, which ligand do you think will form the strongest complex with Co³⁺? Rank them.

Answer: C > B > A > D > E

Exercise: Can anyone guess why D is more basic than A, but forms a weaker CO³⁺ complex than A?

Exercise: From the Pk_as of the conjugate acids, rank the following ligands in terms of their acid strength!



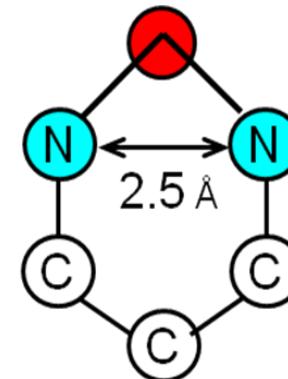
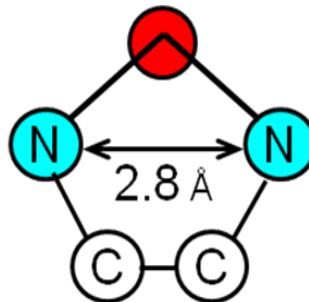
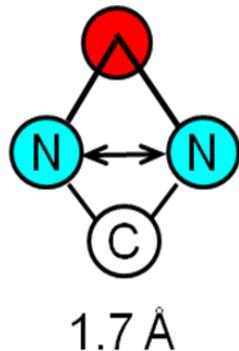
Exercise: Based on what we just learned, which ligand do you think will form the strongest complex with Co³⁺? Rank them.

Answer: C > B > A > D > E

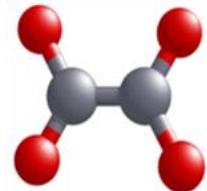
Exercise: Can anyone guess why this is the trend for the acidity with regard to the ammonia and the primary, secondary, and tertiary amines?

Answer: Sterically bulky ligands can counteract bases strength. This is reflected in the decrease in the Pk_a for the tertiary amine, which leads to a less stable complex.

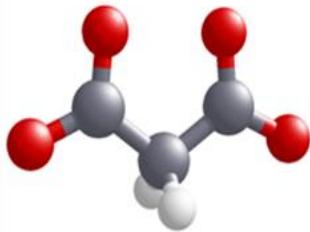
Improved stability in 5-membered rings: The chelate effect



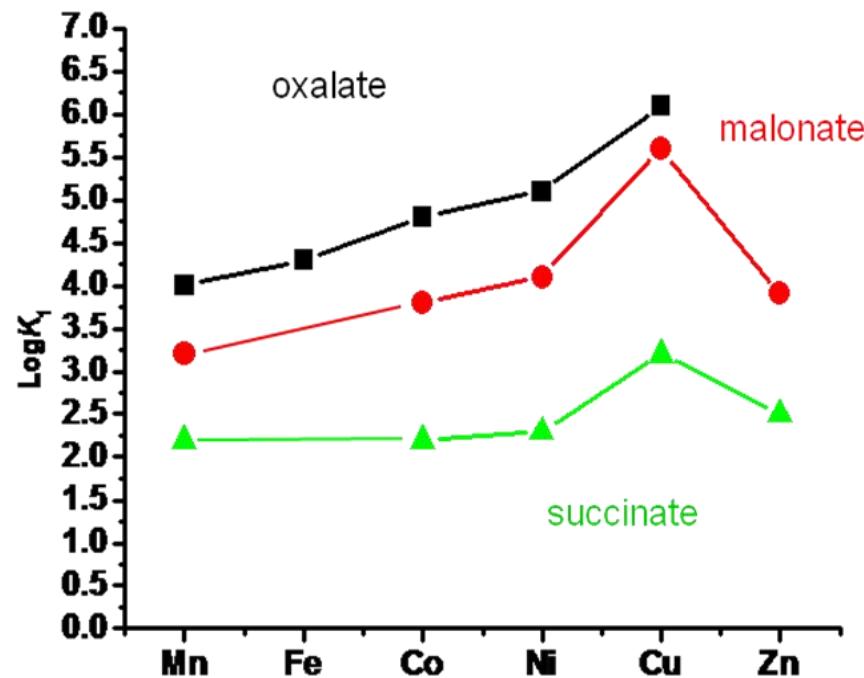
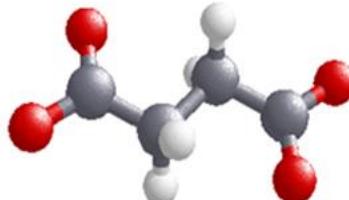
5-membered
oxalato



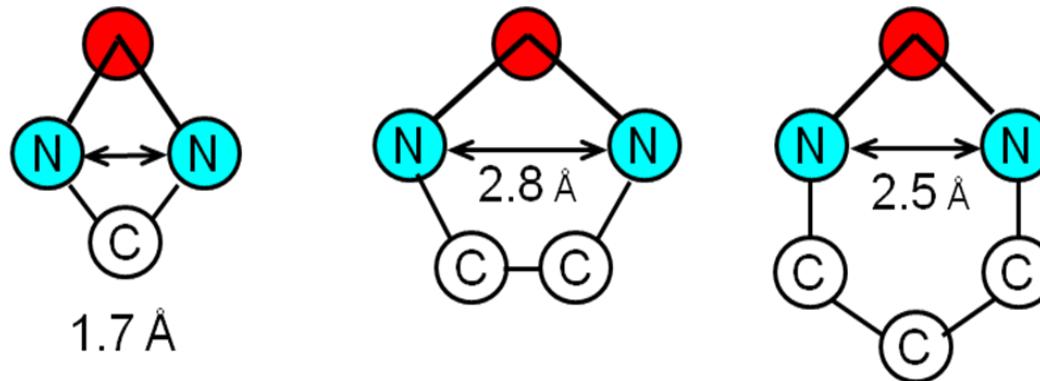
6-membered
malonato



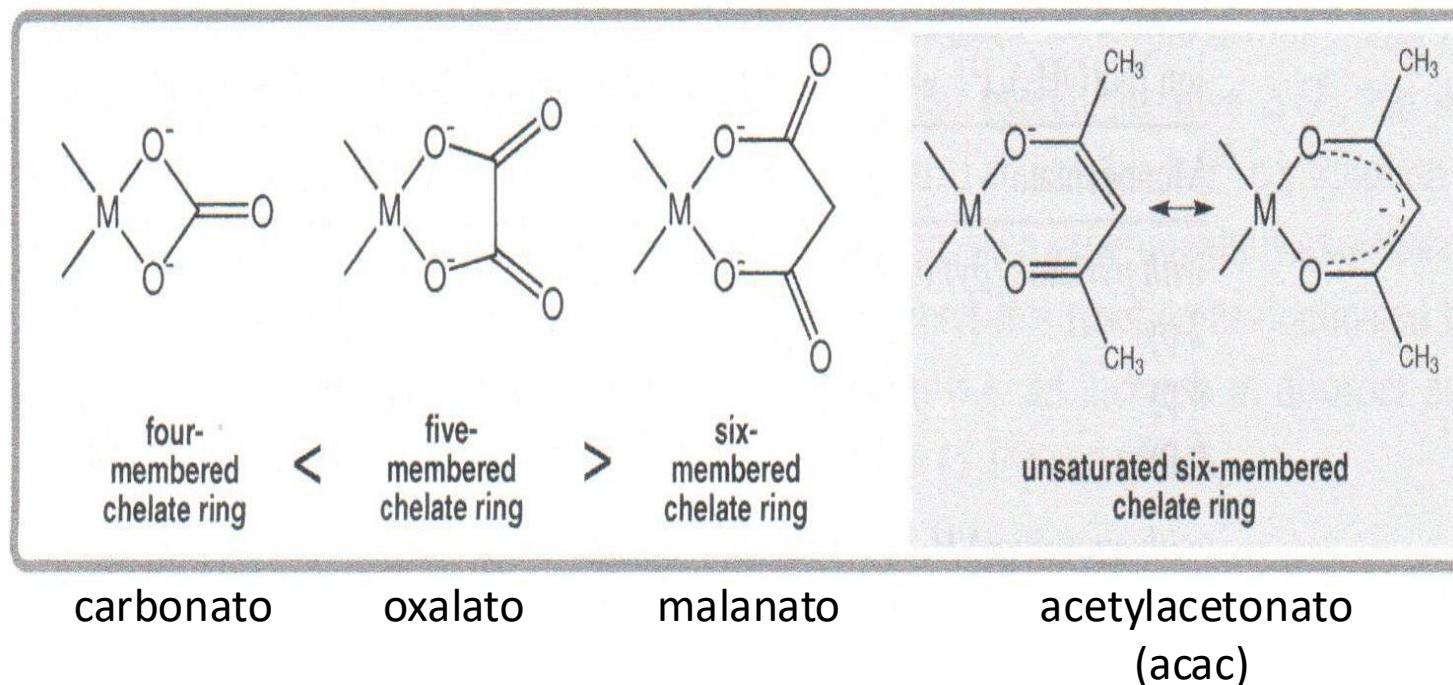
7-membered
succinato



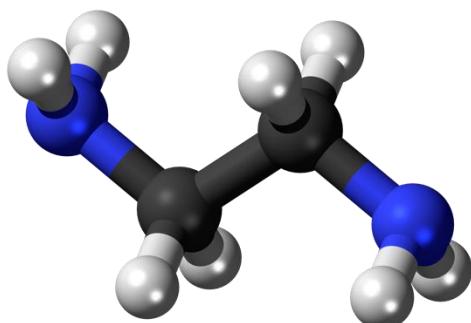
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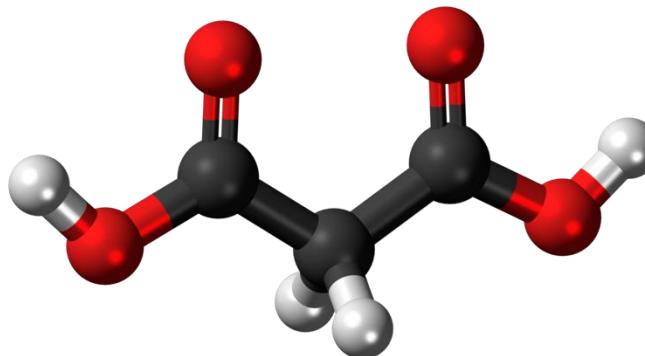
The exception – rings that contain unsaturated carbon atoms



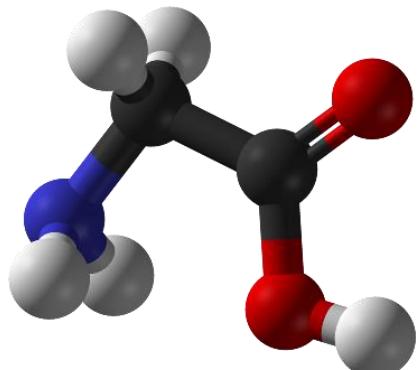
Exercise: Predict the order of stabilities for the following with Ni^{2+}



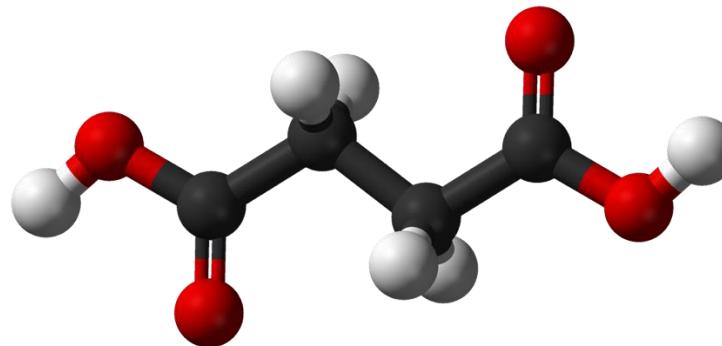
1). Ethylenediamine
 $\text{NH}_2\text{-CH}_2\text{-CH}_2\text{-NH}_2$



2). Malonic acid
 ${}^-\text{O}_2\text{C-CH}_2\text{-CO}_2^-$

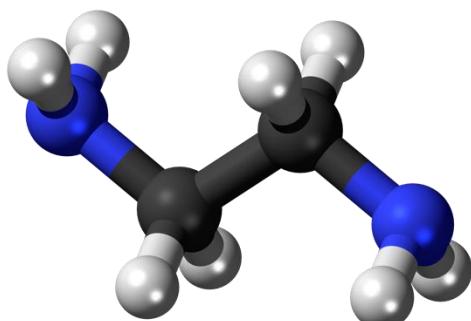


3). Glycine
 $\text{NH}_2\text{-CH}_2\text{-CO}_2^-$

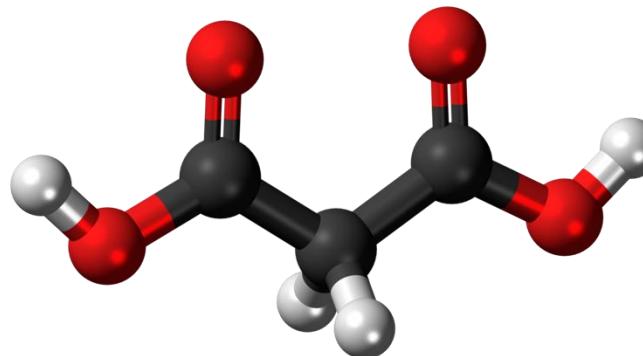


4). Succinic acid
 ${}^-\text{O}_2\text{C-CH}_2\text{-CH}_2\text{-CO}_2^-$

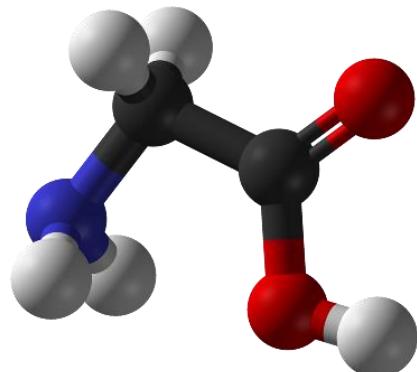
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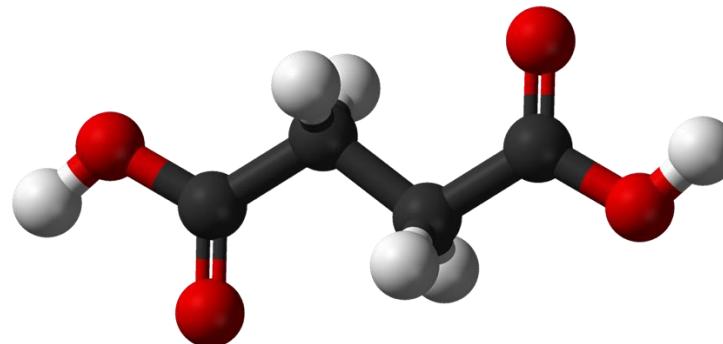
1). Ethylenediamine
 $\text{NH}_2\text{-CH}_2\text{-CH}_2\text{-NH}_2$



2). Malonic acid
 ${}^-\text{O}_2\text{C-CH}_2\text{-CO}_2^-$



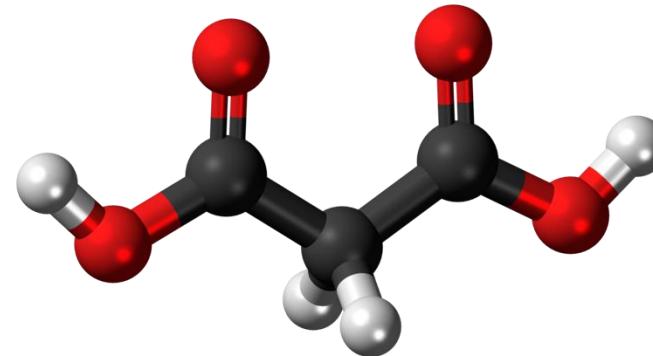
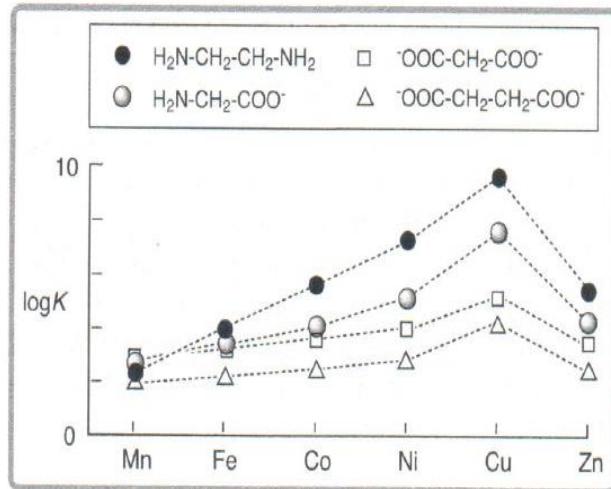
3). Glycine
 $\text{NH}_2\text{-CH}_2\text{-CO}_2^-$



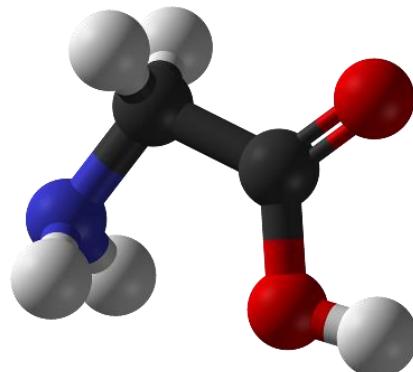
4). Succinic acid
 ${}^-\text{O}_2\text{C-CH}_2\text{-CH}_2\text{-CO}_2^-$

Answer: With Ni^{2+} being intermediate, it makes it difficult to apply HSAB. Considering Bronsted basicity and ring size we have the following stabilities $1 > 3 > 2 > 4$

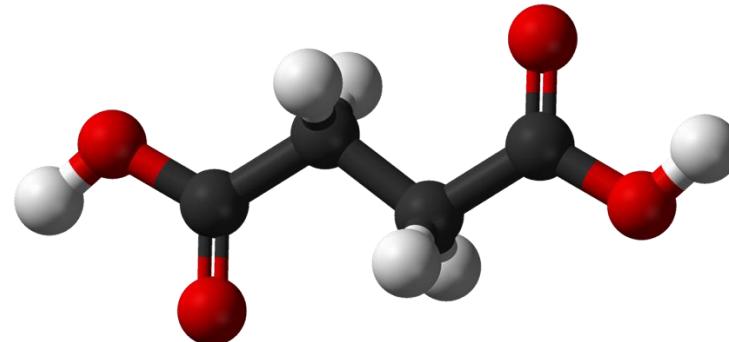
Exercise: Predict the order of stabilities for the following with Ni^{2+}



2). Malonic acid
 $-\text{O}_2\text{C}-\text{CH}_2-\text{CO}_2^-$



3). Glycine
 $\text{NH}_2-\text{CH}_2-\text{CO}_2^-$



4). Succinic acid
 $-\text{O}_2\text{C}-\text{CH}_2-\text{CH}_2-\text{CO}_2^-$

Answer: With Ni^{2+} being intermediate, it makes it difficult to apply HSAB. Considering Bronsted basicity and ring size we have the following stabilities $1 > 3 > 2 > 4$

Answer: Yes according to the Irving Williams Series