

THE PERIODIC TABLE

	1 IA																		18 VIIIA
1	H 1 1.008 Hydrogen																		He 2 4.00 Helium
2	Li 3 6.94 Lithium	Be 4 9.01 Beryllium												B 5 10.81 Boron	C 6 12.01 Carbon	N 7 14.01 Nitrogen	O 8 16.00 Oxygen	F 9 19.00 Fluorine	Ne 10 20.18 Neon
3	Na 11 22.99 Sodium	Mg 12 24.31 Magnesium												Al 13 28.98 Aluminum	Si 14 28.09 Silicon	P 15 30.97 Phosphorus	S 16 32.07 Sulfur	Cl 17 35.45 Chlorine	Ar 18 39.95 Argon
			3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB							
4	K 19 39.10 Potassium	Ca 20 40.08 Calcium	Sc 21 44.96 Scandium	Ti 22 47.88 Titanium	V 23 50.94 Vanadium	Cr 24 52.00 Chromium	Mn 25 54.94 Manganese	Fe 26 55.85 Iron	Co 27 58.93 Cobalt	Ni 28 58.69 Nickel	Cu 29 63.55 Copper	Zn 30 65.39 Zinc	Ga 31 69.72 Gallium	Ge 32 72.61 Germanium	As 33 74.92 Arsenic	Se 34 78.96 Selenium	Br 35 79.90 Bromine	Kr 36 83.80 Krypton	
5	Rb 37 85.47 Rubidium	Sr 38 87.62 Strontium	Y 39 88.91 Yttrium	Zr 40 91.22 Zirconium	Nb 41 92.91 Niobium	Mo 42 95.94 Molybdenum	Tc 43 (97.9) Technetium	Ru 44 101.07 Ruthenium	Rh 45 101.07 Rhodium	Pd 46 106.42 Palladium	Ag 47 107.87 Silver	Cd 48 112.41 Cadmium	In 49 114.82 Indium	Sn 50 118.71 Tin	Sb 51 121.76 Antimony	Te 52 127.60 Tellurium	I 53 126.90 Iodine	Xe 54 131.29 Xenon	
6	Cs 55 132.91 Cesium	Ba 56 137.33 Barium	La 57 138.91 Lanthanum	Hf 72 178.49 Hafnium	Ta 73 180.95 Tantalum	W 74 183.85 Tungsten	Re 75 186.21 Rhenium	Os 76 190.2 Osmium	Ir 77 192.22 Iridium	Pt 78 195.08 Platinum	Au 79 196.97 Gold	Hg 80 200.59 Mercury	Tl 81 204.38 Thallium	Pb 82 207.2 Lead	Bi 83 208.98 Bismuth	Po 84 (209) Polonium	At 85 (210) Astatine	Rn 86 (222) Radon	
7	Fr 87 223.02 Francium	Ra 88 226.03 Radium	Ac 89 227.03 Actinium	Rf 104 (261) Rutherfordium	Db 105 (262) Dubnium	Sg 106 (263) Seaborgium	Bh 107 (262) Bohrium	Hs 108 (265) Hassium	Mt 109 (266) Meitnerium	Unlabeled Discovery 110 Nov. 1994	Unlabeled Discovery 111 Nov. 1994	Unlabeled Discovery 112 1996		Unlabeled Discovery 114 1996	Unlabeled Discovery 116 1996	Unlabeled Discovery 118 1996		Unlabeled Discovery 118 1996	
	ALKALI METALS	ALKALI EARTH METALS																	

LANTHANIDES

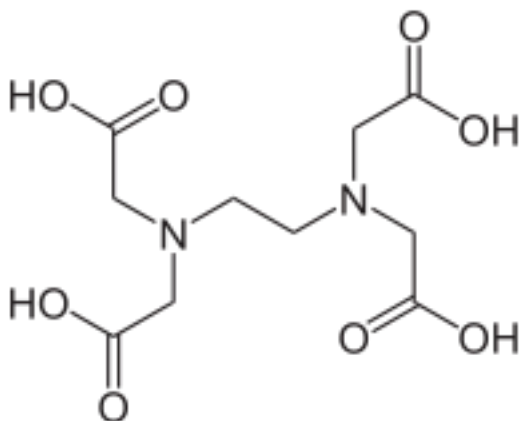
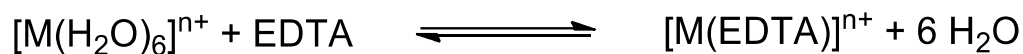
ACTINIDES

Ce 58 140.12 Cerium	Pr 59 140.91 Praseodymium	Nd 60 144.24 Neodymium	Pm 61 (145) Promethium	Sm 62 150.36 Samarium	Eu 63 152.07 Europium	Gd 64 157.25 Gadolinium	Tb 65 158.93 Terbium	Dy 66 162.50 Dysprosium	Ho 67 164.93 Holmium	Er 68 167.26 Erbium	Tm 69 168.93 Thulium	Yb 70 173.04 Ytterbium	Lu 71 174.97 Lutetium
Th 90 232.04 Thorium	Pa 91 231.04 Protactinium	U 92 238.03 Uranium	Np 93 237.05 Neptunium	Pu 94 (244) Plutonium	Am 95 243.06 Americium	Cm 96 (247) Curium	Bk 97 (249) Berkelium	Cf 98 (251) Californium	Es 99 252.08 Einsteinium	Fm 100 257.10 Fermium	Md 101 (257) Mendelevium	No 102 259.10 Nobelium	Lr 103 262.11 Lawrencium

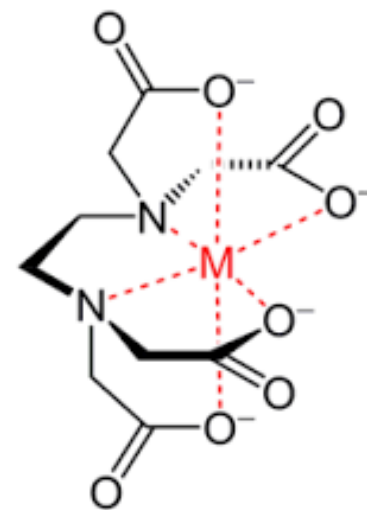
Formation constants of Ni²⁺ ammines, [Ni(NH₃)_n(OH₂)_{6-n}]²⁺

n	pK _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

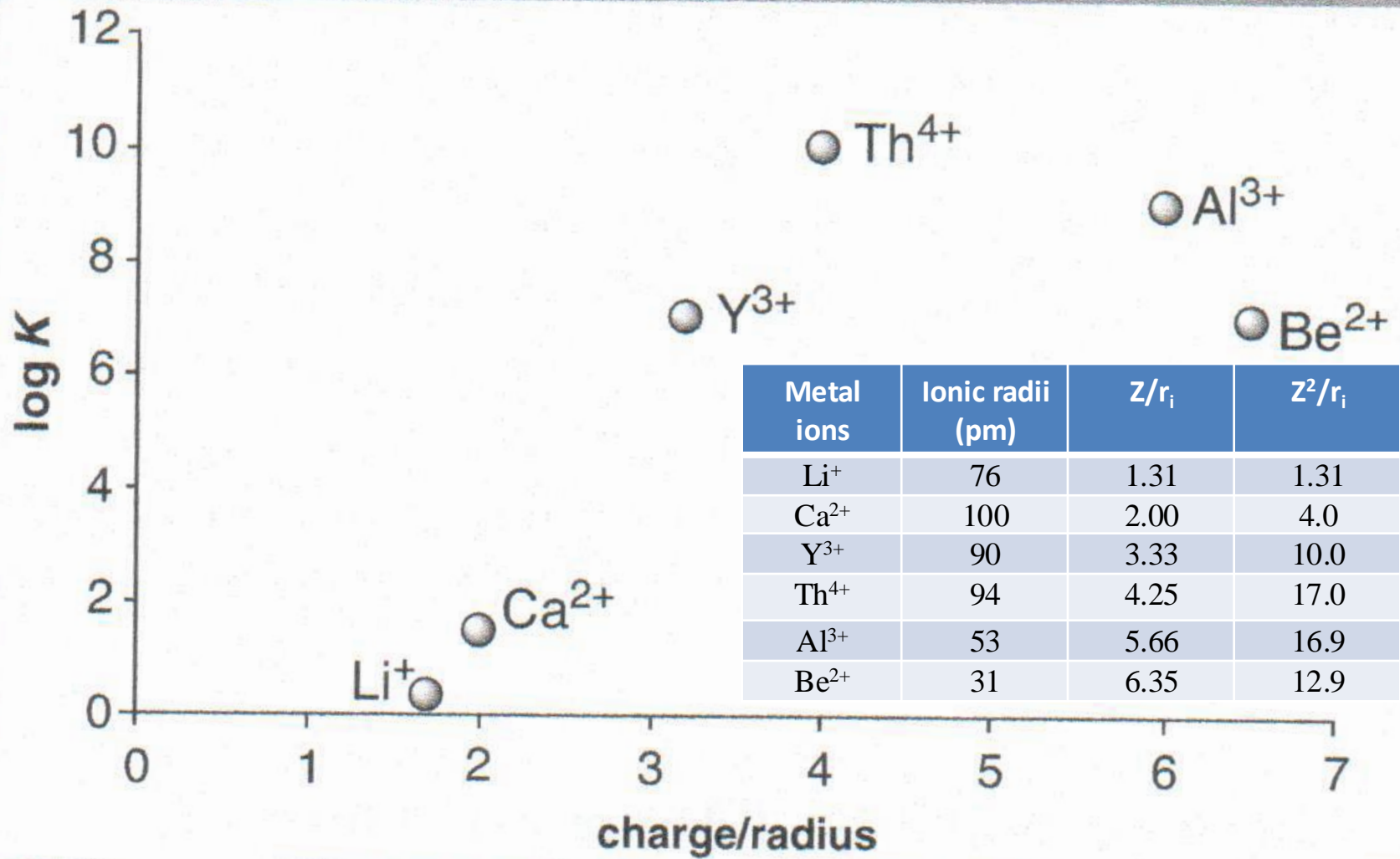
Formation constants of K₁^f for various metal-EDTA complexes



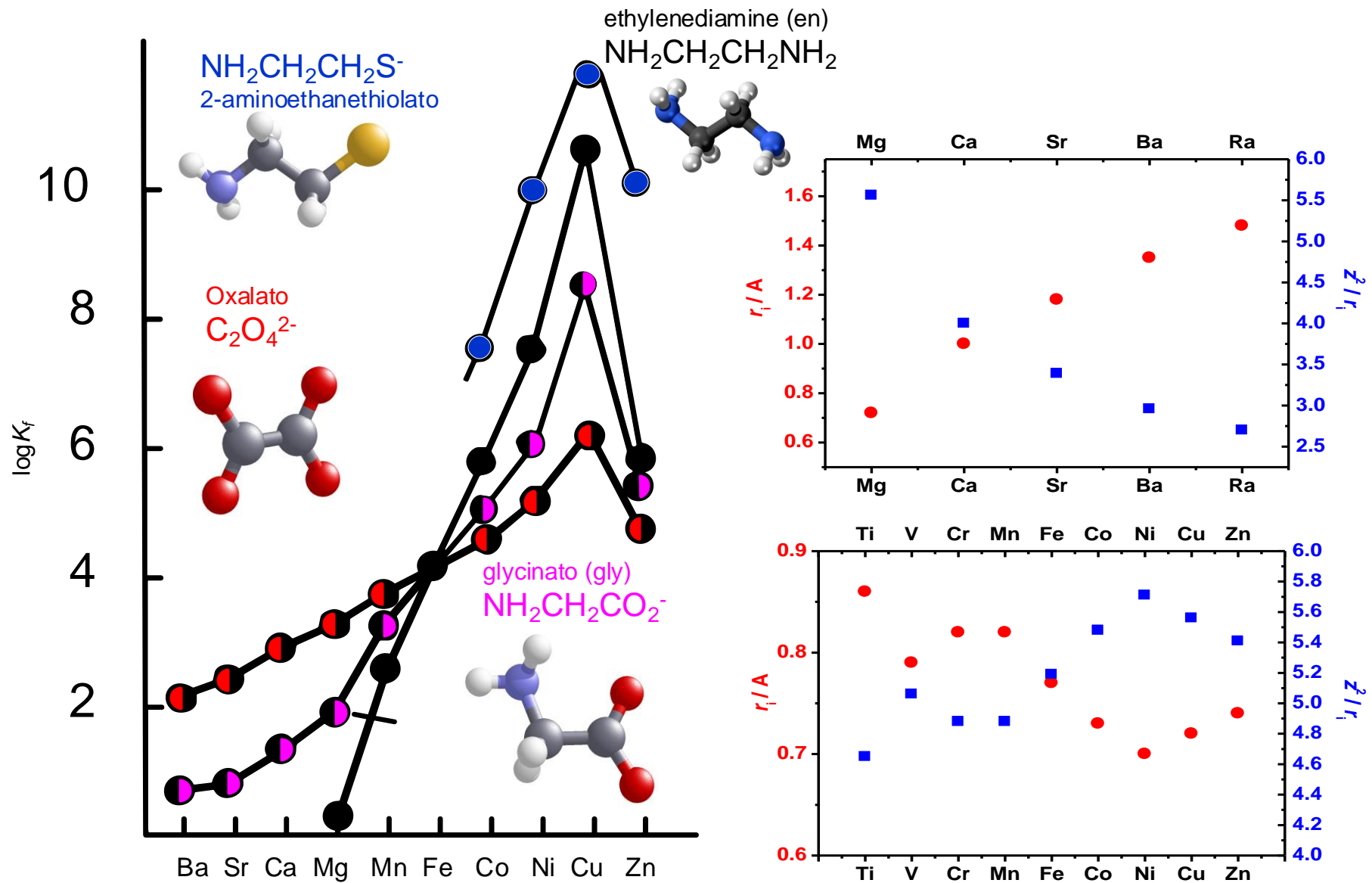
Metal ions	Log (K ₁ ^f)
Ag ⁺	7.3
Ca ²⁺	10.8
Cu ²⁺	18.7
Ni ²⁺	18.6
Fe ²⁺	14.3
Fe ³⁺	25.1
Co ²⁺	16.1
Co ³⁺	36.0
V ²⁺	12.7
V ³⁺	25.9



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^- , H_5C_5N		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.

Complexes of Class A Metal Ions	Ligands			Complexes of Class B Metal Ions
strongest	R_3N	R_2O	F^-	weakest
	R_3P	R_2S	Cl^-	
	R_3As	R_2Se	Br^-	
weakest	R_3Sb	R_2Te	I^-	strongest

Trends:

a. **Hard metals:** high oxidation states > 2 and early transition metals

b. **Soft metals:** late transition metals and low-oxidation states

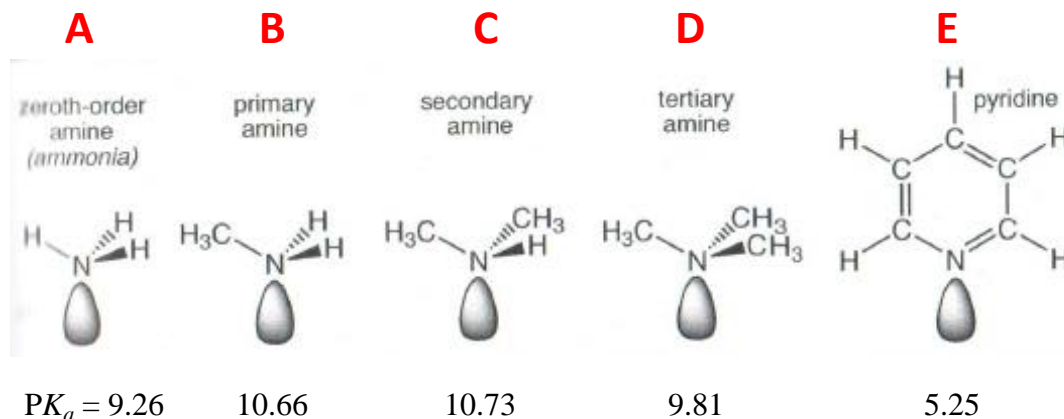
c. **Intermediate metals:** first-row and 2+ oxidation state

d. **Hard ligands:** ligands with donors that are N, O, or halides.

e. **Soft ligands:** are carbon donors or elements found in the second or later rows of the p-block

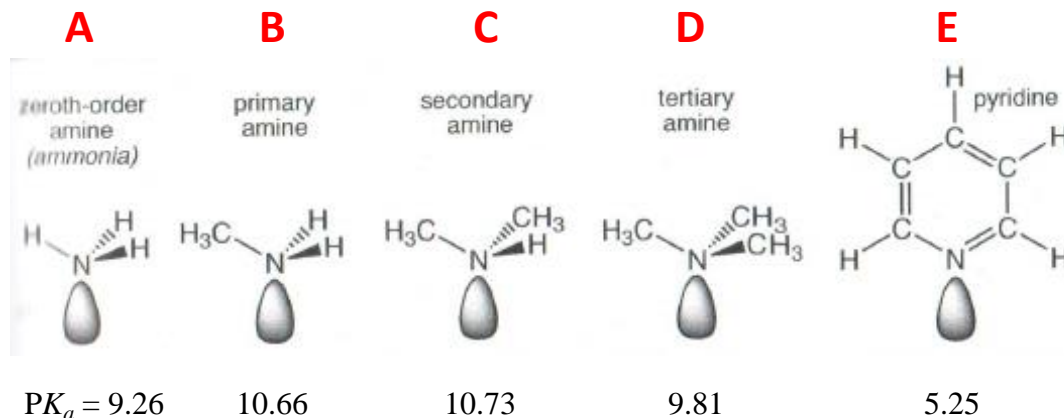
f. Polarizability and hence softness increases going down the periodic chart.

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.

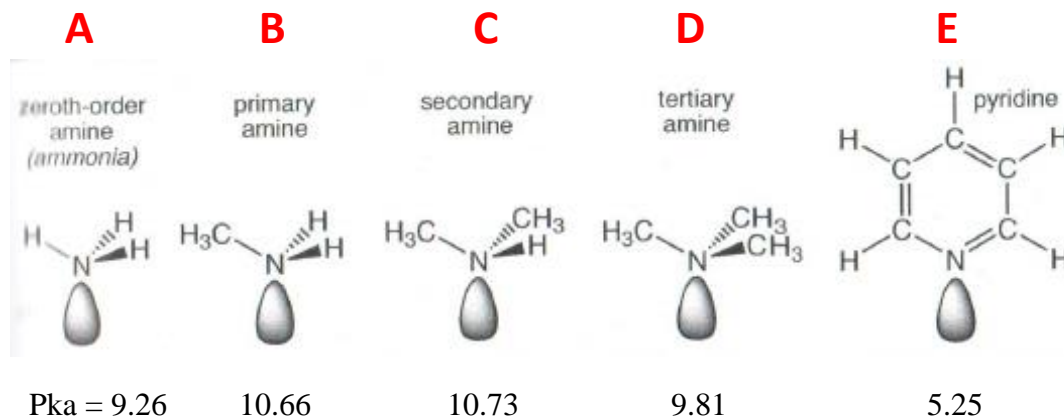
Exercise: From the PK_a s of the conjugate acids, rank the following ligands in terms of their acid strength!



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 P_{K_a} s of the conjugate acids, rank the following ligands in terms of their acid strength!



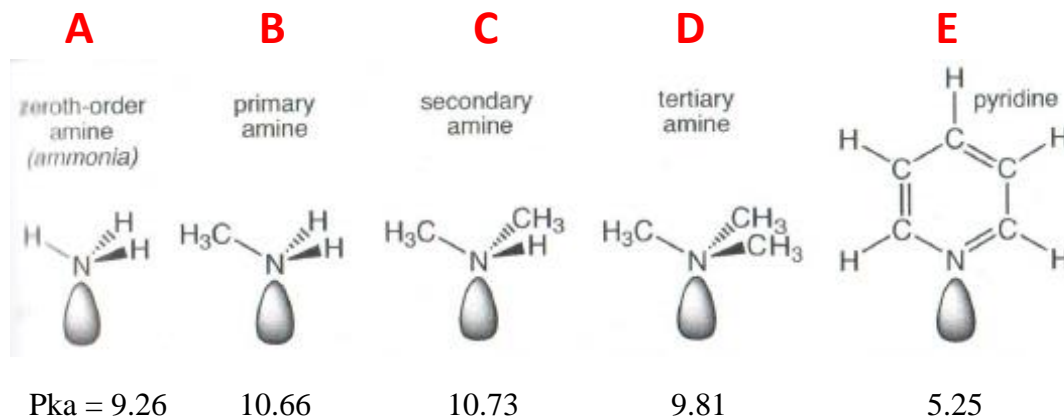
Answer: $E > A > D > B > C$

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

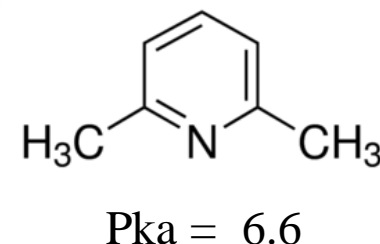
Answer: $C > B > A > D > E$

Exercise: Can anyone guess why D is more basic than A, but forms a weaker Co^{3+} complex than A?

Exercise: From the P_{K_a} s of the conjugate acids, rank the following ligands in terms of their acid strength!



Answer: $E > A > D > B > C$



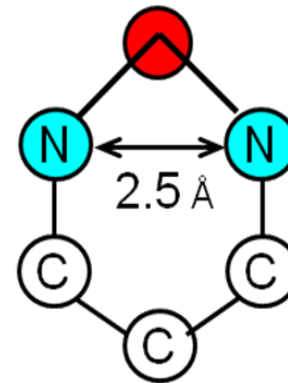
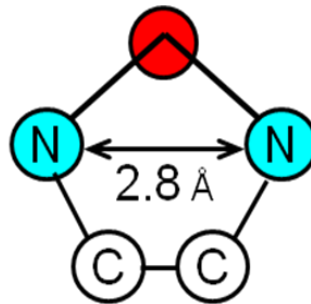
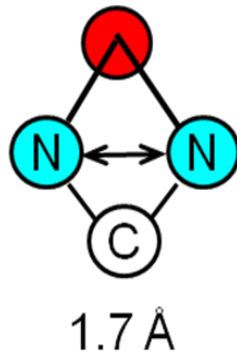
Exercise: Based on what we just learned, which ligand do you think will form the strongest complex with Co^{3+} ? Rank them.

Answer: $C > B > A > D > E$

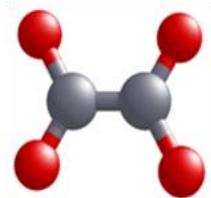
Exercise: Can anyone guess why this is the trend for the acidity with regard to the ammonia and the primary, secondary, and tertiary amines?

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

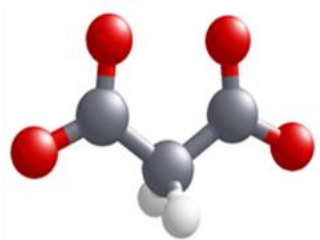
Improved stability in 5-membered rings: The chelate effect



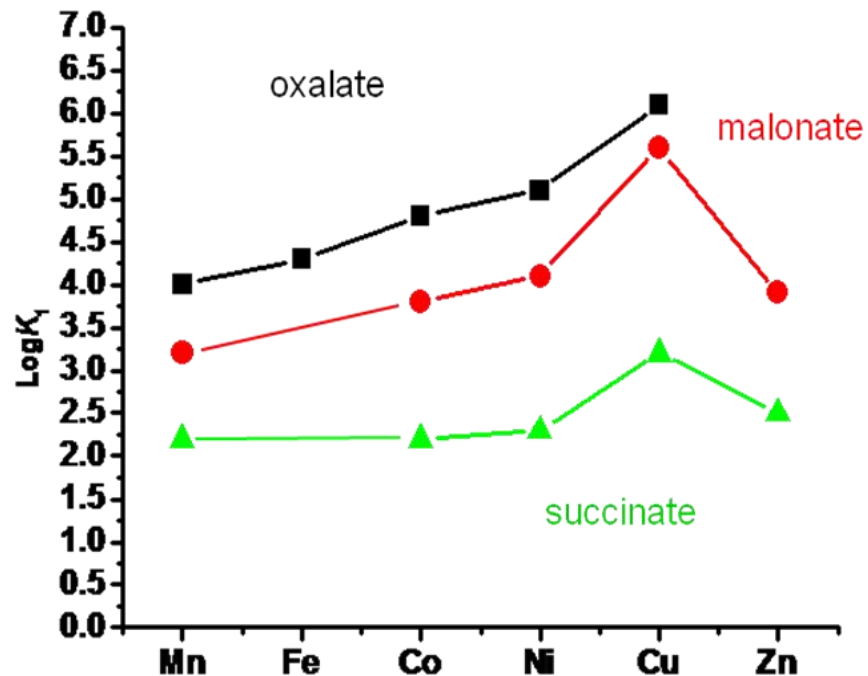
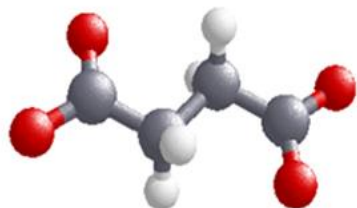
5-membered
oxalato



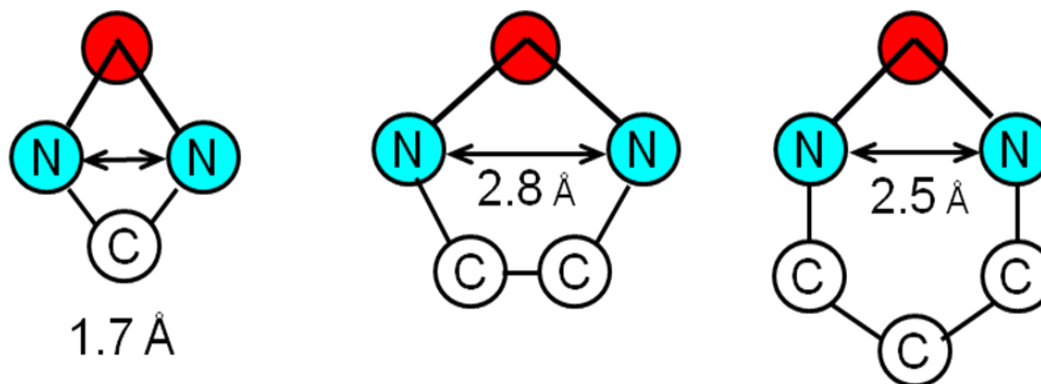
6-membered
malonato



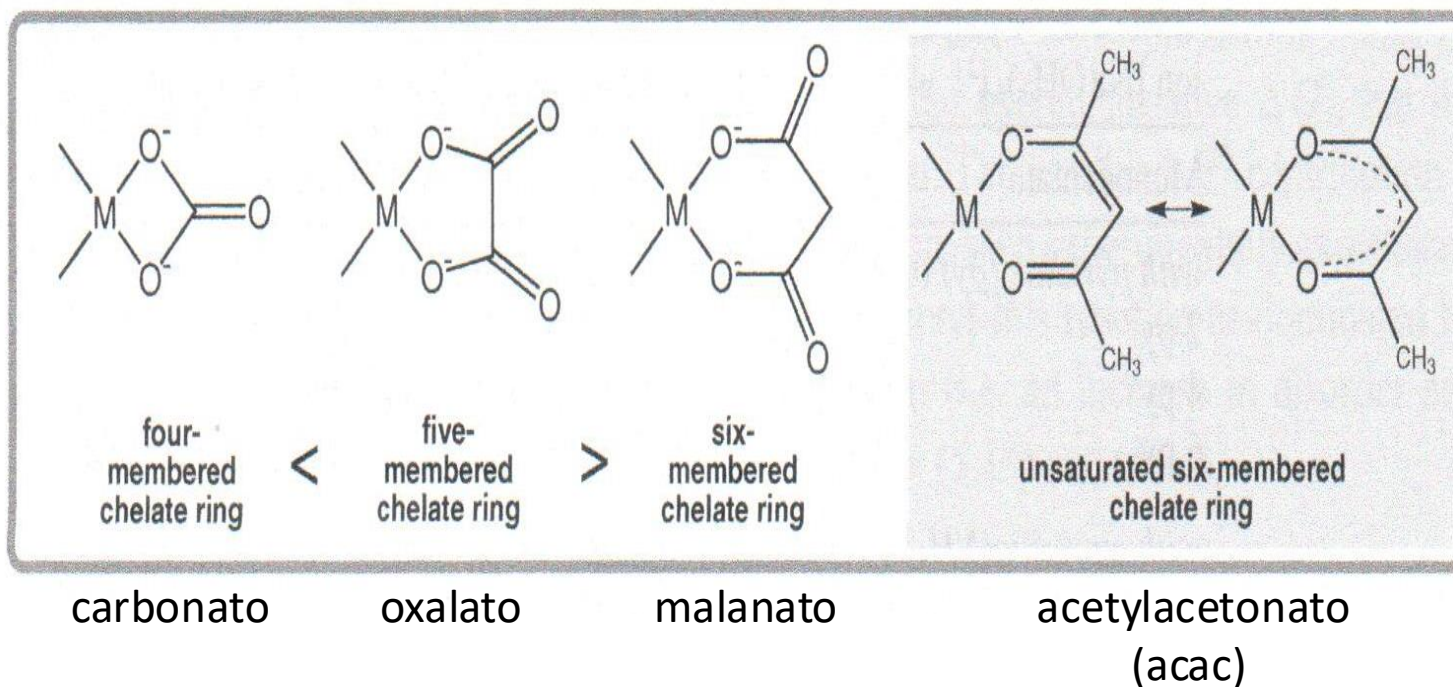
7-membered
succinato



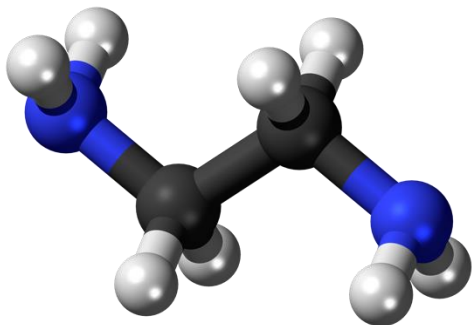
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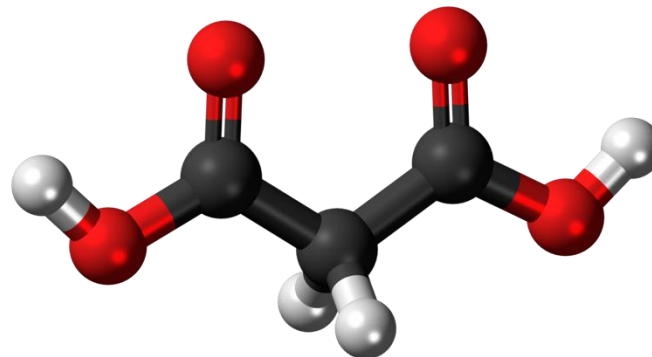
The exception – rings that contain unsaturated carbon atoms



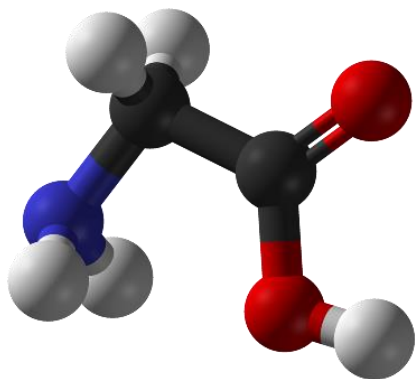
Exercise: Predict the order of stabilities for the following with Ni^{2+}



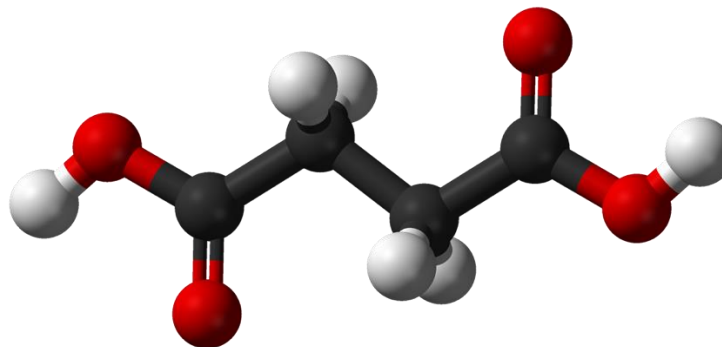
1). Ethylenediamine
 $\text{NH}_2\text{-CH}_2\text{-CH}_2\text{-NH}_2$



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

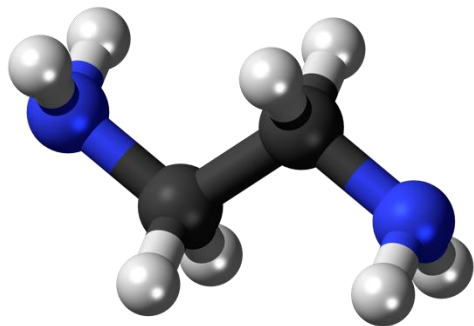


3). Glycine
 $\text{NH}_2\text{-CH}_2\text{-CO}_2\text{^-}$

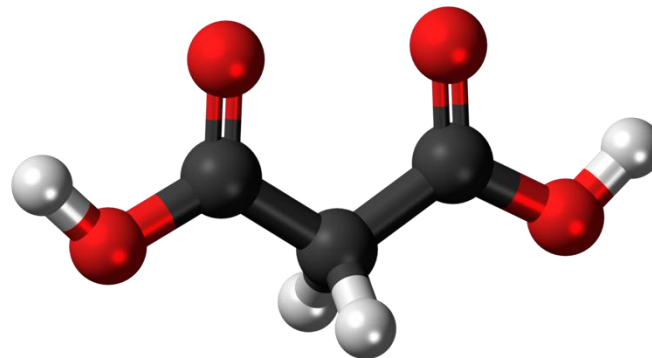


4). Succinic acid
 $\text{^-O}_2\text{C-CH}_2\text{-CH}_2\text{-CO}_2\text{^-}$

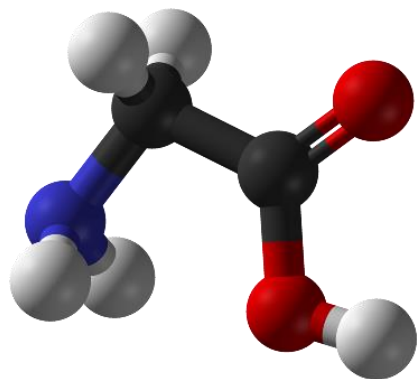
Exercise: Predict the order of stabilities for the following with Ni^{2+}



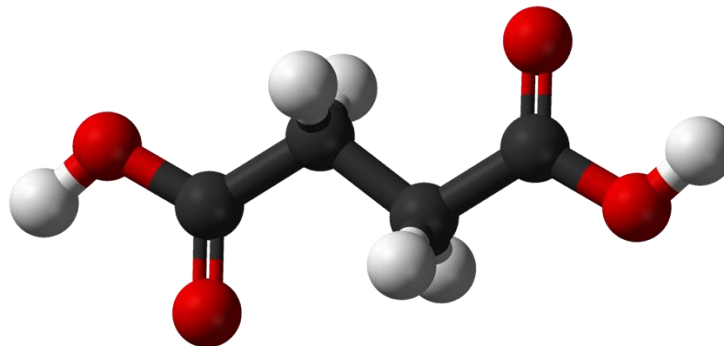
1). Ethylenediamine
 $\text{NH}_2\text{-CH}_2\text{-CH}_2\text{-NH}_2$



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



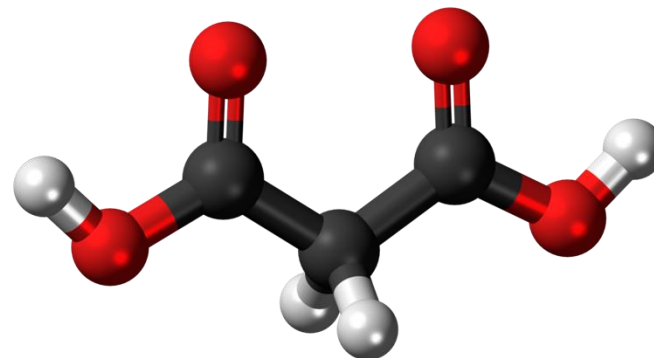
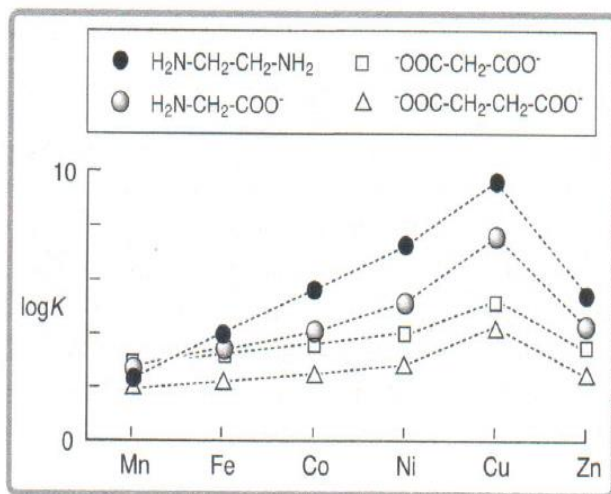
3). Glycine
 $\text{NH}_2\text{-CH}_2\text{-CO}_2\text{^-}$



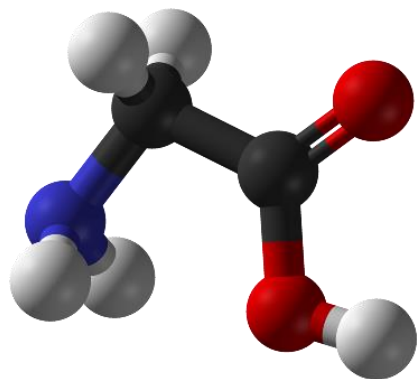
4). Succinic acid
 $\text{^-O}_2\text{C-CH}_2\text{-CH}_2\text{-CO}_2\text{^-}$

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

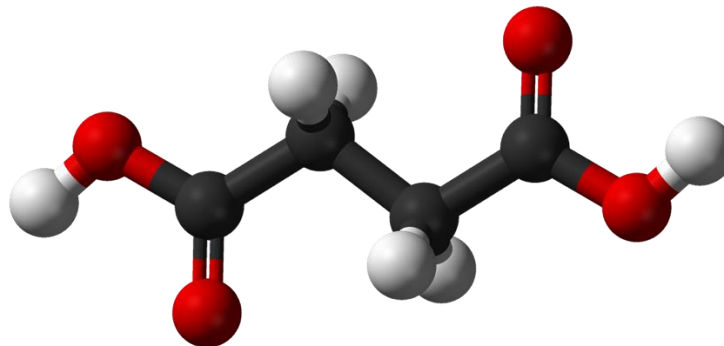
Exercise: Predict the order of stabilities for the following with Ni^{2+}



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



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 $1 > 3 > 2 > 4$

Answer: Yes according to the Irving Williams Series