Problem 1

a) For the following elements, (1) give the electron configuration with the correct atomic orbitals, (2) clearly indicate which electrons are the core electrons and which electrons are the valence electrons, and (3) give the charge and electron configuration of the most stable ion formed by these elements.

(i) S

S: 16 electrons. 1s2 2s2 2p6 3s2 3px2 3py1 3pz1

(1s2 2s2 2p6) core (3s2 3px2 3py1 3pz1) valence

S^{2-} 1s2 2s2 2p6 3s2 3px2 3py2 3pz2

(ii) Mg

Mg: 12 electrons. 1s2 2s2 2p6 3s2

(1s2 2s2 2p6) core (3s2) valence

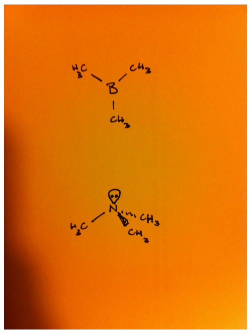
Mg^{2+} 1s2 2s2 2p6

b) Organize the following atoms and ions in terms of size (small to large), and explain your answer:

B^{3+}, Be, Br^{-}, Se

answer: B^{3+}, Be, Se, Br^{-}; B already smaller than Be, cation will be even smaller. Br will be slightly smaller than Se (next to each other in periodic table), but anions are typically twice as large as their atoms, so Br- comes last.

c) What is the 3D structure of (i) $B(CH_3)_3$, and (ii) $N(CH_3)_3$? Explain your answer using Lewis structure drawings and VSEPR theory.

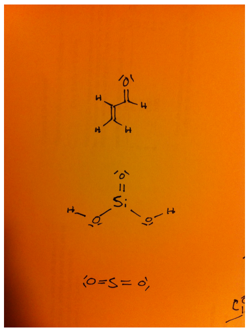


i: trigonal planar: three equal substituents on B.

ii: tetrahedral geometry: three substituents on N, plus a lone pair. If you answer “trigonal pyramidal” that’s also fine, accounting for the non-visibility of the lone pair.

Problem 2

a) draw the complete Lewis structure (including free electron pairs) of:

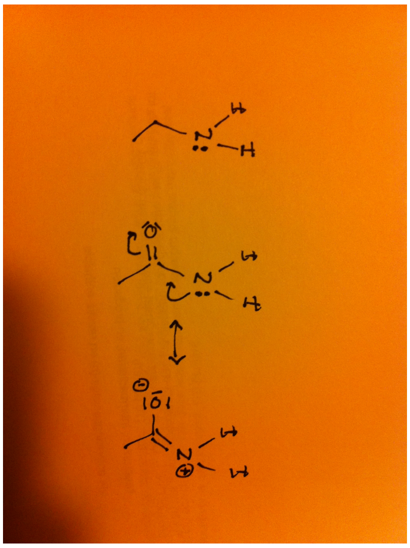


(i) CH_2CHCHO

(ii) H_2SiO_3

(iii) SO_2

b) Ethylamine ($CH_3CH_2NH_2$) and acetamide ($CH_3C(=O)NH_2$ are both water soluble bases, with pK_a values of their conjugate acids of 15.1 and 10.6, respectively. Why is ehtylamine a stronger base than acetamide? Explain your answer using Lewis structures and/or resonance structures.



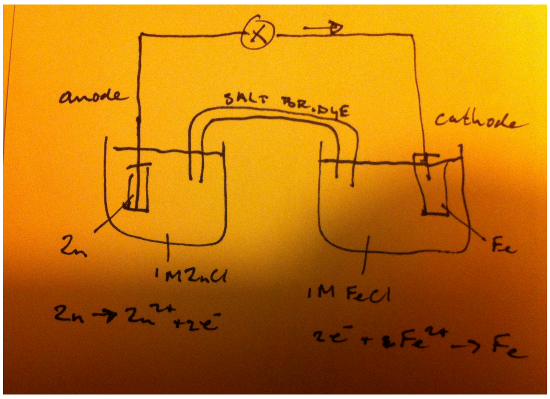
Answer: Lewis structures and resonance show a delocalization of the nitrogen lone pair on acetamide, resulting in a partial positive charge on nitrogen and a reduced tendency to bind H^+. Ethylamine does not have such resonance and thus no stabilization.

Problem 3

Alessandro Volta discovered in the 18th century that a potential difference develops between a copper plate and a zinc plate, when they are brought in contact through a conducting solution. A contemporary of Volta wanted to know if a potential difference also develops between iron and zinc plates in a similar setup. For this purpose, he makes a simple galvanic cell based on these two metals.

a) draw such a galvanic cell, consisting of an iron electrode in 100 mL aqueous 1M $FeCl_2$ solution, and a zinc electrode in 100 mL aqueous 1M $ZnCl_2$ solution. The solutions are connected by a salt bridge, and the electrodes can be connected with a copper wire. Indicate in your drawing what are the cathode and the anode, what half-reactions happen there, and in which direction the current will flow when the anode and cathode are connected.
Ered(Fe2+/Fe) = -0.45
Ered(Zn2+/Zn) = -0.76

>> Fe2+ reduced, Zn oxidized



cathode: Fe^{2+} + 2e -> Fe; positive (reaction draws electrons from electrode)
anode: Zn -> Zn^{2+} + 2e; negative (reaction delivers electrons to electrode)

electrons from anode to cathode

b) What is the potential of the simple galvanic cell in problem 3a? Explain your answer using a simple calculation.
E^0cell = E^0cath- E^0an = -0.45 - - 0.76 = 0.31 V

conc = 1M, T = 298 K >> standard conditions

c) When the cathode and anode are connected through a lamp, this lamp will light up because the cell will generate a current. Indicate what happens in the galvanic cell with the concentrations of the Fe^{2+} ions, the Zn^{2+} ions, and the cell potential after the cell has generated a current for some time.

Fe2+ is reduced, >> concentration drops
Zn(s) is oxidized >> concentration increases

Ecell = E0cell - (RT/nF) ln Q (this is the same as the Nernst equation, which you can also use here.
net reaction:

Fe^{2+} + Zn -> Fe + Zn^{2+} ; n=2

Q = [Zn^{2+}] / [Fe^{2+}]

Q increases > lnQ increases >> Ecell decreases

d) At what concentration of Fe^{2+} and Zn^{2+} will the cell stop providing a current?

Ecell = E0cell - (RT/nF) ln Q (this is the same as the Nernst equation, which you can also use here.

net reaction:

Fe^{2+} + Zn -> Fe + Zn^{2+} ; n=2
1   1
-x   1+x
1-x   1+x
Q = [Zn^{2+}] / [Fe^{2+}] = (1+x)/(1-x)

no current >> Ecell = 0

0 = +0.31 - (8.31*298/ 2*96485) ln Q = +0.31 - 0.0129 ln Q

ln Q = 0.31/0.0126 = 24.14 <=> Q = 3.06 10^{10} = (1+x)/(1-x)

very large number, but x =< 1
assumption: x ~ 1 >> 1+x ~ 2

24 10^{6} = 2/(1-x)
1-x = 2/ 2.4 10^{10}
x = 1 - 2/(2.4*10^{10})
Fe^{2+} = 1-1+ 2/(2.4*10^{10}) = 6.5 10^{-11}; Zn^{2+} = 2.0 M