Week 7 Problem Set - Acid Base Problem Set II

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$$M := \frac{mole}{liter}$$

1.Several years ago, two garbage workers in New York City were exposed to hydrofluoric acid. This acid is usually sold in 500.0 milliliter Teflon bottles (It can not be stored in glass because it will dissolve the bottle!). It has a boiling point of 19.54 °C and a density of 0.991 g cm-3. Hydrofluoric acid causes extremely severe chemical burns and is capable of dissolving bone. Hydrofluoric Acid Safety Video is available from filemedia. The Material Safety Data Sheet for HF is available from J.T.Baker.

a.Write a balanced chemical equation that describes what happens when hydrofluoric acid is added to water.

$$HF + H_2O \longleftrightarrow H_3O^{1+} + F^{1-}$$

b.Write the equilibrium expression for this balanced chemical equation

$$K_a = \frac{C_F \cdot C_{H3O}}{C_{HF}}$$

c.If the entire contents of this bottle is mixed into a 55 gallon barrel of water. What is the equlibrium concentration of HF, H_3O^{1+}, F^{1-}, and OH^{1-}? Clearly show your work and identify any assumptions that you make.

First, the amount of HF.

$$V_{HF} := 500.0 \cdot mL$$

$$\rho_{HF} := 0.991 \cdot gm \cdot mL^{-1}$$

$$mass_{HF} := V_{HF} \cdot \rho_{HF} \qquad mass_{HF} = 495.5 \cdot gm$$

$$MW_{HF} := (1.00794 + 18.9984032) \cdot gm \cdot mole^{-1}$$

$$mole_{HF} := \frac{mass_{HF}}{MW_{HF}} \qquad mole_{HF} = 24.767 \cdot mol$$

The Initial Concentration of HF

$$V_{solution} := 55 \cdot gal$$

$$C_{HF\_initial} := \frac{mole_{HF}}{V_{solution}} \qquad C_{HF\_initial} = 0.119 \cdot M$$

To reach equlibrium the concentration of HF will decrease by X, while the concentration of F^{1-} and H_3O^{1+} will increase by X. This gives an equlibrium expresion where:

$$K_a = \frac{X^2}{C_{HF\_initial} - X}$$

$$K_a := 7.2 \cdot 10^{-4} \cdot M$$

$$X := \begin{pmatrix} \frac{-1}{2} \cdot K_a - \frac{1}{2} \cdot \sqrt{K_a^2 + 4 \cdot K_a \cdot C_{HF\_initial}} \\ \frac{-1}{2} \cdot K_a + \frac{1}{2} \cdot \sqrt{K_a^2 + 4 \cdot K_a \cdot C_{HF\_initial}} \end{pmatrix}$$

$$X = \begin{pmatrix} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{pmatrix} \cdot M$$

Select the appropriate root.

The equlibrium concentrations of each species are:

$$C_{HF} := C_{HF\_initial} - X \qquad C_{HF} = \begin{pmatrix} 0.129 \\ 0.11 \end{pmatrix} \cdot M$$

$$C_{H3O} := X \qquad C_{H3O} = \begin{pmatrix} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{pmatrix} \cdot M$$

$$C_F := X \qquad C_F = \begin{pmatrix} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{pmatrix} \cdot M$$

$$i := 0, 1 .. 1$$

$$C_{OH_i} := \frac{1.0 \cdot 10^{-14} \cdot M^2}{X_i} \qquad C_{OH} = \begin{pmatrix} -1.039 \times 10^{-12} \\ 1.123 \times 10^{-12} \end{pmatrix} \cdot M$$

2.A solution is prepared by diluting 2.50 g of potassium fluoride to 250.0 mL with deionized water. Calculate the concentration of all the ions present in this solution at equlibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$$mass_{KF} := 2.50\cdot gm$$

$$V_{solution} := 250.0\cdot mL$$

$$MW_{KF} := (39.0983 + 18.9984032)\cdot gm\cdot mole^{-1} \qquad MW_{KF} = 58.097\cdot gm\cdot mole^{-1}$$

$$mole_{KF} := \frac{mass_{KF}}{MW_{KF}} \qquad mole_{KF} = 0.043\cdot mol$$

$$C_{KF\_initial} := \frac{mole_{KF}}{V_{solution}} \qquad C_{KF\_initial} = 0.172\cdot M$$

Potassium Fluoride is a salt, so when added to water, it will dissocaite into an anion and a cation. This reaction will go to completion:

KF ---> K^{1+} + F^{1-}

So that we now have the following in solution with water:

$$C_{K\_initial} := C_{KF\_initial} \qquad C_{K\_initial} = 0.172\cdot M$$

$$C_{F\_initial} := C_{KF\_initial} \qquad C_{F\_initial} = 0.172\cdot M$$

A number of possible reactions could occur. Let's write each out and then evaluate what will happen:

First the potassium ions could react with the fluoride ions in the reaction:

K^{1+} + F^{1-} --------- KF

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since KF is a soluble salt, this reaction is not an equlibrium, it goes fully to the left. It favors the reactant. It does not occur. Since this reaction does not occur, we will not work with it. We write it as:

K^{1+} + F^{1-} <--------- KF

Also the potassium ions could also react with the water in the reaction:

K^{1+} + H_2O --------- KOH + H^{1+}

This could also be written as:

K^{1+} + 2 H_2O --------- KOH + H_3O^{1+}

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since KOH is a strong base, this reaction is not an equlibrium, it goes fully to the left. It favors the reactant. It does not occur. Since this reaction does not occur, we will not work with it. We write it as:

K^{1+} + 2 H_2O <--------- KOH + H_3O^{1+}

Finally the fluoride ions could react with the water in the reaction:

F^{1-} + H_2O --------- HF + OH^{1-}

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since HF is a weak acid, this reaction is an equlibrium. So now we have to deal with the equlibrium reaction and expression. We write it as:

F^{1-} + H_2O <---------> HF + OH^{1-}

To work with this, notice that OH^{1-} is produced in this reaction. That is the clue that it is a base reaction. So we can write a base (K_b) expression for the reaction.

$$K_b = \frac{C_{HF} \cdot C_{OH}}{C_F}$$

Next we need the value for K_b

$$K_w = K_a \cdot K_b \qquad K_w := 1.0 \cdot 10^{-14} \cdot M^2$$

$$K_b := \frac{K_w}{K_a}$$

$$K_b = 1.389 \cdot 10^{-11} \cdot M$$

And then rewrite the equlibrium expression:

$$K_b = \frac{X^2}{C_{F\_initial} - X}$$

$$X := \begin{pmatrix} \frac{-1}{2} \cdot K_b - \frac{1}{2} \cdot \sqrt{K_b^2 + 4 \cdot K_b \cdot C_{F\_initial}} \\ \frac{-1}{2} \cdot K_b + \frac{1}{2} \cdot \sqrt{K_b^2 + 4 \cdot K_b \cdot C_{F\_initial}} \end{pmatrix}$$

$$X = \begin{pmatrix} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{pmatrix} \cdot M$$

Calculate the concentration of all ions present:

$$C_{F\_eq} := C_{F\_initial} - X \qquad C_{F\_eq} = \begin{pmatrix} 0.172 \\ 0.172 \end{pmatrix} \cdot M$$

$$C_{HF} := X \qquad C_{HF} = \begin{pmatrix} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{pmatrix} \cdot M$$

$$C_{OH} := X \qquad C_{OH} = \begin{pmatrix} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{pmatrix} \cdot M$$

$$C_{H3O_i} := \frac{K_w}{X_i} \qquad C_{H3O} = \begin{pmatrix} -6.468 \times 10^{-9} \\ 6.468 \times 10^{-9} \end{pmatrix} \cdot M$$

3.A solution is prepared by diluting 2.50 g of potassium chloride to 250.0 mL with deionized water. Calculate the concentration of all the ions present in this solution at equlibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$$mass_{KCl} := 2.50 \cdot gm$$

$$V_{solution} := 250.0 \cdot mL$$

$$MW_{KCl} := (39.0983 + 35.4527) \cdot gm \cdot mole^{-1} \qquad MW_{KCl} = 74.551 \cdot gm \cdot mole^{-1}$$

$$mole_{KCl} := \frac{mass_{KCl}}{MW_{KCl}} \qquad mole_{KCl} = 0.034 \cdot mol$$

$$C_{KCl\_initial} := \frac{mole_{KCl}}{V_{solution}} \qquad C_{KCl\_initial} = 0.134 \cdot M$$

Potassium chloride is a salt, so when added to water, it will dissocaite into an anion and a cation. This reaction will go to completion:

KCl ---> K^{1+} + Cl^{1-}

So that we now have the following in solution with water:

$$C_{K\_initial} := C_{KCl\_initial} \qquad C_{K\_initial} = 0.134 \cdot M$$

$$C_{Cl\_initial} := C_{KCl\_initial} \qquad C_{Cl\_initial} = 0.134 \cdot M$$

A number of possible reactions could occur. Let's write each out and then evaluate what will happen:

First the potassium ions could react with the fluoride ions in the reaction:
K^{1+} + Cl^{1-} --------- KCl

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since KCl is a soluble salt, this reaction is not an equlibrium, it goes fully to the left. It favors the reactant. It does not occur. Since this reaction does not occur, we will not work with it. We write it as:
K^{1+} + Cl^{1-} <--------- KCl

Also the potassium ions could also react with the water in the reaction:

K^{1+} + H_2O -------- KOH + H^{1+}

This could also be written as:

K^{1+} + 2 H_2O -------- KOH + H_3O^{1+}

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since KOH is a strong base, this reaction is not an equlibrium, it goes fully to the left. It favors the reactant. It does not occur. Since this reaction does not occur, we will not work with it. We write it as:

K^{1+} + 2 H_2O <-------- KOH + H_3O^{1+}

Finally the chloride ions could react with the water in the reaction:

Cl^{1-} + H_2O -------- HCl + OH^{1-}

Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equlibrium.

Since HCl is a strong acid, this reaction is not an equlibrium, it goes fully to the left. It favors the reactant. It does not occur. Since this reaction does not occur, we will not work with it. We write it as:

Cl^{1-} + H_2O <-------- HCl + OH^{1-}

Now the only reaction left that has not been considered is the autoionization of water:

2 H_2O <----> H_3O^{1+} + OH^{1-}

The equlibrium expression for this is:

$$K_w = C_{H3O} \cdot C_{OH}$$

$$K_w = X \cdot X$$

$X := \sqrt{K_w}$ $\quad\quad$ $X = 1 \cdot 10^{-7} \cdot M$

$C_{H3O} := X$ $\quad\quad$ $C_{H3O} = 1 \cdot 10^{-7} \cdot M$

$C_{OH} := X$ $\quad\quad$ $C_{OH} = 1 \cdot 10^{-7} \cdot M$

$C_{Cl} := C_{Cl\_initial}$ $\quad\quad$ $C_{Cl} = 0.134 \cdot M$

$C_K := C_{K\_initial}$ $\quad\quad$ $C_K = 0.134 \cdot M$

4.A solution is prepared by adding 2.50 g of hydrochloric acid to 250.0 mL with deionized water. Calculate the concentration of all the ions present in this solution at equlibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$mass_{HCl} := 2.50 \cdot gm$

$V_{solution} := 250.0 \cdot mL$

$MW_{HCl} := (1.00794 + 35.4527) \cdot gm \cdot mole^{-1}$ $\qquad MW_{HCl} = 36.461 \cdot gm \cdot mole^{-1}$

$mole_{HCl} := \frac{mass_{HCl}}{MW_{HCl}}$ $\qquad mole_{HCl} = 0.069 \cdot mol$

$C_{HCl\_initial} := \frac{mole_{HCl}}{V_{solution}}$ $\qquad C_{HCl\_initial} = 0.274 \cdot M$

Hydrochloric acid is a strong acid, so when added to water, it will dissocaite into an anion and a cation. This reaction will go to completion:

$HCl + H_2O \longrightarrow H_3O^{1+} + Cl^{1-}$

So that we now have the following in solution with water:

$C_{H3O} := C_{HCl\_initial}$ $\qquad C_{H3O} = 0.274 \cdot M$

$C_{Cl} := C_{HCl\_initial}$ $\qquad C_{Cl} = 0.274 \cdot M$

$C_{OH} := \frac{K_w}{C_{H3O}}$ $\qquad C_{OH} = 3.646 \cdot 10^{-14} \cdot M$