

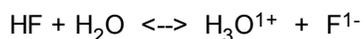
Week 7 Problem Set - Acid Base Problem Set II

By S.E. Van Bramer
Widener University
One University Place
Chester, PA 19013
svanbram@science.widener.edu
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$$M := \frac{\text{mole}}{\text{liter}}$$

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.



b. Write the equilibrium expression for this balanced chemical equation

$$K_a = \frac{C_{\text{F}^-} \cdot C_{\text{H}_3\text{O}^+}}{C_{\text{HF}}}$$

c. If the entire contents of this bottle is mixed into a 55 gallon barrel of water. What is the equilibrium concentration of HF, H₃O¹⁺, F¹⁻, and OH¹⁻? Clearly show your work and identify any assumptions that you make.

First, the amount of HF.

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

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

$$\text{mass}_{\text{HF}} := V_{\text{HF}} \cdot \rho_{\text{HF}}$$

$$\text{mass}_{\text{HF}} = 495.5 \cdot \text{gm}$$

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

$$\text{mole}_{\text{HF}} := \frac{\text{mass}_{\text{HF}}}{\text{MW}_{\text{HF}}}$$

$$\text{mole}_{\text{HF}} = 24.767 \cdot \text{mol}$$

The Initial Concentration of HF

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

$$C_{\text{HF_initial}} := \frac{\text{mole}_{\text{HF}}}{V_{\text{solution}}}$$

$$C_{\text{HF_initial}} = 0.119 \cdot \text{M}$$

To reach equilibrium the concentration of HF will decrease by X, while the concentration of F¹⁻ and H₃O¹⁺ will increase by X. This gives an equilibrium expression where:

$$K_a = \frac{X^2}{C_{\text{HF_initial}} - X}$$

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

$$X := \left(\begin{array}{l} \frac{-1}{2} \cdot K_a - \frac{1}{2} \cdot \sqrt{K_a^2 + 4 \cdot K_a \cdot C_{\text{HF_initial}}} \\ \frac{-1}{2} \cdot K_a + \frac{1}{2} \cdot \sqrt{K_a^2 + 4 \cdot K_a \cdot C_{\text{HF_initial}}} \end{array} \right)$$

$$X = \left(\begin{array}{l} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{array} \right) \cdot \text{M}$$

Select the appropriate root.

The equilibrium concentrations of each species are:

$$C_{\text{HF}} := C_{\text{HF_initial}} - X$$

$$C_{\text{HF}} = \left(\begin{array}{l} 0.129 \\ 0.11 \end{array} \right) \cdot \text{M}$$

$$C_{\text{H}_3\text{O}} := X$$

$$C_{\text{H}_3\text{O}} = \left(\begin{array}{l} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{array} \right) \cdot \text{M}$$

$$C_{\text{F}} := X$$

$$C_{\text{F}} = \left(\begin{array}{l} -9.622 \times 10^{-3} \\ 8.902 \times 10^{-3} \end{array} \right) \cdot \text{M}$$

$$i := 0, 1 \dots 1$$

$$C_{\text{OH}_i} := \frac{1.0 \cdot 10^{-14} \cdot \text{M}^2}{X_i}$$

$$C_{\text{OH}} = \left(\begin{array}{l} -1.039 \times 10^{-12} \\ 1.123 \times 10^{-12} \end{array} \right) \cdot \text{M}$$

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 equilibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$$\text{mass}_{\text{KF}} := 2.50 \cdot \text{gm}$$

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

$$\text{MW}_{\text{KF}} := (39.0983 + 18.9984032) \cdot \text{gm} \cdot \text{mole}^{-1}$$

$$\text{MW}_{\text{KF}} = 58.097 \cdot \text{gm} \cdot \text{mole}^{-1}$$

$$\text{mole}_{\text{KF}} := \frac{\text{mass}_{\text{KF}}}{\text{MW}_{\text{KF}}}$$

$$\text{mole}_{\text{KF}} = 0.043 \cdot \text{mol}$$

$$C_{\text{KF_initial}} := \frac{\text{mole}_{\text{KF}}}{V_{\text{solution}}}$$

$$C_{\text{KF_initial}} = 0.172 \cdot \text{M}$$

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



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

$$C_{\text{K_initial}} := C_{\text{KF_initial}}$$

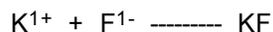
$$C_{\text{K_initial}} = 0.172 \cdot \text{M}$$

$$C_{\text{F_initial}} := C_{\text{KF_initial}}$$

$$C_{\text{F_initial}} = 0.172 \cdot \text{M}$$

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

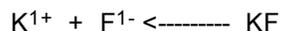
First the potassium ions could react with the fluoride ions in the reaction:



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 equilibrium.

Since KF is a soluble salt, this reaction is not an equilibrium, 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.

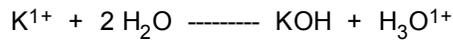
We write it as:



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



This could also be written as:



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 equilibrium.

Since KOH is a strong base, this reaction is not an equilibrium, 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:



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



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 equilibrium.

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



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.

$$K_b = \frac{C_{\text{HF}} \cdot C_{\text{OH}}}{C_{\text{F}}}$$

Next we need the value for K_b

$$K_w = K_a \cdot K_b$$

$$K_w := 1.0 \cdot 10^{-14} \cdot \text{M}^2$$

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

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

And then rewrite the equilibrium expression:

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

$$X := \left(\begin{array}{l} \frac{-1}{2} \cdot K_b - \frac{1}{2} \cdot \sqrt{K_b^2 + 4 \cdot K_b \cdot C_{F_initial}} \\ \frac{-1}{2} \cdot K_b + \frac{1}{2} \cdot \sqrt{K_b^2 + 4 \cdot K_b \cdot C_{F_initial}} \end{array} \right)$$

$$X = \left(\begin{array}{l} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{array} \right) \cdot M$$

Calculate the concentration of all ions present:

$$C_{F_eq} := C_{F_initial} - X$$

$$C_{F_eq} = \left(\begin{array}{l} 0.172 \\ 0.172 \end{array} \right) \cdot M$$

$$C_{HF} := X$$

$$C_{HF} = \left(\begin{array}{l} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{array} \right) \cdot M$$

$$C_{OH} := X$$

$$C_{OH} = \left(\begin{array}{l} -1.546 \times 10^{-6} \\ 1.546 \times 10^{-6} \end{array} \right) \cdot M$$

$$C_{H_3O^+} := \frac{K_w}{X_i}$$

$$C_{H_3O^+} = \left(\begin{array}{l} -6.468 \times 10^{-9} \\ 6.468 \times 10^{-9} \end{array} \right) \cdot M$$

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 equilibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$$\text{mass}_{\text{KCl}} := 2.50 \cdot \text{gm}$$

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

$$\text{MW}_{\text{KCl}} := (39.0983 + 35.4527) \cdot \text{gm} \cdot \text{mole}^{-1}$$

$$\text{MW}_{\text{KCl}} = 74.551 \cdot \text{gm} \cdot \text{mole}^{-1}$$

$$\text{mole}_{\text{KCl}} := \frac{\text{mass}_{\text{KCl}}}{\text{MW}_{\text{KCl}}}$$

$$\text{mole}_{\text{KCl}} = 0.034 \cdot \text{mol}$$

$$C_{\text{KCl_initial}} := \frac{\text{mole}_{\text{KCl}}}{V_{\text{solution}}}$$

$$C_{\text{KCl_initial}} = 0.134 \cdot \text{M}$$

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



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

$$C_{\text{K_initial}} := C_{\text{KCl_initial}}$$

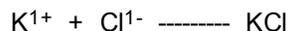
$$C_{\text{K_initial}} = 0.134 \cdot \text{M}$$

$$C_{\text{Cl_initial}} := C_{\text{KCl_initial}}$$

$$C_{\text{Cl_initial}} = 0.134 \cdot \text{M}$$

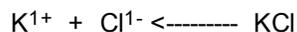
A number of possible reactions could occur. Let's write each out and then evaluate what will happen:

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



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 equilibrium.

Since KCl is a soluble salt, this reaction is not an equilibrium, 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:



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



This could also be written as:

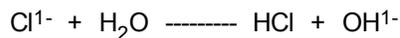


Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equilibrium.

Since KOH is a strong base, this reaction is not an equilibrium, 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:



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

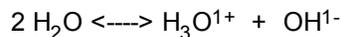


Notice that I did not yet write in the arrow. Now we have to decide what way it goes; to the right, to the left, or an equilibrium.

Since HCl is a strong acid, this reaction is not an equilibrium, 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:



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



The equilibrium expression for this is:

$$K_w = C_{H_3O} \cdot C_{OH}$$

$$K_w = X \cdot X$$

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

$$C_{H_3O} := X$$

$$C_{H_3O} = 1 \cdot 10^{-7} \cdot M$$

$$C_{OH} := X$$

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

$$C_{Cl} := C_{Cl_initial}$$

$$C_{Cl} = 0.134 \cdot M$$

$$C_K := C_{K_initial}$$

$$C_K = 0.134 \cdot M$$

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 equilibrium. Clearly identify any assumptions that you make while solving this problem.

Initial Conditions:

$$\text{mass}_{\text{HCl}} := 2.50 \cdot \text{gm}$$

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

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

$$MW_{\text{HCl}} = 36.461 \cdot \text{gm} \cdot \text{mole}^{-1}$$

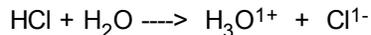
$$\text{mole}_{\text{HCl}} := \frac{\text{mass}_{\text{HCl}}}{MW_{\text{HCl}}}$$

$$\text{mole}_{\text{HCl}} = 0.069 \cdot \text{mol}$$

$$C_{\text{HCl_initial}} := \frac{\text{mole}_{\text{HCl}}}{V_{\text{solution}}}$$

$$C_{\text{HCl_initial}} = 0.274 \cdot \text{M}$$

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



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

$$C_{\text{H}_3\text{O}^+} := C_{\text{HCl_initial}}$$

$$C_{\text{H}_3\text{O}^+} = 0.274 \cdot \text{M}$$

$$C_{\text{Cl}^-} := C_{\text{HCl_initial}}$$

$$C_{\text{Cl}^-} = 0.274 \cdot \text{M}$$

$$C_{\text{OH}^-} := \frac{K_w}{C_{\text{H}_3\text{O}^+}}$$

$$C_{\text{OH}^-} = 3.646 \cdot 10^{-14} \cdot \text{M}$$