

Acid Base Equilibrium Problem Set I

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

1. For a 0.1 M solution of HCl calculate the equilibrium concentration of

a. H_3O^{1+}

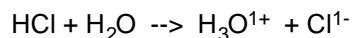
b. Cl^{1-}

c. OH^{1-}

Given the initial concentration of HCl:

$$C_{\text{HCl}} := 0.1 \cdot \text{M}$$

Since HCl is a strong acid, it undergoes complete dissociation by the reaction:



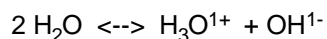
$$C_{\text{H}_3\text{O}} := C_{\text{HCl}}$$

$$C_{\text{H}_3\text{O}} = 0.1 \cdot \text{M}$$

$$C_{\text{Cl}} := C_{\text{HCl}}$$

$$C_{\text{Cl}} = 0.1 \cdot \text{M}$$

The concentration of OH^{1-} is determined by the equilibrium reaction:



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

$$K_w = C_{\text{H}_3\text{O}} \cdot C_{\text{OH}}$$

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

$$C_{\text{OH}} = 1 \cdot 10^{-13} \cdot \text{M}$$

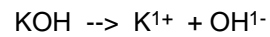
2. For a 0.1 M solution of KOH calculate the equilibrium concentration of

- a. K^{1+}
- b. H_3O^{1+}
- c. OH^{1-}

Given the initial concentration of KOH:

$$C_{KOH} := 0.1 \cdot M$$

Since KOH is a strong base, it undergoes complete dissociation by the reaction:



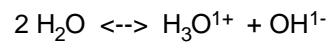
$$C_K := C_{KOH}$$

$$C_K = 0.1 \cdot M$$

$$C_{OH} := C_{KOH}$$

$$C_{OH} = 0.1 \cdot M$$

The concentration of H_3O^{1+} is determined by the equilibrium reaction:



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

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

$$C_{H_3O} := \frac{K_w}{C_{OH}}$$

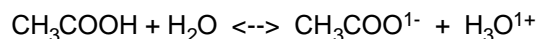
$$C_{H_3O} = 1 \cdot 10^{-13} \cdot M$$

3. For a 0.1 M solution of acetic acid ($K_a = 1.8 \cdot 10^{-5}$) calculate the equilibrium concentration of
- CH_3COOH
 - $\text{CH}_3\text{COO}^{1-}$
 - H_3O^{1+}
 - OH^{1-}

Given the initial concentration of acetic acid:

$$C_{\text{CH}_3\text{COOH}} := 0.1 \cdot \text{M}$$

The acetic acid is in equilibrium with acetate ion in the following reaction



The equilibrium expression for this is:

$$K_A = \frac{C_{\text{CH}_3\text{COO}^-} \cdot C_{\text{H}_3\text{O}^+}}{C_{\text{CH}_3\text{COOH}}}$$

At equilibrium the concentration of each of these is:

$$C_{\text{CH}_3\text{COOH}_{\text{eq}}} = C_{\text{CH}_3\text{COOH}} - X$$

$$C_{\text{CH}_3\text{COO}_{\text{eq}}} = X$$

$$C_{\text{H}_3\text{O}_{\text{eq}}} = X$$

$$K_a = \frac{X \cdot X}{C_{\text{CH}_3\text{COOH}} - X}$$

$$1.8 \cdot 10^{-5} \cdot \text{M} = \frac{X^2}{0.1 \cdot \text{M} - X}$$

$$X := \left[\begin{array}{l} -0.0013506709730779748818 \cdot \text{M} \\ 0.0013326709730779748818 \cdot \text{M} \end{array} \right]$$

The two possible roots for X,
Solved using the quadratic.
Only one of these roots gives a
possible solution below.

$$C_{\text{CH}_3\text{COOH}_{\text{eq}}} := (C_{\text{CH}_3\text{COOH}} - X)$$

$$C_{\text{CH}_3\text{COOH}_{\text{eq}}} = \left[\begin{array}{l} 0.101 \\ 0.099 \end{array} \right] \cdot \text{M}$$

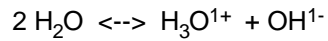
$$C_{\text{CH}_3\text{COO}_{\text{eq}}} := X$$

$$C_{\text{CH}_3\text{COO}_{\text{eq}}} = \left[\begin{array}{l} -1.351 \cdot 10^{-3} \\ 1.333 \cdot 10^{-3} \end{array} \right] \cdot \text{M}$$

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

$$C_{\text{H}_3\text{O}_{\text{eq}}} = \left[\begin{array}{l} -1.351 \cdot 10^{-3} \\ 1.333 \cdot 10^{-3} \end{array} \right] \cdot \text{M}$$

The concentration of OH¹⁻ is determined by the equilibrium reaction:



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

$$K_w = C_{\text{H}_3\text{O}} \cdot C_{\text{OH}}$$

$$C_{\text{H}_3\text{O}} := C_{\text{H}_3\text{O}_{\text{eq}_1}}$$

From the results above.

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

$$C_{\text{OH}} = 7.504 \cdot 10^{-12} \text{ M}$$

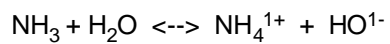
4. For a 0.1 M solution of Ammonia ($K_b = 1.78 \cdot 10^{-5}$) calculate the equilibrium concentration of

- a. NH₃
- b. NH₄¹⁺
- c. H₃O¹⁺
- d. OH¹⁻

Given the initial concentration of ammonia:

$$C_{\text{NH}_3} := 0.1 \cdot \text{M}$$

The ammonia is in equilibrium with ammonium ion in the following reaction



The equilibrium expression for this is:

$$K_B = \frac{C_{\text{NH}_4} \cdot C_{\text{OH}}}{C_{\text{NH}_3}}$$

At equilibrium the concentration of each of these is:

$$C_{\text{NH}_3_{\text{eq}}} = C_{\text{NH}_3} - X$$

$$C_{\text{NH}_4_{\text{eq}}} = X$$

$$C_{\text{OH}_{\text{eq}}} = X$$

$$K_b = \frac{X \cdot X}{C_{\text{NH}_3} - X}$$

$$1.78 \cdot 10^{-5} \cdot \text{M} = \frac{X^2}{0.1 \cdot \text{M} - X}$$

$$X := \begin{bmatrix} -0.0013430960912849355219 \cdot \text{M} \\ 0.0013252960912849355219 \cdot \text{M} \end{bmatrix}$$

The two possible roots for X, Solved using the quadratic. Only one of these roots gives a possible solution below.

$$C_{\text{NH}_3_{\text{eq}}} := (C_{\text{NH}_3} - X)$$

$$C_{\text{NH}_3_{\text{eq}}} = \begin{bmatrix} 0.101 \\ 0.099 \end{bmatrix} \text{M}$$

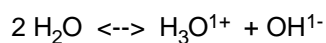
$$C_{\text{NH}_4_{\text{eq}}} := X$$

$$C_{\text{NH}_4_{\text{eq}}} = \begin{bmatrix} -1.343 \cdot 10^{-3} \\ 1.325 \cdot 10^{-3} \end{bmatrix} \text{M}$$

$$C_{\text{OH}_{\text{eq}}} := X$$

$$C_{\text{OH}_{\text{eq}}} = \begin{bmatrix} -1.343 \cdot 10^{-3} \\ 1.325 \cdot 10^{-3} \end{bmatrix} \text{M}$$

The concentration of H_3O^{1+} is determined by the equilibrium reaction:



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

$$K_w = C_{\text{H}_3\text{O}} \cdot C_{\text{OH}}$$

$$C_{\text{OH}} := C_{\text{OH}_{\text{eq}_1}}$$

From the results above.

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

$$C_{\text{H}_3\text{O}} = 7.545 \cdot 10^{-12} \text{M}$$