Equilibrium III: Basic Acid-Base Equilibrium

1. What are the species (equilibrium) concentrations of H_3O^+, OH^-, and Cl^- in 0.10 M hydrochloric acid?

$$[H_3O^+] = [Cl^-] = 0.10\text{ M} \qquad pH = -\log(0.10) = 1.0$$

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{1.0\times10^{-14}}{0.10} = 1.0\times10^{-13}\text{ M}$$

2. What are the concentrations of each species in a solution prepared to be 0.10 M acetic acid (CH_3COOH)? $K_a = 1.75 \times 10^{-5}$

$$\begin{array}{lccccccccc} & \text{HOAc} & + & H_2O & \rightleftarrows & \text{OAc}^- & + & H_3O^+ \\ \text{at equilibrium} & 0.10 - x & & & & x & & x \end{array}$$

$$K_a = \frac{[\text{OAc}^-][H_3O^+]}{[\text{HOAc}]} = 1.75\times10^{-5} = \frac{x^2}{0.10-x} \quad x\text{ may be small compared to 0.10, so...}$$

$$1.75\times10^{-5} \cong \frac{x^2}{0.10} \qquad x = [\text{OAc}^-] = [H_3O^+] = \sqrt{1.75\times10^{-6}} = 1.33\times10^{-3}\text{ M}$$

$$\boxed{\begin{array}{l}\text{Check to see if assumption is acceptable:}\\ \dfrac{0.00133}{0.1}\times100 = 1.3\%\ (< 5\%,\text{ so accept assumption})\end{array}}$$

$$[\text{HOAc}] = 0.10\text{ M} - 0.00133\text{ M} = 0.099\text{ M}$$

$$[OH^-] = \frac{1.0\times10^{-14}}{0.00133} = 7.6\times10^{-12}\text{ M}$$

3. What is the approximate pH of 0.075 M formic acid? $K_a = 1.7 \times 10^{-4}$

This problem is virtually identical to problem 2.

4. What is the K_a of nitrous acid if a 0.050 M solution has a pH of 2.34?

$$[\mathrm{H_3O^+}] = 10^{-2.34} = 4.57\times10^{-3}\ \mathrm{M}\quad (=[\mathrm{NO_2^-}])$$

$$C_{\mathrm{HNO_2}} = 0.050\ \mathrm{M}\quad [\mathrm{HNO_2}] = 0.050\ \mathrm{M} - 4.57\times10^{-3}\ \mathrm{M} = 0.0454\ \mathrm{M}$$

$$K_\mathrm{a} = \frac{(4.57\times10^{-3})^2}{0.0454} = 4.6\times10^{-4}$$

5. What is the pH of 0.010 M ammonia? Kb = 1.8 × 10^{-5}

$$\begin{array}{lccccccc} & \mathrm{NH_3} & + & \mathrm{H_2O} & \rightleftarrows & \mathrm{NH_4^+} & + & \mathrm{OH^-} \\ \text{at equilibrium} & 0.010-x & & & & x & & x \end{array}$$

$$K_\mathrm{a} = \frac{[\mathrm{NH_4^+}][\mathrm{OH^-}]}{[\mathrm{NH_3}]} = 1.8\times10^{-5} = \frac{x^2}{0.010-x}\quad x \text{ is small compared to 0.010, so...}$$

$$1.8\times10^{-5} \cong \frac{x^2}{0.010}\qquad x = [\mathrm{NH_4^+}] = [\mathrm{OH^-}] = \sqrt{1.8\times10^{-7}} = 4.24\times10^{-4}\ \mathrm{M}$$

(Demonstrate yourself that x is small compared to 0.010 M)

$$[\mathrm{NH_3}] = 0.010\ \mathrm{M} - 4.24\times10^{-4}\ \mathrm{M} = 9.6\times10^{-3}\ \mathrm{M}$$

$$[\mathrm{H_3O^+}] = \frac{1.0\times10^{-14}}{4.24\times10^{-4}} = 2.36\times10^{-11}\ \mathrm{M}\qquad \mathrm{pH} = -\log(2.36\times10^{-11}) = 10.6$$

6. Assuming that K_a = 1.75 × 10^{-5} for acetic acid, what is K_b for acetate ion? What is the pH of 0.010 M sodium acetate?

$$K_\mathrm{b} = \frac{K_\mathrm{w}}{K_\mathrm{a}} = \frac{1.0\times10^{-14}}{1.75\times10^{-5}} = 5.71\times10^{-10}$$

$$\begin{array}{lccccccc} & \mathrm{OAc^-} & + & \mathrm{H_2O} & \rightleftarrows & \mathrm{HOAc} & + & \mathrm{OH^-} \\ \text{at equilibrium} & 0.010-x & & & & x & & x \end{array}$$

$$5.71\times10^{-10} = \frac{[\mathrm{HOAc}][\mathrm{OH^-}]}{[\mathrm{OAc^-}]} = \frac{x^2}{0.010-x} \cong \frac{x^2}{0.010}$$

$$x = [\mathrm{HOAc}] = [\mathrm{OH^-}] = 2.4\times10^{-6}\ \mathrm{M}\qquad \mathrm{pOH} = 5.62$$

$$p\mathrm{H} = 14 - p\mathrm{OH} = 8.38$$