Calculating the pH of a Salt Solution: Salty *and* Delicious!

To calculate the pH of a salt solution, follow the thrilling three step process shown below!

1. Identify the ion of the salt that is acting as a weak acid or base. (This will be the ion that came from the weak acid/base in the neutralization reaction).
   a. If the ion is acting as a weak acid, write the hydrolysis reaction of the ion with water and set up a RICE table using the K_a expression.
      i. The hydrolysis reaction for an acidic salt will always be the cation reacting with water to form H_3O^+ and a weak base.
   b. If the ion is acting as a weak base, write the hydrolysis reaction of the ion with water and set up a RICE table using the K_b expression.
      i. The hydrolysis reaction for an basic salt will always be the anion reacting with water to form OH^- and a weak acid.
   c. **WATCH OUT**: A classic trick question is to only provide K_a values even when a K_b value is needed. Use the relationship below to convert if needed!

$$1 \times 10^{-14} = K_a \times K_b$$

2. Use one of the equations below to solve for $[H_3O^+]$ or $[OH^-]$.

$$K_a = \frac{[x][x]}{[HA]_0} \text{ where } x = [H_3O^+] \qquad \text{or} \qquad K_b = \frac{[x][x]}{[B]_0} \text{ where } x = [OH^-]$$

3. Once you've calculated $[H_3O^+]$ or $[OH^-]$, solve for pH or pOH.

$$pH = -\log[H_3O^+] \quad \text{or} \quad pOH = -\log[OH^-]$$

Guided Practice

1. Calculate the pH of a 0.10 *M* NH_4Cl solution. The K_a value for NH_4^+ is 5.6×10^{-10}.

NH_3: WB HCl = SA (no hydrolysis)

$$NH_4^+{}_{(aq)} + H_2O_{(\ell)} \rightleftharpoons H_3O^+{}_{(aq)} + NH_{3(aq)}$$

$$K_a = \frac{[H_3O^+][NH_3]}{[NH_4^+]} = \frac{x^2}{0.10 - x} \approx \frac{x^2}{0.10} = 5.6E-10$$

$K_a \ll 1$, x negligible

$$x = [H_3O^+] = \sqrt{(0.10)(5.6E-10)} = 7.5E-6\ M$$

$$pH = -\log(7.5E-6) = \boxed{5.13}$$

2. Calculate the pH of a 0.30 *M* NaF solution. The K_a value for HF is 7.2×10^{-4}.

NaF → NaOH: SB (no hydrolysis); HF: WA

$F^-_{(aq)} + H_2O_{(l)} \rightleftharpoons HF_{(aq)} + OH^-_{(aq)}$

F^- acting as a weak base ⇒ need $K_b = \frac{K_w}{K_a} = \frac{1E-14}{7.2E-4} = 1.4E-11$

$$K_b = \frac{[HF][OH^-]}{[F^-]} = \frac{x^2}{0.30 - x} \approx \frac{x^2}{0.30} = 1.4E-11$$

$K_b \ll 1$, x negligible

$$x = [OH^-] = \sqrt{(0.30)(1.4E-11)} = 2.0E-6\ M$$

$$pOH = -\log(2.0E-6) = 5.69 \Rightarrow pH = 14 - 5.69 = \boxed{8.31}$$

Multiple Choice Practice

NaOH: SB, HCN: WA

3. What is the pH of a 1.0×10^{-2} M solution of NaCN? (For HCN, $K_a = 1.0 \times 10^{-10}$).

   a. between 0 and 3
   b. between 3 and 7
   c. between 7 and 10
   (d.) between 10 and 14

$K_b(CN^-) = \frac{1E-14}{1E-10} = 1E-4$

$$K_b = \frac{x^2}{1E-2} = 1E-4 \Rightarrow x = [OH^-] = \sqrt{(1E-2)(1E-4)} = \sqrt{1E-6} = 1E-3$$

$\Rightarrow pOH = 3$

$pH = 14 - 3 = 11$

favored = weaker!

$$650\ kJ + HCO_3^-(aq) + HC_2O_4^-(aq) \leftrightarrow CO_3^{2-}(aq) + H_2C_2O_4(aq)$$

A B CB CA

4. If K > 1, all of the following statements are true about the reaction above EXCEPT:

   (a.) $HC_2O_4^-$ is a weaker base than CO_3^{2-}.
   b. HCO_3^- and $H_2C_2O_4$ are both acting as acids in the reaction.
   c. The reaction lies far to the right (favors products).
   d. Lowering the temperature of the solution will decrease the value of K.

5. Which of the following would form a basic solution when dissolved in water?

   a. HCl — SA!
   b. LiCl → LiOH (SB) + HCl (SA) ⇒ neutral
   c. NH_4Cl → NH_3 (WB) + HCl (SA) ⇒ acidic
   (d.) $NaC_2H_3O_2$ → NaOH (SB) + $HC_2H_3O_2$ (WA)