II) Weak Base Equilibrium & $K_b$

Write a reaction for and find the pH for 0.10M NaOH. Why is it considered a strong base?

\[ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \]

Write a reaction for 0.10M NH$_3$ solution. Why is it considered a weak base?

How would you find the pH of a weak base solution?

\[ \text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^- \]

Weak base problems such as the one previous can be solved using the $K_b$ constant, a $K_b$ for weak bases (similar to $K_a$ for weak acids).

The larger the $K_b$, the stronger the base (the more $\text{H}^+$ it will accept).

Write a $K_b$ expression:

\[ K_b = \frac{[\text{OH}^-][\text{NH}_4^+]}{[\text{NH}_3]} \]

Relationship of $K_w$, $K_a$, and $K_b$ for a Conjugate Acid-Base Pair

Write the \( K_a \) for HF:

\[ \frac{[\text{H}_3\text{O}^+][\text{F}^-]}{[\text{HF}]} \]

Write the $K_b$ for $\text{OH}^-$:

\[ \frac{[\text{OH}^-][\text{H}_3\text{O}^+]}{[\text{HF}]} \]

Multiply the $K_a$ of HF by the $K_b$ of F:

\[ K_a \cdot K_b = \frac{[\text{H}_3\text{O}^+][\text{F}^-]}{[\text{HF}]} \cdot \frac{[\text{OH}^-][\text{H}_3\text{O}^+]}{[\text{HF}]} = [\text{H}_2\text{O}^+][\text{OH}^-] = K_w \]

What results?

\[ K_w = K_a \cdot K_b = 1.0 \times 10^{-14} \text{ (at 25°C)} \]

Conclusion?

$K_b = \frac{K_w}{K_a}$ use the $K_a$ of the conjugate acid.

(lock up the base on the BASE SIDE! (right)... and use \( K_a \))
The acid-base table only lists acid $K_a$ values. Using what you learned above, how would you get the $K_b$ for the corresponding conjugate base?

$$K_a \text{ (conj. acid)} \cdot K_b \text{ (base)} = K_w = 1.0 \times 10^{-14}$$

Example:

Determine $K_b$ for the weak base $SO_2^-\text{aq}$.

$$\text{base} \quad \text{conj. acid} \quad H_2SO_3^-\text{aq}$$

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.2 \times 10^{-2}} = 8.3 \times 10^{-12}$$

Example:

Determine $K_b$ for $HCO_3^-\text{aq}$.

$$\text{HCO}_3^-\text{aq} = 1.5 \times 10^{-3}$$

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{4.3 \times 10^{-8}} = 2.3 \times 10^{-7}$$

Practice Questions: Determine the $K_b$ values for the following:

a) $HPO_4^{2-}\text{aq}$ (accepting $H^+$)

$$\text{conj. acid} = H_2PO_4^-\text{aq}$$

$$K_b = \frac{1.0 \times 10^{-14}}{6.2 \times 10^{-6}} = 1.6 \times 10^{-8}$$

b) $H_3PO_4\text{aq}$

$$\text{conj. acid} = H_2PO_4^-\text{aq}$$

$$K_b = \frac{1.0 \times 10^{-14}}{7.5 \times 10^{-3}} = 1.3 \times 10^{-12}$$

Assignment 2: Hebdon p. 152 #77, 80, 82 & p.130 #35bce, 36
Weak base quantitative problems can be broken into three types.

**Type I Problems: Finding the pH of a weak base solution.**

Example: Calculate the [OH⁻] and pH for a 0.25M solution of the weak base H₂S.

\[ K_c \ \text{H₂S} + \text{H₂O} \rightleftharpoons \text{H₃O⁺} + \text{OH⁻} \]

1. \[ K_c = \frac{[\text{H₃O⁺}] [\text{OH⁻}]}{[\text{H₂S}]} \]

<table>
<thead>
<tr>
<th>[ C ]</th>
<th>0.25M</th>
<th>0</th>
<th>0</th>
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\[ E \ \text{assumption} \]

\[ K_b = \frac{[\text{OH⁻}]^2}{[\text{H₂S}]} = \frac{x^2}{0.25} \]

\[ K_b = 1.0 \times 10^{-14} \]

\[ x = \sqrt{K_b \cdot 0.25} = \sqrt{1.0 \times 10^{-14} \cdot 0.25} = 1.1 \times 10^{-7} \]

\[ \text{pH} = -\log (1.1 \times 10^{-7}) = 6.95 \]

Sometimes when salts dissolve in water, one of the ions can act as a weak acid in solution, such as the salt in the next example.

Example: Calculate the pH of a 0.10M solution of K₂C₂O₄.

\[ K_c \ \text{K₂C₂O₄} \rightleftharpoons 2 \text{K⁺} + [\text{C₂O₄}^{2⁻}] \]

1. \[ K_a = \frac{[\text{H⁺}] [\text{C₂O₄}^{2⁻}]}{[\text{C₂O₄}^{2⁻}]} \]

2. \[ K_b = \frac{[\text{OH⁻}]^2}{[\text{C₂O₄}^{2⁻}]} \]

| \[ C \] | 0.10M | 0 | 0 |

\[ E \ \text{assumption} \]

\[ K_b = \frac{[\text{OH⁻}]^2}{[\text{C₂O₄}^{2⁻}]} = \frac{x}{0.10} \]

\[ K_b = 1.1 \times 10^{-5} \]

\[ x = \sqrt{K_b \cdot 0.10} = \sqrt{1.1 \times 10^{-5} \cdot 0.10} = 3.3 \times 10^{-5} \]

\[ \text{pH} = -\log (3.3 \times 10^{-5}) = 4.5 \]

\[ \text{pH} = 14.5 - 4.5 = 10.0 \]
Type 2 Problems: Calculating the Initial Concentration of a Weak Base

Example: A solution of NO$_2^-$ has a pH of 8.900. Calculate the [NO$_2^-$] that would have been required to make this solution.

\[
\begin{align*}
\text{pH} & = 8.900 \\
\text{pOH} & = 14 - 8.900 = 5.100 \\
[\text{OH}^-] & = 10^\text{pOH} = 5.100 \\
[\text{OH}^-] & = 7.94 \times 10^{-6} M \\
\text{C} & = 7.94 \times 10^{-6} M \\
\text{E} & \left(\frac{x - 7.94 \times 10^{-6}}{7.94 \times 10^{-6}}\right) = x \\
\end{align*}
\]

\[\text{K}_b = \frac{[\text{OH}^-]^2}{[\text{NO}_2^-]} = \frac{(7.94 \times 10^{-6})^2}{x - 7.94 \times 10^{-6}}
\]

\[x = 2.94 \times 10^{-6} M = [\text{NO}_2^-]
\]

Example: A solution of ammonia, NH$_3$ has a pH of 10.50. Calculate the [NH$_3$] used to make the solution.

\[
\begin{align*}
\text{pH} & = 10.50 \\
\text{pOH} & = 14 - 10.50 = 3.50 \\
[\text{OH}^-] & = 10^{-3.50} = 3.16 \times 10^{-4} M \\
\text{C} & = 3.16 \times 10^{-4} M \\
\text{E} & \left(\frac{x - 3.16 \times 10^{-4}}{3.16 \times 10^{-4}}\right) = x \\
\end{align*}
\]

\[\text{K}_b = \frac{[\text{OH}^-]^2}{[\text{NH}_3]} = \frac{(3.16 \times 10^{-4})^2}{x - 3.16 \times 10^{-4}}
\]

\[x = 5.9 \times 10^{-3} = [\text{NH}_3]
\]

Type 3 Problems: Finding the $K_b$ of an Unknown Weak Base

Example: A 0.44M solution of the weak base B has a pH of 11.12. Calculate the $K_b$ for this base, and the $K_a$ for the conjugate acid, HB at 25°C.

\[
\begin{align*}
\text{pH} & = 11.12 \\
\text{pOH} & = 14 - 11.12 = 2.88 \\
[\text{OH}^-] & = 10^{-2.88} = 1.31 \times 10^{-3} M \\
\text{C} & = 1.31 \times 10^{-3} M \\
\text{E} & \left(\frac{0.441 - x \equiv 0.441}{\text{K}_b}ight) = x \\
\end{align*}
\]

\[\text{K}_b = \frac{[\text{OH}^-]^2}{[\text{B}^-]} = \frac{(1.31 \times 10^{-3})^2}{0.441 - 1.31 \times 10^{-3}} = 3.97 \times 10^{-6}
\]

\[\text{K}_a = \frac{\text{K}_w}{\text{K}_b} = \frac{1 \times 10^{-14}}{3.97 \times 10^{-6}} = 2.5 \times 10^{-9} = \text{K}_a
\]

(Not an acid/base pair listed in our table)
III) Writing Formula (Molecular), Complete Ionic, and Net Ionic Equations for Acid/Base Reactions

1. **Strong Acid/Strong Base** (Neutralization):

   F: \[ \text{HCl}_{aq} + \text{NaOH}_{aq} \rightarrow \text{________} + \text{________} \]

   C: \[ \rightarrow \]

   N: \[ \rightarrow \]