Calculating the pH of weak acid solutions
- Weak acids only partially dissociate in water, determining how much H\(^+\) they donate to water is more difficult than strong acids.
- We must perform equilibrium calculations (i.e. set up an ICE table).

Question: Consider a 0.80 M solution of HCN. The K\(_a\) value for HCN is 6.2 \times 10^{-10}.

(a) What are the major species in solution?

(b) Of the two choices for the primary reaction, which controls the pH?

\[
\text{HCN (aq) + H}_2\text{O (l)} \rightleftharpoons \text{H}_3\text{O}^+ \text{ (aq) + CN}^- \text{ (aq)} \quad \text{K}_a = 6.2 \times 10^{-10}
\]

\[
\text{H}_2\text{O (l) + H}_2\text{O (l)} \rightleftharpoons \text{H}_3\text{O}^+ \text{ (aq) + OH}^- \text{ (aq)} \quad \text{K}_a = 1.0 \times 10^{-14}
\]

(c) Calculate the pH of the HCN solution.

(d) Calculate the % dissociation of the weak acid.
Chapter 14 #67

The pH of a 1.00 x 10^{-2} M solution of cyanic acid (HOCN) is 2.77 at 25°C. Calculate $K_a$ for HOCN from this result.

Weak Base Calculations

- Bases accept protons.
- The weak bases have the form: B(nitrogen containing bases) and A^- (conjugate bases of weak acids, HA).

(a) $\text{B (aq)} + H_2O (l) \rightleftharpoons \text{BH}^+ (aq) + OH^- (aq) \quad K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$

B = NH_3, (CH_3)_3N, HONH_2, etc.

(b) $\text{A}^- (aq) + H_2O (l) \rightleftharpoons \text{HA (aq)} + OH^- (aq) \quad K_b = \frac{[\text{HA}][\text{OH}^-]}{[\text{A}^-]}$

A^- = F^-, NO_2^-, C_2H_3O_2^-, OCl^-, etc.

- Remember $K_b$ values are related to base strength.

Example: Chapter 14 # 85a

Calculate $[\text{OH}^-], [\text{H}^+], and the pH of 0.20 M solutions of each of the following amines:

(a) triethylamine [(C_2H_5)_3N, $K_b = 4.0 \times 10^{-4}$]
Chapter 14 #91

Codeine (C$_{18}$H$_{21}$NO$_3$) is a derivative of morphine that is used as an analgesic, narcotic, or antitussive. It was one commonly used in cough syrups but is now available only by prescription because of its addictive properties. If the pH of a 1.7 x 10$^{-3}$ M solution of codeine is 9.59, calculate $K_b$.

**Question:** Calculate the pH of a 0.10 M solution of NaOCN. The $K_a$ for HOCN is 1.3 x 10$^{-4}$.
We have discussed four types of pH calculations:

(a) pH of a strong acid solution (determine \( [H^+] \) by assuming 100% dissociation of strong acid)
(b) pH of a strong bases solution (determine \([OH^-]\) by assuming 100% dissociation of strong base)
(c) pH of a weak acid solution (determine \([H^+]\) by solving equilibrium problem using \( K_a \) reaction and an ICE table)
(d) pH of a weak base solution (determine \([OH^-]\) by solving equilibrium problem using \( K_b \) reaction and ICE table)

Review Problem

<table>
<thead>
<tr>
<th>Acid</th>
<th>( K_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>7.2 \times 10^{-4}</td>
</tr>
<tr>
<td>( C_6H_5NH_3^+ )</td>
<td>2.6 \times 10^{-5}</td>
</tr>
<tr>
<td>HC( _2H_3O_2 )</td>
<td>1.8 \times 10^{-5}</td>
</tr>
<tr>
<td>HCN</td>
<td>6.2 \times 10^{-10}</td>
</tr>
<tr>
<td>( NH_4^+ )</td>
<td>5.6 \times 10^{-10}</td>
</tr>
</tbody>
</table>

Will 1.0 M solutions of the following compounds have a pH = 7.00, greater than 7.00 or less than 7.00?

1. NaCN
2. \( NH_4NO_3 \)
3. KI
4. LiC\( _2H_3O_2 \)
5. KF
6. \( C_6H_5NH_3Cl \)
7. NaNO\( _3 \)
8. HClO\( _4 \)
9. Ca(OH)\( _2 \)
10. \( NH_4CN \)
11. \( NH_4C_2H_3O \)

Polyprotic Acids

- Typically for polyprotic acids \( K_{a1} \gg K_{a2} \gg K_{a3} \)
- From the relative sizes of the \( K_a \) values we can make the assumption that polyprotic acids lose their protons one at a time.
- For \( H_3PO_4 \):
\[
\begin{align*}
\text{H}_3\text{PO}_4 \text{ (aq)} & \rightleftharpoons \text{H}_2\text{PO}_4^- \text{ (aq)} + \text{H}^+ \text{ (aq)} \quad K_{a1} = 7.5 \times 10^{-3} = \frac{[\text{H}_2\text{PO}_4^-][\text{H}^+]}{[\text{H}_3\text{PO}_4]} \\
\text{H}_2\text{PO}_4^- \text{ (aq)} & \rightleftharpoons \text{HPO}_4^{2-} \text{ (aq)} + \text{H}^+ \text{ (aq)} \quad K_{a2} = 6.2 \times 10^{-8} = \frac{[\text{HPO}_4^{2-}][\text{H}^+]}{[\text{H}_2\text{PO}_4^-]} \\
\text{HPO}_4^{2-} \text{ (aq)} & \rightleftharpoons \text{PO}_4^{3-} \text{ (aq)} + \text{H}^+ \text{ (aq)} \quad K_{a3} = 4.8 \times 10^{-13} = \frac{[\text{PO}_4^{3-}][\text{H}^+]}{[\text{HPO}_4^{2-}]} 
\end{align*}
\]

- You should be able write down reactions that refer to \( K_a \) values as well as write out equilibrium expressions for any \( K_a \) value.
- We won’t do pH calculations involving polyprotic acids until later.
- Except for sulfuric acid, all polyprotic acids are weak acids.
- Determining the pH of \( \text{H}_2\text{SO}_4 \) solutions is a more complicated calculation because it involves a strong acid and a weak acid problem in one calculation.
- You are capable to do these problems but they generally involve the use of the quadratic equation.
- We will not hold you responsible for calculating the pH of sulfuric acid solutions.

### Metal Oxides in Solution

**Nonmetal oxides** form **acidic** solutions when dissolved in water.

**Examples:**

\[
\begin{align*}
\text{SO}_3 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_4 \\
\text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{CO}_3
\end{align*}
\]

**Metal oxides** form **basic** solutions when dissolved in water.

**Examples:**

\[
\begin{align*}
\text{CaO} + \text{H}_2\text{O} & \rightarrow \text{Ca(OH)}_2 \\
\text{K}_2\text{O} + \text{H}_2\text{O} & \rightarrow 2 \text{ KOH}
\end{align*}
\]