Acid-Base Properties of Salt Solutions

Acid-base Strength

Acid and base solutions can be ranked by the extent they ionize in an aqueous solution. The reaction of an acid with water is given by the following general expression:

\[ \text{HA}(aq) + \text{H}_2(\text{l}) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{A}^-(aq) \]

Water is the base that reacts with the acid HA, A\(^-\) is the conjugate base of the acid HA, and the hydronium ion is the conjugate acid of water. A strong acid yields 100% (or very nearly so) of H\(_3\)O\(^+\) and A\(^-\) when the acid ionizes in water. As for weaker acids, their relative strength can be found by measuring the equilibrium constant of their ionization reaction. Stronger acids yield a higher concentration of the hydronium ion. A higher acid-ionization constant (K\(_a\)) also indicates a stronger acid property. The reported concentrations are the equilibrium concentration in the reaction.

\[ K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} \]

Relative base strength can be identified in the same manner. A base reaction in water and base-ionization constant equation are given by the following expressions:

\[ \text{B}(aq) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{HB}^+(aq) + \text{OH}^-(aq) \]

\[ K_b = \frac{[\text{HB}^+][\text{OH}^-]}{[\text{B}]} \]

Water acts as an acid that reacts with the base, HB\(^+\) is the conjugate acid of the base B, and the hydroxide ion is the conjugate base of water.

![Relative acid strength](image1)

![Relative conjugate base strength](image2)

Figure 1 Relative strength of conjugate acid-base pairs [4]
A strong base yields 100% (or very nearly so) of OH\(^-\) and HB\(^+\) when it reacts with water. Similar to acids \(K_a\), \(K_b\) indicates the relative strength of bases as well. Stronger bases produce a higher concentration of hydroxide ion. Figure 1 and Figure 2 indicate the relative strength of conjugate acid-base pairs [1], [2].

<table>
<thead>
<tr>
<th>Acid</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>perchloric acid</td>
<td>(\text{HClO}_4)</td>
</tr>
<tr>
<td>sulfuric acid</td>
<td>(\text{H}_2\text{SO}_4)</td>
</tr>
<tr>
<td>hydrogen iodide</td>
<td>(\text{HI})</td>
</tr>
<tr>
<td>hydrogen bromide</td>
<td>(\text{HBr})</td>
</tr>
<tr>
<td>hydrogen chloride</td>
<td>(\text{HCl})</td>
</tr>
<tr>
<td>nitric acid</td>
<td>(\text{HNO}_3)</td>
</tr>
<tr>
<td>hydronium ion</td>
<td>(\text{H}_3\text{O}^+)</td>
</tr>
<tr>
<td>hydrogen sulfate ion</td>
<td>(\text{HSO}_4^-)</td>
</tr>
<tr>
<td>phosphoric acid</td>
<td>(\text{H}_3\text{PO}_4)</td>
</tr>
<tr>
<td>hydrogen fluoride</td>
<td>(\text{HF})</td>
</tr>
<tr>
<td>nitrous acid</td>
<td>(\text{HNO}_2)</td>
</tr>
<tr>
<td>acetic acid</td>
<td>(\text{CH}_3\text{CO}_2\text{H})</td>
</tr>
<tr>
<td>carbonic acid</td>
<td>(\text{H}_2\text{CO}_3)</td>
</tr>
<tr>
<td>hydrogen sulfide</td>
<td>(\text{H}_2\text{S})</td>
</tr>
<tr>
<td>ammonium ion</td>
<td>(\text{NH}_4^+)</td>
</tr>
<tr>
<td>hydrogen cyanide</td>
<td>(\text{HCN})</td>
</tr>
<tr>
<td>hydrogen carbonate ion</td>
<td>(\text{HCO}_3^-)</td>
</tr>
<tr>
<td>water</td>
<td>(\text{H}_2\text{O})</td>
</tr>
</tbody>
</table>

Hydrolysis

Hydrolysis is defined as the dissolution of salts in water to produce \(\text{H}_3\text{O}^-\) or OH\(^-\). Hydrolysis solutions normally show acidic or basic natures, considering the strength of ions hydrolyzing in water. Different structures of salts will produce various pH ranges in an aqueous solution. Salt is defined as the formed ionic compound derived from a neutralization reaction between an acid and a base. Therefore, the comprising cations and anions are respectively the conjugate acids and conjugate bases of the used acid and base compounds.

Depending on the relative strength of the salt ions, basic and acidic salts will form when dissolved in an aqueous solution [3].

Figure 2: Relative strengths of conjugate acid-base pairs. [4]
Basic Salts
Basic salts are formed from the neutralization reaction between a strong acid and a weak base. In basic salts, the anion is the conjugate base of a weak acid. In general, anions $A^-$ can be considered the conjugate base of the acid $HA$. Depending on the strength of the corresponding acid:

- $A^-$, the conjugate base of a weak acid, acts as a weak base.
- $A^-$, the conjugate base of a strong acid, acts as a pH-neutral.

For example, the F- anion is the conjugate base of HF, a weak acid; therefore, it produces a basic solution when dissolved in water.

On the other hand, the Cl- anion is the conjugate base of HCl, a strong acid; thus, it shows neither acidic nor basic nature and acts as a pH-neutral agent in water.

Acidic Salts
Since the cation acts as weak, a salt with an anion of a strong acid and a cation of a weak base produces an acidic solution with a pH less than 7. In this case, the anion becomes the spectator ion, while the weak acid dissociates in water and yields $H_3O^+$ ions. Therefore,

- $HB^+$, the conjugate acid of a weak base, acts as a weak acid.
- $HB^+$, the conjugate acid of a strong base, acts as a pH-neutral.

For example, NH$_4$Cl yields an acidic solution since the NH$_4^+$, the cation of base NH$_3$, reacts with water and forms a weak acid, while the Cl-, the anion of strong acid HCl, forms a spectator ion.

Neutral Salts
Salts that are from strong acids and strong bases normally do not hydrolyze and no reaction occurs between the ions and water; therefore, the solution remains neutral with a pH=7.

For example, salts consisting of halides (except F-) and alkaline metals dissociate in water, but do not affect since the anion does not attract $H_3O^-$ and the cation does not change the $H_3O^+$.

The anions of strong acids are the halide ions (except F-) and those of strong oxoacids like NO$_3^-$ and ClO$_4^-$. Group 1A (1) and Ca$^{2+}$, Sr$^{2+}$, and Ba$^{2+}$ from group 2A (2) consist of the cations of the strong bases.

Salts of Weak Acids and Weak Bases
In this case, both the anion and the cation react with water; therefore, we can predict whether the solution will be basic, acidic, or neutral by comparing the $K_a$ value for the acidic ion with the $K_b$ value for the basic ion. Table 1 shows a summary of acid-base properties of the salts [1], [3].
Methodology
We need to look at the salt and ask these questions:

- Which acid and which base reacted to form it?
- Is the acid strong or weak?
- Is the base strong or weak?

Note that the strong acid or base dissociates completely and the resulting ion is a spectator. The remaining ion of the salt reacts with water.

- If you predict a basic solution, the hydrolysis reaction will be:
  
  \[ B(aq) + H_2O(l) \leftrightarrow HB^+(aq) + OH^-(aq) \]

- If you predict an acidic solution, the hydrolysis reaction will be:
  
  \[ HA(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + A^-(aq) \]

References


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