Acid Base Properties of Salt Solutions

Ions can exhibit acidic or basic properties. For example, NH$_4^+$ is acidic, and F$^-$ is basic.

Salts, being strong electrolytes, dissociate completely in aqueous solution to produce the ions which they are composed of. Therefore, salt solutions can be acidic, basic or neutral.

**POINT OF EMPHASIS:** The *weaker* the acid, the *stronger* the base.

The ions may react with water in a *hydrolysis reaction* to produce H$^+$ (aq) or OH$^-$ (aq).

Hydrolysis is a general term for the splitting of a water molecule. For example, the acetate ion, C$_2$H$_3$O$_2^-$, reacts with water to form:

$$
\text{C}_2\text{H}_3\text{O}_2^- (\text{aq}) + \text{H}_2\text{O} (\text{l}) \rightleftharpoons \text{HC}_2\text{H}_3\text{O}_2 (\text{aq}) + \text{OH}^- (\text{aq})
$$

The production of the OH$^-$ ion makes the solution basic.

Note that all cations, except those of alkali and alkaline earth metals (which do not hydrolyze in water and, therefore, do not affect pH), act as weak acids in solution. The relative concentrations of these ions then determine the acidic or basic properties of the solution.

*Note:* The ions of strong acids and strong bases do *not* hydrolyze! They are so weak that they are known as *spectator ions*. Only ions of weak acids and bases hydrolyze.

**Polyprotic ions** are anions of substances capable of dissociating more than one proton in water, such as HCO$_3^-$, which could either gain or lose a proton in aqueous solution. This property of being acidic or basic is known as *amphotericism*.

The behaviour of the anions of polyprotic ions is determined by the relative magnitudes of its $K_a$ and $K_b$.

For example, if the ion's $K_b > K_a$, the ion has a greater tendency to be protonated rather than deprotonated and thus the solution is basic. The reverse is also true.

**EXAMPLE:**

*Predict whether the salt Na$_2$HPO$_4$ will form an acidic or basic solution when dissolved in water.*

We know that $K_a$ for HPO$_4^{2-}$ is $4.2 \times 10^{-13}$ and $K_a$ for H$_2$PO$_4^-$ is $6.2 \times 10^{-8}$.

Na$^+$, a spectator ion, does not affect the acidity or basicity of a solution, but HPO$_4^{2-}$ could. The two possible reactions that it could undergo are:

**Reaction A:**

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\[ \text{HPO}_4^{2-} \text{(aq)} \rightleftharpoons \text{H}^+ \text{(aq)} + \text{PO}_4^{3-} \text{(aq)} \]

**Reaction B:**

\[ \text{HPO}_4^{2-} \text{(aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{H}_2\text{PO}_4^- \text{(aq)} + \text{OH}^- \text{(aq)} \]

Whether this ion will cause the solution to be acidic or basic depends on whether the Ka for reaction A is bigger than the Kb for reaction B.

- Ka for HPO$_4^{2-}$ is $4.2 \times 10^{-13}$.
- Ka for H$_2$PO$_4^-$ is $6.2 \times 10^{-8}$.

The Kb of reaction B is related to the Ka of H$_2$PO$_4^-$ by Kb = Kw / Ka:

\[ \text{Kb} = \frac{1.0 \times 10^{-14}}{6.2 \times 10^{-8}} = 1.6 \times 10^{-7} \text{ for HPO}_4^{2-} \]

K$_b$ > K$_a$, so the solution will be **basic**.

**Qualitative Determination of pH**

We can predict whether a solution will be acidic basic or neutral by qualitatively finding the pH:

1. **Salts from a strong acid and a strong base**:
   - no hydrolysis of cation or anion
   - pH = 7.00

2. **Salts from a strong base and a weak acid**:
   - hydrolysis of anion from the weak acid (to produce OH$^-$ ions)
   - pH > 7.00 (basic)

3. **Salts from a weak base and a strong acid**:
   - hydrolysis of cation from weak base (to produce H$^+$ ions)
   - pH < 7.00 (acidic)

4. **Salts from a weak base and a weak acid**:
   - both cation and anion hydrolyze
   - if K$_b$ of hydrolysis of an anion is greater than K$_a$ of hydrolysis of a cation, the solution is basic (pH > 7.00), and vice versa.