

Acid base titration

Theories of acid base indicators

- Acid-base indicators are substances that change color depending on the pH of the solution they are in.
- They are typically weak organic acids or bases that exhibit different colors in their protonated and deprotonated forms.
- These indicators are crucial in titrations as they signal the endpoint of the reaction by undergoing a visible color change.

There are two main theories that explain the behavior of acid-base indicators:

A. Ostwald Theory (Ionization Theory)

- The Ostwald theory explains the behavior of acid-base indicators based on the ionization equilibrium of weak acids or bases.
- According to this theory:
 - **Ionization Equilibrium:** In the presence of a base, a weak acidic indicator (HIn) can lose a proton (H^+) to form its conjugate base (In^-).
$$HIn \leftrightarrow H^+ + In^-$$
 - **Color Change:** Both the protonated form (HIn) and the deprotonated form (In^-) have different colors due to differences in their electronic structures.
 - **pH Dependence:** The equilibrium shifts based on the pH of the solution, causing a color change as the concentration of H^+ ions changes.

➤ Examples

1. Phenolphthalein

- **Ionization Equilibrium:**



- **Behavior:**

- In **acidic solutions**, the equilibrium favors the colorless protonated form (HIn).
- In **basic solutions**, the equilibrium shifts towards the pink deprotonated form (In^-).

2. Methyl Orange

- **Ionization Equilibrium:**



- **Behavior:**

- In acidic solutions $\rightarrow$ red protonated form (HIn) predominates.

- In basic solutions → yellow deprotonated form (In^-) predominates.

B. Quinonoid Theory (Resonance or Quasi-Valence Theory)

- The quinonoid theory explains the color change of indicators based on the resonance structures and electron distribution within the molecules.
- According to this theory:
 - **Resonance Structures:** Indicators can exist in two tautomeric forms—benzenoid and quinonoid structures—which have different colors.
 - **Electron Distribution:** Gaining or losing a proton changes the electron distribution, altering the absorption of light in the visible spectrum and thus the color.
 - **Color Dependence:** The color of the indicator is determined by the predominant resonance structure at a given pH.
- **Examples**

1. Phenolphthalein

- **Structural Change:**
 - In **acidic solutions**, phenolphthalein exists in its colorless lactone (benzenoid) form.
 - In **basic solutions**, it loses a proton to form a pink-colored quinonoid structure.
- **Color Change Mechanism:** The shift from the lactone form to the quinonoid form changes the electron delocalization, resulting in a color change.

2. Methyl Orange

- **Structural Change:**
 - In **acidic conditions**, methyl orange exists in a red-colored benzenoid form.
 - In **alkaline conditions**, it shifts to a yellow-colored quinonoid form.
- **Color Change Mechanism:** The change in resonance structures alters the wavelengths of light absorbed, leading to a visible color change.

Classification and Theory of acid base titrations

- Acid-base titrations can be classified into different categories based on the nature of the acid and base involved, as well as the type of reaction taking place.
- The theory behind titrations involving strong, weak, and very weak acids and bases is based on chemical equilibrium, ionization, and the pH scale.

The main classifications include

1. Strong Acid - Strong Base Titration

Theory:

- In a titration involving a strong acid and a strong base, both the acid and the base completely ionize in water, producing a high concentration of H^+ and OH^- ions, respectively.
- The reaction results in the formation of water and a neutral salt.
- The pH at the equivalence point is close to 7.0.

Example:

- **Reaction:**



- Hydrochloric acid (HCl) reacts with sodium hydroxide (NaOH) to form sodium chloride (NaCl) and water.

Procedure:

- A burette is used to carefully add the NaOH solution to the HCl solution until the equivalence point is reached, where the moles of H^+ ions equal the moles of OH^- ions.
- The pH at the equivalence point is near 7.0, indicating neutrality.
- Indicator: Phenolphthalein, which is colorless in acidic solutions and turns pink in basic solutions.
- As NaOH is added, the solution remains colorless until the endpoint is reached, where the pink color indicates neutralization.

Calculation:

- By measuring the volume of NaOH required to reach the endpoint, the concentration of the HCl solution can be calculated using stoichiometry and the known concentration of NaOH.

2. Weak Acid - Strong Base Titration

Theory:

- In this case, the weak acid only partially ionizes, producing a relatively low concentration of H^+ ions, while the strong base completely ionizes, producing a high concentration of OH^- ions.
- The reaction forms a basic salt, and the pH at the equivalence point will be greater than 7.0 due to the basic nature of the salt.

Example:

- Reaction:



- Acetic acid (CH_3COOH) reacts with sodium hydroxide (NaOH) to form sodium acetate (CH_3COONa) and water.

Procedure:

- A burette is used to add NaOH to the acetic acid solution until the equivalence point is reached, where the moles of H^+ ions from the acid equal the moles of OH^- ions from the base.
- The pH at the equivalence point is greater than 7.0, indicating a slightly basic solution due to sodium acetate.
- Indicator: Phenolphthalein is used, turning from colorless to pink at the endpoint.

Calculation:

- By measuring the volume of NaOH needed to reach the endpoint, the concentration of the acetic acid solution can be calculated.

3. Strong Acid - Weak Base Titration**Theory:**

- The strong acid completely ionizes in water, producing a high concentration of H^+ ions, while the weak base only partially ionizes, resulting in a lower concentration of OH^- ions.
- The reaction forms an acidic salt, and the pH at the equivalence point will be less than 7.0.

Example:

- Reaction:



- Hydrochloric acid (HCl) reacts with ammonia (NH_3) to form ammonium chloride (NH_4Cl).

Procedure:

- A burette is used to add ammonia solution to the HCl solution until the equivalence point, where the moles of H^+ ions equal the moles of NH_3 .
- The pH at the equivalence point is less than 7.0, indicating a slightly acidic solution due to ammonium chloride.
- Indicator: Methyl orange, which is red in acidic solutions and turns yellow in basic solutions, can be used to signal the endpoint.

Calculation:

- By measuring the volume of ammonia required to reach the endpoint, the concentration of the HCl solution can be calculated using the stoichiometry of the reaction.

4. Weak Acid - Weak Base Titration**Theory:**

- In this case, both the weak acid and weak base only partially ionize, producing low concentrations of H^+ and OH^- ions.

- The pH at the equivalence point can vary depending on the relative strengths of the acid and base and may be close to, less than, or greater than 7.0.
- The titration endpoint is less distinct, making precise pH measurement techniques important.

Example:

- Reaction:



- Acetic acid (CH_3COOH) reacts with ammonia (NH_3) to produce ammonium acetate ($\text{CH}_3\text{COONH}_4$).

Procedure:

- A burette is used to add the ammonia solution to the acetic acid solution until the equivalence point is reached.
- The pH at the equivalence point can be close to, less than, or greater than 7.0, depending on the strengths of the acid and base.
- Indicator: Due to the less distinct endpoints, a potentiometric titration using a pH meter is often used.

Calculation:

- By measuring the volume of ammonia required to reach the endpoint, the concentration of the acetic acid can be calculated.
- However, the titration of weak acid and weak base is less precise and accurate compared to other titrations.

Preparation and Standardization of Titrants: Hydrochloric Acid (HCl)

Basic idea

- Hydrochloric acid is a strong acid commonly used as a titrant in acid–base titrations.
- Concentrated hydrochloric acid is diluted with distilled water to prepare the required concentration.

Preparation

- The required volume of concentrated hydrochloric acid is calculated.
- Distilled water is placed in a volumetric flask.
- Concentrated hydrochloric acid is added slowly to the water with continuous stirring.
- The solution is diluted to the required volume with distilled water.
- The solution is mixed thoroughly.



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