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**:

$$HIn\ (colorless) \leftrightarrow H^+ + In^-\ (pink)$$

- **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**:

$$HIn\ (red) \leftrightarrow H^+ + In^-\ (yellow)$$

- **Behavior**:
  - In acidic solutions → red protonated form (HIn) predominates.

Copyright © 2025 by Engacy Learning Private Limited. All rights reserved. Reproduction or distribution without written consent is strictly prohibited.

- 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 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:

Copyright © 2025 by Engacy Learning Private Limited. All rights reserved. Reproduction or distribution without written consent is strictly prohibited.

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:**

  HCl (strong acid) + NaOH (strong base) → NaCl (salt) + H_2O (water)

- 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**:

CH_3COOH (weak acid) + NaOH (strong base) → CH_3COONa (basic salt) + H_2O (water)

Copyright © 2025 by Engacy Learning Private Limited. All rights reserved. Reproduction or distribution without written consent is strictly prohibited.

- 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**:

  HCl (strong acid) + NH_3 (weak base) → NH_4Cl (acidic salt)

- 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:

Copyright © 2025 by Engacy Learning Private Limited. All rights reserved. Reproduction or distribution without written consent is strictly prohibited.

First Hope

FREE PREVIEW

Click here to visit our website

PHARMACY PREMIUM NOTES

Complete subject and semesters are available on FirstHope app only.

Scan or click here

Click here to get the app >

Available on Google Play

JOIN THE FIRSTHOPE COMMUNITY

Join our Telegram channel

Click here to join Telegram >

Scan or click here

@FirstHopeNotes

Instagram

@firsthope.official

Click here to follow >

YouTube channel

FirstHope-Pharmacy / Live streams

Click here to watch >

WhatsApp channel

Follow FirstHope on WhatsApp

Click here to join >

FirstHope website

firsthope.co.in

Click here to visit >

B.Pharm / D.Pharm / M.Pharm / Pharm.D

Preview notes. Complete subjects and semesters in the FirstHope app.