Many analytical applications of acid-base chemistry involve acid-base titrations. The gradual neutralization of an acid or base during a titration is associated with a change in the $[\text{H}_3\text{O}^+]$. This change can be used with a variety of end points to assess the equivalence point in the titration.

It is useful to think of an acid-base titration as one of four analyte-titrant types: strong acid-strong base, strong base-strong acid, weak acid-strong base and weak base-strong acid. Note that the titrant is always a strong acid or strong base.

**Check for Understanding 9.1**

1. What is the problem with titrating a weak acid with a weak base, or a weak base with a weak acid?

**Strong Acid-Strong Base Titrations**

A plot of the solution pH as a function of titrant volume is given in Figure 9.1 for the titration of 50.0 mL of 0.200 M HNO$_3$ with 0.100 M NaOH. Note that the volume of base needed to reach the equivalence point is twice the volume of acid since the base concentration is half that of the acid.

![Figure 9.1 Curve for the titration of a strong acid with a strong base](image)
Important characteristics of a strong acid-strong base titration

- titration reaction net ionic equation: \( \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow 2\text{H}_2\text{O}(l) \)
- equivalence point pH ~ 7
- very large change in pH around equivalence point
- before equivalence point pH depends on amount of excess strong acid present; after equivalence point pH depends on amount of excess base added

Strong Base-Strong Acid Titrations

A plot of the solution pH as a function of titrant volume is given in Figure 9.2 for the titration of 100.0 mL of 0.50 M NaOH with 1.0 M HCl. Note that the volume of acid needed to reach the equivalence point is half the volume of base since the acid concentration is twice that of the base.

![Figure 9.2 Curve for the titration of a strong base with a strong acid](image-url)
Important characteristics of a strong base-strong acid titration

- titration reaction net ionic equation: $\text{OH}^-(aq) + \text{H}_3\text{O}^+(aq) \rightarrow 2\text{H}_2\text{O}(l)$
- equivalence point pH ~ 7
- very large change in pH around equivalence point
- before equivalence point pH depends on amount of excess strong base present; after equivalence point pH depends on amount of excess acid added

Weak Acid-Strong Base Titrations

A plot of the solution pH as a function of titrant volume is given Figure 9.3 for the titration of 50.0 mL of 0.100 M $\text{HC}_2\text{H}_3\text{O}_2$ with 0.100 M NaOH. Note that the volume of base needed to reach the equivalence point is the same as the volume of acid since the base concentration is the same as that of the acid.

![Figure 9.3](image)

**Figure 9.3** Curve for the titration of a weak acid with a strong base
Important characteristics of a weak acid-strong base titration

- titration reaction net ionic equation: $\text{HA(aq)} + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O(l)} + \text{A}^-(\text{aq})$
- equivalence point pH > 7 (conjugate base of a weak acid is formed)
- smaller change in pH around equivalence point
- in the region before equivalence point a buffer is formed and the pH does not change very much with added base; after equivalence point pH depends on amount of excess base added
- halfway to the equivalence point half the weak acid has been converted to its conjugate base, $[\text{weak acid}] \sim [\text{conjugate base}]$ and buffer pH $\sim pK_a$

Weak Base-Strong Acid Titrations

A plot of the solution pH as a function of titrant volume is given Figure 9.4 for the titration of 100.0 mL of 0.050 M $\text{NH}_3$ with 0.10 M $\text{HCl}$. Note that the volume of acid needed to reach the equivalence point is half the volume of base since the acid concentration is twice that of the base.

![Figure 9.4](image_url) Figure 9.4 Curve for the titration of a weak base acid with a strong acid
Important characteristics of a weak base-strong acid titration

- titration reaction net ionic equation: $\text{A}^-(\text{aq}) + \text{H}_3\text{O}^+\text{(aq)} \rightarrow \text{HA(}\text{aq}) + \text{H}_2\text{O(l)}$

- equivalence point pH < 7 (conjugate acid of a weak base is formed)

- smaller change in pH around equivalence point

- in the region before equivalence point a buffer is formed and the pH does not change very much with added acid; after equivalence point pH depends on amount of excess acid added

- halfway to the equivalence point half the weak base has been converted to its conjugate acid, $[\text{weak base}] \sim [\text{conjugate acid}]$ and buffer pH $\sim pK_a$

A very simple approach can be used to reliably estimate the equivalence point pH for a weak acid or weak base titration. The general rule is to take the average of the “buffer plateau” pH ($\sim pK_a$) before the equivalence point and the final pH plateau ($\sim$ the pH of the titrant) after the equivalence point.

**Example 9.1**

**Problem**

Estimate the equivalence point pH for the $\text{HC}_2\text{H}_3\text{O}_2$/NaOH titration shown in Figure 9.3.

**Solution**

The $\text{HC}_2\text{H}_3\text{O}_2$/C$_2$H$_3$O$_2^-$ buffer formed before the equivalence point has a pH $\sim pK_a = 4.8$. The pH of the 0.1 M NaOH titrant in large excess after the equivalence point is about 13. The average of these values is $(4.8 + 13)/2 = 8.9$, which is very close to the actual pH found at the equivalence point (pH = 8.7).
Check for Understanding 9.2

1. Estimate the equivalence point pH for the NH$_3$/HCl titration in Figure 9.4.