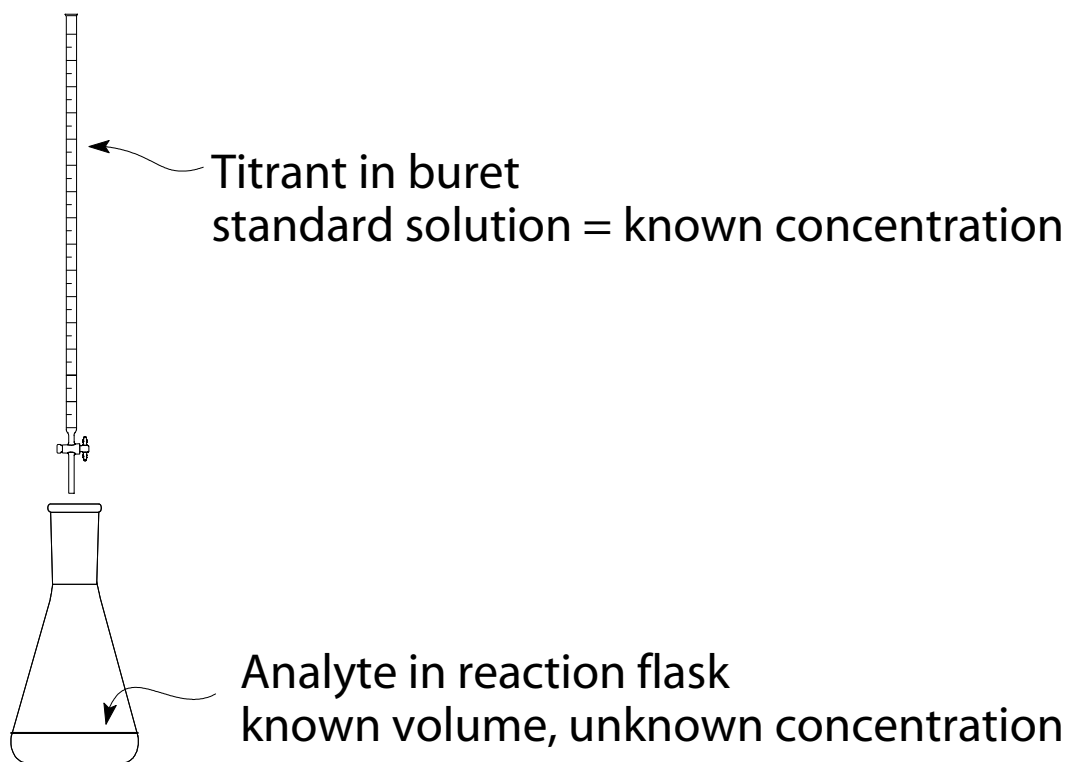


Titration

- ☞ Titration is the addition of a standard solution (the **titrant**) to a measured volume of a solution with unknown concentration (the **analyte**) to react according to a known stoichiometry.



Titration Basic Concepts and Definitions



- ✓ At any point in the titration, if volume is in mL,

$$\text{millimol titrant added} = M_t \times V_t$$

- ✓ **Equivalence point** - Volume of titrant necessary to achieve complete conversion of analyte into products.

- ☞ At the equivalence point, millimoles of analyte initially present is related to millimoles of titrant added by

$$M_a \times V_a = (m/n) \times M_t \times V_t$$

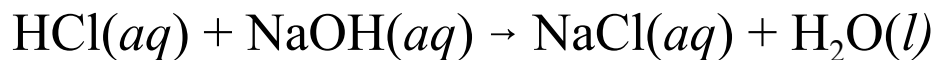
- ✓ **End point** - Volume of titrant added when an indicator changes color, ideally signaling the equivalence point.

Types of Acid-Base Titrations

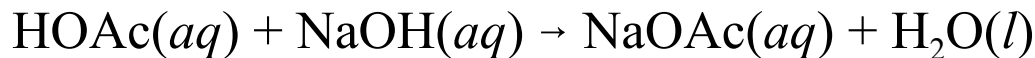
Analyte	Titrant
Weak or strong base	Strong acid (e.g., HCl)
Weak or strong acid	Strong base (e.g., NaOH)

Examples:

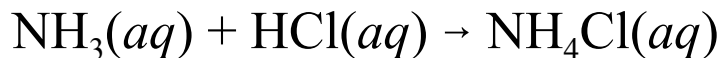
strong acid - strong base (acid or base analyte; base or acid titrant)



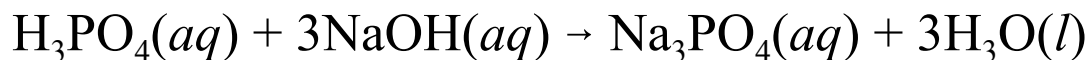
Weak acid (analyte) - strong base (titrant)



Weak base (analyte) - strong acid (titrant)



Weak triprotic acid (analyte) - strong base (titrant)

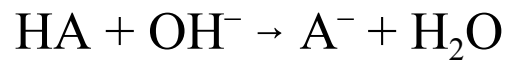


Acid-Base Titrations
Net Ionic Equations by Type

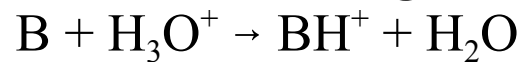
Strong Acid-Strong Base



Weak Acid-Strong Base



Weak Base-Strong Acid



**Acid-Base Titration
Relationships at Equivalence Point
(Monoprotic Cases)**

initial millimoles analyte = millimoles titrant added

$$\Rightarrow V_a M_a = V_b M_b \Rightarrow$$

Strong Acid-Strong Base

initial millimoles H_3O^+ = millimoles OH^- added

or

initial millimoles OH^- = millimoles H_3O^+ added

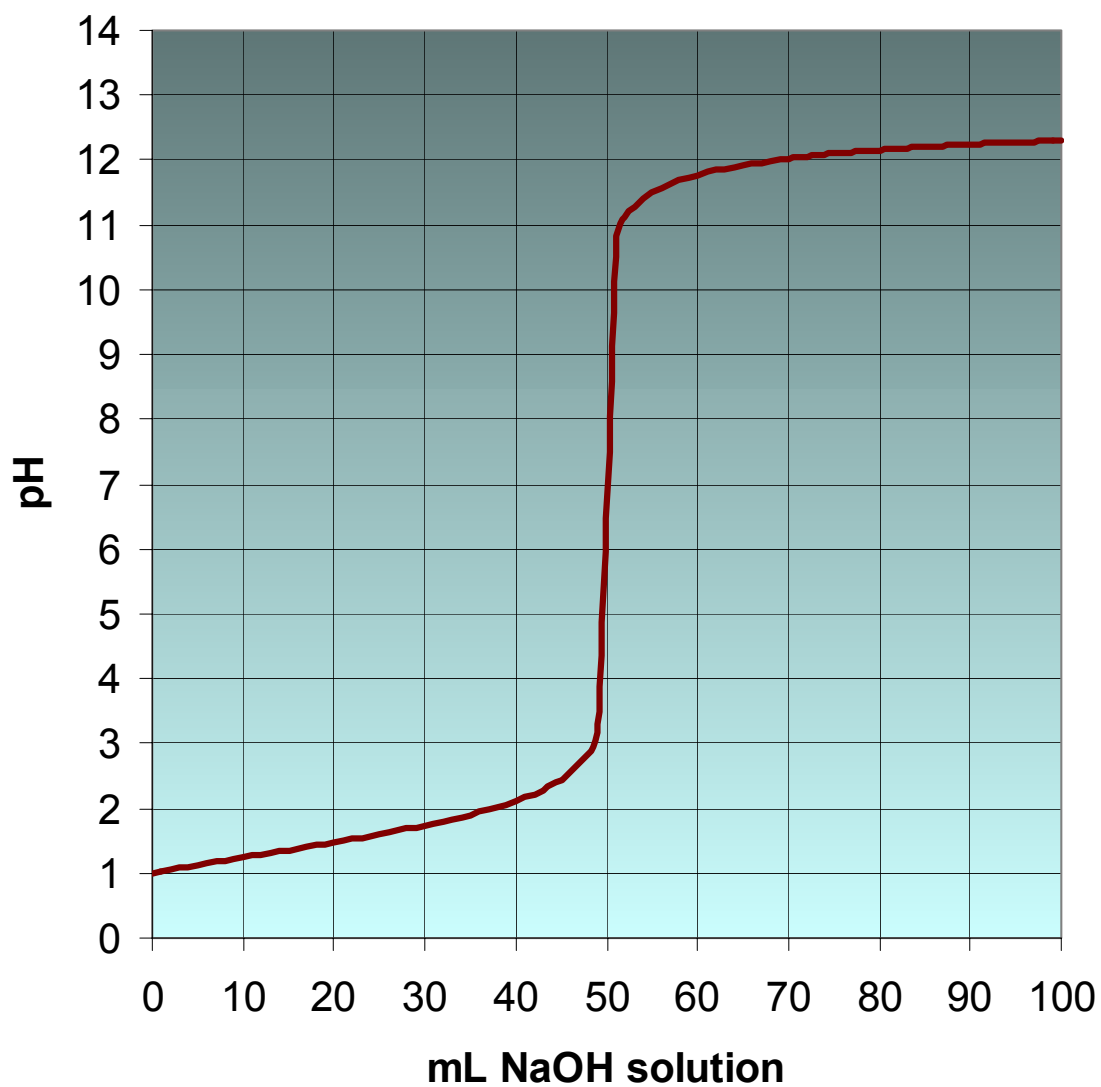
Weak Acid-Strong Base

initial millimoles HA = millimoles OH^- added

Weak Base-Strong Acid

initial millimoles B = millimoles H_3O^+ added

**Titration of 25.00 mL of 0.100 M HCl
with 0.0500 M NaOH**



Regions in a Weak Acid Titration

1. Initial Point (no added titrant):

✓ Pure HA in water

☞ Use K_a and C_{HA} to find $[\text{H}_3\text{O}^+]$ and pH.

2. Before Equivalence Point (buffer region):

✓ Significant $[\text{HA}]$ and $[\text{A}^-]$

☞ Use K_a or Henderson-Hasselbalch equation to find $[\text{H}_3\text{O}^+]$ and pH, just like a buffer.

3. Equivalence Point:

✓ All HA converted to A^-

☞ Calculate K_b for A^- as K_w/K_a^{HA} .

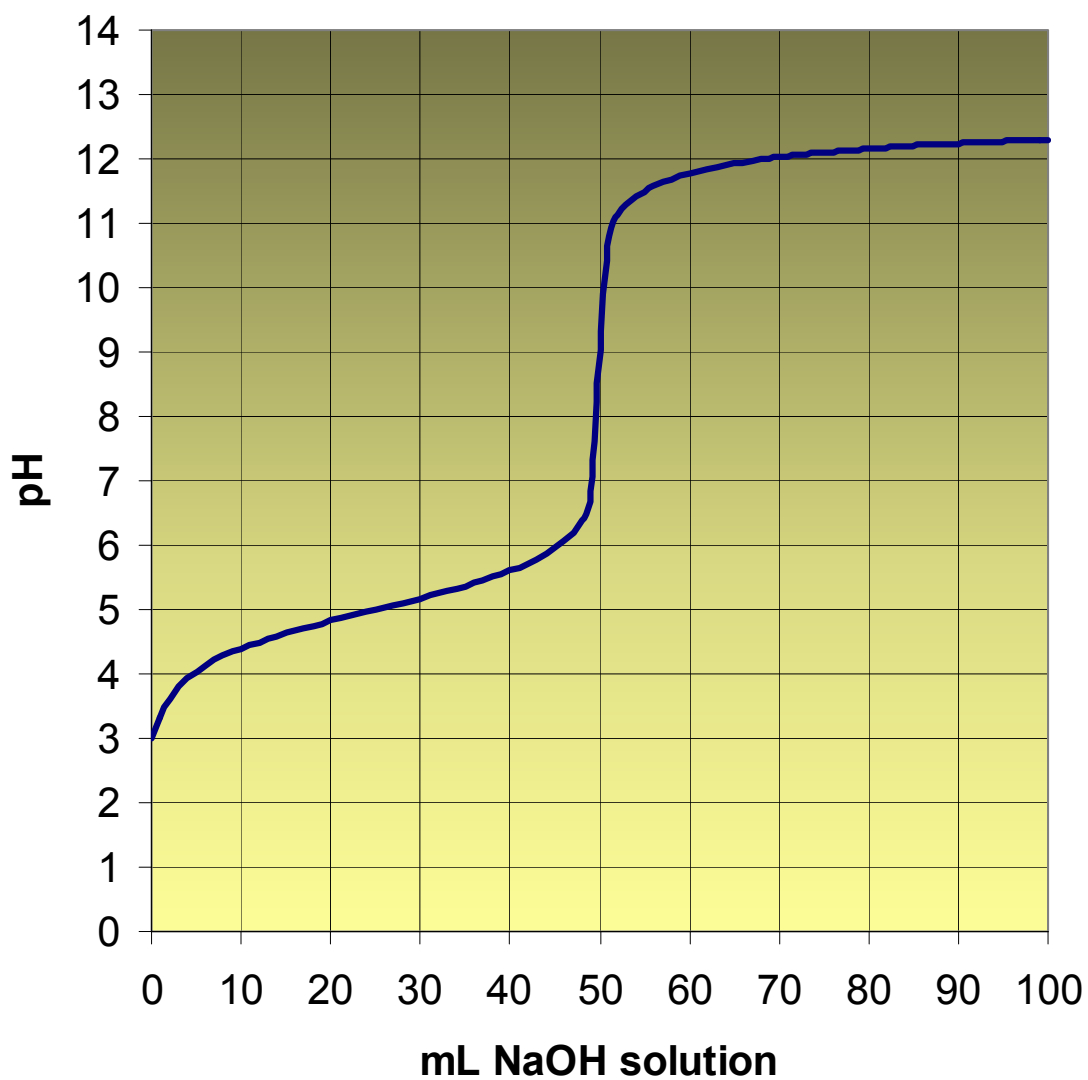
☞ Find $[\text{OH}^-]$ and pOH as for a solution of pure A^- in water, then pH.

4. Beyond Equivalence Point:

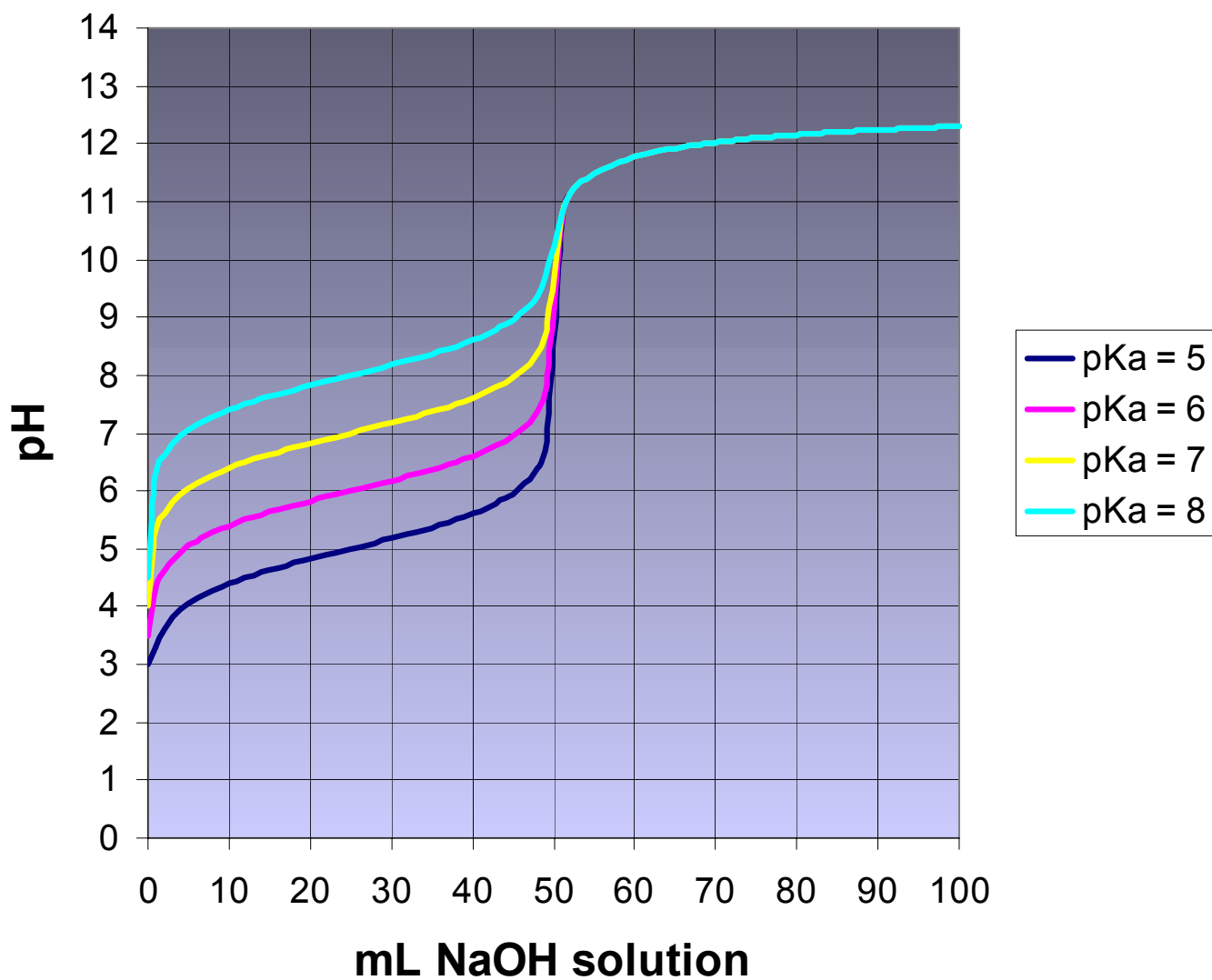
✓ Excess OH^-

☞ Calculate $[\text{OH}^-]$ and pOH, then pH, as in the strong acid-base case.

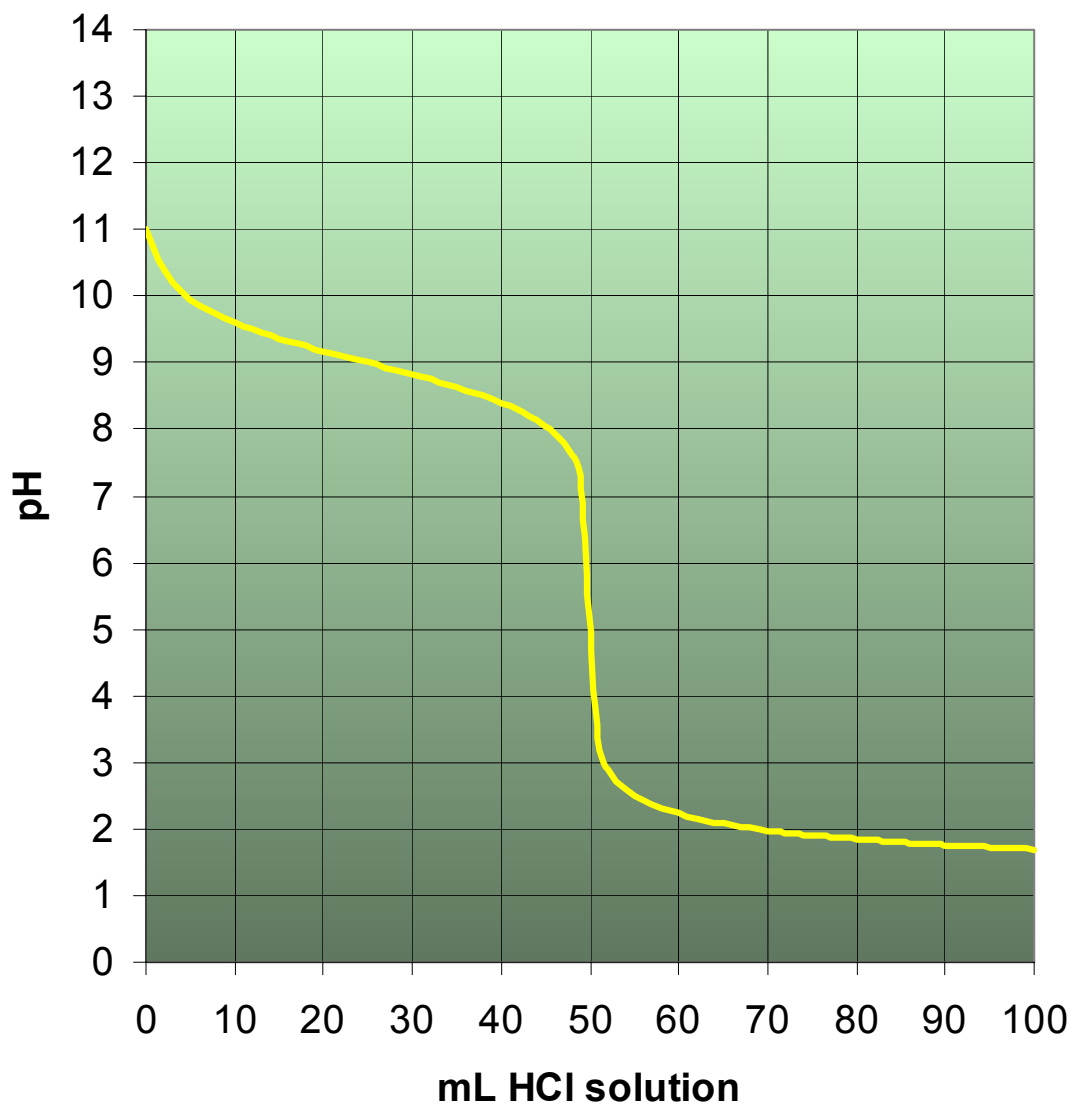
**Titration of 25.00 mL of 0.100 M HA
(pKa = 5.00) with 0.0500 M NaOH**



Titration of 25.00 mL of 0.100 M HA with 0.0500 M NaOH - Effect of pKa

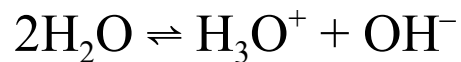


**Titration of 25.00 mL of 0.100 M B
($pK_b = 5.00$) with 0.0500 M HCl**



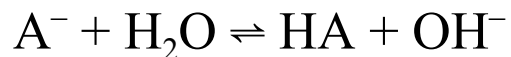
pH at the Equivalence Point

- ✓ Strong acid – strong base titration:



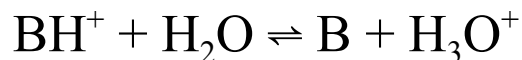
☞ pH = 7

- ✓ Weak acid – strong base titration:



☞ pH > 7

- ✓ Weak base – strong acid titration:



☞ pH < 7

Summary of Calculations for Weak Acid Titrations Before Equivalence Point

Region	Calculation of $[\text{H}_3\text{O}^+]$
Initial (no added titrant)	$K_a = \frac{[\text{H}_3\text{O}^+]^2}{[\text{HA}]}$ $= \frac{[\text{H}_3\text{O}^+]^2}{C_{\text{HA}} - [\text{H}_3\text{O}^+]}$ <p>Often, $[\text{H}_3\text{O}^+] = \sqrt{K_a C_{\text{HA}}}$</p>
Before Equivalence Point (Buffer Region)	$K_a = \frac{[\text{H}_3\text{O}^+] C_{\text{A}^-}}{C_{\text{HA}}}$ $[\text{H}_3\text{O}^+] = K_a \times \left(\frac{\text{mmol HA}}{\text{mmol A}^-} \right)$
Half Titration Point	$[\text{A}^-] = [\text{HA}]$ $[\text{H}_3\text{O}^+] = K_a$ $\text{pH} = \text{p}K_a$

Summary of Calculations for Weak Acid Titrations Equivalence Point and Beyond

Region	Calculation of $[\text{OH}^-]$
Equivalence Point	$K_b^{\text{A}^-} = \frac{K_w}{K_a^{\text{HA}}}$ $[\text{OH}^-] = \sqrt{K_b^{\text{A}^-} C_{\text{A}^-}}$
After Equivalence Point	$[\text{OH}^-] = \left(\frac{\text{mmol excess OH}^-}{\text{total volume}} \right)$

Summary of Calculations for Weak Base Titrations Before Equivalence Point

Region	Calculation of $[\text{OH}^-]$
Initial (no added titrant)	$K_b = \frac{[\text{OH}^-]^2}{[\text{B}]}$ $= \frac{[\text{OH}^-]^2}{C_B - [\text{OH}^-]}$ <p>Often, $[\text{OH}^-] = \sqrt{K_b C_B}$</p>
Before Equivalence Point (Buffer Region)	$K_b = \frac{[\text{OH}^-] C_{\text{BH}^+}}{C_B}$ $[\text{OH}^-] = K_b \times \left(\frac{\text{mmol B}}{\text{mmol BH}^+} \right)$
Half Titration Point	$[\text{BH}^+] = [\text{B}]$ $[\text{OH}^-] = K_b$ $\text{pOH} = \text{p}K_b$

Summary of Calculations for Weak Base Titrations Equivalence Point and Beyond

Region	Calculation of $[\text{H}_3\text{O}^+]$
Equivalence Point	$K_a^{\text{BH}^+} = \frac{K_w}{K_b^{\text{B}}}$ $[\text{H}_3\text{O}^+] = \sqrt{K_a^{\text{BH}^+} C_{\text{BH}^+}}$
After Equivalence Point	$[\text{H}_3\text{O}^+] = \left(\frac{\text{mmol excess H}_3\text{O}^+}{\text{total volume}} \right)$