

Acid-Base Titrations

Titration is a form of analysis in which we measure the volume of material of known concentration sufficient to react with the substance being analyzed.

Titration

a solution of known concentration, called a *standard solution* is added gradually to another solution of unknown concentration until the chemical reaction between the two solutions is complete

equivalence point

- the exact number of moles required for the reaction
- detected by a color change in an *acid-base indicator* or electronically

Acid-Base Titrations

How does the pH change during the course of the following kinds of titration?

strong acid-strong base

weak acid-strong base

weak base-strong acid

Titration Involving a Strong Acid and a Strong Base

Titration Involving a Strong Acid and a Strong Base

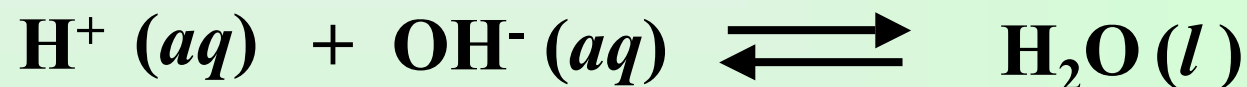
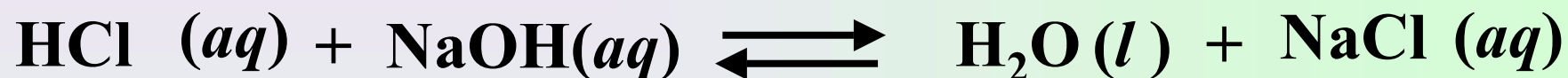
**titrate 25.0 mL of 0.100 M HCl with
0.100 M NaOH**

Note: $\frac{\text{mmol}}{\text{mL}}$ and $\frac{\text{mol}}{\text{L}}$

are equivalent

Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 10.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?

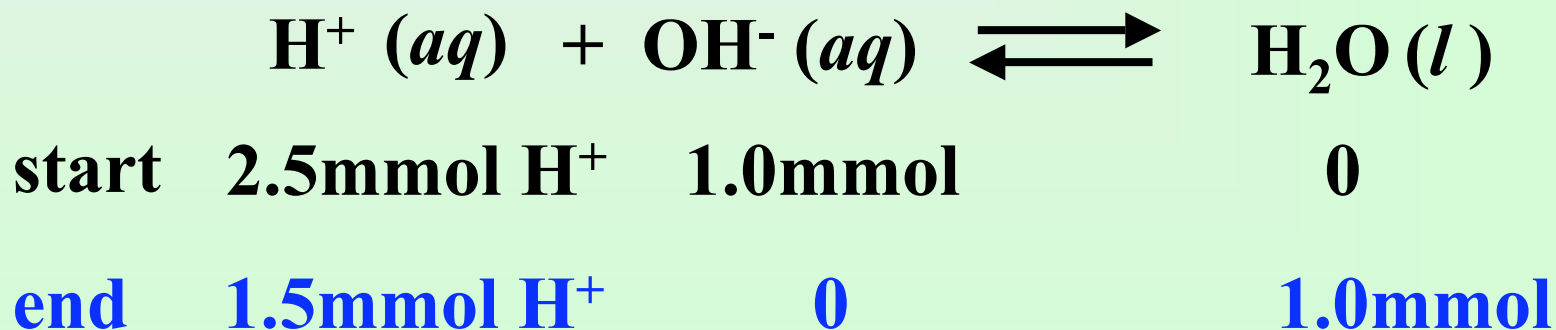


Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 10.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?

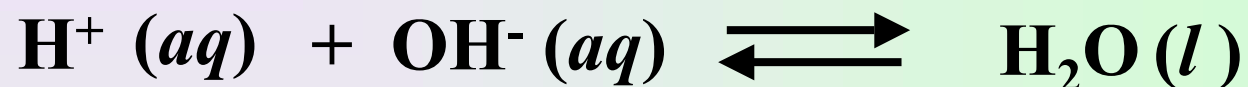
$$10\text{ml} \times \frac{0.1\text{mmol NaOH}}{\text{mL}} = 1.0\text{mmol OH}^-$$

$$25\text{ml} \times \frac{0.1\text{mmol HCl}}{\text{mL}} = 2.5\text{mmol H}^+$$



Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 10.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?



$$[\text{H}^+] = \frac{1.5 \text{ mmol H}^+}{35.0 \text{ mL (solution)}} = 4.28 \times 10^{-2} \text{ M}$$

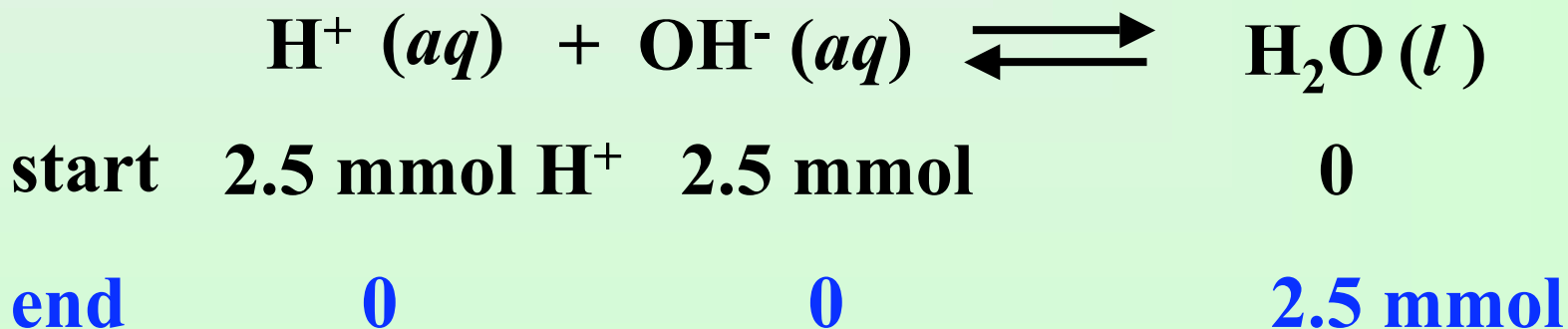
$$\text{pH} = 1.37$$

Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 25.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?

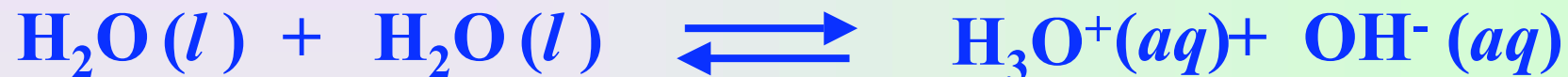
$$25\text{ml} \times \frac{0.1\text{mmol NaOH}}{\text{mL}} = 2.5\text{mmol OH}^-$$

$$25\text{ml} \times \frac{0.1\text{mmol HCl}}{\text{mL}} = 2.5\text{mmol H}^+$$



Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 25.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?

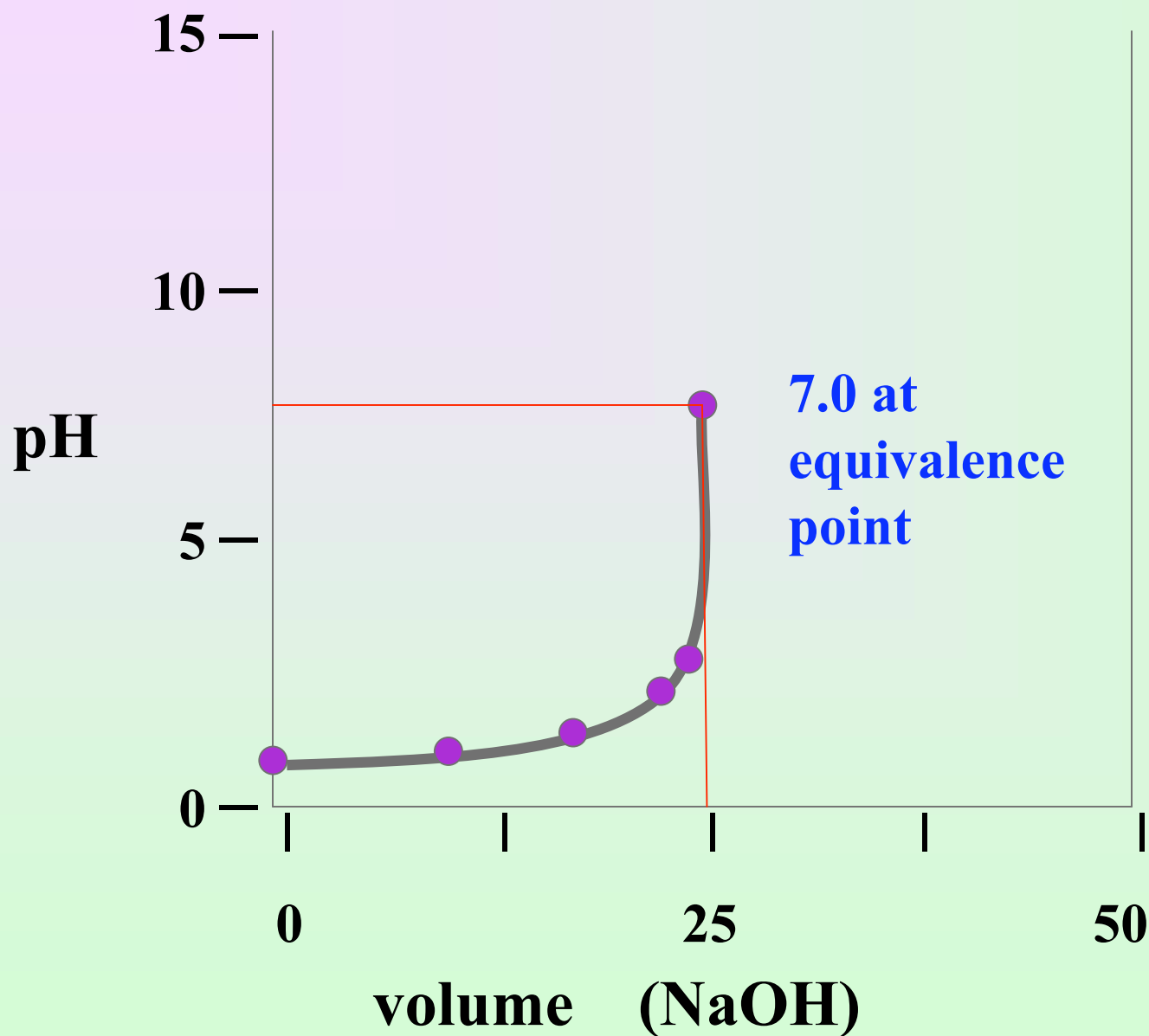


$$[\text{H}^+] = 1.0 \times 10^{-7} \text{ M}$$

$$\text{pH} = 7.0$$

pH versus ml 0.10 M NaOH added

volume (NaOH)	volume (total)	mmol (HCl)	[H⁺] <i>M</i>	pH
0	25.0ml	2.5	0.10	1.00
10.0 ml	35.0 ml	1.5	0.043	1.37
20.0 ml	45.0 ml	0.5	0.011	1.95
24.0 ml	49.0 ml	0.1	0.002	2.69
24.5 ml	49.5 ml	0.05	0.001	3.00
25.0 ml	50.0 ml	0	10⁻⁷	7.00



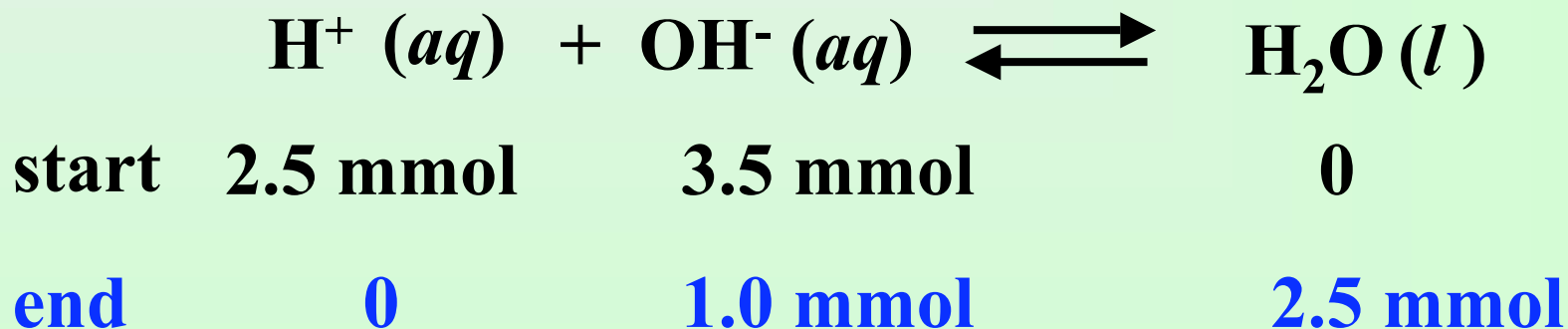
**Titration of
25.00 ml of
0.100 M
HCl with
0.100 M
NaOH**

Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 35.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?

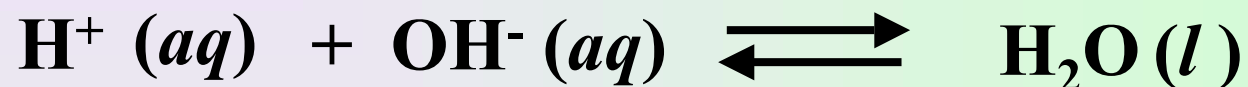
$$35\text{ml} \times \frac{0.1\text{mmol NaOH}}{\text{mL}} = 3.5\text{mmol OH}^-$$

$$25\text{ml} \times \frac{0.1\text{mmol HCl}}{\text{mL}} = 2.5\text{mmol H}^+$$



Titration Involving a Strong Acid and a Strong Base

What is the pH after the addition of 35.0 mL of 0.100 M NaOH to 25.0 mL of 0.100 M HCl ?



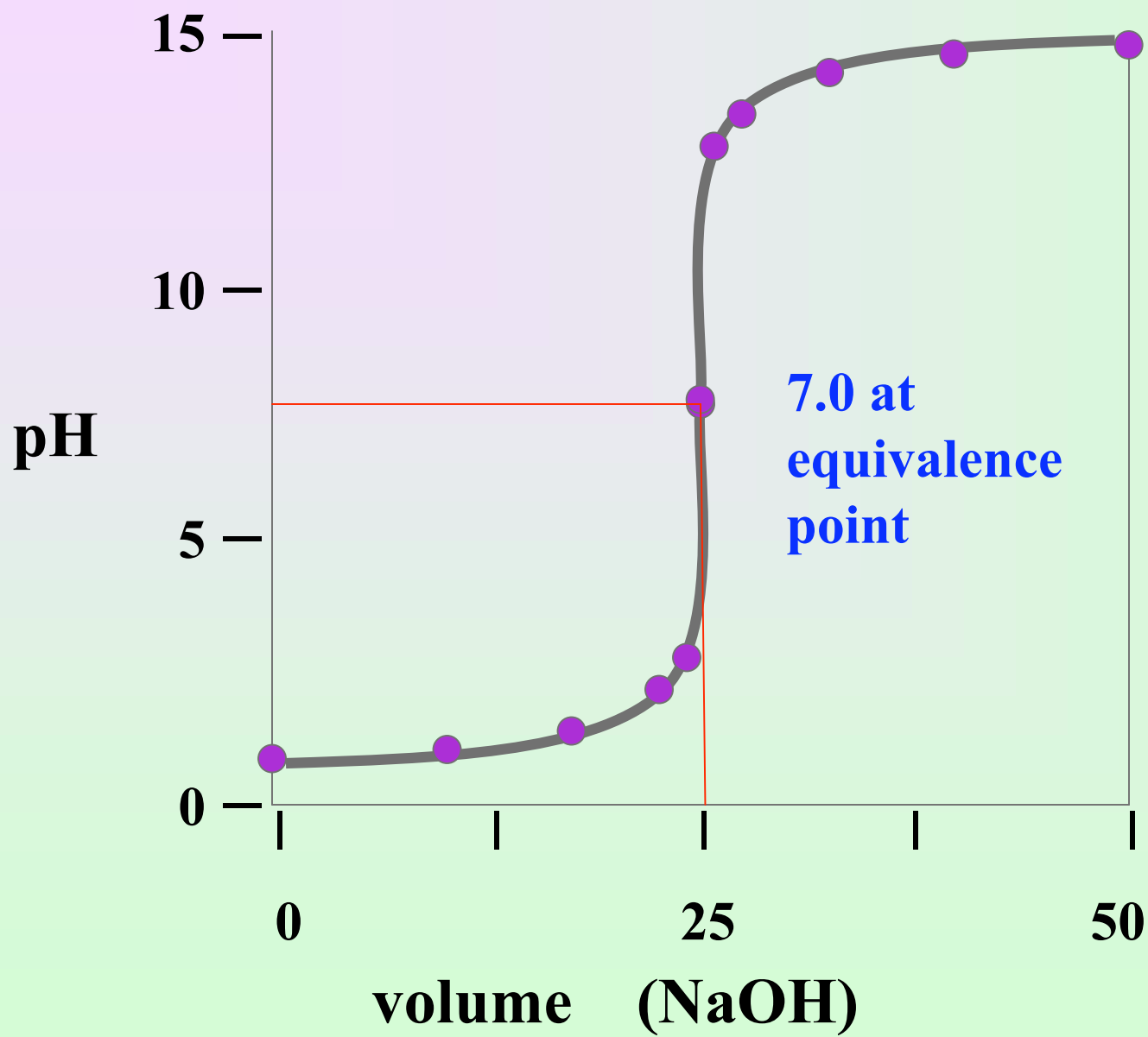
$$[\text{OH}^-] = \frac{1.0 \text{ mmol OH}^-}{60.0 \text{ mL (solution)}} = 1.66 \times 10^{-2} \text{ M}$$

$$\text{pOH} = 1.78$$

$$\text{pH} = 12.22$$

pH versus ml 0.10 M NaOH added

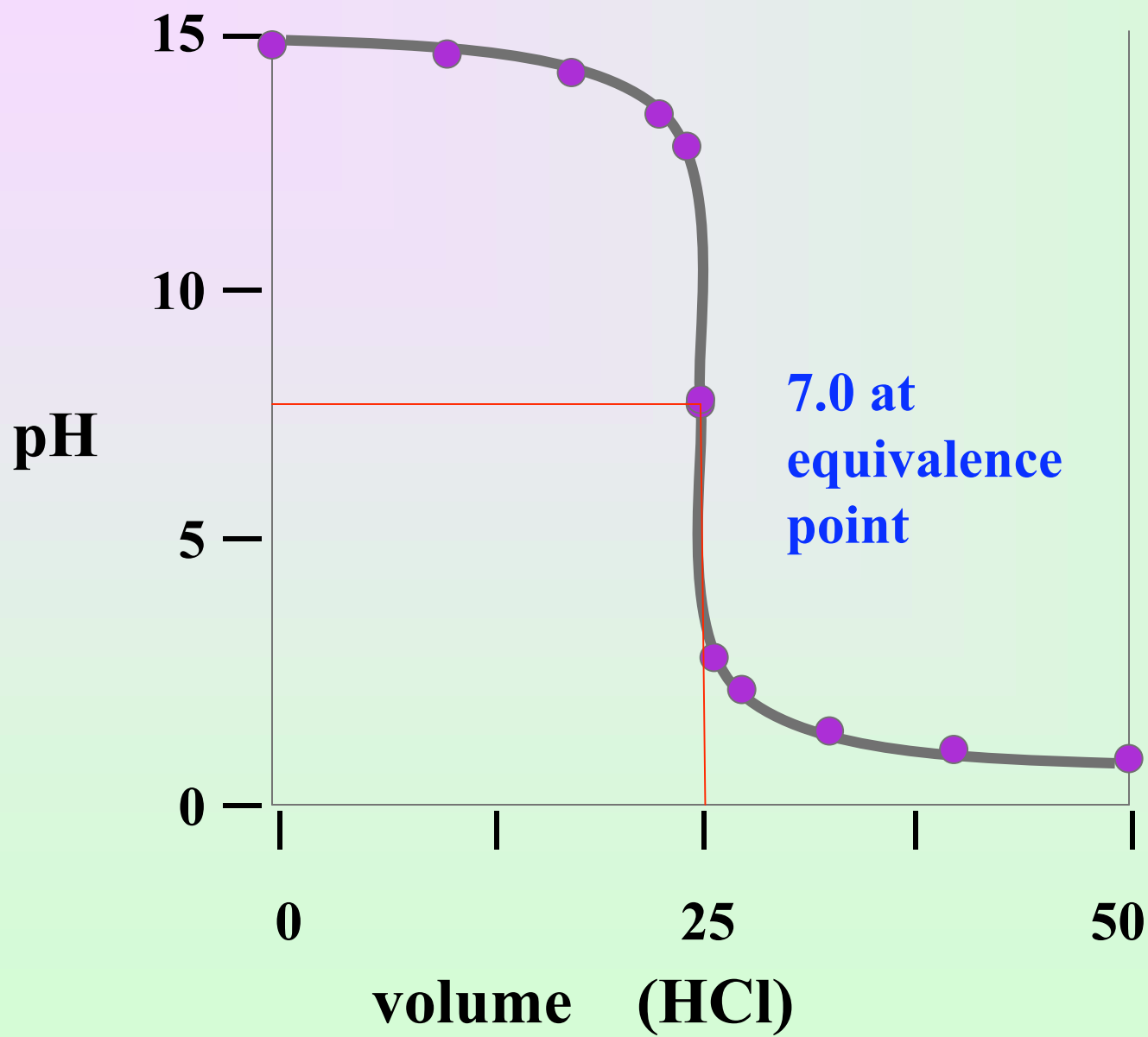
volume (NaOH)	volume (total)	mmol (HCl)	[H ⁺] <i>M</i>	pH
25.0 ml	50.0ml	0	10 ⁻⁷	7.00
		mmol (NaOH)	[OH⁻] <i>M</i>	
25.5 ml	50.5 ml	0.05	0.001	11.00
26.0 ml	51.5 ml	0.10	0.002	11.29
30.0 ml	55.0 ml	0.50	0.009	11.96
40.5 ml	65.0 ml	1.50	0.023	12.36
50.0 ml	75.0 ml	2.50	0.033	12.52



**Titration of
25.00 ml of
0.100 M
HCl with
0.100 M
NaOH**

Titration Involving a Strong Base and a Strong Acid

just the opposite of the case we have just discussed

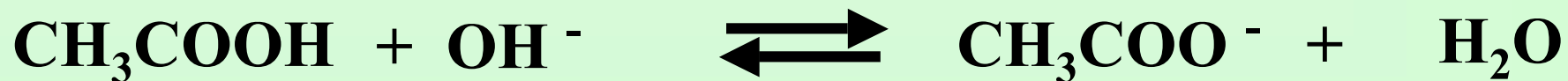
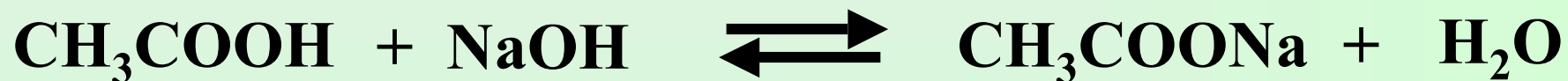


**Titration of
25.00 ml of
0.100 M
HCl with
0.100 M
NaOH**

Titration Involving a weak Acid and a Strong Base

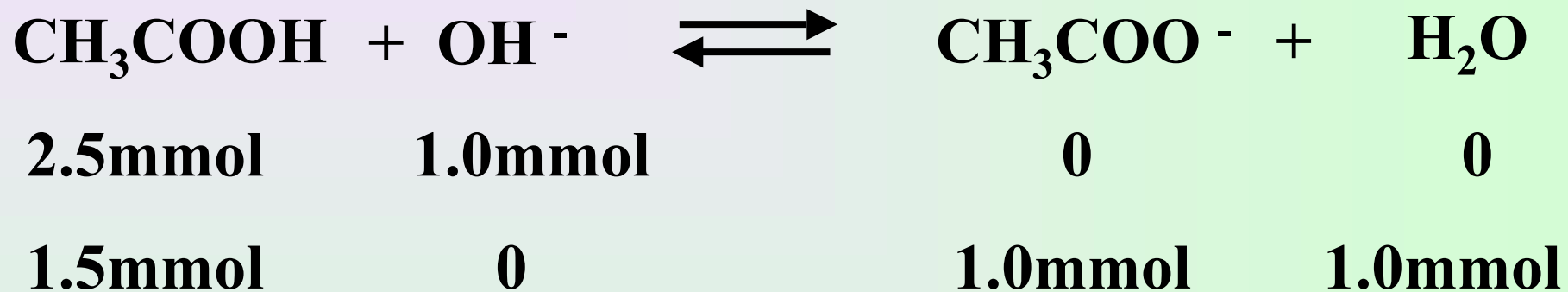
Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (a) 10.00 mL of 0.100 M NaOH, (b) 25.0 mL of 0.100 M NaOH, and (c) 35.0 mL of 0.100 M NaOH.

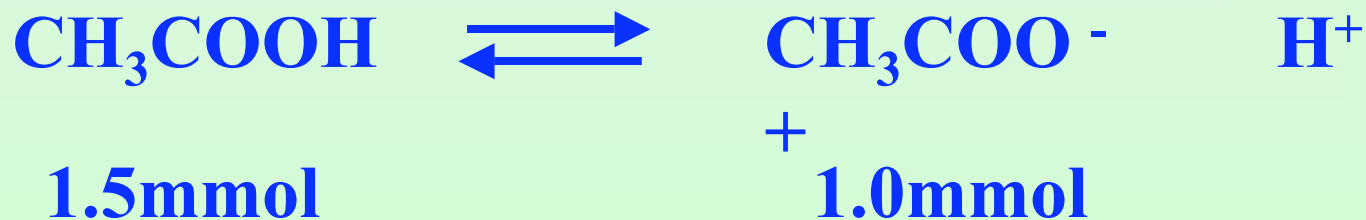


Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (a) 10.00 mL of 0.100 M NaOH.

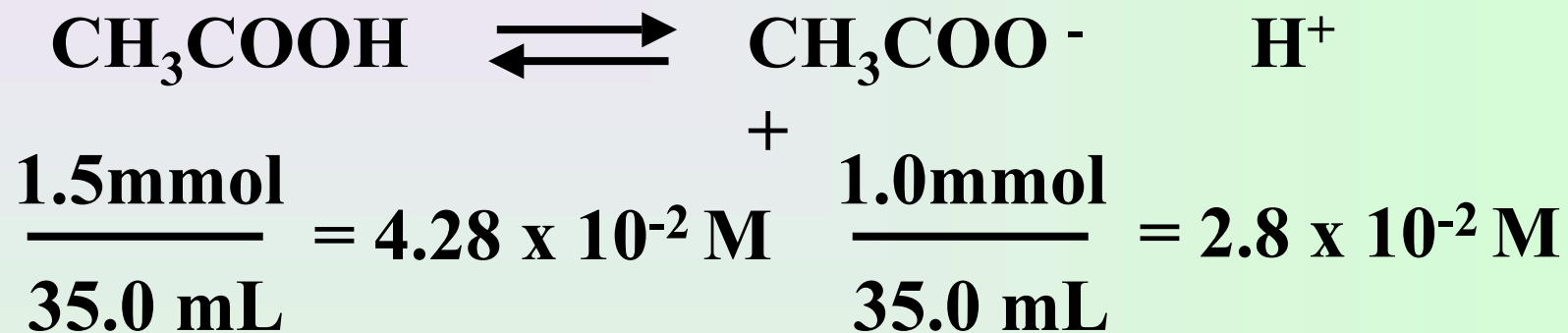


$$K_a = 1.8 \times 10^{-5}$$



Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (a) 10.00 mL of 0.100 M NaOH.



$$K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}^+]}{[\text{CH}_3\text{COOH}]} \quad [\text{H}^+] = \frac{[\text{CH}_3\text{COOH}] K_a}{[\text{CH}_3\text{COO}^-]}$$

Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (a) 10.00 mL of 0.100 M NaOH.

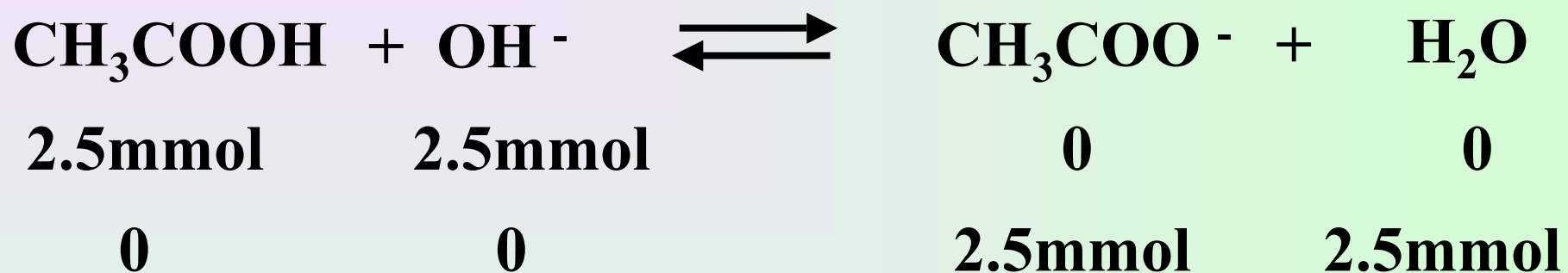


$$[\text{H}^+] = \frac{(4.2 \times 10^{-2} \text{ M})(1.8 \times 10^{-5})}{2.8 \times 10^{-2} \text{ M}} = 2.7 \times 10^{-5}$$

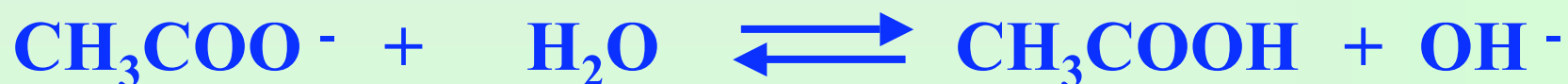
$$\text{pH} = 4.57$$

Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (b) 25.0 mL of 0.100 M NaOH.



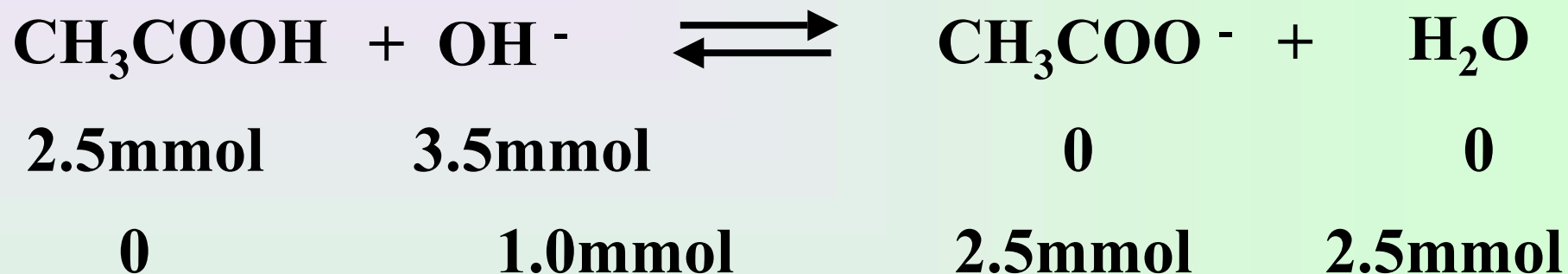
$$K_b = 5.6 \times 10^{-10}$$



$$\frac{2.5\text{mmol}}{50.0 \text{ mL}} = 5.0 \times 10^{-2} \text{ M}$$

Titration Involving a weak Acid and a Strong Base

Calculate the pH in the titration of 25.0 mL of 0.100 M acetic acid with 0.100 M NaOH after adding (c) 35.0 mL of 0.100 M NaOH.



$$\frac{1.0\text{mmol OH}^-}{60.0 \text{ mL (solution)}}$$

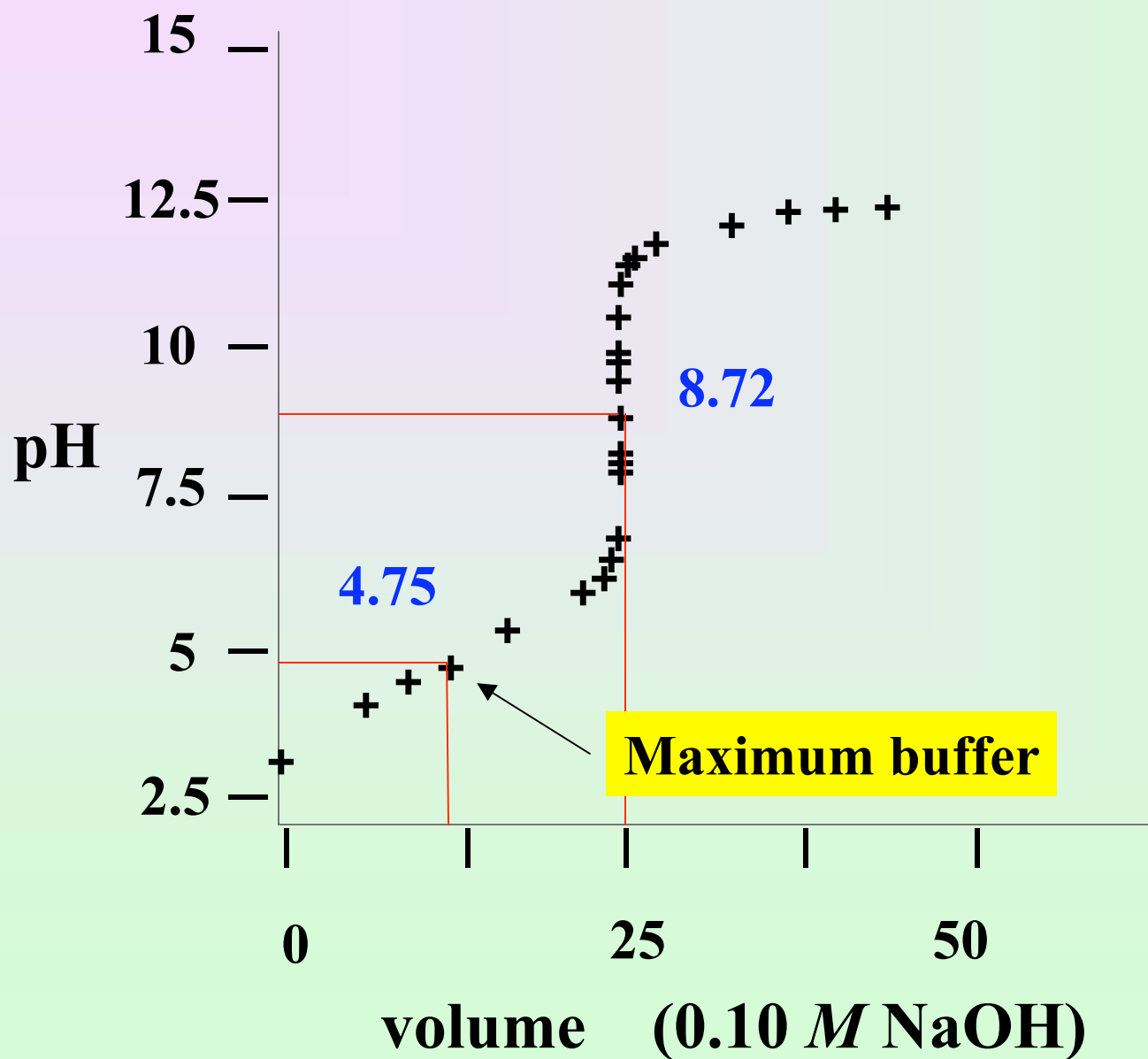
$$= 1.67 \times 10^{-2} \text{ M}$$

$$\text{pOH} = 1.78$$

$$\text{pH} = 12.22$$

pH versus ml 0.10 M NaOH added

volume (NaOH)	volume (total)	mmol (HOAc)	mmol (NaOAc)	[H⁺]	pH
0 ml	25.0ml	2.5	0	1.3 x 10⁻³	2.87
10.0 ml	35.5 ml	1.5	1	2.7 x 10⁻⁵	4.57
25.0 ml	50.0 ml	0	2.5	1.9 x 10⁻⁹	8.72
			mmol (NaOH)	[OH⁻]	
35.0 ml	60.0 ml	0	1	1.7 x 10⁻²	12.22

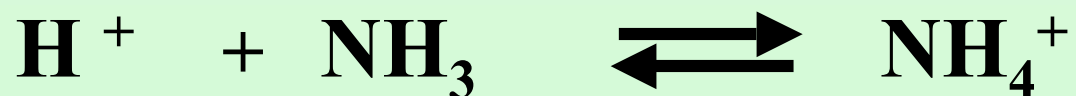
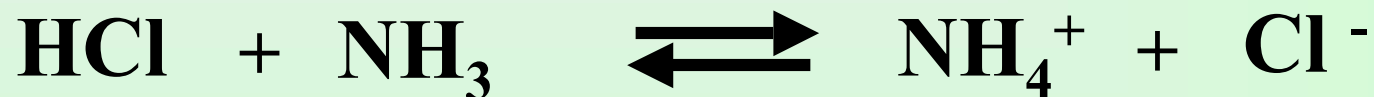


**Titration of
25.0 ml of
0.10 M
acetic acid
with 0.10 M
NaOH**

Titration Involving a Strong Acid and a Weak Base

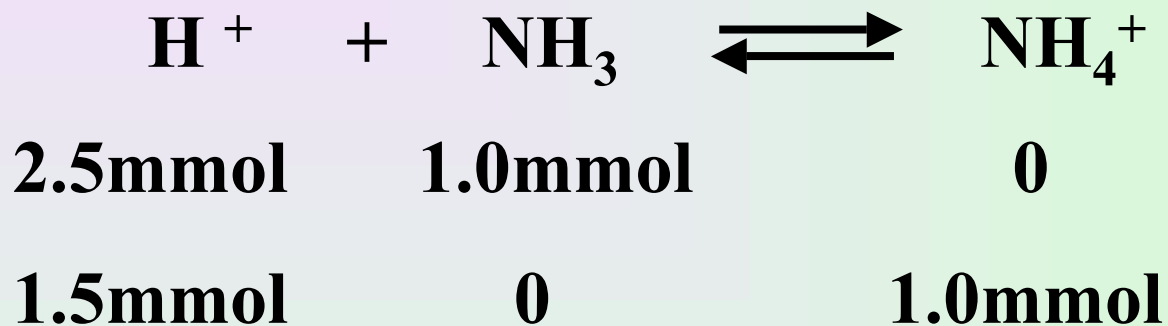
Titration Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (a) 10.00 mL of 0.100 M NH₃, (b) 25.0 mL of 0.100 M NH₃, and (c) 35.0 mL of 0.100 M NH₃.



Titration Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (a) 10.00 mL of 0.100 M NH₃.

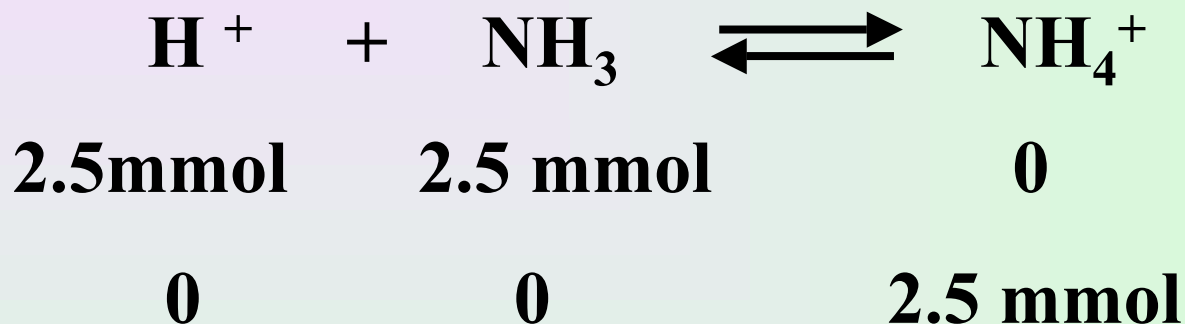


$$[\text{H}^+] = \frac{1.5 \text{ mmol H}^+}{35.0 \text{ mL}} = 4.29 \times 10^{-2}$$

$$\text{pH} = 1.37$$

Titration Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (b) 25.0 mL of 0.100 M NH₃.



$$K_a = 5.6 \times 10^{-10}$$



$$\frac{2.5\text{mmol}}{50.0\text{ mL}} = 5.0 \times 10^{-2}\text{M}$$

Titration Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (b) 25.0 mL of 0.100 M NH₃.

$$K_a = 5.6 \times 10^{-10}$$



$$5.0 \times 10^{-2} - x \qquad x \qquad x$$

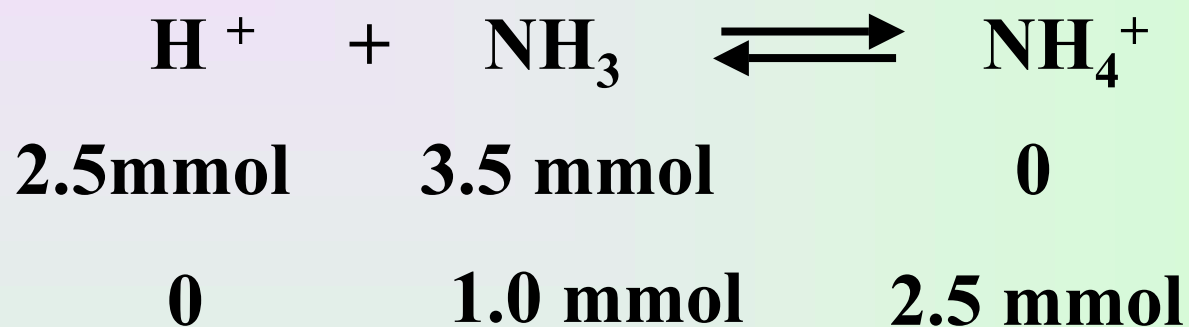
$$5.6 \times 10^{-10} = \frac{x^2}{(5.0 \times 10^{-2} - x)}$$

$$[\text{H}^+] = x = 5.29 \times 10^{-6}$$

$$\text{pH} = 5.28$$

Titrations Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (c) 35.0 mL of 0.100 M NH₃.



$$K_a = 5.6 \times 10^{-10}$$



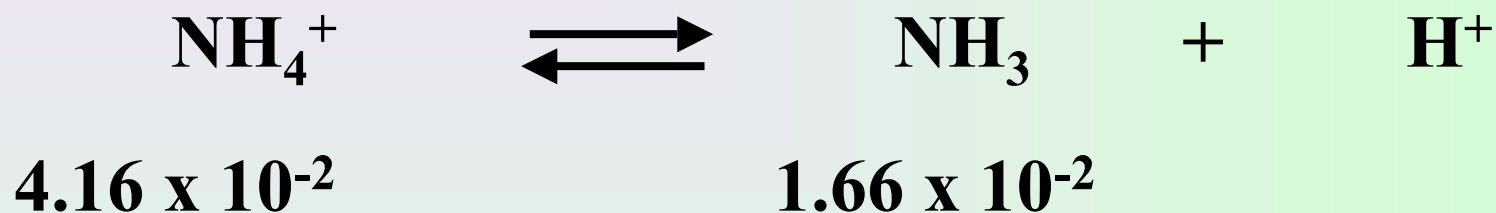
$$\frac{2.5\text{mmol}}{60.0\text{ mL}} = 4.1 \times 10^{-2}\text{M}$$

$$\frac{1.0\text{mmol}}{60.0\text{ mL}} = 1.66 \times 10^{-2}\text{M}$$

Titration Involving a Strong Acid and a Weak Base

Calculate the pH in the titration of 25.0 mL of 0.100 M HCl with 0.100 M NH₃ after adding (c) 35.0 mL of 0.100 M NH₃.

$$K_a = 5.6 \times 10^{-10}$$

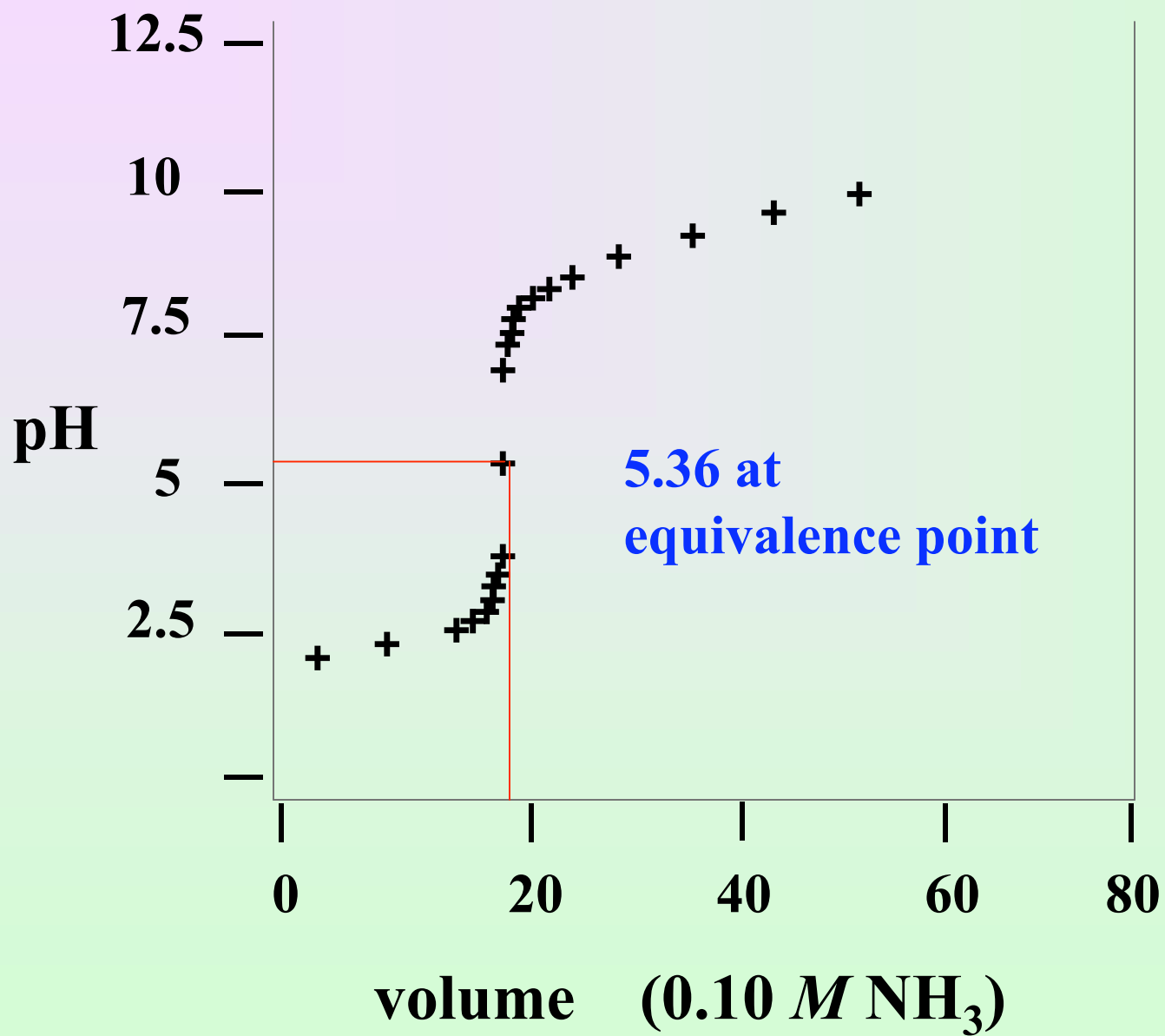


$$[\text{H}^+] = \frac{[\text{NH}_4^+] K_a}{[\text{NH}_3]} = \frac{(4.16 \times 10^{-2})(5.6 \times 10^{-10})}{1.66 \times 10^{-2}} = 1.4 \times 10^{-9}$$

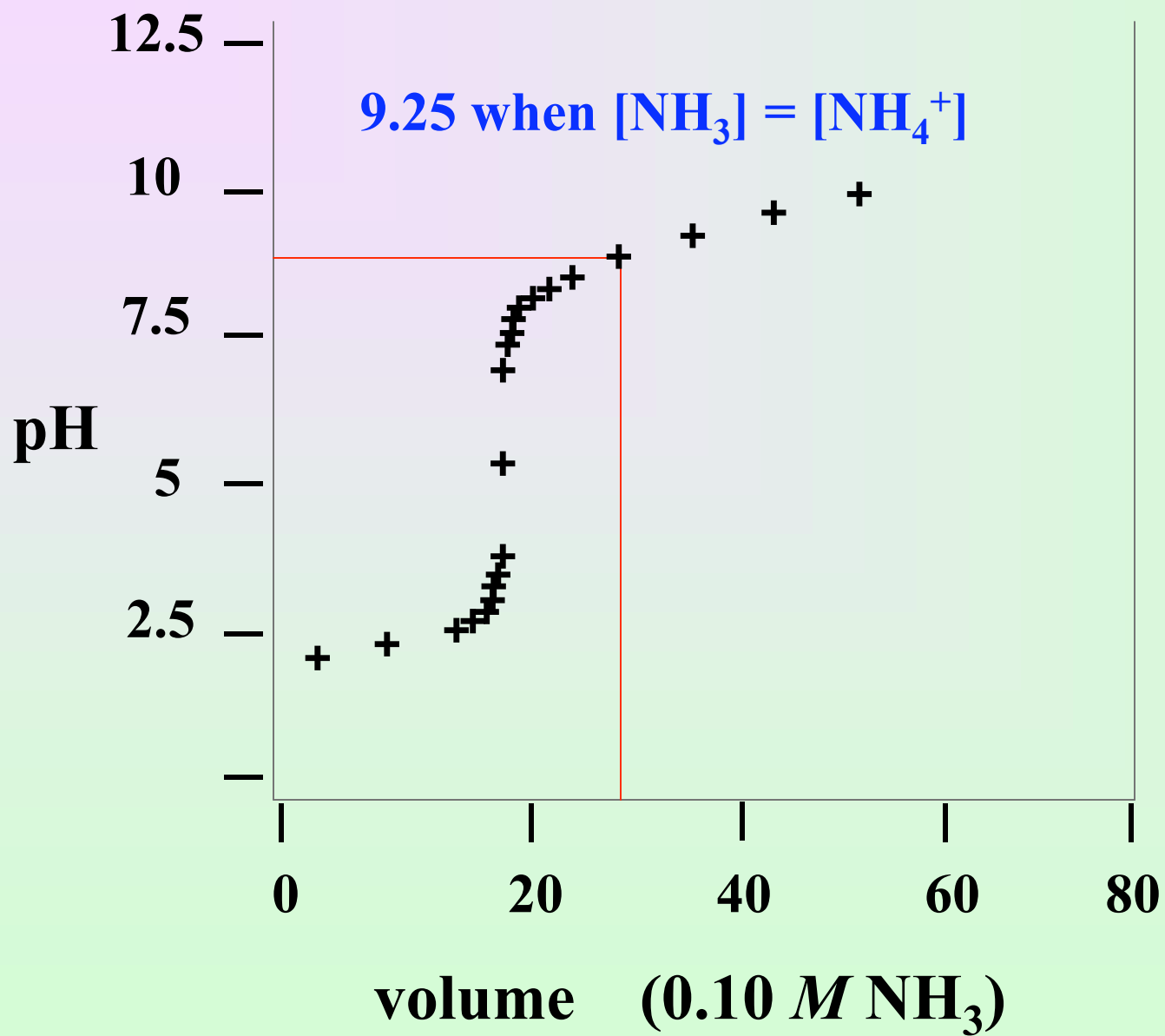
$$\text{pH} = 8.85$$

pH versus ml 0.10 M NH₃ added

volume (NH₃)	volume (total)	mmol (HCl)	[H⁺]	pH
0 ml	25.0ml	2.5	0.1	1.0
10.0 ml	35.0 ml	1.5	0.0429	1.37
		mmol (NH₄⁺)	mmol (NH₃)	
25.0 ml	50.0 ml	2.5	0	5.28
35.0 ml	60.0 ml	2.5	1	8.85



**Titration of
25.0 ml of
0.10 M HCl
acid with
0.10 M NH₃**



**Titration of
25.0 ml of
0.10 M HCl
acid with
0.10 M NH₃**