

Titration Problems

- 1) A 0.15 M solution of NaOH is used to titrate 200. mL of 0.15 M HCN. What is the pH at the equivalence point? ($K_a = 4.9 \times 10^{-10}$)

- 2) A 0.25 M solution of HCl is used to titrate 0.25 M NH_3 . What is the pH at the equivalence point? ($K_b = 1.8 \times 10^{-5}$)

- 3) What volume of 0.175 M solution of KOH is needed to titrate 30.0 mL of 0.200 M H_2SO_4 ?

- 4) 35.0 mL of a 0.040 M aqueous solution of perchloric acid reacts with 40.0 mL of a 0.090 M aqueous solution of lithium hydroxide. What is the pH of the solution?

- 5) A 25.0 cm^3 sample of vinegar, $\text{HC}_2\text{H}_3\text{O}_2$, is neutralized by using 37.38 cm^3 of a 0.500 M NaOH solution. Calculate:
 - (a) the concentration of the vinegar.
 - (b) the mass of vinegar in 1.00 dm^3 .
 - (c) the mass percent of the vinegar assuming a density of 1.00 g/cm^3 .

Solutions

1) **[HCN] = 0.15 M** **[NaOH] = 0.15 M**

$V_a = 200. \text{ mL}$ **$K_a = 4.9 \times 10^{-10}$**

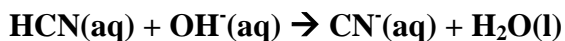
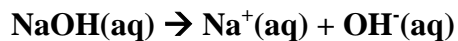
$[\text{HCN}] = n_a/V_a$

$n_a = [\text{HCN}] \times V_a$

$n_a = 0.15 \text{ mol HCN}/1 \text{ L} \times 200. \text{ mL} \times 1 \text{ L}/10^3 \text{ mL} = 0.030 \text{ mol HCN}$

$[\text{NaOH}] = n_b/V_b$

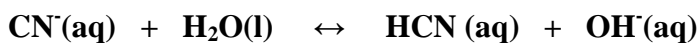
**$V_b = n_b/[\text{NaOH}] = 0.030 \text{ mol NaOH}/0.15 \text{ M} = 0.20 \text{ L} \times 10^3 \text{ mL}/1 \text{ L}$
 $= 2.0 \times 10^2 \text{ mL NaOH}$**



mol before rxn:	0.030	0.030	0
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mol after rxn:	0	0	0.030
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$[\text{CN}^-] = n/V = 0.030 \text{ mol CN}^-/(400. \text{ mL} \times 1 \text{ L}/10^3 \text{ mL}) = 0.075 \text{ M}$



[]_i	0.075	0	0
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[]_c	-x	+x	+x
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[]_e	0.075 - x	x	x
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$$K_a \times K_b = K_w = 1.00 \times 10^{-14}$$

$$K_b = K_w/K_a = (1.00 \times 10^{-14})/(4.9 \times 10^{-10}) = 2.0 \times 10^{-5}$$

$$K_b = [\text{HCN}] \times [\text{OH}^-]/[\text{CN}^-]$$

$$2.0 \times 10^{-5} = x \cdot x/(0.075 - x) \approx x^2/0.075$$

$$[\text{OH}^-] = 1.2 \times 10^{-3} \text{ M}$$

$$\% \text{ ion} = [\text{HCN}]/[\text{CN}^-] \times 100\%$$

$$\% \text{ ion} = (1.2 \times 10^{-3} \text{ M})/(0.075 \text{ M}) \times 100\% = 1.6\%$$

Because the % ion < 5%, $0.075 - x \approx 0.075$ is a valid assumption.

$$K_w = [\text{H}^+] \times [\text{OH}^-]$$

$$[\text{H}^+] = K_w/[\text{OH}^-] = (1.00 \times 10^{-14})/(1.2 \times 10^{-3}) = 8.3 \times 10^{-12}$$

$$\text{pH} = -\log[\text{H}^+] = -\log(8.3 \times 10^{-12}) = \mathbf{11.08}$$

2) $[\text{HCl}] = 0.25 \text{ M}$ $K_b = 1.8 \times 10^{-5}$

$[\text{NH}_3] = 0.25 \text{ M}$

Assume $V_a = V_b = 100. \text{ mL}$.

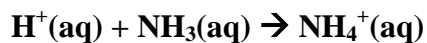
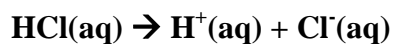
$[\text{HCl}] = n_a/V_a$

$n_a = [\text{HCl}] \times V_a$

$n_a = 0.25 \text{ mol HCl}/1 \text{ L} \times 100. \text{ mL} \times 1 \text{ L}/10^3 \text{ mL} = 0.025 \text{ mol HCl}$

$[\text{NH}_3] = n_b/V_b$

$n_b = [\text{NH}_3] \times V_b = 0.025 \text{ mol NH}_3$



mol before rxn: 0.025 0.025 0

mol after rxn: 0 0 0.025

$[\text{NH}_4^+] = n/V = 0.025 \text{ mol NH}_4^+/(200. \text{ mL} \times 1 \text{ L}/10^3 \text{ mL}) = 0.12 \text{ M}$

$K_a \times K_b = K_w = 1.00 \times 10^{-14}$

$K_a = K_w/K_b = (1.00 \times 10^{-14})/(1.8 \times 10^{-5}) = 5.6 \times 10^{-10}$



[]_i 0.12 0 0

[]_c -x +x +x

[]_e 0.12 - x x x

$$K_a = [\text{H}^+] \times [\text{NH}_3]/[\text{NH}_4^+]$$

$$5.6 \times 10^{-10} = x \cdot x/(0.12 - x) \approx x^2/0.12$$

$$[\text{H}^+] = 8.2 \times 10^{-6} \text{ M}$$

$$\% \text{ ion} = [\text{H}^+]/[\text{NH}_4^+] \times 100\%$$

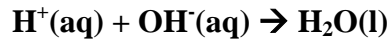
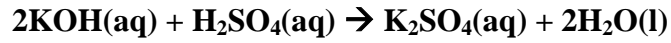
$$\% \text{ ion} = (8.2 \times 10^{-6} \text{ M})/(0.12 \text{ M}) \times 100\% = 6.8 \times 10^{-3}\%$$

Because the % ion < 5%, $0.12 - x \approx 0.12$ is a valid assumption.

$$\text{pH} = -\log[\text{H}^+] = -\log(8.2 \times 10^{-6}) = \mathbf{5.09}$$

3) $[\text{KOH}] = 0.175 \text{ M}$ $[\text{H}_2\text{SO}_4] = 0.200 \text{ M}$

$V_b = ?$ $V_a = 30.0 \text{ mL}$



$$[\text{H}_2\text{SO}_4] = n_a/V_a$$

$$n_a = n_b$$

$$[\text{H}_2\text{SO}_4] \times V_a = [\text{KOH}] \times V_b$$

$$0.200 \text{ mol H}_2\text{SO}_4/\text{L} \times 30.0 \text{ mL} \times 1 \text{ L}/10^3 \text{ mL} \times 2 \text{ mol H}^+/1 \text{ mol H}_2\text{SO}_4 =$$

$$0.175 \text{ mol KOH}/\text{L} \times V_b \times 1 \text{ mol OH}^-/1 \text{ mol KOH}$$

$$V_b = 0.0686 \text{ L} \times 10^3 \text{ mL}/\text{L} = \mathbf{68.6 \text{ mL KOH}}$$

4) $[\text{HClO}_4] = 0.040 \text{ M}$ $[\text{LiOH}] = 0.090 \text{ M}$

$V_a = 35.0 \text{ mL}$ $V_b = 40.0 \text{ mL}$

$$[\text{HClO}_4] = n_a/V_a$$

$$n_a = [\text{HClO}_4] \times V_a$$

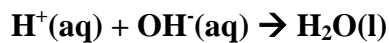
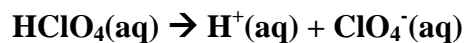
$$n_a = 0.040 \text{ mol HClO}_4 / 1 \text{ L} \times 35.0 \text{ mL} \times 1 \text{ L} / 10^3 \text{ mL} \times 1 \text{ mol H}^+ / 1 \text{ mol HClO}_4$$

$$n_a = 0.0014 \text{ mol H}^+$$

$$[\text{LiOH}] = n_b/V_b$$

$$n_b = 0.090 \text{ mol LiOH} / 1 \text{ L} \times 40.0 \text{ mL} \times 1 \text{ L} / 10^3 \text{ mL} \times 1 \text{ mol OH}^- / 1 \text{ mol LiOH}$$

$$n_b = 0.0036 \text{ mol OH}^-$$



mol before rxn:	0.0014	0.0036
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mol after rxn:	0	0.0022
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$$[\text{OH}^-] = n/V = 0.0022 \text{ mol OH}^- / (75.0 \text{ mL} \times 1 \text{ L} / 10^3 \text{ mL}) = 0.029 \text{ M}$$

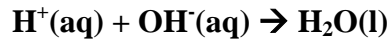
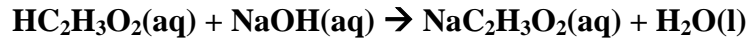
$$\text{pH} = -\log[\text{OH}^-] = -\log(0.029) = 1.54$$

$$\text{pH} + \text{pOH} = 14.00$$

$$\text{pH} = 14.00 - \text{pOH} = 14.00 - 1.54 = \mathbf{12.46}$$

5) $[\text{HC}_2\text{H}_3\text{O}_2] = ?$ $[\text{NaOH}] = 0.500 \text{ M}$

$V_a = 25.0 \text{ cm}^3$ $V_b = 37.38 \text{ cm}^3$



(a) $[\text{HC}_2\text{H}_3\text{O}_2] = n_a/V_a$ $[\text{NaOH}] = n_b/V_b$

$$n_a = n_b$$

$$[\text{HC}_2\text{H}_3\text{O}_2] \times V_a = [\text{NaOH}] \times V_b$$

$$[\text{HC}_2\text{H}_3\text{O}_2] = [\text{NaOH}] \times V_b/V_a$$

$$[\text{HC}_2\text{H}_3\text{O}_2] = 0.500 \text{ M} \times 37.38 \text{ cm}^3/25.0 \text{ cm}^3 = \mathbf{0.748 \text{ M}}$$

(b) $[\text{HC}_2\text{H}_3\text{O}_2] = n_a/V_a$

$$n_a = [\text{HC}_2\text{H}_3\text{O}_2] \times V_a$$

$$n_a = 0.748 \text{ mol HC}_2\text{H}_3\text{O}_2/\text{L} \times 1.00 \text{ dm}^3 \times 1 \text{ L}/1 \text{ dm}^3 = 0.748 \text{ mol HC}_2\text{H}_3\text{O}_2$$

$$m_a = 0.748 \text{ mol HC}_2\text{H}_3\text{O}_2 \times 60.06 \text{ g HC}_2\text{H}_3\text{O}_2/1 \text{ mol HC}_2\text{H}_3\text{O}_2$$

$$m_a = \mathbf{44.9 \text{ g HC}_2\text{H}_3\text{O}_2}$$

(c) $D = M/V$

$$M = D \times V = 1.00 \text{ g/cm}^3 \times 1.00 \text{ L} \times 10^3 \text{ cm}^3/1 \text{ L} = 1.00 \times 10^3 \text{ g}$$

$$m\% = m_a/m_{\text{soln}} \times 100\% = 44.9 \text{ g}/(1.00 \times 10^3 \text{ g}) \times 100\% = \mathbf{4.49\%}$$