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, $HC_2H_3O_2$, 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. mL $K_a = 4.9 \times 10^{-10}$

[HCN] = n_a/V_a

n_a = [HCN] x V_a

n_a = 0.15 mol HCN/1 ~~L~~ x 200. ~~mL~~ x 1 ~~L~~/10^3 ~~mL~~ = 0.030 mol HCN

[NaOH] = n_b/V_b

V_b = n_b/[NaOH] = 0.030 mol NaOH/0.15 M = 0.20 ~~L~~ x 10^3 mL/1 ~~L~~

= 2.0×10^2 mL NaOH

$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

	$HCN(aq)$	$+ OH^-(aq)$	$\rightarrow CN^-(aq) + H_2O(l)$
mol before rxn:	0.030	0.030	0
mol after rxn:	0	0	0.030

$[CN^-]$ = n/V = 0.030 mol CN^-/(400. ~~mL~~ x 1 L/10^3 ~~mL~~) = 0.075 M

	$CN^-(aq)$ + $H_2O(l)$	$\leftrightarrow$	$HCN(aq)$	+ $OH^-(aq)$
$[\ ]_i$	0.075		0	0
$[\ ]_c$	-x		+x	+x
$[\ ]_e$	0.075 - x		x	x

K_a x K_b = K_w = 1.00 x 10^{-14}

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

K_b = [HCN] x [OH^-]/[CN^-]

2.0 x 10^{-5} = x · x/(0.075 - x) ≈ x^2/0.075

[OH^-] = 1.2 x 10^{-3} M

% ion = [HCN]/[CN^-] x 100%

% ion = (1.2 x 10^{-3} ~~M~~)/(0.075 ~~M~~) x 100% = 1.6%

Because the % ion < 5%, 0.075 - x ≈ 0.075 is a valid assumption.

K_w = [H^+] x [OH^-]

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

pH = -log[H^+] = -log(8.3 x 10^{-12}) = 11.08

2) **[HCl] = 0.25 M** **K_b = 1.8 x 10^{-5}**

$[NH_3]$ = 0.25 M

Assume $V_a = V_b$ = 100. mL.

[HCl] = n_a/V_a

n_a = [HCl] x V_a

n_a = 0.25 mol HCl/1 ~~L~~ x 100. ~~mL~~ x 1 ~~L~~/10^3 ~~mL~~ = 0.025 mol HCl

$[NH_3] = n_b/V_b$

$n_b = [NH_3]$ x V_b = 0.025 mol NH_3

HCl(aq) → H^+(aq) + Cl^-(aq)

	H^+(aq) +	NH_3(aq) →	NH_4^+(aq)
mol before rxn:	**0.025**	**0.025**	**0**
mol after rxn:	**0**	**0**	**0.025**

$[NH_4^+]$ = n/V = 0.025 mol NH_4^+/(200. ~~mL~~ x 1 L/10^3 ~~mL~~) = 0.12 M

K_a x K_b = K_w = 1.00 x 10^{-14}

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

	NH_4^+ (aq) ↔	H^+(aq) +	NH_3(aq)
$[\ ]_i$	**0.12**	**0**	**0**
$[\ ]_c$	**-x**	**+x**	**+x**
$[\ ]_e$	**0.12 - x**	**x**	**x**

$K_a = [H^+] \times [NH_3]/[NH_4^+]$

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

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

% ion = $[H^+]/[NH_4^+] \times 100\%$

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

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

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

3) **[KOH] = 0.175 M** **$[H_2SO_4]$ = 0.200 M**

V_b = ? **V_a = 30.0 mL**

$2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

$[H_2SO_4] = n_a/V_a$

$n_a = n_b$

$[H_2SO_4] \times V_a = [KOH] \times V_b$

0.200 ~~mol H_2SO_4~~/L x 30.0 ~~mL~~ x 1 L/10^3 ~~mL~~ x 2 mol H^+/1 ~~mol H_2SO_4~~ =

0.175 ~~mol KOH~~/L x V_b x 1 mol OH^-/1 ~~mol KOH~~

V_b = 0.0686 ~~L~~ x 10^3 mL/~~L~~ = 68.6 mL KOH

4) $[HClO_4] = 0.040$ M $\quad$ $[LiOH] = 0.090$ M

$V_a = 35.0$ mL $\quad$ $V_b = 40.0$ mL

$[HClO_4] = n_a/V_a$

$n_a = [HClO_4] \times V_a$

$n_a = 0.040$ ~~mol $HClO_4$~~/1 ~~L~~ x 35.0 ~~mL~~ x 1 ~~L~~/10^3 ~~mL~~ x 1 mol H^+/1 ~~mol HClO4~~

$n_a = 0.0014$ mol H^+

$[LiOH] = n_b/V_b$

$n_b = 0.090$ ~~mol LiOH~~/1 ~~L~~ x 40.0 ~~mL~~ x 1 ~~L~~/10^3 ~~mL~~ x 1 mol OH^-/1 ~~mol LiOH~~

$n_b = 0.0036$ mol OH^-

$HClO_4(aq) \rightarrow H^+(aq) + ClO_4^-(aq)$

$LiOH(aq) \rightarrow Li^+(aq) + OH^-(aq)$

	$H^+(aq)$	$+ OH^-(aq) \rightarrow H_2O(l)$
mol before rxn:	0.0014	0.0036
mol after rxn:	0	0.0022

$[OH^-]$ = n/V = 0.0022 mol OH^-/(75.0 ~~mL~~ x 1 L/10^3 ~~mL~~) = 0.029 M

pH = -log$[OH^-]$ = -log(0.029) = 1.54

pH + pOH = 14.00

pH = 14.00 – pOH = 14.00 – 1.54 = 12.46

5) $[HC_2H_3O_2] = ?$ $[NaOH] = 0.500\ M$

$V_a = 25.0\ cm^3$ $V_b = 37.38\ cm^3$

$HC_2H_3O_2(aq) + NaOH(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l)$

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

(a) $[HC_2H_3O_2] = n_a/V_a$ $[NaOH] = n_b/V_b$

$n_a = n_b$

$[HC_2H_3O_2] \times V_a = [NaOH] \times V_b$

$[HC_2H_3O_2] = [NaOH] \times V_b/V_a$

$[HC_2H_3O_2] = 0.500\ M \times 37.38\ \cancel{cm^3}/25.0\ \cancel{cm^3} = 0.748\ M$

(b) $[HC_2H_3O_2] = n_a/V_a$

$n_a = [HC_2H_3O_2] \times V_a$

$n_a = 0.748\ mol\ HC_2H_3O_2/\cancel{L} \times 1.00\ \cancel{dm^3} \times 1\ \cancel{L}/1\ \cancel{dm^3} = 0.748\ mol\ HC_2H_3O_2$

$m_a = 0.748\ \cancel{mol\ HC_2H_3O_2} \times 60.06\ g\ HC_2H_3O_2/1\ \cancel{mol\ HC_2H_3O_2}$

$m_a = 44.9\ g\ HC_2H_3O_2$

(c) $D = M/V$

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

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