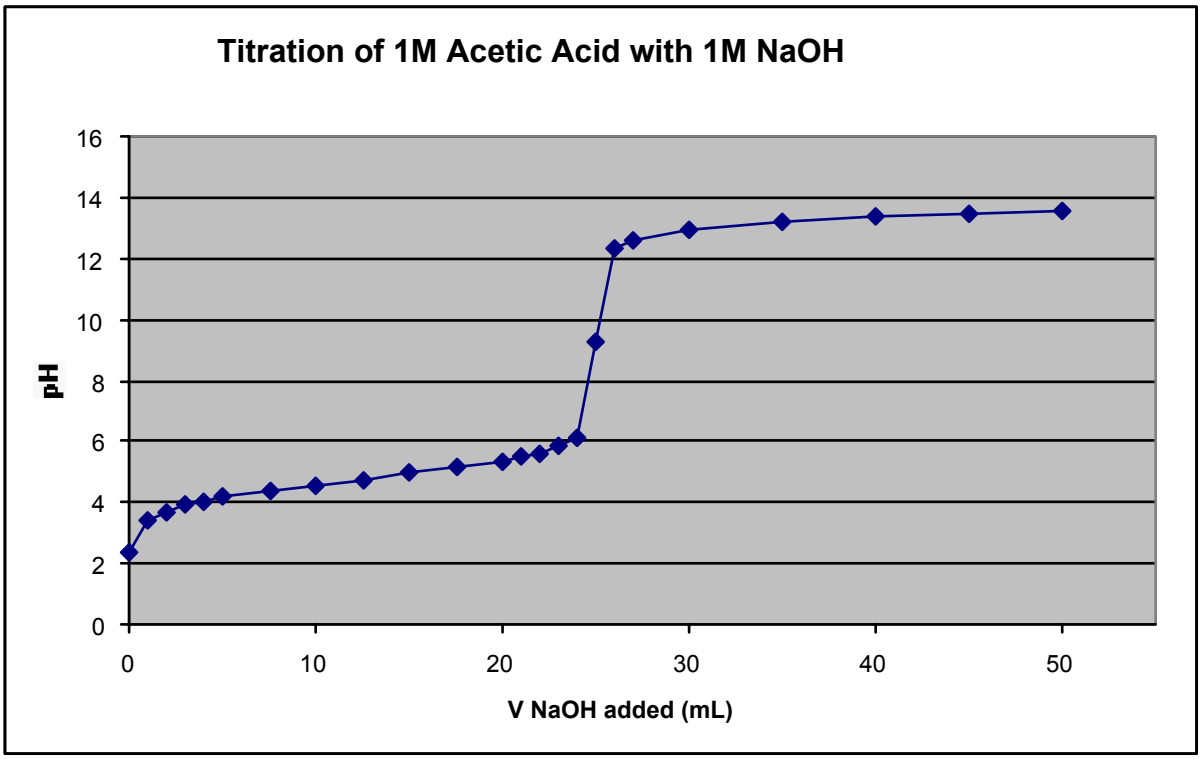
Lecture Notes S: Acid Base Chemistry VI

Titration of weak acids with strong bases

Titration of 25 mL of 1M acetic acid (HAc) with a solution of 1M NaOH



The process:

mL	pH	[H3O+]	[OH-]	[HAc]	[Ac-]	[HAc]/[Ac-]
0	2.38	4.17E-03	2.40E-12	9.96E-01	4.13E-03	2.41E+02
1	3.39	4.07E-04	2.45E-11	9.23E-01	3.89E-02	2.37E+01
2	3.7	2.00E-04	5.01E-11	8.52E-01	7.43E-02	1.15E+01
3	3.9	1.26E-04	7.94E-11	7.86E-01	1.07E-01	7.35E+00
4	4.04	9.12E-05	1.10E-10	7.24E-01	1.38E-01	5.25E+00
5	4.16	6.92E-05	1.45E-10	6.67E-01	1.67E-01	3.99E+00
7.5	4.39	4.07E-05	2.45E-10	5.38E-01	2.31E-01	2.33E+00
10	4.59	2.57E-05	3.89E-10	4.28E-01	2.86E-01	1.50E+00
12.5	4.76	1.74E-05	5.75E-10	3.33E-01	3.33E-01	1.00E+00
15	4.94	1.15E-05	8.71E-10	2.50E-01	3.75E-01	6.67E-01
17.5	5.13	7.41E-06	1.35E-09	1.76E-01	4.12E-01	4.27E-01
20	5.36	4.37E-06	2.29E-09	1.11E-01	4.44E-01	2.50E-01
21	5.48	3.31E-06	3.02E-09	8.70E-02	4.56E-01	1.91E-01
22	5.63	2.34E-06	4.27E-09	6.38E-02	4.68E-01	1.36E-01
23	5.82	1.51E-06	6.61E-09	4.17E-02	4.79E-01	8.71E-02
24	6.14	7.24E-07	1.38E-08	2.04E-02	4.90E-01	4.16E-02
25	9.24	5.75E-10	1.74E-05	1.67E-05	5.00E-01	3.34E-05
26	12.31	4.90E-13	2.04E-02	1.40E-08	4.90E-01	2.86E-08
27	12.6	2.51E-13	3.98E-02	7.00E-09	4.81E-01	1.46E-08
30	12.97	1.07E-13	9.33E-02	2.80E-09	4.54E-01	6.17E-09
35	13.24	5.75E-14	1.74E-01	1.40E-09	4.17E-01	3.36E-09
40	13.38	4.17E-14	2.40E-01	9.33E-10	3.85E-01	2.42E-09
45	13.47	3.39E-14	2.95E-01	7.00E-10	3.57E-01	1.96E-09
50	13.54	2.88E-14	3.47E-01	5.60E-10	3.33E-01	1.68E-09

The starting point (0 mL of NaOH added)

	HAc	+	H_2O	⇄	H_3O^+	+	Ac^-	$K_a=1.76 \times 10^{-5}$
Initial:	1.0				0		0	
Good Start:	1.0				0		0	
Change:	-x				+x		+x	
Equil:	1.0 - x				+x		+x	
Assume x<<1.0	1.0				+x		+x	

$$1.76 \times 10^{-5} = \frac{x^2}{1.0} \quad x = [H_3O^+] = 4.19 \times 10^{-3} \qquad pH = 2.38$$

1 mL of NaOH added

Dilution: [HAc] = 1M (25/26) = 0.962M NaOH = 1M (1/26) = 0.0384M

	HAc	+	OH^-	⇄	H_2O	+	Ac^-
Initial:							
Good Start:							
Change:							
Equil:							
Assume							

5 mL of NaOH added

Dilution: [HAc] = 1M (25/30) = 0.833M NaOH = 1M (5/30) = 0.167M

	HAc +	OH^- ⇄	H_2O +	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:	0.833	0.167		0	
Good Start:	0.666	0		0.167	
Change:	+x	+x		-x	
Equil:	0.666 + x	+x		0.167-x	
Assume x<<0.167	0.666	+x		0.167	

$$1.76 \times 10^9 = \frac{0.167}{.666x} \qquad x = [OH^-] = 1.42 \times 10^{-10} \quad pOH = 9.85 \quad pH = 4.15$$

12.5 mL of NaOH added

Dilution: [HAc] = 1M (25/37.5) = 0.667M NaOH = 1M (12.5/37.5) = 0.333M

	HAc +	OH^- ⇄	H_2O +	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:	0.667	0.333		0	
Good Start:	0.333	0		0.333	
Change:	+x	+x		-x	
Equil:	0.333 + x	+x		0.333-x	
Assume x<<0.333	0.333	+x		0.333	

$$1.76 \times 10^9 = \frac{0.333}{.333x} \qquad x = [OH^-] = 5.68 \times 10^{-10} \quad pOH = 9.24 \quad pH = 4.76$$

24 mL of NaOH added

Dilution: [HAc] = 1M (25/49) = 0.510M NaOH = 1M (24/49) = 0.490M

	HAc	+	OH^-	⇄	H_2O	+	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:	0.510		0.490				0	
Good Start:	0.020		0				0.490	
Change:	+x		+x				-x	
Equil:	0.020 + x		+x				0.490-x	
Assume	0.020		+x				0.490	

x<<0.020

$$1.76 \times 10^9 = \frac{0.490}{.020x} \qquad x = [OH^-] = 1.39 \times 10^{-8} \quad pOH = 6.14 \quad pH = 7.86$$

25 mL of NaOH added

Dilution: [HAc] = 1M (25/50) = 0.500M NaOH = 1M (25/50) = 0.500M

	HAc	+	OH^-	⇄	H_2O	+	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:	0. 500		0. 500				0	
Good Start:	0		0				0. 500	
Change:	+x		+x				-x	
Equil:	+x		+x				0. 500-x	
Assume	+x		+x				0. 500	

x<<0. 500

$$1.76 \times 10^9 = \frac{0.500}{x^2} \qquad x = [OH^-] = 1.68 \times 10^{-5} \quad pOH = 4.78 \quad pH = 9.22$$

26 mL of NaOH added

Dilution: [HAc] = 1M (25/51) = 0.490M NaOH = 1M (26/51) = 0.510M

	HAc	+	OH^-	⇄	H_2O	+	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:	0. 490		0. 510				0	
Good Start:	0		0.020				0. 490	
Change:	+x		+x				-x	
Equil:	+x		0.020 + x				0. 490 - x	
Assume	+x		0.020				0. 490	

x<<0. 020

$$1.76 \times 10^9 = \frac{0.490}{0.020x} \qquad x = 1.39 \times 10^{-8} \quad [OH^-] = 0.020M \quad pOH = 1.7 \quad pH = 12.3$$

50 mL of NaOH added

Dilution: [HAc] = 1M (25/75) = 0.333M NaOH = 1M (50/75) = 0.667M

	HAc	+	OH^-	⇄	H_2O	+	Ac^-	$K = 1/K_b = 1.79 \times 10^9$
Initial:								
Good Start:								
Change:								
Equil:								

Assume
x<<0. 333

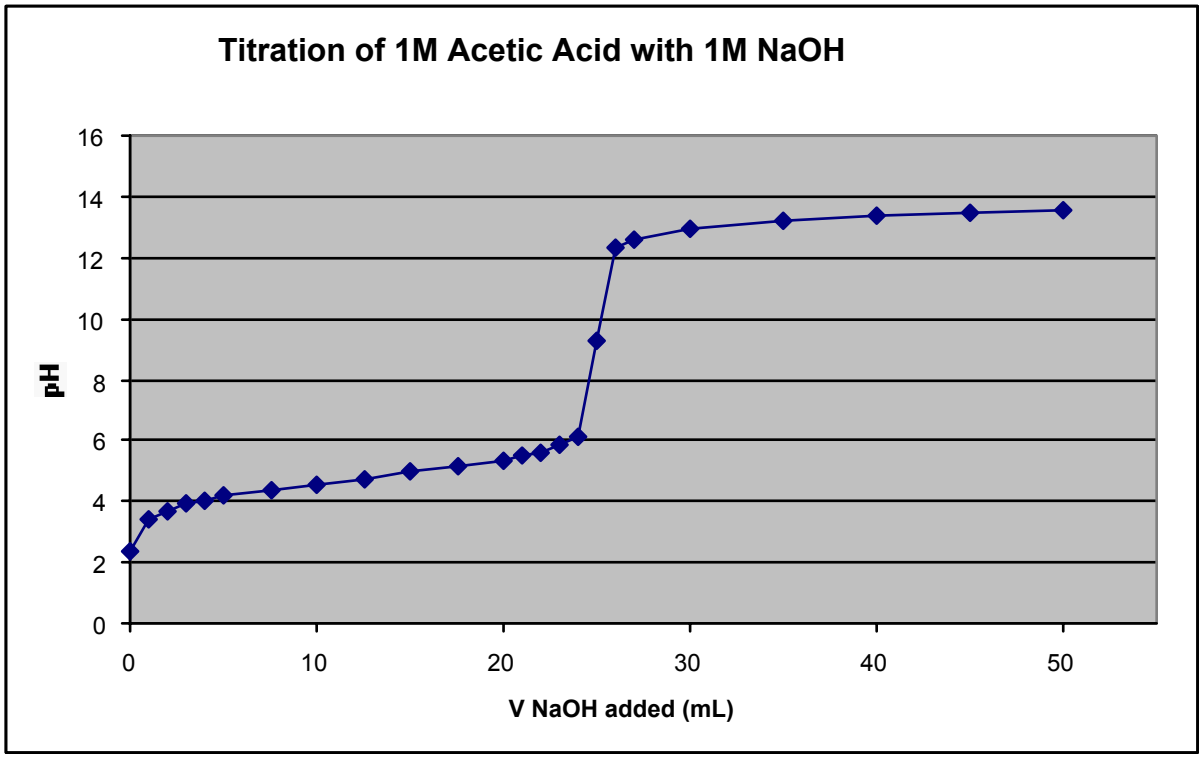
Reactions used:

Acid dissociation:

$HAc + H_2O \leftrightarrow H_3O^+ + Ac^-$ $K = K_a = 1.76 \times 10^{-5}$ ($pK_a = 4.75$)

Base hydrolysis:

$Ac^- + H_2O \leftrightarrow OH^- + HAc$ $K = K_b = K_w/K_a = 5.68 \times 10^{-10}$


Titration of 1M Acetic Acid with 1M NaOH
pH
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
V NaOH added (mL)