Titration of weak acid with strong base

Remember:

- Before adding the base: It is a weak acid HA (Ka)
- After adding the base: It is a buffer: pH = pK_a + log [base]/[acid]
- At half the volume of the equivalence point: [base]=[acid] or [A-] = [HA]
    - pH = pK_a
    - So, [H^+] = K_a
    - Buffer is most effective
- At the equivalence point: It is a weak base ($K_b = 10^{-14}/K_a$
    - pH is governed by the concentration of the buffer base (A-)
    - pH at the equivalence point is greater than 7 (pH > 7).
- After the equivalence point: It is a strong base.
- [ ] = moles / Volume (L)

Note: For the titration of weak base with a strong acid. The pH at the equivalence point is lower than 7 (pH < 7)

Indicator: pH = pK_a $\pm$ 1

The pKa of the weak acid to be used in the buffer should be as close as possible to the desired pH.

PH = pKa + log [base]/[acid]. For most effective buffer: [base]/[acid] = 1

Case Study

50 ml (0,05 l) of 0.1M acetic acid solution ($HC_2H_3O_2$, $K_a = 1.8 \times 10^{-5}$) with 0.1 M NaOH.

1) First calculate the volume of the base needed for the equivalence point:

$$M\ acid \times V\ acid = M\ base \times V\ base$$
$$0.1 \times 50 = 0.1 \times V\ base$$
$$V\ base = 50\ ml$$

So, we need 50 ml of NaOH to completely neutralize the 50 mL of acetic acid.

2) At a volume half the volume of the equivalence point, $pH = pK_a$

So, at 25 ml, $pH = pK_a = -\log K_a = -\log 1.8 \times 10^{-5}$

3) Calculate the moles of the acid;

Moles of $HC_2H_3O_2$ = moles of H^+ = Volume x Molarity
= 0.05 x 0.1 = 0.005 moles

A) No base is added:

It is a weak acid

	$HC_2H_3O_2$	=	$C_2H_3O_2^-$	+	H^+
Initial	0.1				
Change	- X		X		X
Equilibrium	0.1 - X		X		X

$K_a = x^2 / 0.1$

$X = 1.3 \times 10^{-3}$ M

pH = **2.87**

B) Add 10 mL of 0.1 M NaOH:

Calculate the moles of NaOH = Molarity x Volume (L)
= 0.1 x 0.01= 0.001mole
Mole of $HC_2H_3O_2$ = 0.005 mole

Total volume is: 50 + 10 = 60 ml = 0.060 Liter

	$HC_2H_3O_2$	+ OH^-	= $C_2H_3O_2^-$	+ H_2O
Before reaction	0.005 mole	0.001		
After reaction	0.005 - 0.001	0	0.001	
	= 0.004 mole		0.001	
[ ] :	0.004/ 0.06		0.001 / 0.06	

Buffer: pH = pK_a + log [base]/[acid] = -log 1.8 x 10^{-5} + log (0.001/0.06) x (0.06/0.004)

` pH = **4.14**

C) Add 25 mL of NaOH

Half the volume of the equivalence point: $pH = pK_a$

So, $[H^+] = K_a$

D) Add 40 mL of NaOH

pH = **5.35**

E) Add 50 mL of 0.1 M NaOH:

Calculate the moles of NaOH = Molarity x Volume (L)
= 0.1 x 0.05 = 0.005 mole

Mole of $HC_2H_3O_2$ = 0.005 mole

Total volume is: 50 + 50 = 100 ml = 0.1 Liter

	$HC_2H_3O_2$	+	OH^-	=	$C_2H_3O_2^-$	+	H_2O
Before reaction	0.005 mole		0.005				
After reaction	0.005 - 0.005 = 0 mole				0.005		
[.] :					0.005/0.1 = 0.05M		

Flip the reaction; $C_2H_3O_2^-$ is a weak base.

	$C_2H_3O_2^-$	+	H_2O	=.	$HC_2H_3O_2$	+	OH^-
Initial	0.05						
Change	- X				X		X
Equilibrium	0.05 -X				X		X

$K_b = 10^{-14}/K_a$

$K_b = 10^{-14}/1.8 \times 10^{-5}$

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

$K_b = x^2 / 0.05$

$X = 5.3 \times 10^{-6} = [OH^-]$

pH = 14- pOH = **8.72**

F) Add 60 mL of 0.1 M NaOH

Calculate the moles of NaOH = Molarity x Volume (L)
= 0.1 x 0.06 = 0.006 mole

Mole of $HC_2H_3O_2$ = 0.005 mole

Total volume is: 50 + 60 = 110 ml = 0.11 Liter

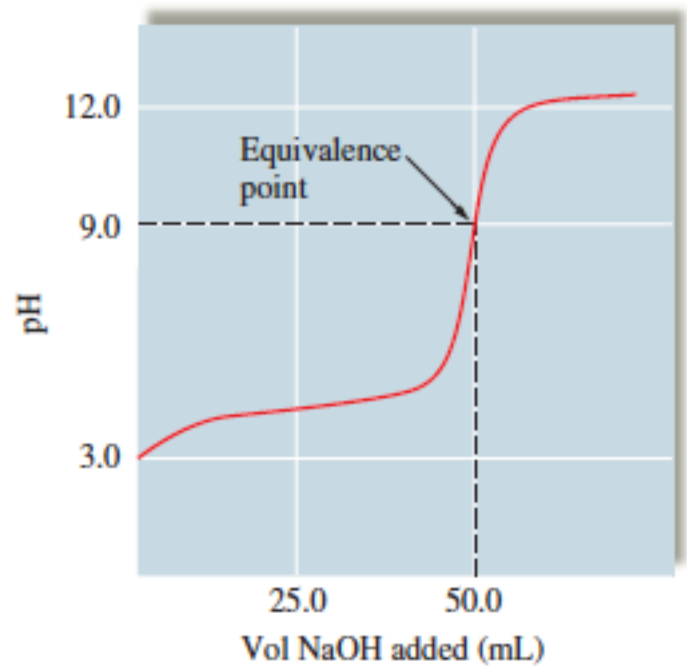
	$HC_2H_3O_2$ +	OH^-	= $C_2H_3O_2^-$ + H_2O
Before reaction	0.005 mole	0.006	
After reaction	0.005 - 0.005 = 0 mole	0.006-0.005 = 0.001	
[.] :		0.001/0.11 = 9.1 x 10^{-3} M	

$[OH^-]$ = 9.1 x 10^{-3} M

pH = 14 - pOH = **11.96**

G) Add 75 mL of 0.1 M NaOH

pH = 14 - pOH = **12.3**



Titration of strong acid with strong base.

Titration of 50 mL (0.05 L) of 0.200 M HNO_3 with 0.100 M solution of NaOH.

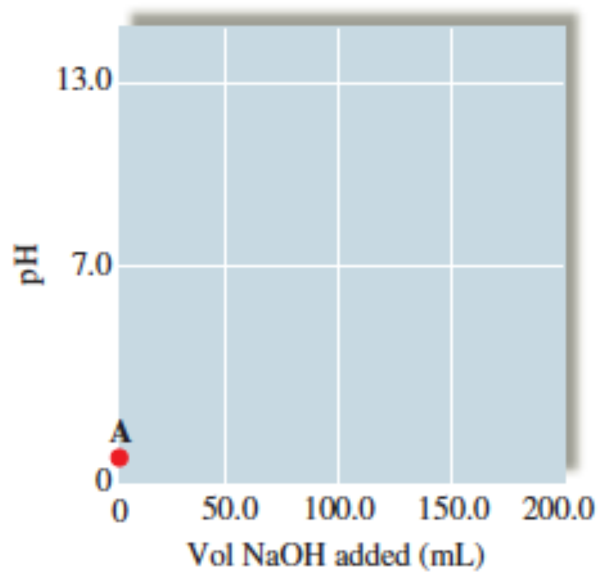
[ ] = Molarity = Moles / Volume (L)

Moles = Molarity x Volume (L)
Moles of HNO_3 = moles of H^+ = Volume x Molarity = 0.05 x 0.2 = 0.01 moles

A) No NaOH was added

1) $[HNO_3] = [H^+] = 0.2$ M,

pH = -log [H^+] = -log 0.2 = **0.699**



B) Add 10 mL (0.01L) of 0.1 M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.01 x 0.1= 0.001 moles of OH^-

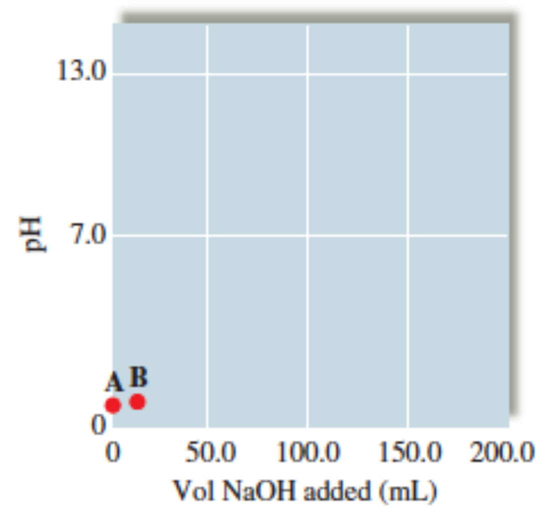
Total volume: 0.05 + 0.01 = 0.06 Liter = Vt

Moles of HNO_3 = 0.01 moles of H^+

	H^+	+	OH^-	=.	H_2O
Before addition	0.01		0.001		
After addition	0.01-0.001		0		
	0.009 moles				

[H^+] = moles/Vt 0.009/0.06 = 0.15 M

pH = -log [H^+] = -log 0.15 = **0.82**



C) Add 20 mL (0.02 L) of 0.1 M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.02 x 0.1= 0.002 moles of OH^-

Total volume: 0.05 + 0.02 = 0.07 Liter = Vt

Moles of HNO_3 = 0.01 moles H^+

	H^+	+	OH^-	=.	H_2O
Before addition	0.01		0.002		
After addition	0.01-0.002		0		
	0.008 moles				

[H^+] = moles/Vt 0.008/0.07 = 0.11 M

pH = -log 0.11 = **0.942**

D) Add 50 mL (0.05 L) of 0.1 M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.05 x 0.1= 0.005 moles of OH^-

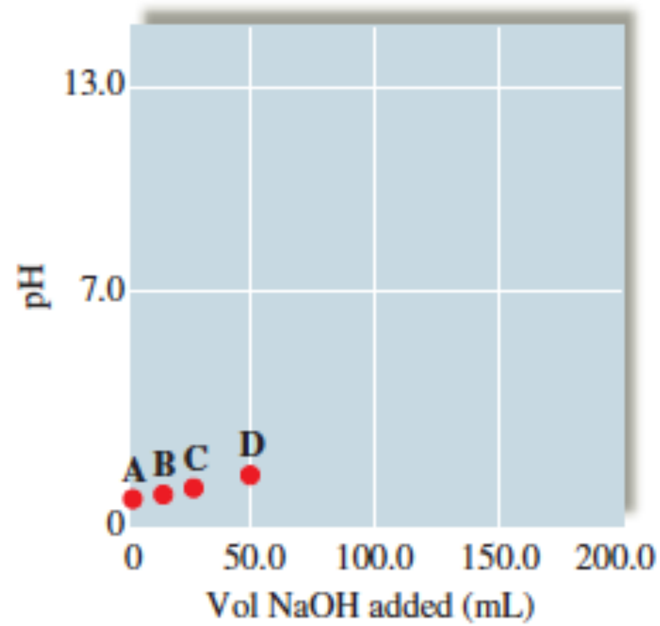
Total volume: 0.05 + 0.05 = 0.1 Liter = Vt

Moles of HNO_3 = 0.01 moles of H^+

	H^+	+ OH^-	=.	H_2O
Before addition	0.01	0.005		
After addition	0.01-0.005	0		
	0.005 moles			

[H^+] = moles/Vt 0.005/0.1= 0.05 M

pH = -log 0.05 = **1.3**

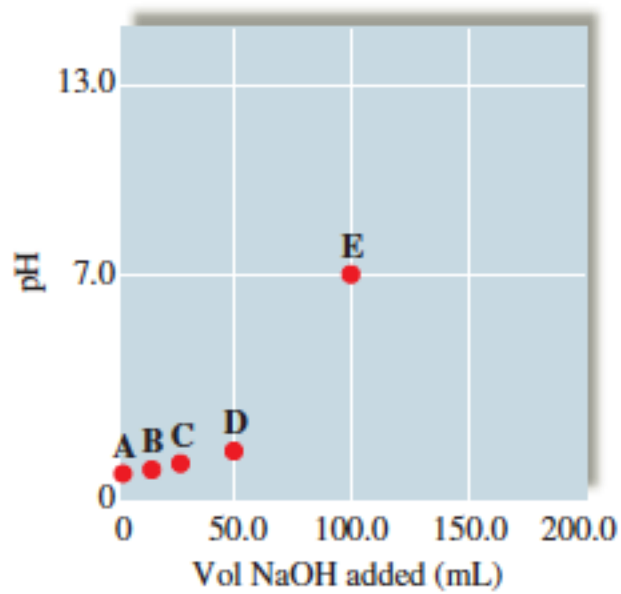


E) Add 100 mL (0.1 L) of 0.1 M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.1 x 0.1= 0.01 moles of OH^-

Moles of HNO_3 = 0.01 moles of H^+

Equivalence point: pH = **7**



F) Add 150 mL (0.15 L) of 0.1M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.15 x 0.1= 0.015 moles of OH^-

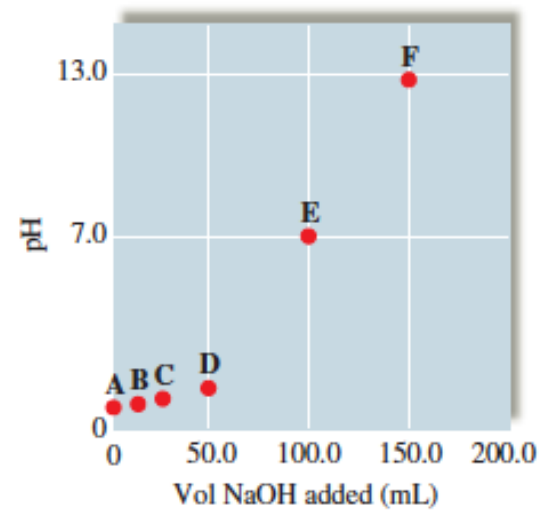
Total volume: 0.05 + 0.15 mL = 0.2 Liter = Vt

Moles of HNO_3 = 0.01 moles H^+

	H^+	+	OH^-	=.	H_2O
Before addition	0.01		0.015		
After addition	0.01-0.01		0.015-0.01		
	0		0.005 mole		
$[OH^-]$ = moles/Vt			0.005 /0.2 = 0.025 M		

pOH = -log $[OH^-]$= -log 0.025

pH = 14 - pOH = **12.4**



G) Add 200 mL (0.2 L) of 0.1M NaOH

Moles of NaOH = Volume (l) x Molarity = 0.2 x 0.1= 0.02 moles of OH^-

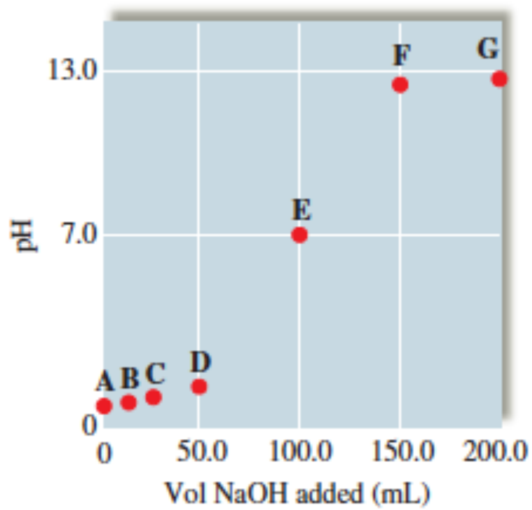
Total volume: 0.05 + 0.2 = 0.25 Liter = Vt

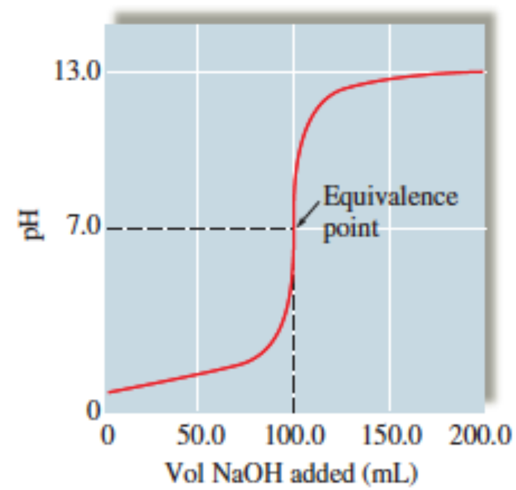
Moles of HNO_3 = 0.01 moles H^+

	H^+	+ OH^-	=.	H_2O
Before reaction	0.01	0.02		
After reaction	0.01-0.01	0.02-0.01		
	0	0.01mole		
[OH^-] = moles/Vt		0.01/0.25 = 0.04 M		

pOH = -log [OH^-]= -log 0.04

pH = 14 - pOH = **12.60**


13.0
7.0
0
pH
A
B
C
D
E
F
G
0
50.0
100.0
150.0
200.0
Vol NaOH added (mL)


13.0
7.0
0
pH
Equivalence point
0
50.0
100.0
150.0
200.0
Vol NaOH added (mL)

Titration of strong base with strong acid

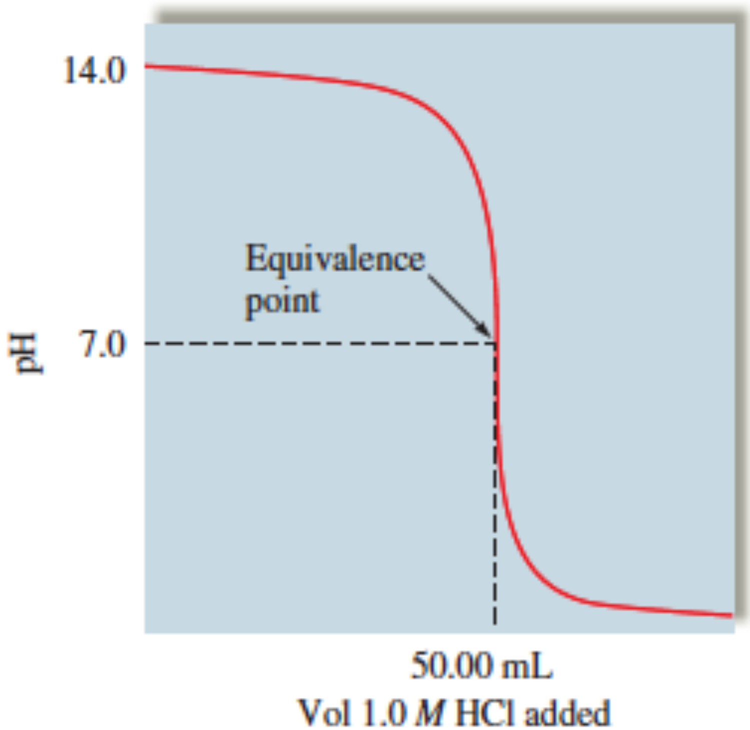


FIGURE 15.2
The pH curve for the titration of 100.0 mL of 0.50 *M* NaOH with 1.0 *M* HCl. The equivalence point occurs at 50.00 mL of HCl added, since at this point 5.0 mmol H^+ has been added to react with the original 5.0 mmol OH^-.