16.2 Strong-Acids / Strong-Bases Titration

Dr. Fred Omega Garces
Chemistry 201
Miramar College

Reaction Between Acid - Base

What is the pH of a solution when an acid is mixed with a base?

Stoichiometry Problem:

$$\begin{array}{rcl} HA & \rightarrow & H_3O^+ + A^- \\ MOH & \rightarrow & OH^- + M^+ \\ \hline MOH + HA & \rightarrow & H_2O + MA \end{array}$$

Stoichiometry Problem:

The amount of H_3O^+ or OH^- remaining after a portion is neutralize determines the pH of the solution.

In an acid - base reaction, H^+ & OH^- always combine together to form water and an ionic compound (a salt):

Neutralization Reaction.

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$$

Analysis is a Stoichiometry problem only if a strong acid is combined with a strong base.

Titration

Acid/Base Titration

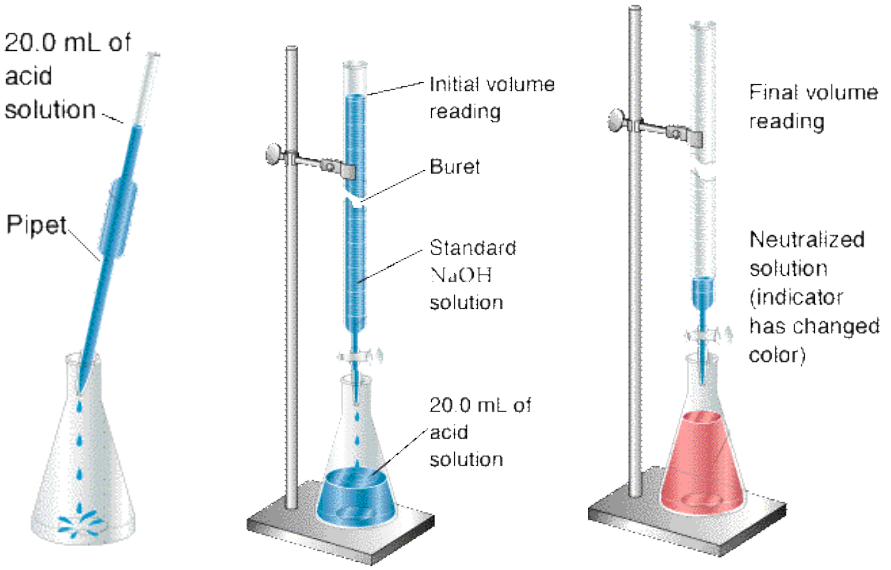
A technique of chemical analysis to determine the amount of a substance in a sample. i.e., What is the acidic content of Lake Miramar?

A sample can be tested by titration. In a titration experiment, a known volume of a standard concentrated solution (the titrant) is used to analyze a sample (the analyte). One is usually an acid, the other a base. An indicator is added to the analyte to signal when the titration is complete. This is called the endpoint. When the moles of acid(H_3O^+) and moles of base (OH^-) are equal in a titration experiment, the stoichiometric equivalent point is reached. This is called the equivalent point.

Indicator changes color @ endpoint

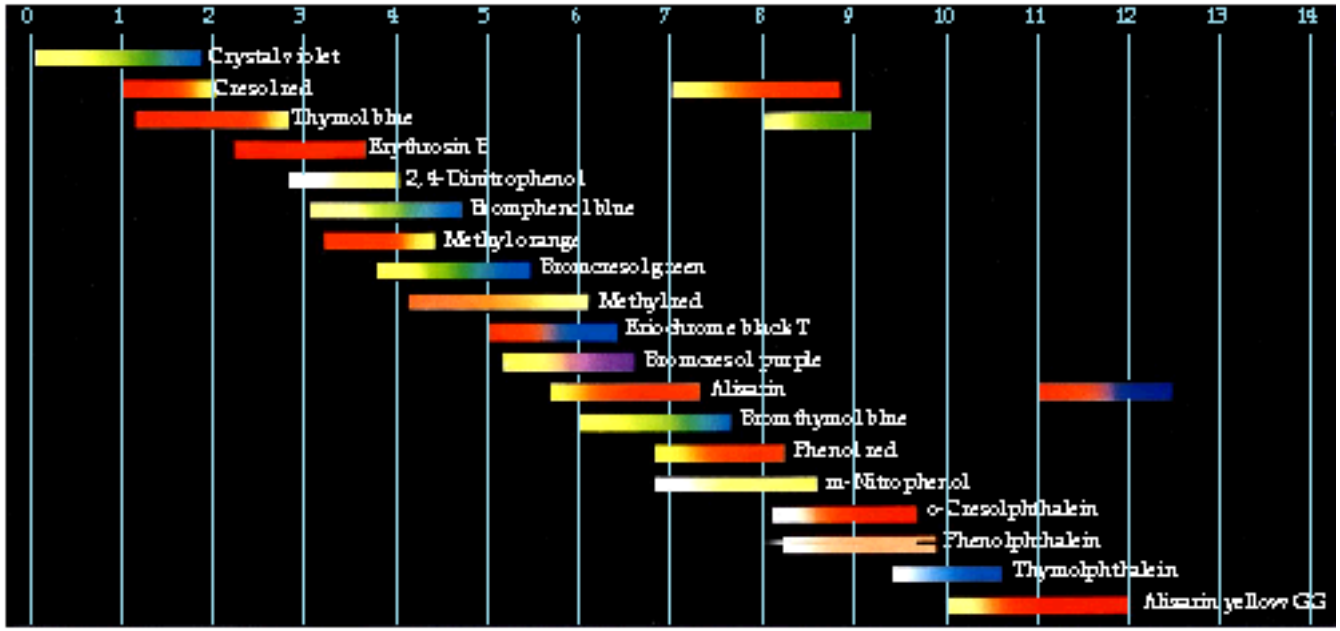
moles titrant = moles analyte.

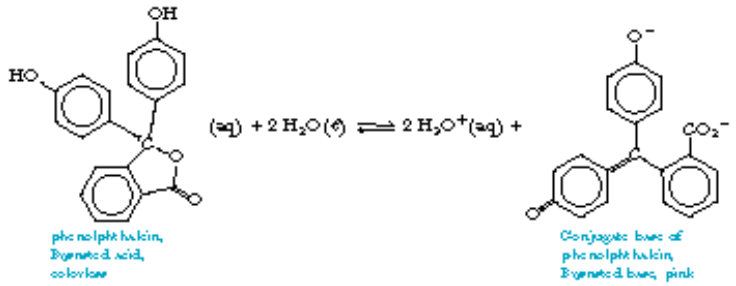
@ equivalent point.

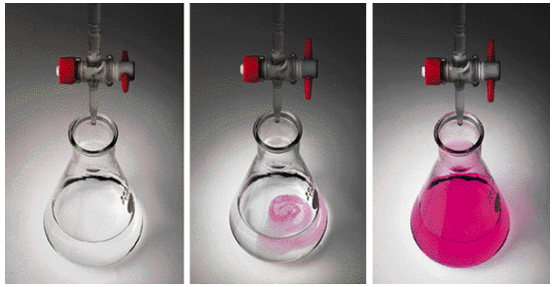


Acid-Base Indicator

Some common acid-base indicators. The color changes occur over a range of pH values. Notice that a few indicators have two color changes over two different pH ranges.







Mechanism for phenolphthalein indicator. At Low pH phenolphthalein is colorless and has a structure in which there is a five membered ring. In the presence of excess acid the five membered ring is broken and the resulting change in conformation gives rise to a compound which is pink.

S Acid- S Base Analysis

Indicator changes color @ endpoint.

Indicator is chosen so that endpoint occurs at equivalent pt.

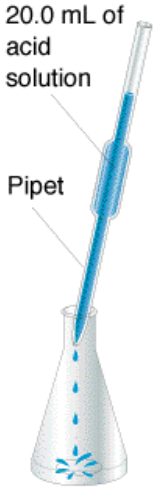
The following is true at the equivalence point.

moles H_3O^+ = moles OH^-

$M_{acid} \cdot V_{acid} = M_{base} \cdot Vbase$ For monoprotic A & B

$M_{acid} \cdot V_{acid} \neq M_{base} \cdot Vbase$ For polyprotic A & B

but $N_{acid} \cdot V_{acid} = N_{base} \cdot V_{base}$ for monoprotic and polyprotic A & B

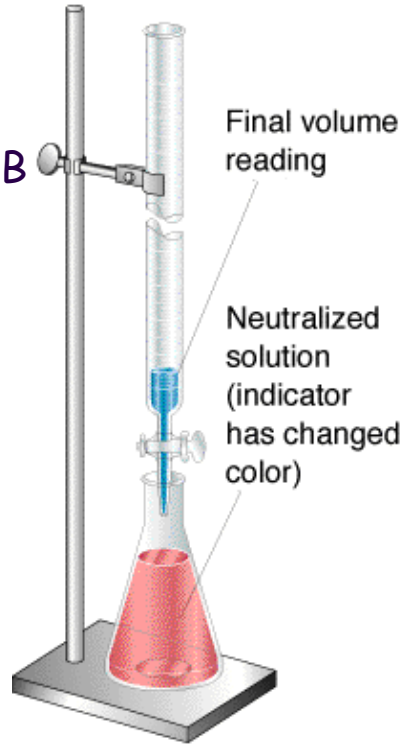


$$\frac{\text{eq } H_3O^+}{\text{L Soln}} \cdot \text{L } H_3O^+ = \frac{\text{eq } OH^-}{\text{L Soln}} \cdot \text{L } OH^-$$

For Acid base calculation at Equivalence pt:

Sometimes: $M_{acid} \cdot V_{acid} = M_{base} \cdot V_{base}$

but always: $N_{acid} \cdot V_{acid} = N_{base} \cdot V_{base}$



S Acid- S Base Calculation

Titration of HCl with NaOH (Reger 14.1)

A titration is used to detm' conc. of HCl solution. Exactly 20.00mL of the acid solution was placed in a flask, with phenolphthalein added. 18.34mL of 0.0982 M NaOH was needed to reach the endpoint. What is the conc. of the HCl ?

Rxn: $NaOH \rightarrow OH \quad 100\%$

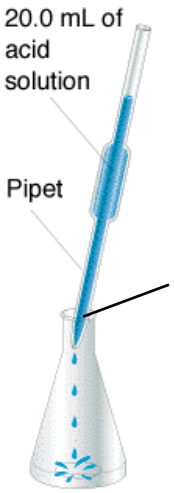
$HCl \rightarrow H^+ \quad 100\%$

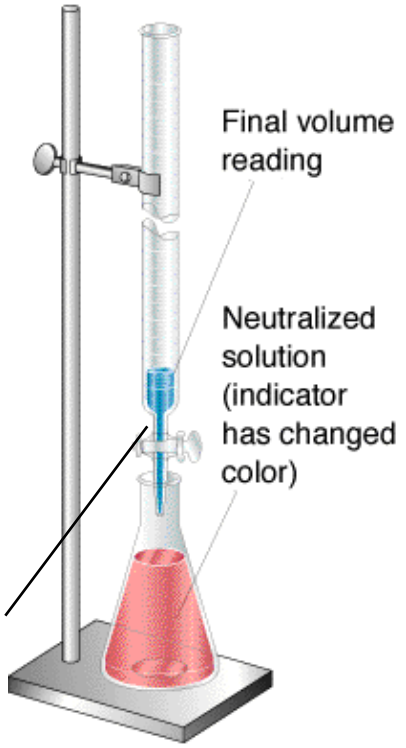
Net $H^+ + OH^- \rightarrow H_2O$

Conc H_3O^+:

$$= \frac{0.0982 \text{ mol } OH^-}{1 \text{ L}} \cdot 18.34 \text{ mL} \cdot \frac{1 \text{ mol } H^+}{1 \text{mol } OH^-} \cdot \frac{1}{20.00 \text{ ml}}$$

[HCl] = 0.09005 M





Titration: Thought Experiment

Consider the titration of a Strong acid with a Strong Base.

What is the pH after incremental addition of some moles of base to the acid.

Amt NaOH $[OH^-]$	Amt HCl $[H_2O^+]$	Amt H_2O	Remaining (mol)	pH or pOH
0	100 H+	-	$100H^+$	$pH = - \log [100 / v_T]$
20	100-20	20 H_2O	80 H^+	$- \log [80 / v_T]$
50	100-50	50 H_2O	50 H^+	$- \log [50 / v_T]$
99	100-99	99 H_2O	1 H^+	$- \log [1 / v_T]$
100	100-100	100 H_2O	0 H^+	$- \log [0 / v_T]$ pH = ?*
101	100-101	100 H_2O	1 OH-	$pOH = - \log [1 / v_T]$
200	100-200	100 H_2O	100 OH-	$pOH = - \log [100 / v_T]$

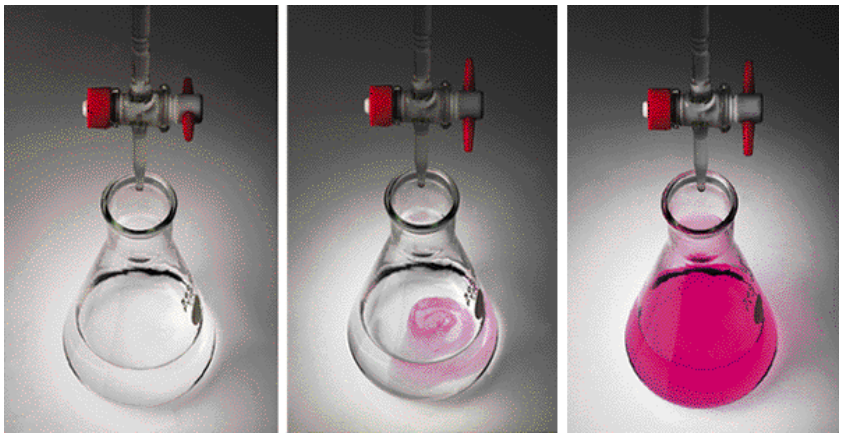
* Neutral pH is determine by the Autoionization of water pH = 7.0

Titration S Acid - S Base: Example

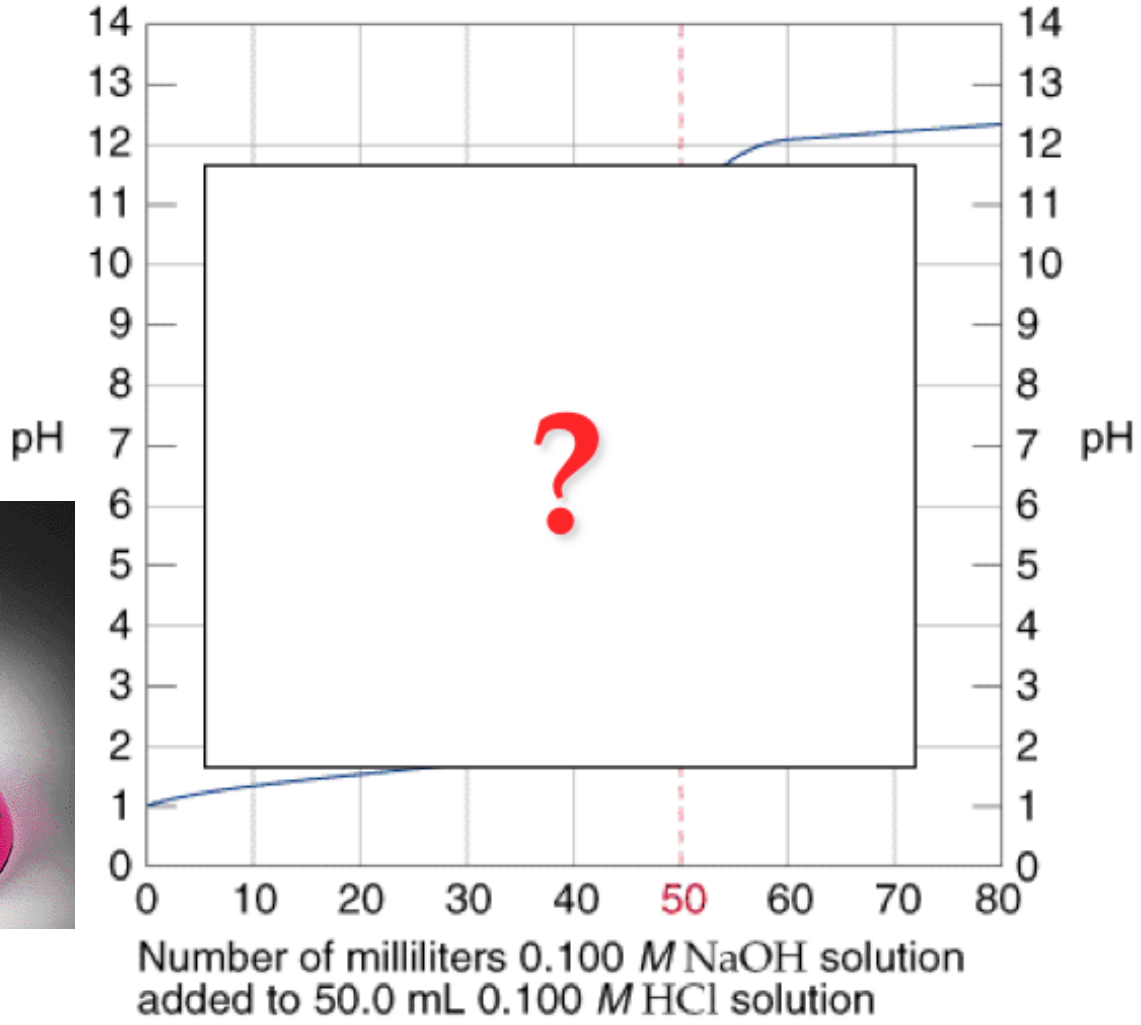
A 0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH. What is the pH after addition of 0.00, 20.00, 49.00, 50.00, 51.00 and 60.00 mL of base.

Titration curve between strong acid and strong base. Analyte is HCl and titrant is NaOH.

Rxn:	NaOH	→	OH	100%
	H Cl	→	H+	100%
Net	$H^+ + OH^-$	→	H_2O	



Click for simulation



Titration Strong Acid - Strong Base: Example (0.0 & 25.0 ml)

i) 0.00 mL Base

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 0.00mL of base.

pH based on the $[H_3O+]$ of HCl

HCl is a strong acid, therefore $[HCl] = [H_3O^+]$

$[HCl] = [H_3O^+] = 0.100\ M = 1 \cdot 10^{-1}\ M \rightarrow$ pH = 1.00

ii) 25.00 mL Base: V_{total} = 75 ml solution

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 25.00mL of base

mol HCl = 0.100M · (50mL) =$5.00 \cdot 10^{-3}$ mol HCl or 5.0 mmol = H_3O^+

mol NaOH = 0.100M · (25mL) = $2.5 \cdot 10^{-3}$ mol NaOH or 2.5 mmol = OH^-

pH based on the excess HCl remaining. Since HCl is a strong acid.

	HCl +	NaOH →	H_2O +	Na^+ +	Cl^-
s	5 mmol	2.5 mmol	-	-	-
R	2.5	2.5	2.5	2.5	2.5
f	2.5	0	2.5	2.5	2.5
[c]	2.5 mmol / 75.00 ml = $3.3 \cdot 10^{-2}$ M				

$[HCl] = [H_3O^+] = 3.3 \cdot 10^{-2}\ M \rightarrow$ pH = 1.48

Titration S Acid - S Base: Example (49.0 & 50.0 mL)

iii) 49..00 mL Base: V_{total} = 99 ml solution

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 49.00mL of base.

mol HCl = 0.100M · (50mL) = 5.0 mmol HCl = H_3O^+

mol NaOH = 0.100M · (49mL) = 4.9 mmol NaOH = OH^-

	HCl +	NaOH →	H_2O +	Na +	Cl-
s	5.0 mmol	4.9 mmol	-	-	-
R	-4.9	-4.9	-	-	-
f	0.1 mmol	0	-	-	-
[c]	0.1 mmol / 99.0 ml = $1.01 \cdot 10^{-3}$ M				

[HCl] = [H_3O^+] = $1.01 \cdot 10^{-3}$ M → pH = 3.0

iv) 50.00 mL Base: V_{total} = 99 ml solution

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 50.00mL of base.

mol HCl = 0.100M · (50mL) = 5.0 mmol HCl = H_3O^+

mol NaOH = 0.100M · (50mL) = 5.0 mmol NaOH = OH^-

	HCl +	NaOH →	H_2O +	Na +	Cl-
s	5.0 mmol	5.0 mmol	-	-	-
R	-5.0	-5.0	-	-	-
f	0.1 mmol	0	-	-	-
[c]	0.1 mmol / 100.0 ml = 0 M	Is the pH = zero ?			

No, Autoionization Water has [H_3O^+] = $1.00 \cdot 10^{-7}$ M → pH = 7.0

Titration S Acid - S Base: Example (51.0 & 60.0 mL)

v) 51.00 mL Base: V_{total} = 101 ml solution

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 51.00mL of base.

mol HCl = 0.100M · (50mL) = 5.0 mmol HCl = H_3O^+

mol NaOH = 0.100M · (51mL) = 5.1 mmol NaOH = OH^-

	HCl +	NaOH →	H_2O +	Na +	Cl-
s	5.0 mmol	5.1 mmol	-	-	-
R	-5.0	-5.0	-	-	-
f	0 mmol	0.1	-	-	-
[c]		0.1 mmol / 101.0 ml = $9.90 \cdot 10^{-4}$ M			

$[NaOH]_{excess} = [OH^-] = 9.90 \cdot 10^{-4}$ M → pOH = 3.00 → pH = 11.0

vi) 60.00 mL Base: V_{total} = 110 ml solution

0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH 60.00 mL of base.

mol HCl = 0.100M · (50 mL) = 5.0 mmol HCl = H_3O^+

mol NaOH = 0.100M · (60 mL) = 6.0 mmol NaOH = OH^-

	HCl +	NaOH →	H_2O +	Na +	Cl-
s	5.0 mmol	6.0 mmol	-	-	-
R	-5.0	-5.0	-	-	-
f	0 mmol	1.0	-	-	-
[c]		1.0 mmol / 110.0 ml = $9.90 \cdot 10^{-3}$ M			

$[NaOH]_{excess} = [OH^-] = 9.90 \cdot 10^{-3}$ M → pOH = 2.04 → pH = 11.96

Titration: Result Summary

Summary of the titration of 0.100 M HCl with 0.100 M NaOH.

What is the pH after incremental addition of some moles of base to the acid.

Vol NaOH (mL)	Amt NaOH (mmol)	Amt HCl-NaOH (mmol)	Net H_3O^+ (mmol)	Conc H+ or OH- (M)	pH or pOH
0	0	5mmol - 0	5	5 / 50=0.1	pH = 1.0
25	2.5	5 - 2.5	2.5	$2.5/75=3.3\cdot10^{-2}$	pH = 1.48
49	4.9	5 - 4.9	0.1	$0.1/99=1.01\ 10^{-3}$	pH = 3.00
50	5.0	5 - 5	0	0/100 = 0	pH = 7
51	5.1	5.1 [OH] - 5	0 H^+	$0.1/101=9.9e^{-4}$	pOH=3, pH=11
60	6.0	6 [OH] - 5	1 OH^-	$1/110= 9.9e^{-3}$	pOH=2, pH=12

Titration: Result Summary

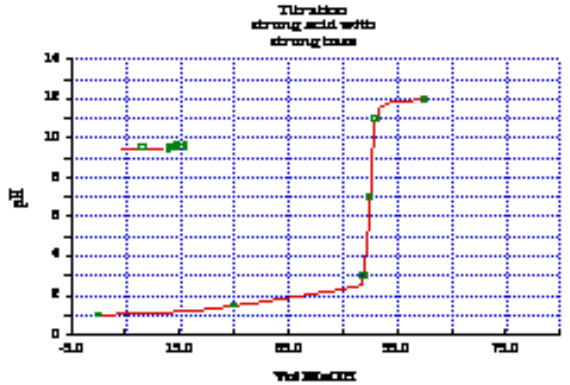
Summary of the titration of 0.100 M HCl with 0.100 M NaOH.

Titration of a Strong Acid with a Strong Base

analyte : 50.00 ml of 0.100M HCl
Titrate: 0.100 M NaOH

$$NaOH + HCl \rightarrow H_2O + Na^+ + Cl^-$$

Net ionic: $OH^- + H_3O^+ \rightarrow 2\,H_2O$



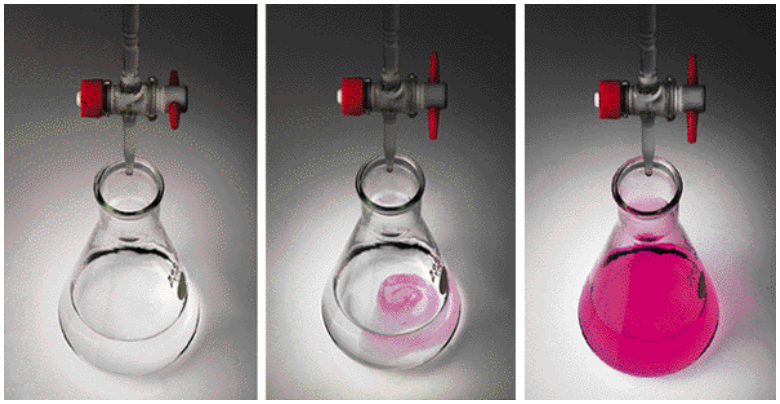
NaOH Vol. added	NaOH (mmol)	HCl (initial) (mmol)	H_3O^+ or OH^- Net (mmol)	Total Vol (ml)	H_3O^+ or OH^- conc [M]	pH or pOH
0.00ml	0	0.100 M • 50.00ml = 5 mmol	5 mmol - 0 = 5 mmol (H_3O^+)	50ml	H_3O^+ 0.100M	pH=1.00
5.00ml	0.100M•5.0ml = .5 mmol	5 mmol	5 mmol - .5 mmol = 4.5 mmol (H_3O^+)	55ml	H_3O^+ $8.18•10^{-2}$	pH=1.09
25.00ml	0.100M•25.0ml = 2.5 mmol	5 mmol	5 mmol - 2.5 mmol = 2.5 mmol (H_3O^+)	75ml	H_3O^+ $3.33•10^{-2}$	pH=1.48
49.00ml	0.100M•49.0ml = 4.9 mmol	5 mmol	5 mmol -4.9 mmol = 0.1 mmol (H_3O^+)	99ml	H_3O^+ $1.01•10^{-3}$	pH=3.00
50.00ml	0.100M•49.0ml = 5.0 mmol	5 mmol	5 mmol -5 mmol = 0.0 mmol (H_3O^+)	100ml	?????	pH= ???
51.00ml	0.100M•51.0ml = 5.1 mmol	5 mmol	5 mmol -5.1mmol = 0.1 mmol (OH^-)	101ml	OH^- $9.90•10^{-4}$	pOH=3.00 pH=11.00
60.00ml	0.100M•60.0ml = 6.0 mmol	5 mmol	5 mmol -6.0 mmol = 1.0 mmol (OH^-)	110ml	OH^- $9.09•10^{-3}$	pOH=2.04 pH=11.96

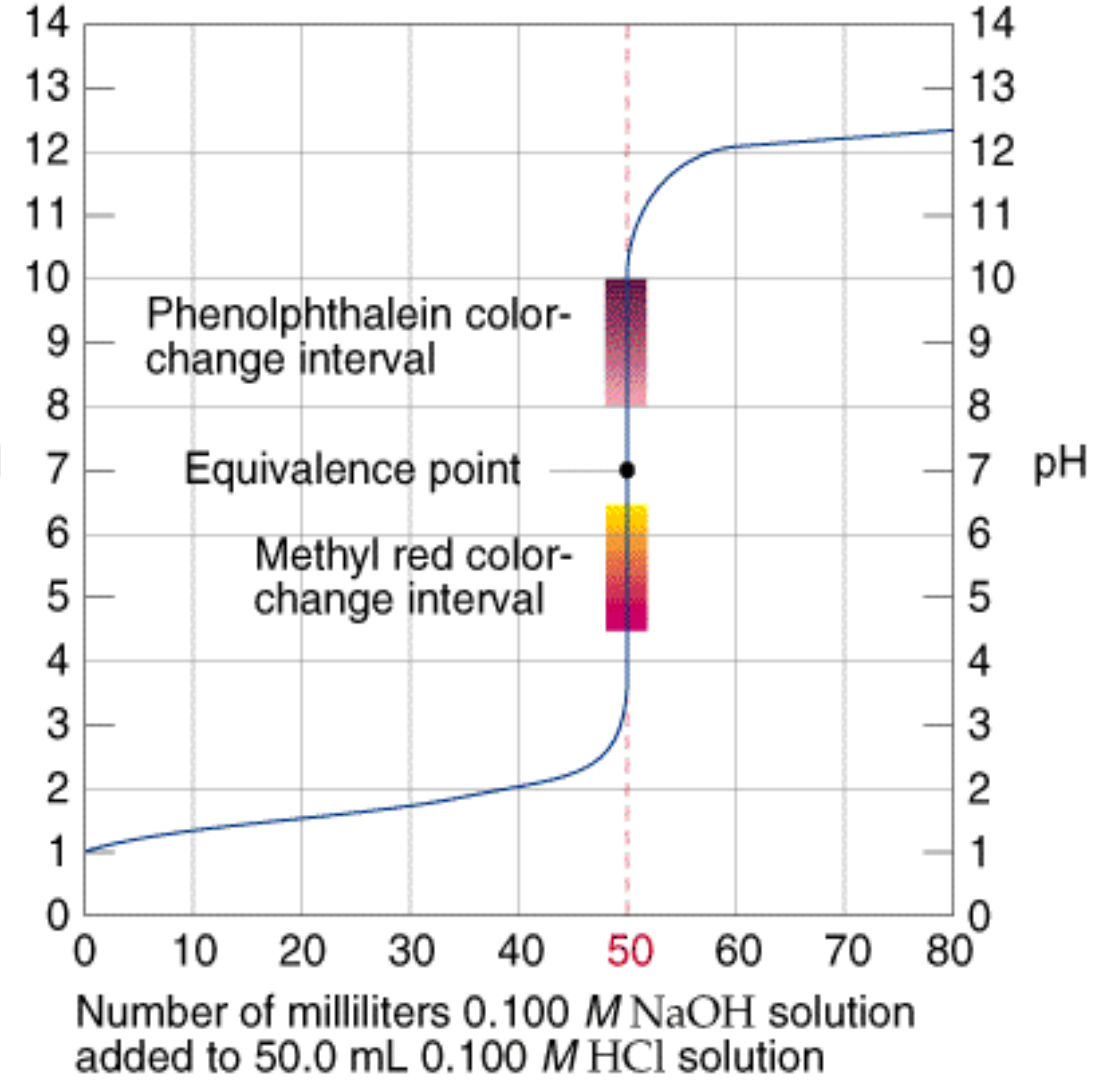
Result: Titration Curve

A 0.100M HCl (50.00mL) is to be titrated with 0.100 M NaOH. What is the pH after addition of 0.00, 20.00, 49.00, 50.00, 51.00 and 60.00 mL of base.

Titration curve between strong acid and strong base. Analyte is HCl and titrant is NaOH.

Rxn:	NaOH	→	OH	100%
	H Cl	→	H+	100%
Net	$H^+ + OH^-$	→	H_2O	

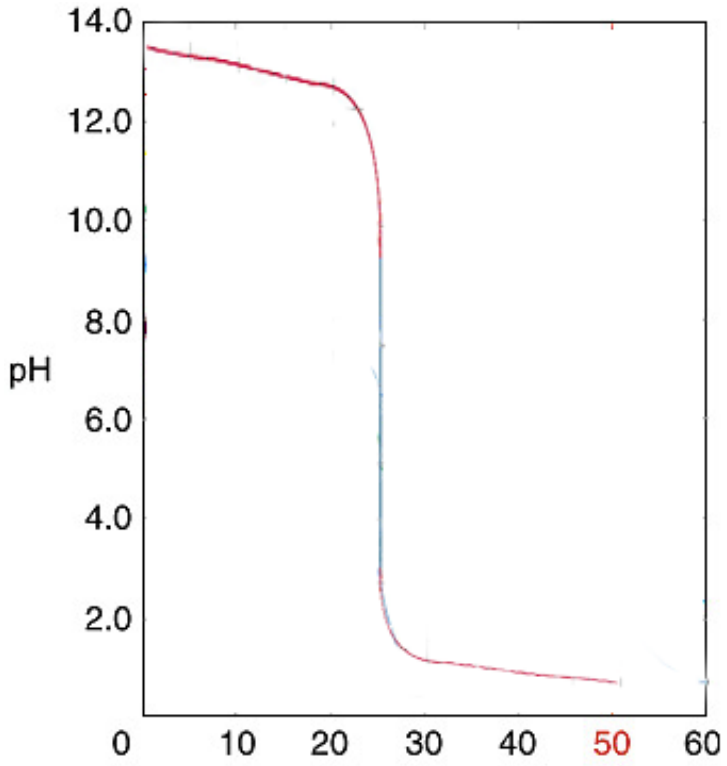




Titration Curve
In or Out of Class Exercise

Design a problem in which NaOH (analyte) of some concentration and 50-mL volume is titrated with HCl of some concentration. Design the problem in such a way that the the following conditions are met.

	HCl Added	pH soln
1	0.00 mL	13.500
2	10.00 mL	13.199
3	15.0 mL	12.988
4	20.0 ml	12.655
5	24.6 ml	11.530
6	25.4 ml	2.475
7	30.0 ml	1.403
8	35.0 ml	1.290
9	40.0 ml	0.977
10	50.0 ml	0.801



. . . remember

That a titration problem is nothing more than a Stoichiometry problem