Slide 1

What's in your beaker?

Slide 2

What's a titration?

A titration is a chemical reaction conducted with a controlled addition of one of the reactants. By carefully monitoring the amount of the reactant added, we can figure out how much of the other reactant must have been there.

Slide 3

Titration example

50.00 mL of an unknown acid is titrated with 0.1234 M NaOH. It required 22.67 mL of titrant to reach the endpoint. What was the pH of the original acid solution?

Like all chemistry problems, we begin with…

Slide 4

A BALANCED EQUATION!

$NaOH + H^+ \rightarrow Na^+ + H_2O$

$NaOH + H_3O^+ \rightarrow Na^+ + 2\ H_2O$

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

Either way, the point is:

1 mol NaOH = 1 mol H^+

Slide 5

Titration example

50.00 mL of an unknown acid is titrated with 0.1234 M NaOH. It required 22.67 mL of titrant to reach the endpoint. What was the pH of the original acid solution?

0.1234 M NaOH * 22.67 mL NaOH = ? M H^+ * 50.00 mL H^+

5.595×10^{-2} M H^+

pH = - log (5.595×10^{-2} M) = 1.25

Slide 6

How does a titration actually occur?

You add one reactant (NaOH in this case) drop by drop until the other reactant (H^+ in this case) is completely reacted (neutralized).

How do you know the reaction is over?

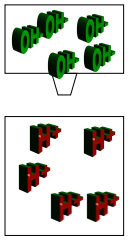
Some kind of indicator: another chemical compound, pH.

Slide 7

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

As I make water, by adding OH^- to H^+ (or H^+ to OH^-), the pH changes.

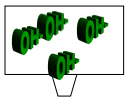
Slide 8



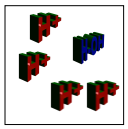
pH is low

Slide 9

B

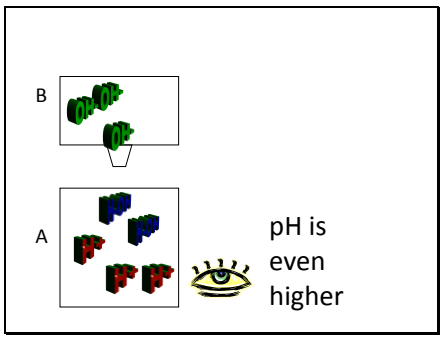


A

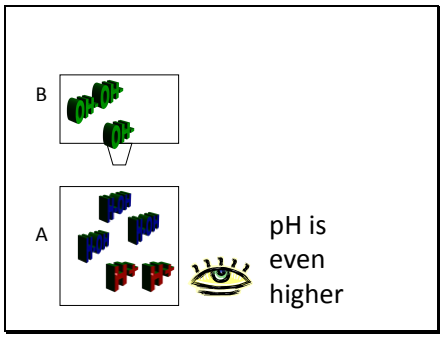


pH is getting higher

Slide 10



Slide 11



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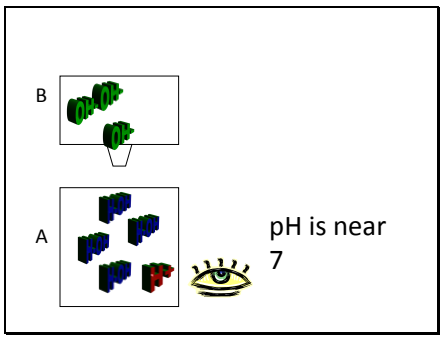

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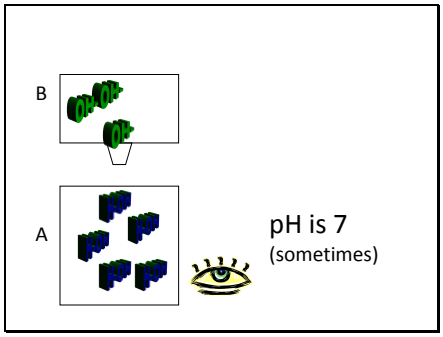

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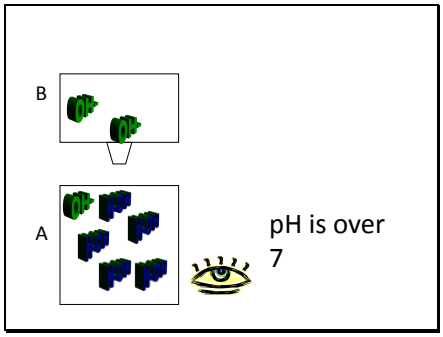
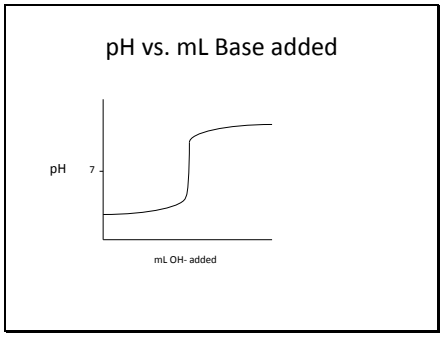


Slide 15



Slide 16

Could we calculate the pH all along the way?

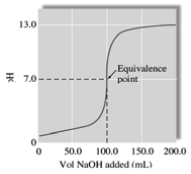
Sure, why not? It's all a question of what's in the beaker!

Slide 17

Potentiometric Titrations

A **potentiometric titration** combines a titration with a pH measurement. A graph of pH vs. titrant volume is called a **titration curve**.

The **equivalence point** (stoichiometric point) occurs when moles of base (B or A-) = moles of H+ donated by the acid (HA or BH+).



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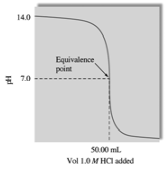
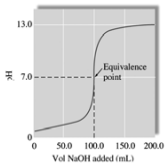
Strong Acid - Strong Base Titrations

Analyte is strong base
Titrant is a strong acid



Analyte is strong acid
Titrant is a strong base



Slide 19

50.00 mL of 0.100 M HCl is titrated with 0.100 M NaOH. Calculate the pH at 10.0 mL increments from 0.00 mL titrant added until 100.0 mL of titrant.

We begin with…

Slide 20

A Balanced Equation!

$HCl + NaOH \rightarrow NaCl + H_2O$

At 0.00 mL added, what's in the beaker?
50.00 mL of 0.100 M HCl
– nothing but HCl and H_2O

Slide 21

pH of 50.00 mL of 0.100 M HCl

What do we know about HCl?
It's a strong acid!
What do we know about strong acids?
They completely dissociate.

0.100 M HCl = 0.100 M H^+

pH = - log (0.100 M H^+) = 1.0

Slide 22

Add 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+ H_2O
Start	0.005 mol	0	0	LOTS
Add	.001 mol			

What does NaOH do?
Neutralizes HCl.
How much HCl?
0.001 mol HCl

Slide 23

Add 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+	H_2O
I	0.005 mol	0.001 mol	0		LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol		+0.001
=	0.004 mol	0 mol	0.001 mol		LOTS

So the pH is….?

$pH = -\log\left(\frac{.004\ mol}{0.060\ L}\right) = 1.17$

Slide 24

Add another 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+	H_2O
I	0.004 mol	0.001 mol	0.001 mol		LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol		+0.001
=	0.003 mol	0 mol	0.002 mol		LOTS

So the pH is….

$pH = -\log\left(\frac{.003\ mol}{0.070\ L}\right) = 1.37$

Slide 25

Add another 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+ H_2O	
I	0.003 mol		0.001 mol	0.002 mol	LOTS
C	- 0.001 mol		-0.001 mol	+0.001 mol	+0.001
=	0.002 mol		0 mol	0.003 mol	LOTS

So the pH is….

$pH = -\log\left(\frac{.002\ mol}{0.080\ L}\right) = 1.60$

Slide 26

Add another 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+ H_2O	
I	0.002 mol		0.001 mol	0.003 mol	LOTS
C	- 0.001 mol		-0.001 mol	+0.001 mol	+0.001
=	0.001 mol		0 mol	0.004 mol	LOTS

So the pH is….

$pH = -\log\left(\frac{.001\ mol}{0.090\ L}\right) = 1.95$

Slide 27

Add another 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+ H_2O	
I	0.001 mol		0.001 mol	0.004 mol	LOTS
C	- 0.001 mol		-0.001 mol	+0.001 mol	+0.001
=	0.000 mol		0 mol	0.005 mol	LOTS

So the pH is….

$pH = -\log\left(\frac{.000\ mol}{0.100\ L}\right) =$ WTF?

Slide 28

WHAT'S IN THE BEAKER?

HCl + NaOH → NaCl + H_2O
I 0.001 mol 0.001 mol 0.004 mol LOTS
C - 0.001 mol -0.001 mol +0.001 mol +0.001
= 0.000 mol 0 mol 0.005 mol LOTS

NO HCl, so NO H^+ from there. I have NaCl which is…
A salt
Acidic or basic?
Neither
What else is in the beaker?
Water
So what?
K_w

Slide 29

Add another 10.0 mL of 0.100 M NaOH

HCl + NaOH → NaCl + H_2O
I 0.001 mol 0.001 mol 0.004 mol LOTS
C - 0.001 mol -0.001 mol +0.001 mol +0.001
= 0.000 mol 0 mol 0.005 mol LOTS

So the pH is….

$$pH = 7$$

Slide 30

Add another 10.0 mL of 0.100 M NaOH

HCl + NaOH → NaCl + H_2O
I 0.000 mol 0.001 mol 0.005 mol LOTS
C 0.000 mol +0.000 mol +0.000 mol 0
= 0.000 mol 0.001 mol 0.005 mol LOTS

So the pH is….

$$14 - pOH = 14 - \left(-\log\left(\frac{.001\ mol}{0.110\ L}\right)\right) = 11.96$$

Slide 31

Add another 10.0 mL of 0.100 M NaOH

	HCl	+ NaOH →	NaCl	+ H_2O	
I	0.000 mol		0.002 mol	0.005 mol	LOTS
C	0.000 mol	+0.000 mol		+0.000 mol	0
=	0.000 mol		0.002 mol	0.005 mol	LOTS

So the pH is….

$$14 - pOH = 14 - \left(-\log\left(\frac{.002\ mol}{0.120\ L}\right)\right) = 12.22$$

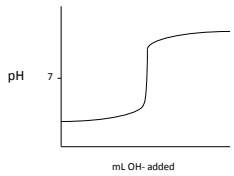
Slide 32

Summarizing

mL 0.100 M NaOH added	pH
0	1.00
10	1.17
20	1.37
30	1.60
40	1.95
50	7
60	11.96
70	12.22
80	12.36
90	12.46
100	12.52

Slide 33

pH vs. mL Base added



Slide 34

Do they all look like that?

No, it depends on what's in the beaker!

Slide 35

50.00 mL of 0.100 M HOAc is titrated with 0.100 M NaOH. Calculate the pH at 10.0 mL increments from 0.00 mL titrant added until 100.0 mL of titrant.

We begin with…

Slide 36

A Balanced Equation!

$HOAc + NaOH \rightarrow NaOAc + H_2O$

At 0.00 mL added, what's in the beaker?
50.00 mL of 0.100 M HOAc
– nothing but HOAc and H_2O

Slide 37

pH of 50.00 mL of 0.100 M HOAc

What do we know about HOAc?
It's a weak acid!
What do we do about weak acids?
Equilibrium, baby! 3 parts!

Slide 38

$K_a=1.8x10^{-5}$

$HOAc + H_2O \leftrightharpoons OAc^- + H_3O^+$

I	**0.100 M**	-	**0**	**0**
C	-x	-	+x	+x
E	0.100-x	-	x	x

$1.8 \times 10^{-5} = \frac{[x][x]}{0.100-x}$

$x=1.34x10^{-3}$ M
$pH = -\log(1.34x10^{-3}\ M) = 2.87$

Slide 39

Add 10.0 mL of 0.100 M NaOH

	HOAc	+ NaOH →	NaOAc	+ H_2O
I	0.005 mol	0.001 mol	0	LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001
=	0.004 mol	0 mol	0.001 mol	LOTS

$[HOAc] = \frac{0.004\ mol}{0.060\ L} = 6.67x10^{-2}$ M

And then….WHAT'S IN THE BEAKER?

Slide 40

$K_a=1.8x10^{-5}$

$HOAc + H_2O \leftrightharpoons OAc^- + H_3O^+$

I	**0.0667 M**	-	**0.0167 M**	**0**
C	-x	-	+x	+x
E	0.0667-x	-	0.0167 +x	x

What is this?

It's a BUFFER!!!

Slide 41

$K_a=1.8x10^{-5}$

$HOAc + H_2O \leftrightharpoons OAc^- + H_3O^+$

I	**0.0667 M**	-	**0.0167 M**	**0**
C	-x	-	+x	+x
E	0.0667-x	-	0.0167 +x	x

$$pH = pKa + log\frac{[Base]}{[Acid]}$$

$pH = 4.74 + log\frac{[0.0167]}{[0.0667]}$=4.14

Slide 42

Add another 10.0 mL of 0.100 M NaOH

	HOAc	+ NaOH →	NaOAc	+ H_2O
I	0.004 mol	0.001 mol	0.001 mol	LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001
=	0.003 mol	0 mol	0.002 mol	LOTS

$pH = 4.74 + log\frac{[0.002\ mol]}{[0.003\ mol]}$=4.56

Slide 43

Add another 10.0 mL of 0.100 M NaOH

	HOAc	+ NaOH	→ NaOAc	+ H_2O
I	0.003 mol	0.001 mol	0.002 mol	LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001
=	0.002 mol	0 mol	0.003 mol	LOTS

$pH = 4.74 + log\frac{[0.003\ mol]}{[0.002\ mol]}$=4.92

Slide 44

Add another 10.0 mL of 0.100 M NaOH

	HOAc	+ NaOH	→ NaOAc	+ H_2O
I	0.002 mol	0.001 mol	0.003 mol	LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001
=	0.001 mol	0 mol	0.004 mol	LOTS

$pH = 4.74 + log\frac{[0.004\ mol]}{[0.001\ mol]}$=5.34

Slide 45

Add another 10.0 mL of 0.100 M NaOH

	HOAc	+ NaOH	→ NaOAc	+ H_2O
I	0.001 mol	0.001 mol	0.004 mol	LOTS
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001
=	0.000 mol	0 mol	0.005 mol	LOTS

$pH = 4.74 + log\frac{[0.005\ mol]}{[0.000\ mol]}$=WTF?

Is the pH = 7?

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WHAT'S IN THE BEAKER?

	HOAc	+ NaOH	→ NaOAc	+ H_2O	
I	0.001 mol	0.001 mol	0.004 mol	LOTS	
C	- 0.001 mol	-0.001 mol	+0.001 mol	+0.001	
=	0.000 mol	0 mol	0.005 mol	LOTS	

I have NaOAc which is…

A salt

Acidic or basic?

NaOH is a strong base, HOAc is a weak acid. OAc^- is a weak base.

Slide 47

OMG IT'S A K_B PROBLEM!

	OAc^-	+ H_2O	⇋ HOAc	+ OH^-
I	$\frac{0.005\ mol}{0.100\ L}$	-	0	0
C	–x	-	+x	+x
E	0.05 M-x		x	x

$$K_b = \frac{K_w}{K_a} = 5.56 \times 10^{-10} = \frac{[x][x]}{0.05 - x}$$

$X=5.27 \times 10^{-6}$

$pOH=-\log(5.27 \times 10^{-6}) = 5.28$

$pH = 14 - 5.28 = 8.72$

Slide 48

Add another 10.0 mL of 0.100 M NaOH

Now it's just all about the excess NaOH!

Just like before.

Slide 49

Summarizing

mL 0.100 M NaOH added	pH
0	2.87
10	4.14
20	4.56
30	4.92
40	5.34
50	8.72
60	11.96
70	12.22
80	12.36
90	12.46
100	12.52

Slide 50

Comparing

mL 0.100 M NaOH weak acid	pH
0	2.87
10	4.14
20	4.56
30	4.92
40	5.34
50	8.72
60	11.96
70	12.22
80	12.36
90	12.46
100	12.52

mL 0.100 M NaOH Strong acid	pH
0	1.00
10	1.17
20	1.37
30	1.60
40	1.95
50	7
60	11.96
70	12.22
80	12.36
90	12.46
100	12.52

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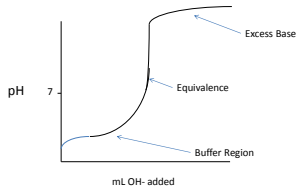
pH vs. mL Base added
weak acid/strong base



Slide 52

CB If benzoic acid, pKa = 4.05, is titrated with NaOH(aq), the equivalence point is:

A. Acidic if the initial concentration of acid was higher than that of base.
B. Always Acidic
C. Basic if the initial concentration of base was higher than that of acid.
D. Always Basic
E. Neutral

Slide 53

CB If methyl amine, pKb = 9.2, is titrated with HCl(aq), the equivalence point is:

A. Acidic if the initial concentration of acid was higher than that of base.
B. Always Acidic
C. Basic if the initial concentration of base was higher than that of acid.
D. Always Basic
E. Neutral

Slide 54

The reverse happens with a weak base/strong acid

$HCl + NH_4OH \rightarrow NH_4Cl + H_2O$

When you start adding base, you've got excess strong acid, so only [HCl] matters - "excess strong acid"

At equivalence, you have an acidic salt, so the pH is less than 7.

After equivalence, you've got a weak base and its conjugate acid – buffer region!