# N41 – Acid Base

## Titration

Link to YouTube Presentation: https://youtu.be/9p9wnazGp9l

# **N41 – Acid Base** Titration

#### Target: I can perform titration calculations.



## **Titration Set Up**



## **Strong Acid/Strong Base Titration**





## **Weak Acid/Strong Base Titration**





## **Strong Acid/Weak Base Titration**





## **Strong Acid/Strong Base Titration**









Acid-Bas	e Dece	ision secies in system	ADAPTED FROM: J. Chem. Ed. 2007. 84, 0540
ACID STRONG ACID (Ka>71) OR NEAK ACID (Ka<1)? Strong acid dissociated 100% Fring acid diss	BASE STRONG BASE (K) WEAK BASE (K) STRONG BASE WEAK BASE WEAK BASE WEAK STRONG BASE STRONG STRONG STRONG STRONG STRONG STRONG STRONG STRONG STRONG STRONG STRONG STRONG ST	Mixt Mixt Mixt ALI) Hear Acid + Hits Carr Base BUFFER Solution BUFFER Solution PH=pKa+lg[E PH=pKa+lg[E Mixt PH=pKa+lg[E CAT NRITE OUT RXN W/ Hall Determine CoH-J From I table + Ka expression POH=-log(COH-J) PH=14-POH	J. Chem. Ed. 2007, 84, p.340 Dre of ACID + BASE STRONG ACID + BASE STRONG ACID + BASE W NEAK ACID/BASE W NEAK ACID DI HE-IN/CITION WEITER W NEAK ACID DI HE-IN/CITION W NIX OF HAAA'' BUFFER ANAAYKE IS I IMIN' NEAK ACID DI HE-IN/CITION W NIX OF HAAA'' BUFFER ANAAYKE IS I IMIN' ANAAYKE IS I IMIN' I I I I I I I I I I I I I I I I I I I

#### BRACEVOURSELF







TITRATION

**LCULATIONS ARE COMING** 



BRACEVOURSELF



## **Calculations to Plot a Titration Curve**

#### 1. Starting pH

If weak, then ICE table then pH

#### 2. Early on during titration

• Stoich then He-Ha

#### 3. Equivalence Point

- mol acid = mol base
- No more buffer! Reverse rxn
- Calc new K value ICE then pH

#### 4. <sup>1</sup>/<sub>2</sub> Way Point

- ½ moles @ eq.pt
- pH = pKa

#### 5. Towards end of titration

- Extra titrant left over
- Stoich then simple pH





### Lets look at the titration of acetic acid w/ NaOH BEFORE TITRATION

- Starting point:
  - -25 ml of 0.15M Acetic Acid (K<sub>a</sub> = 1.8E<sup>-5</sup>)
    - Calculate pH before any titrant is added
      - ICE TABLE! Then pH calculation

$C_2H_3O_2H$	$\leftrightarrow  H^{\scriptscriptstyle +}$	$C_2H_3O_2^{-1}$
0.15 M	0 M	0 M
- X	+ x	+ x
0.15 – x	Х	x
0.15	x	x

$$K = \frac{[H^+][C_2H_3O_2^-]}{[C_2H_3O_2H]}$$
  
1.8 x 10<sup>-5</sup> =  $\frac{(x)(x)}{0.15}$   
x = 1.64 x 10<sup>-3</sup>

$$pH = -log[H^+]$$

$$pH = -log(1.64 \times 10^{-3})$$

$$pH @ starting point$$

= 2.78

## **DURING THE TITRATION**

- Add 10ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have a buffer now.
    - You have a conjugate base!
    - Use He-Ha eq.

People like to use these "mole tables" – they are NOT ICE TABLES! They have moles not concentrations. **BE CAREFUL!** 

<b>T</b> i	$C_2H_3O_2H$	OH- €	$\rightarrow$ H <sub>2</sub> O	$C_2H_3O_2^-$
<b>LABL</b>	3.75 mmol	1 mmol	0	0
	-1 mmol	-1 mmol	+1 mmol	+1 mmol
Σ	2.75 mmol	0 mmol	1mmol	1mmol

Have to convert to M before using He-Ha!

## **DURING THE TITRATION**

- Add 10ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have a buffer now.
    - You have a conjugate base!
    - Use He-Ha eq.

$$[C_2H_3O_2H] = \frac{2.75 \times 10^{-3} mol}{(0.025 L + 0.010 L)} = 0.0786 M$$

$$[C_2H_3O_2^{-}] = \frac{1.00 \ x \ 10^{-3} mol}{(0.025 \ L + 0.010 \ L)} = 0.0286 \ M$$

$$pH = pKa + log\left(rac{[A^-]}{[HA]}
ight)$$

 $pH = -log(1.8x10^{-5}) + log\left(\frac{0.0286\,M}{0.0786\,M}\right)$ 

pH = 4.31



## they are NOT ICE TABLES! They have **DURING THE TITRATION AGAIN** moles not concentrations. **BE CAREFUL!**

- Add 25ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have a buffer now.
    - You have a conjugate base!
    - Use He-Ha eq.

Ē	$C_2H_3O_2H$	OH- ←	→ H <sub>2</sub> O	$C_2H_3O_2^-$
TABL	3.75 x10 <sup>-3</sup>	2.5 x10 <sup>-3</sup>	0	0
OLE '	-2.5 x10 <sup>-3</sup>	-2.5 x10 <sup>-3</sup>	+2.5 x10 <sup>-3</sup>	+2.5 x10 <sup>-3</sup>
Σ	1.25 x10 <sup>-3</sup>	0	2.5 x10 <sup>-3</sup>	2.5 x10 <sup>-3</sup>

People like to use these "mole tables" -

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Have to convert to M before using He-Ha!

### **DURING THE TITRATION AGAIN**

- Add 25ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have a buffer now.
    - You have a conjugate base!
    - Use He-Ha eq.

$$[C_2H_3O_2H] = \frac{1.25 \times 10^{-3} mol}{(0.025 L + 0.025 L)} = 0.025 M$$
$$[C_2H_3O_2^{-}] = \frac{2.50 \times 10^{-3} mol}{(0.025 L + 0.025 L)} = 0.050 M$$

$$pH = pKa + log\left(rac{[A^-]}{[HA]}
ight)$$

 $pH = -log(1.8x10^{-5}) + log\left(\frac{0.050 M}{0.025 M}\right)$ pH = 5.05



### **AT EQUIVALENCE POINT**

- Add ? ml of 0.10 M NaOH
  - Determine stoichiometry



## AT EQUIVALENCE POINT

- Add 37.5 ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have NO BUFFER LEFT

**MOLE TABLE!** 

You have NO weak acid left!!

People like to use these "mole tables" – they are NOT ICE TABLES! They have moles not concentrations. **BE CAREFUL!** 

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	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> H	OH-	$\leftrightarrow$ H <sub>2</sub> O	$C_2H_3O_2^-$
	3.75 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>	0	0
) 1	-3.75 x10 <sup>-3</sup>	-3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>
:	0	0	3.75 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>

Have to Reverse the Rxn, new ICE table!

25 mL	1 L	0.15 mol	- 2 75×10-3
	1000 mL	1 L	mol acid
37.5mL	1 L	0.10 mol	- <b>2 75 v10</b> -3
	1000 mL	1 L	mol base

#### **AT EQUIVALENCE POINT**

- Add 37.5 ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have NO BUFFER LEFT!
    - You have NO weak acid left!!

## Remember to use M in ICE Table not moles!

$$[C_2H_3O_2^{-}] = \frac{3.75 \, x \, 10^{-3} mol}{(0.025 \, L + 0.0375 \, L)} = 0.060 \, M$$

People like to use these "mole tables" – they are NOT ICE TABLES! They have moles not concentrations. **BE CAREFUL!** 

$C_2H_3O_2H$	OH- ←	H <sub>2</sub> O	$C_2H_3O_2^-$
3.75 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>	0	0
-3.75 x10 <sup>-3</sup>	-3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>	+3.75x10 <sup>-3</sup>
0	0	3.75 x10 <sup>-3</sup>	3.75x10 <sup>-3</sup>

#### Have to Reverse the Rxn, new ICE table!

$C_2H_3O_2^{-1}$	H₂O ←	$\rightarrow C_2H_3O_2H$	OH-
0.06 M	-	0	0
- X	-	+ X	+ X
0.06	-	x	х



#### **AT EQUIVALENCE POINT**

- Add 37.5 ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have NO BUFFER LEFT!
    - You have NO weak acid left!!

#### Remember to use Kb this time!

$$Kw = Ka \ x \ Kb \qquad Kb = \frac{Kw}{Ka}$$

$$Kb = \frac{(1 \ x \ 10^{-14})}{(1.8 \ x \ 10^{-5})} = 5.56 \ x \ 10^{-10}$$

People like to use these "mole tables" – they are NOT ICE TABLES! They have moles not concentrations. **BE CAREFUL!** 

$C_2H_3O_2H$	он- ←	→ H <sub>2</sub> O	$C_2H_3O_2^-$
3.75 x10 <sup>-3</sup>	<b>3.75</b> x10 <sup>-3</sup>	0	0
-3.75 x10 <sup>-3</sup>	-3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>
0	0	3.75 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>

#### Have to Reverse the Rxn, new ICE table!

$C_2H_3O_2^{-1}$	H₂O ←	$\rightarrow C_2H_3O_2H$	OH-
0.06 M	-	0	0
- X	-	+ X	+ X
0.06	-	X	Х



### AT EQUIVALENCE POINT

- Add 37.5 ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have NO BUFFER LEFT!
    - You have NO weak acid left!!

#### Remember to use Kb this time!

$$Kw = Ka \ x \ Kb \qquad Kb = \frac{Kw}{Ka}$$

$$Kb = \frac{(1 \ x \ 10^{-14})}{(1.8 \ x \ 10^{-5})} = 5.56 \ x \ 10^{-10}$$

$C_2H_3O_2^{-1}$	H₂O ←	→C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> H	OH-
0.06 M	-	0	0
- X	-	+ X	+ X
0.06	-	х	Х

5.56 x 10<sup>-10</sup> = 
$$\frac{(x)(x)}{0.06}$$

$$x = 5.77 \ x \ 10^{-6} = [OH^{-}]$$

#### Now you can do pH calculation!



## **AT EQUIVALENCE POINT**

- Add 37.5 ml of 0.10 M NaOH
  - Determine stoichiometry
  - Notice! You have NO BUFFER LEFT!
    - You have NO weak acid left!!

Stop and check that it makes sense! Weak Acid + Strong Base Equivalence Point should be Basic Yes, 8.76 makes sense!

#### Now you can do pH calculation!

 $x = 5.77 x 10^{-6} = [OH^{-}]$   $pOH = -log(5.77 x 10^{-6}) = 5.24$  pH = 14 - pOH pH = 14 - 5.24 pH = 8.76

#### AT 1/2 WAY POINT

- It took 37.5 ml of NaOH to get to eq.pt
  - So half way to eq. pt. would be 18.75 mL of NaOH

@  $\frac{1}{2}$  way point pH = pKa

$$pH = -log(1.8 \times 10^{-5})$$
 pH = 4.74

Why calculate pH at the <sup>1</sup>/<sub>2</sub> way point? It is a nice point to plot on a graph to help get the curve. Also - when doing a titration, you can figure out the Ka by finding the pH at the halfway point.

#### AT THE END OF TITRATION

- Add 50mL of 0.10 M NaOH
  - Still no buffer anymore...used up all the weak acid.
  - BUT...you are past the equivalence point!
  - Now you have excess OH-

50mL	1 L	0.10 mol	- <b>5 v10</b> -3
	1000 mL	1 L	mol base

#### Do stoich to find how much left

$C_2H_3O_2H$	он- ↔	H <sub>2</sub> O	$C_2H_3O_2^-$
3.75 x10 <sup>-3</sup>	5 x10 <sup>-3</sup>	0	0
-3.75 x10 <sup>-3</sup>	– 3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>	+3.75 x10 <sup>-3</sup>
0	1.25 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>	3.75 x10 <sup>-3</sup>

Remember to use M in pH calculations!

 $[OH^{-}] = \frac{1.25 \ x \ 10^{-3} \ mol}{(0.025 \ L + 0.050 \ L)}$ 

 $[OH^{-}] = 0.0167 M$ 

pOH = -log(0.0167) = 1.78

pH = 14 - pOH = 14 - 1.78

pH = 12.22



## **Selection of Indicators**



## pH Indicators and Ranges

How do you know which indicator to pick for a reaction?

Pick the one that changes color in a pH range that is near where your equivalence point is,

If you know the pKa of an indicator, it will change color in a pH range +/- 1 from that pKa

**Example:** pKa of phenolphthalein is 9.3. So it is a good indicator if your equivalence point is between 8.3-10.3



## **Some Acid-Base Indicators**



Indicator	pH Range in which Color Change Occurs	Color Change as pH Increases
Crystal violet	0.0 - 1.6	yellow to blue
Thymol blue	1.2 - 2.8	red to yellow
Orange IV	1.4 - 2.8	red to yellow
Methyl orange	3.2 - 4.4	red to yellow
Bromcresol green	3.8 - 5.4	yellow to blue
Methyl red	4.8 - 6.2	red to yellow
Chlorophenol red	5.2 - 6.8	yellow to red
Bromthymol blue	6.0 - 7.6	yellow to blue
Phenol red	6.6 - 8.0	yellow to red
Neutral red	6.8 - 8.0	red to amber
Thymol blue	8.0 - 9.6	yellow to blue
Phenolphthalein	8.2 - 10.0	colourless to pink
Thymolphthalein	9.4 - 10.6	colourless to blue
Alizarin yellow	10.1 - 12.0	yellow to blue
Indigo carmine	11.4 - 13.0	blue to yellow

### What is Higher [] at Each Point in Titration



















GLUE

## Careful with ½ way point on a base titration!

pH @ 1/2 Way Point = 9.75

That is the pKa for BH+ !!!

- So <u>pKb</u> for <u>B</u> is...
  - pKb = 14 pKa
- = 14 9.75 = 4.25



## **Extra Titration Calculation Practice**

# 15 ml of 0.25M Acetic Acid ( $K_a = 1.8E^{-5}$ ) is titrated with 0.15 M NaOH

- 1. pH before any NaOH is added
- 2. pH after 5 mL NaOH added
- 3. mL of NaOH added to reach Equivalence point
- 4. pH at the Equivalence Point
- 5. mL of NaOH to reach half way point
- 6. pH at the half way point
- 7. pH after 60mL NaOH added

- 1. pH = 2.67
- 2. pH = 4.14
- 3. 25 mL
- 4. pH = 8.86
- 5. 12.5 mL
- 6. pH = 4.74
- 7. pH = 12.85

\*Note – answers were autogenerated. If you think there is a typo let me know!

# 30 ml of 0.15 M Methanoic Acid ( $K_a = 1.6E^{-5}$ ) is titrated with 0.45 M NaOH

- 1. Concentration of H+ before any NaOH is added
- 2. pH before any NaOH is added
- 3. pH after 15 mL NaOH added
- 4. mL of NaOH added to reach Equivalence point
- 5. pH at the Equivalence Point
- 6. mL of NaOH to reach half way point
- 7. pH at the half way point
- 8. pH after 40mL NaOH added

- 1.  $[H^+] = 1.5 \times 10^{-3} M$
- 2. pH = 2.81
- 3. pH = 12.7
- 4. 10 mL
- 5. pH = 8.92
- 6. 5 mL
- 7. pH = 4.8
- 8. pH = 13.29

\*Note – answers were autogenerated. If you think there is a typo let me know!

# 12 ml of 0.85 M Methanoic Acid ( $K_a = 1.6E^{-5}$ ) is titrated with 0.35 M NaOH

- 1. Concentration of H<sup>+</sup> before any NaOH is added
- 2. pH before any NaOH is added
- 3. pH after 8 mL NaOH added
- 4. mL of NaOH added to reach Equivalence point
- 5. pH at the Equivalence Point
- 6. mL of NaOH to reach half way point
- 7. pH at the half way point
- 8. pH after 58mL NaOH added

- 1.  $[H^+] = 3.7 \times 10^{-3}$
- 2. pH = 2.43
- 3. pH = 4.38
- 4. 29.1 mL
- 5. pH = 9.1
- 6. 14.6 mL
- 7. pH = 4.8
- 8. pH = 13.16

\*Note – answers were autogenerated. If you think there is a typo let me know!

# 15 ml of 0.1 M Methylamine $(K_b = 4.4E^{-4})$ is titrated with 0.05 M HCI

- 1. pH before any HCl is added
- 2. pH after 5 mL HCl added
- 3. mL of HCI added to reach Equivalence point
- 4. pH at the Equivalence Point
- 5. mL of HCI to reach half way point
- 6. pH at the half way point
- 7. pH after 50mL HCI added

- 1. pH = 11.81
- 2. pH = 11.34
- 3. 30 mL
- 4. pH = 6.06
- 5. 15 mL
- 6. pH = 10.64
- 7. pH = 1.81

\*Note – answers were autogenerated. If you think there is a typo let me know!

#### **YouTube Link to Presentation**

https://youtu.be/okVYe933E4k