N41 – Acid Base

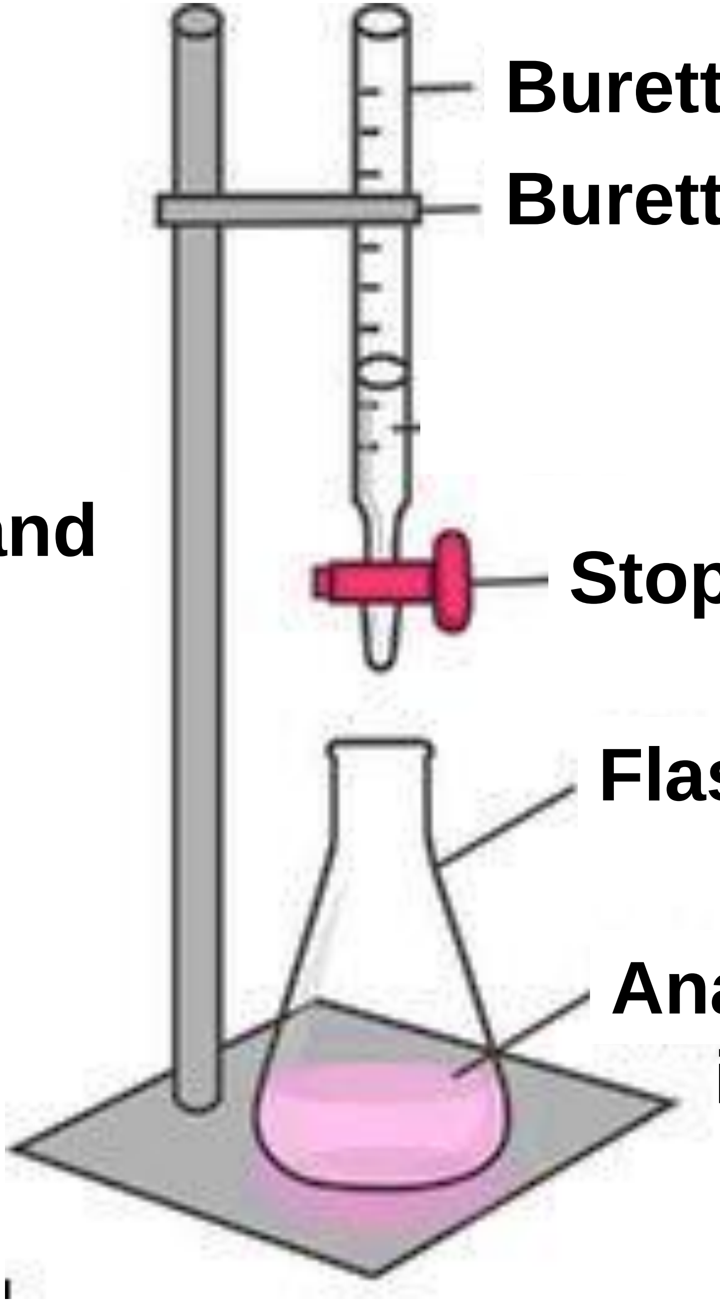
Titration

N41 – Acid Base

Titration

Target: I can perform titration calculations.

Titration Set Up



Burette filled with Titrant

Burette clamp

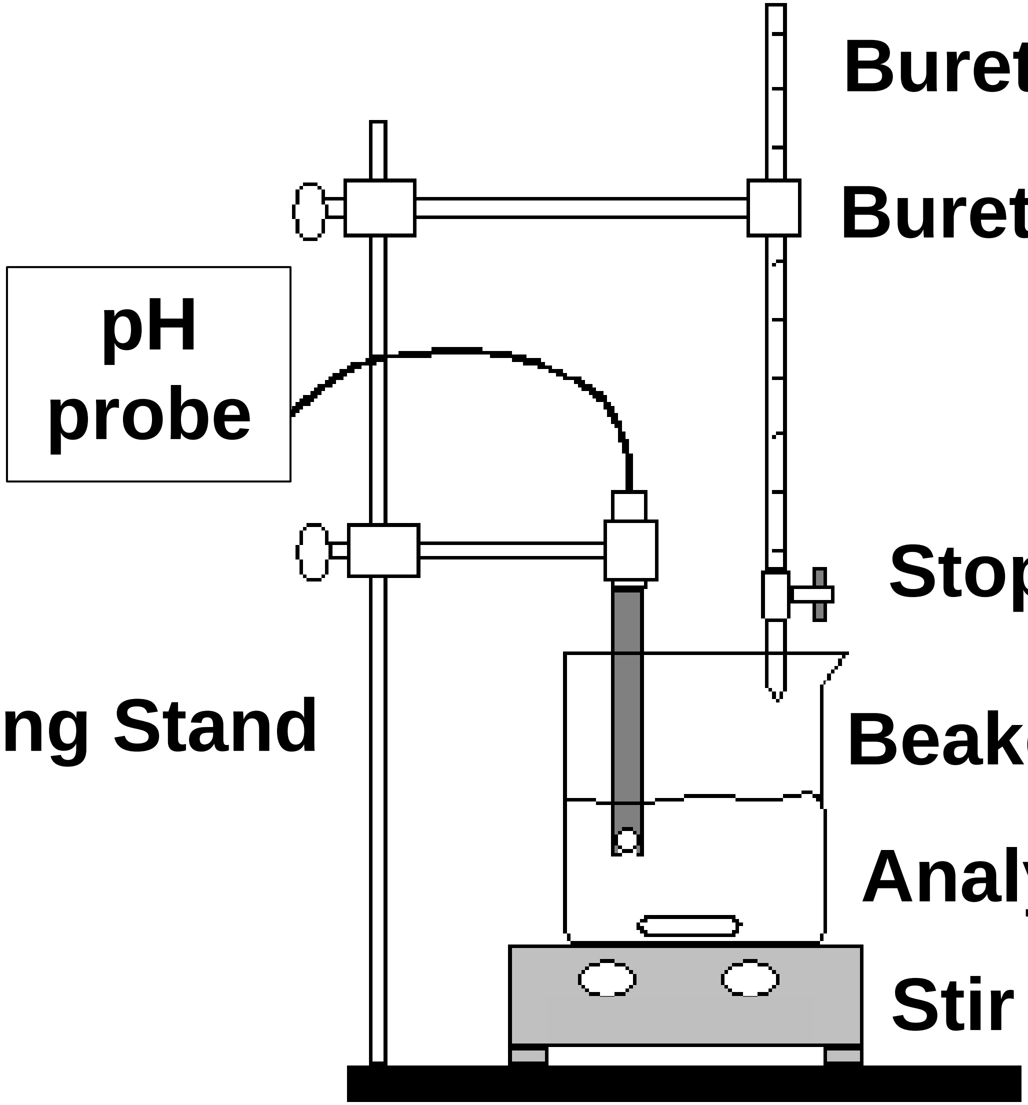
Ring Stand

Stopcock

Flask

Analyte solution with
indicator added

Titration Set Up



Burette filled with Titrant

Burette clamp

Stopcock

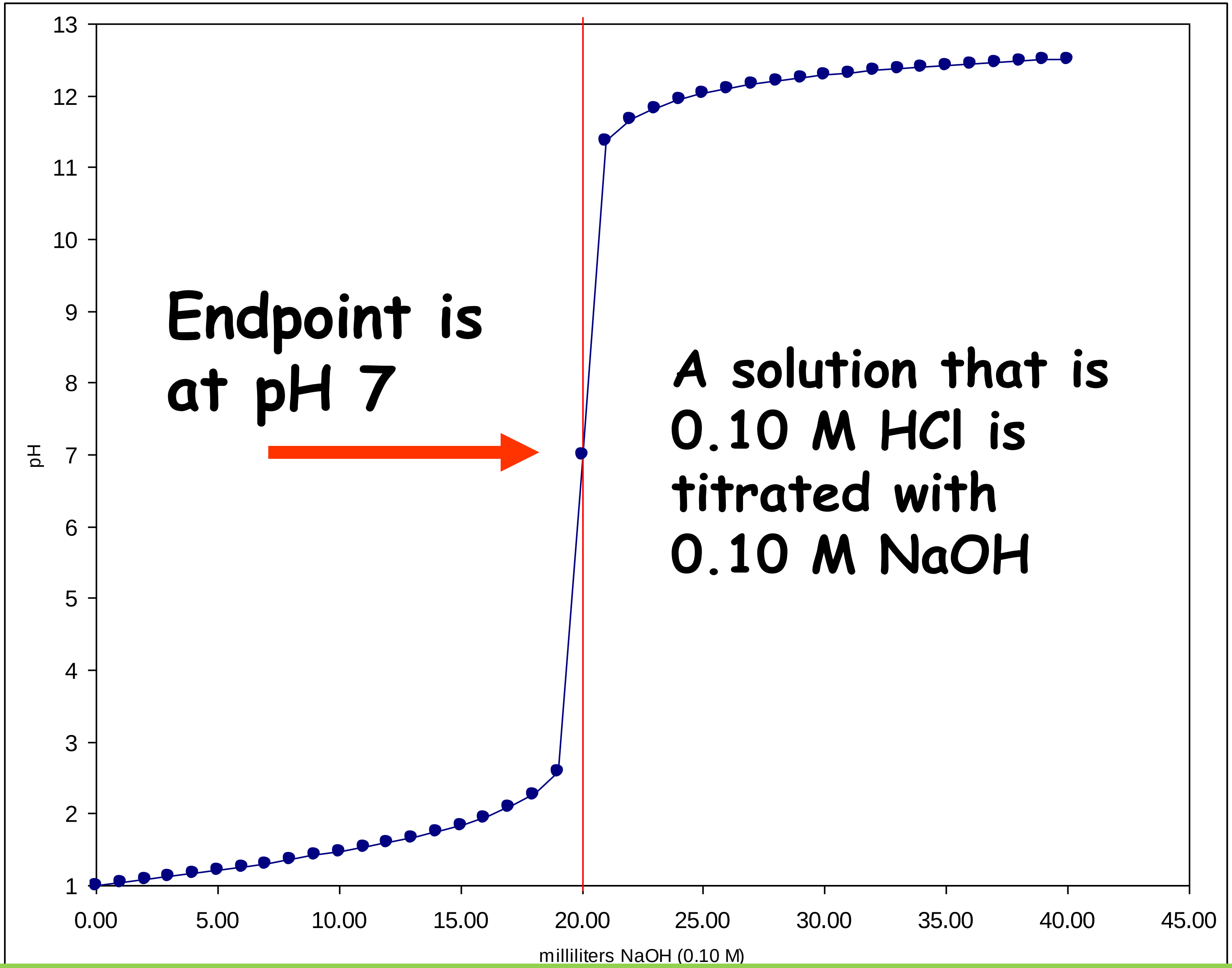
Ring Stand

Beaker with stir bar

Analyte Solution

Stir Plate

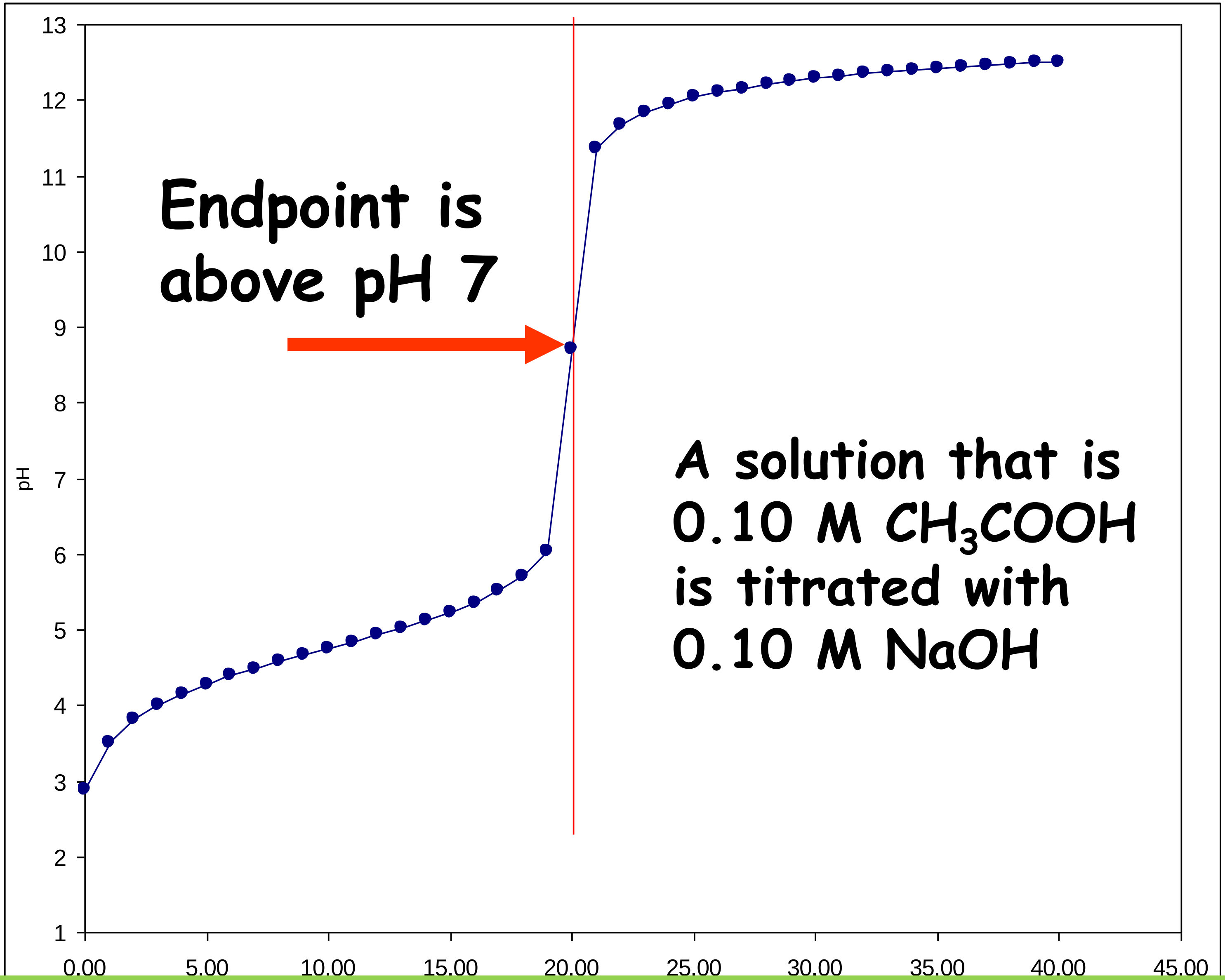
Strong Acid/Strong Base Titration



Endpoint is at pH 7

A solution that is 0.10 M HCl is titrated with 0.10 M NaOH

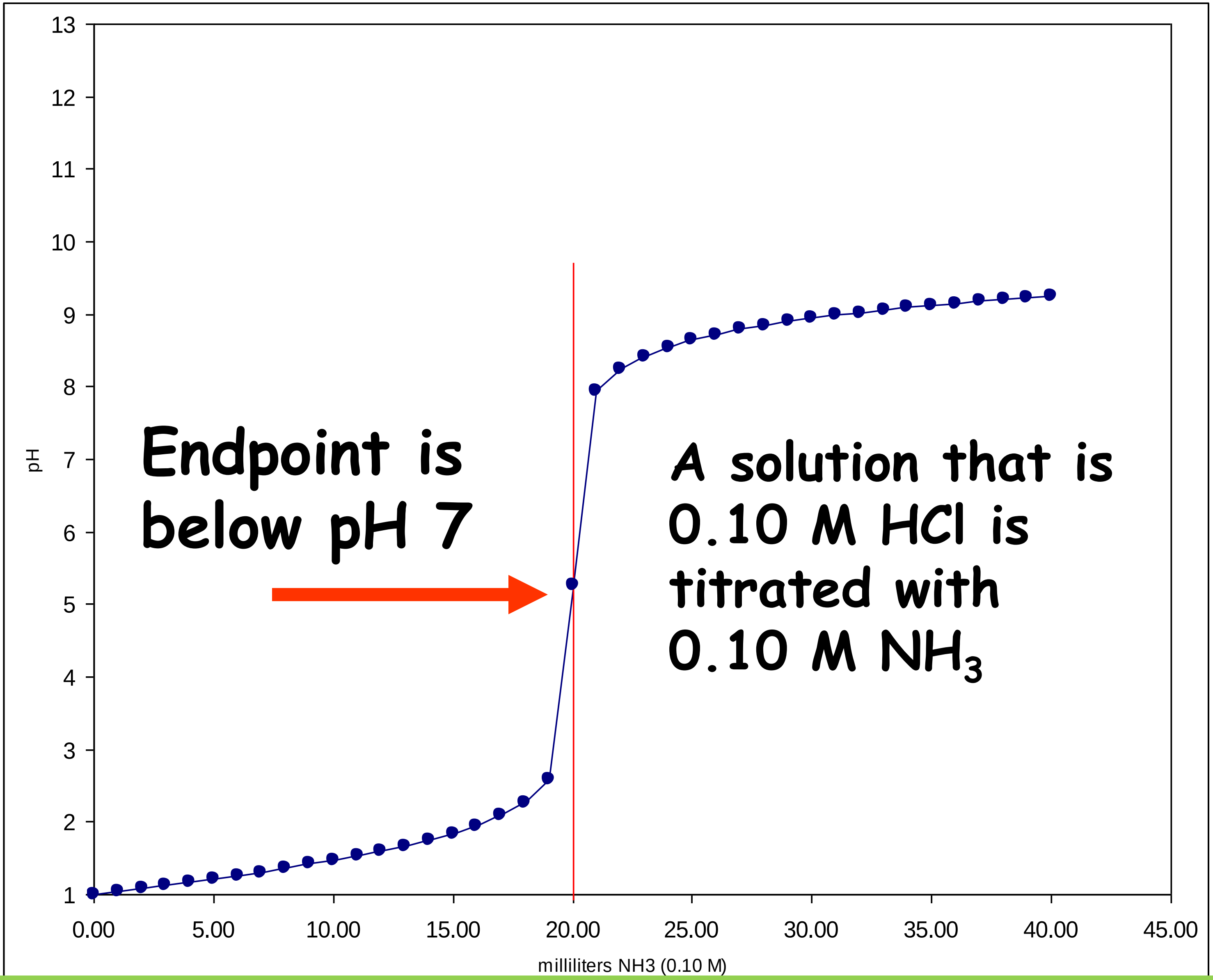
Weak Acid/Strong Base Titration



Endpoint is above pH 7

A solution that is 0.10 M CH_3COOH is titrated with 0.10 M $NaOH$

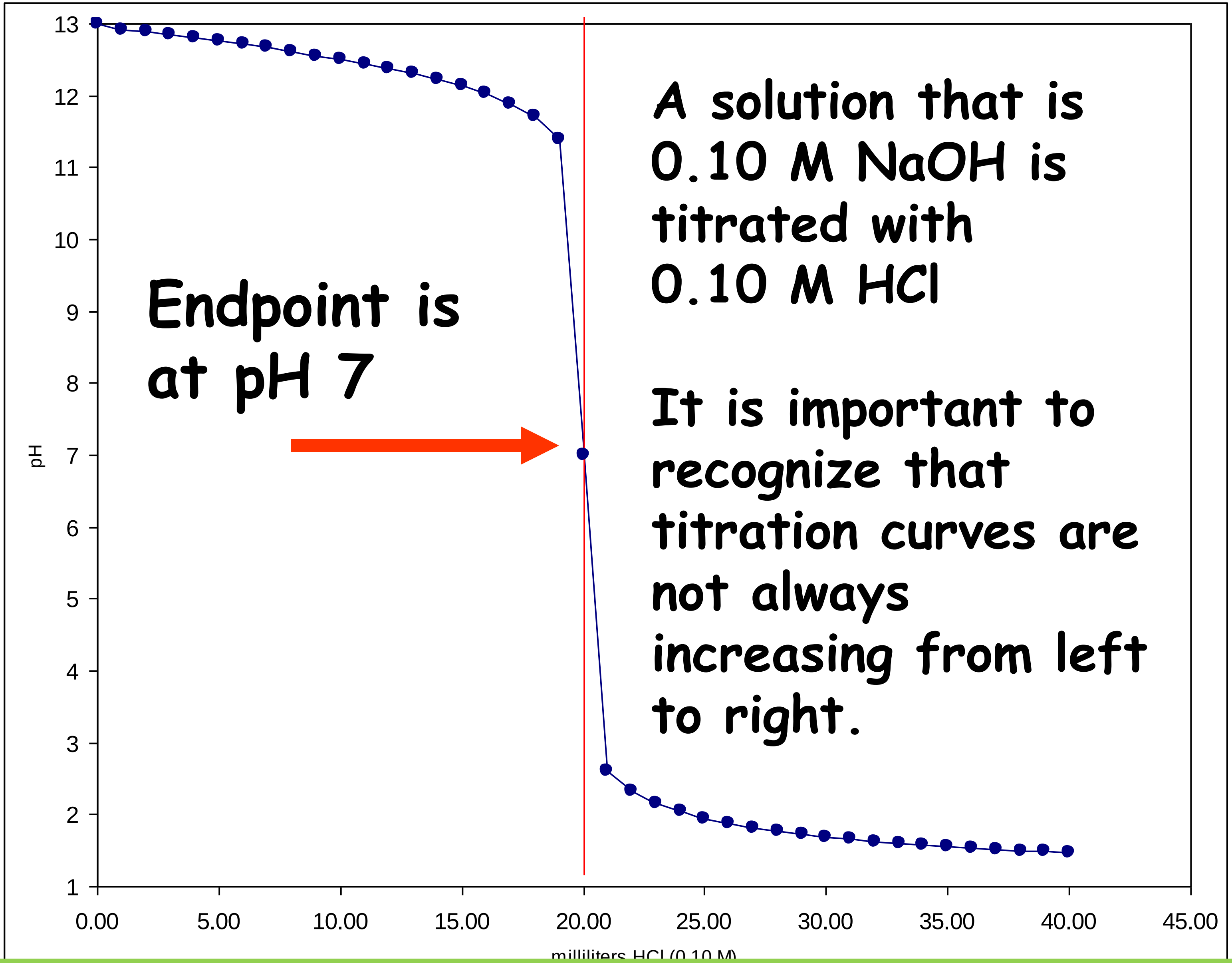
Strong Acid/Weak Base Titration



Endpoint is below pH 7

A solution that is 0.10 M HCl is titrated with 0.10 M NH_3

Strong Acid/Strong Base Titration



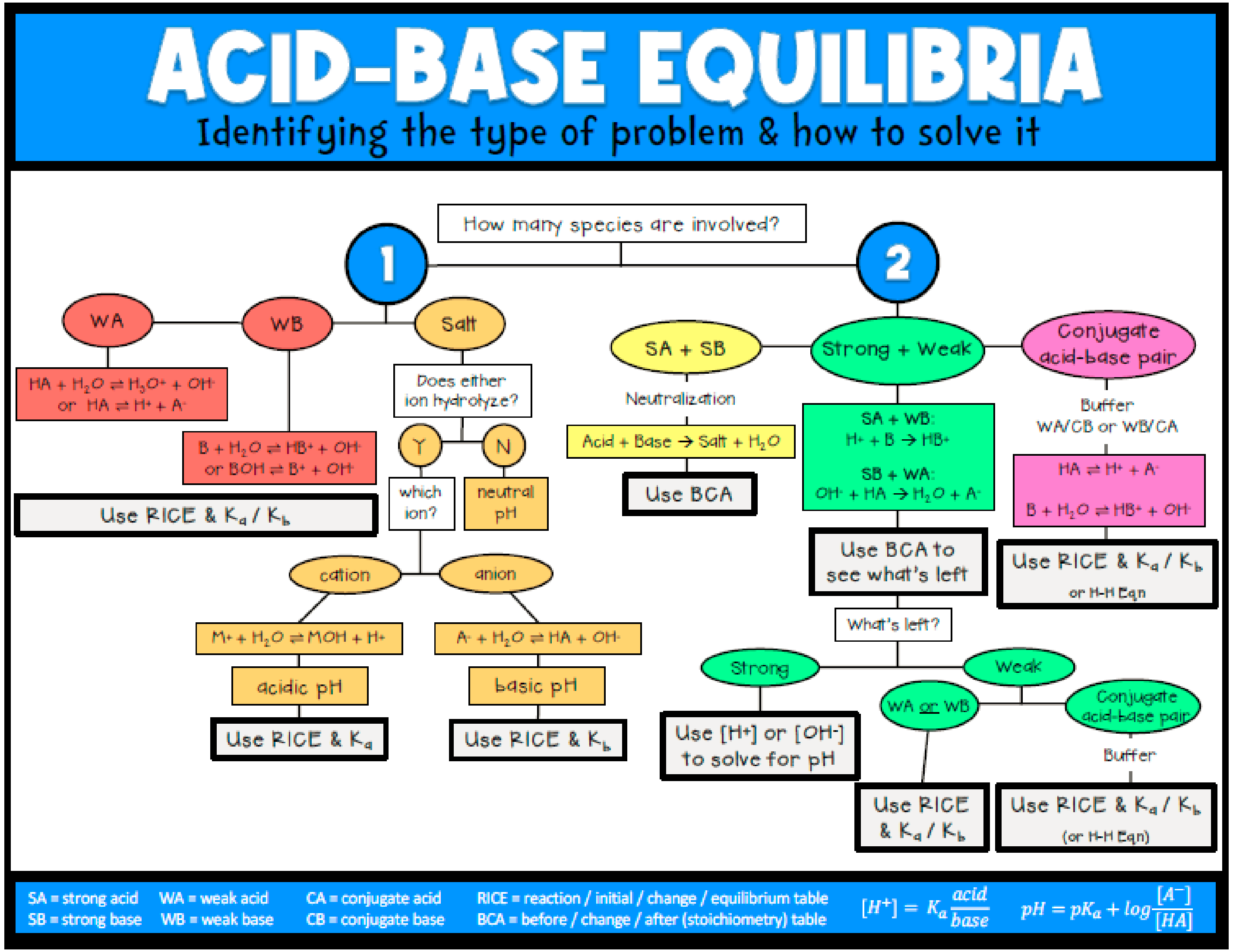
Endpoint is at pH 7

A solution that is 0.10 M NaOH is titrated with 0.10 M HCl

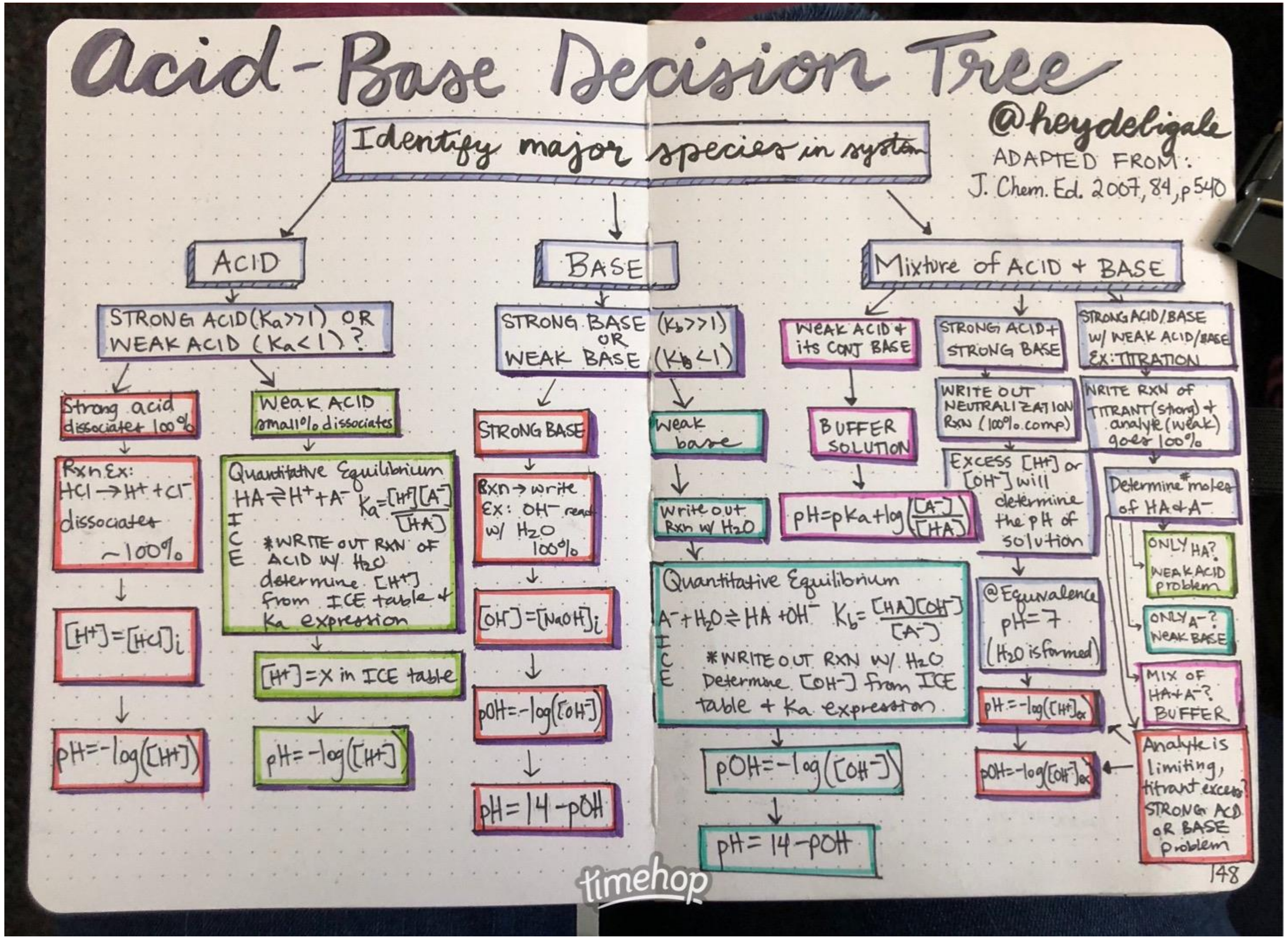
It is important to recognize that titration curves are not always increasing from left to right.

Titration Calculations…

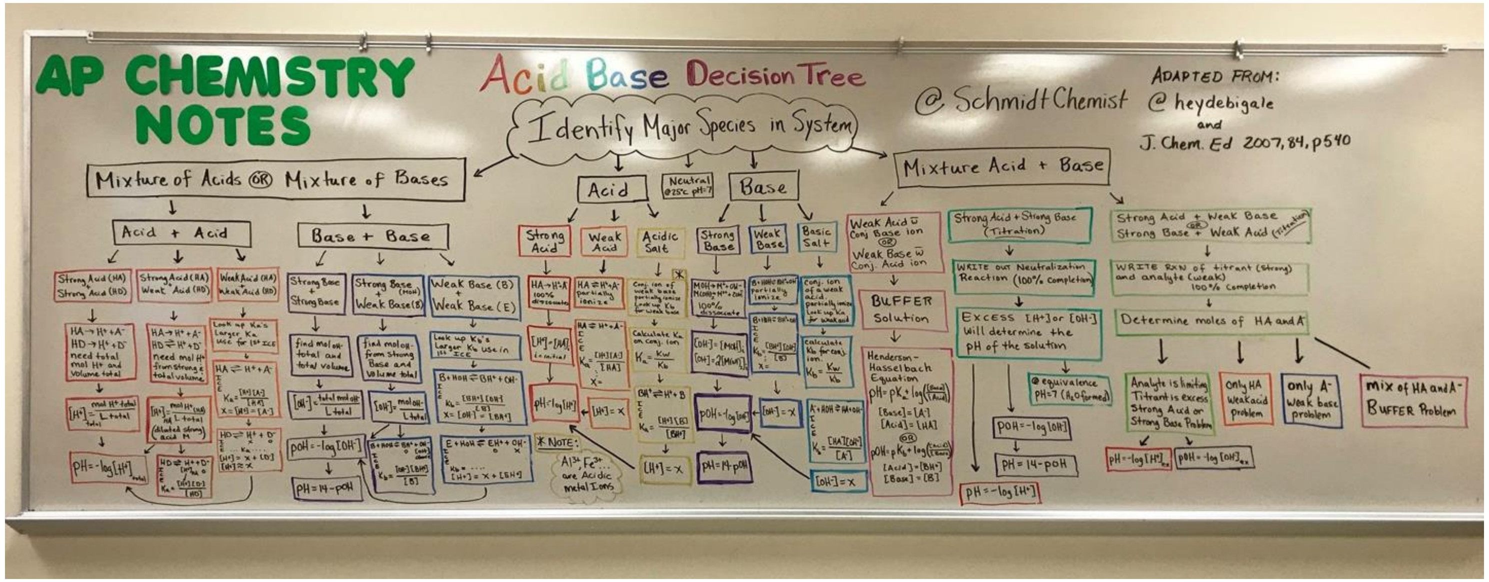
Titration Calculations…



Titration Calculations…

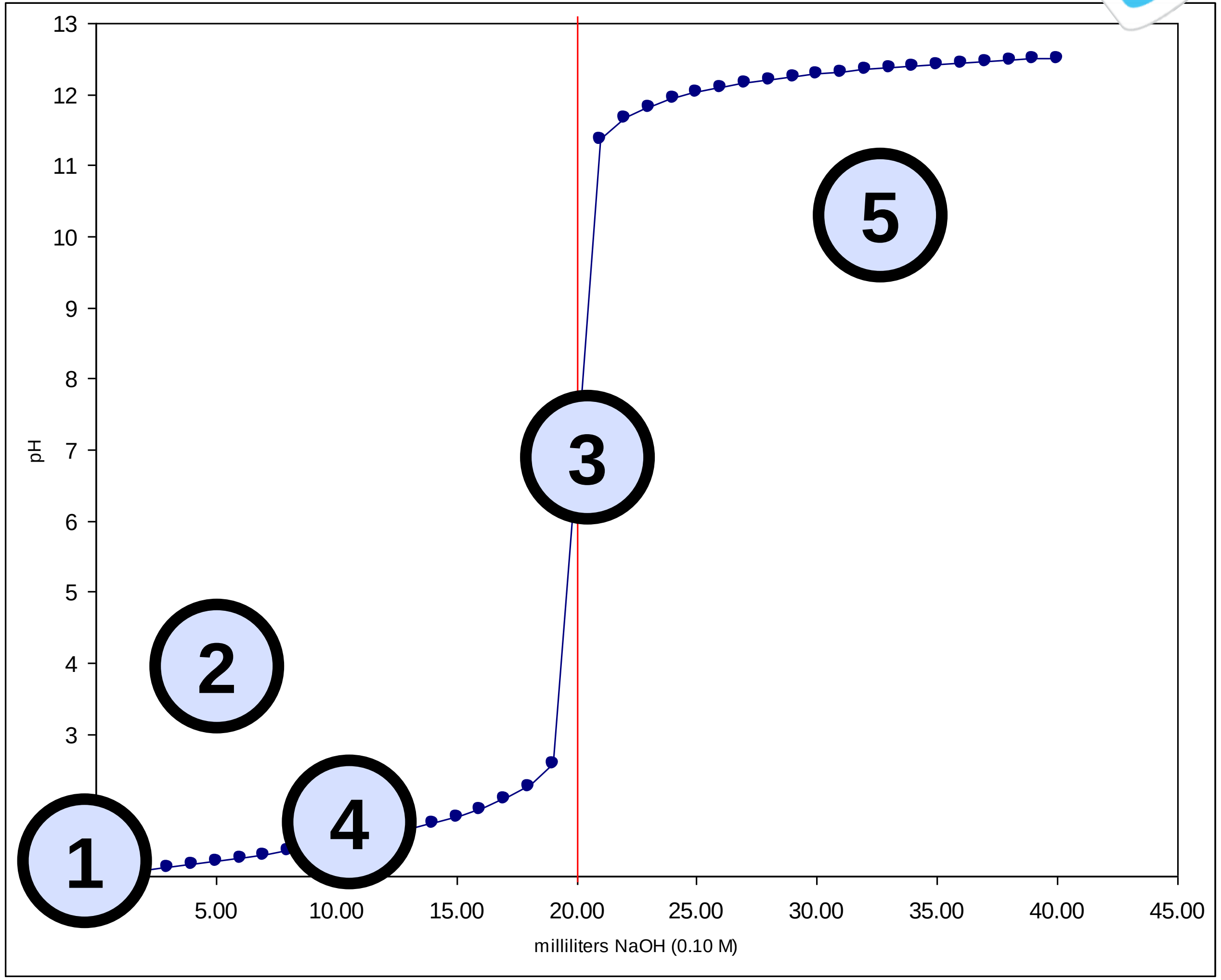


Titration Calculations…



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. **½ Way Point**
   - ½ moles @ eq.pt
   - pH = pKa
5. **Towards end of titration**
   - Extra titrant left over
   - Stoich then simple pH



Titration Calculations

Lets look at the titration of acetic acid w/ NaOH

BEFORE TITRATION

- **Starting point:**
  - 25 ml of 0.15M Acetic Acid ($K_a = 1.8E^{-5}$)
    - Calculate pH before any titrant is added
      - ICE TABLE! Then pH calculation

$C_2H_3O_2H$	$\leftrightarrow$ H^+	$C_2H_3O_2^-$
0.15 M	0 M	0 M
- x	+ x	+ x
0.15 – x	x	x
0.15	x	x

$$K = \frac{[H^+][C_2H_3O_2{}^-]}{[C_2H_3O_2H]}$$

$$1.8\ x\ 10^{-5} = \frac{(x)(x)}{0.15}$$

$$x = 1.64\ x\ 10^{-3}$$

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

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

$$pH\ @\ starting\ point$$

= 2.78

Titration Calculations

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.

25 mL	1 L	0.15 mol
	1000 mL	1 L

= $3.75\text{x}10^{-3}$ mol acid

10 mL	1 L	0.10 mol
	1000 mL	1 L

= $1.0\ \text{x}10^{-3}$ mol base

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_2O	$C_2H_3O_2^-$
3.75 mmol	**1 mmol**	0	0
-1 mmol	-1 mmol	+1 mmol	+1 mmol
2.75 mmol	0 mmol	1mmol	1mmol

Have to convert to M before using He-Ha!

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

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

NOW you can use He-Ha

Titration Calculations

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.

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

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

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

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

pH = 4.31

Titration Calculations

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

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.

$C_2H_3O_2H$	OH^- $\leftrightarrow$	H_2O	$C_2H_3O_2^-$
3.75 mmol	**2.5 mmol**	0	0
-2.5 mmol	-2.5 mmol	+2.5mmol	+2.5mmol
1.25 mmol	0 mmol	2.5 mmol	2.5 mmol

Have to convert to M before using He-Ha!

$$\frac{25\text{ mL}}{} \,\Big|\, \frac{1\text{ L}}{1000\text{ mL}} \,\Big|\, \frac{0.15\text{ mol}}{1\text{ L}} = 3.75\text{x}10^{-3}\text{ mol acid}$$

$$\frac{25\text{ mL}}{} \,\Big|\, \frac{1\text{ L}}{1000\text{ mL}} \,\Big|\, \frac{0.10\text{ mol}}{1\text{ L}} = 2.5\text{ x}10^{-3}\text{ mol base}$$

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

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

NOW you can use He-Ha

Titration Calculations

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.

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

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

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

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

pH = 5.05

Titration Calculations

AT EQUIVALENCE POINT

- Add ? ml of 0.10 M NaOH
  - Determine stoichiometry

$$\frac{25\text{ mL}}{} \left| \frac{1\text{ L}}{1000\text{ mL}} \right| \frac{0.15\text{ mol}}{1\text{ L}} = 3.75\text{x}10^{-3}\text{ mol acid}$$

$$\frac{3.75\text{x}10^{-3}\text{ mol}}{} \left| \frac{1\text{ L}}{0.10\text{ mol}} \right| \frac{1000\text{ mL}}{1\text{ L}} = 37.5\text{ mL}$$

base to get to equivalence point

Titration Calculations

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!!

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

$C_2H_3O_2H$	OH^-	$\leftrightarrow H_2O$	$C_2H_3O_2^-$
3.75mmol	**3.75mmol**	0	0
-3.75mmol	-3.75mmol	+3.75mmol	+3.75mmol
0 mmol	0 mmol	3.75mmol	3.75mmol

Have to Reverse the Rxn, new ICE table!

25 mL	1 L	0.15 mol
	1000 mL	1 L

$= 3.75\text{x}10^{-3}$ mol acid

37.5mL	1 L	0.10 mol
	1000 mL	1 L

$= 3.75\ \text{x}10^{-3}$ mol base

Titration Calculations

3

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!!

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_2O	$C_2H_3O_2^-$
3.75mmol	**3.75mmol**	0	0
-3.75mmol	-3.75mmol	+3.75mmol	+3.75mmol
0 mmol	0 mmol	3.75mmol	3.75mmol

Have to Reverse the Rxn, new ICE table!

Remember to use M in ICE Table not moles!

$$[C_2H_3O^{\,-}] = \frac{3.75\ x\ 10^{-3} mol}{(0.025\ L + 0.0375\ L)} = 0.060\ M$$

$C_2H_3O_2^-$	H_2O ↔	$C_2H_3O_2H$	OH-
0.06 M	-	0	0
- x	-	+ x	+ x
0.06	-	x	x

Titration Calculations

3

AT EQUIVALENCE POINT

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

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

$C_2H_3O_2H$	$OH^- \leftrightarrow$	H_2O	$C_2H_3O_2^-$
3.75mmol	**3.75mmol**	0	0
-3.75mmol	-3.75mmol	+3.75mmol	+3.75mmol
0 mmol	0 mmol	3.75mmol	3.75mmol

Have to Reverse the Rxn, new ICE table!

Remember to use Kb this time!

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

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

$C_2H_3O_2^-$	$H_2O \leftrightarrow$	$C_2H_3O_2H$	OH-
0.06 M	-	0	0
- x	-	+ x	+ x
0.06	-	x	x

Titration Calculations

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!!

$C_2H_3O_2^-$	$H_2O \leftrightarrow$	$C_2H_3O_2H$	OH-
0.06 M	-	0	0
- x	-	+ x	+ x
0.06	-	x	x

Remember to use Kb this time!

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

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

$$5.56 \; x \; 10^{-10} = \frac{(x)(x)}{0.06}$$

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

Now you can do pH calculation!

Titration Calculations

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!

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

$$\boldsymbol{pOH = -log\left(5.77\ x\ 10^{-6}\right) = 5.24}$$

$$\boldsymbol{pH = 14\ - pOH}$$

$$\boldsymbol{pH = 14\ - 5.24}$$

pH = 8.76

Titration Calculations

AT ½ 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

@ ½ way point pH = pKa

$$pH = -log(1.8\, x\, 10^{-5})$$

pH = 4.74

Why calculate pH at the ½ 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.

Titration Calculations

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
	1000 mL	1 L

= 5 x10^{-3} mol base

Do stoich to find how much left

$C_2H_3O_2H$	OH^{-} $\leftrightarrow$	H_2O	$C_2H_3O_2^{-}$
3.75mmol	5 mmol	0	0
-3.75mmol	– 3.75mmol	+3.75mmol	+3.75mmol
0	1.25mmol	3.75mmol	3.75mmol

Remember to use M in pH calculations!

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

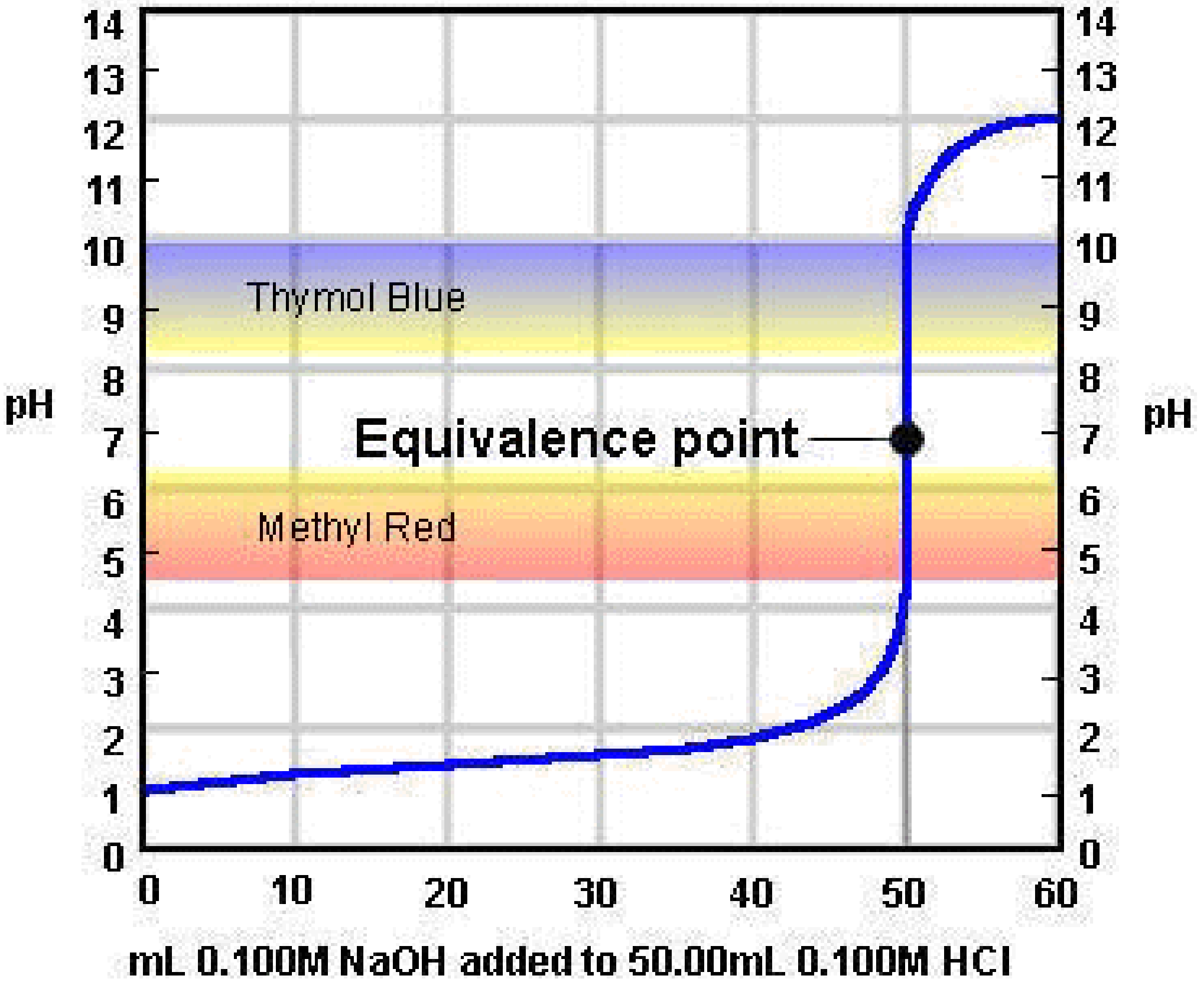
$$[OH^{-}] = 0.0167\ M$$

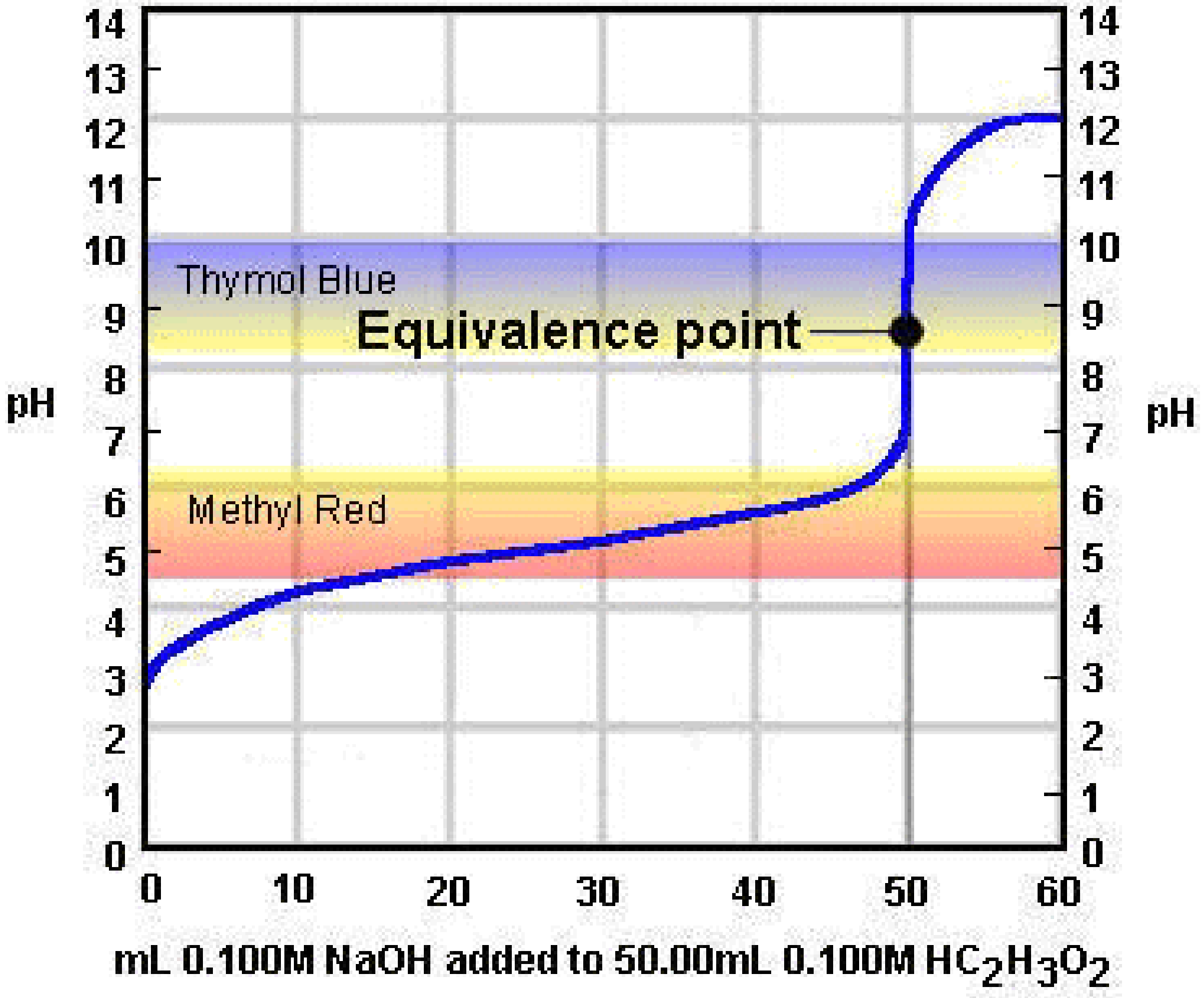
$$pOH = -log(0.0167) = 1.78$$

$$pH = 14 - pOH \quad = 14 - 1.78$$

pH = 12.22

Selection of Indicators





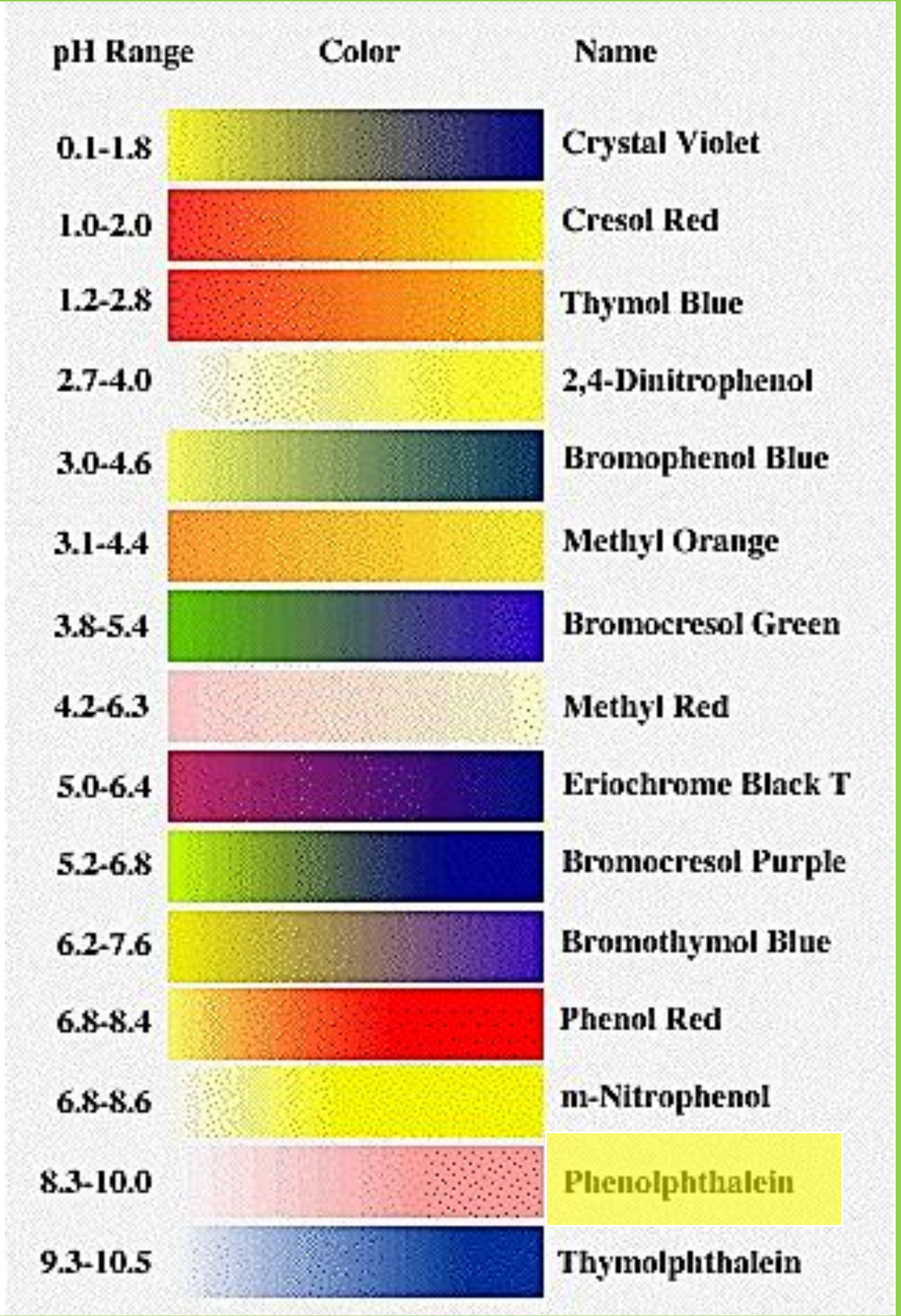
pH Indicators and Ranges

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

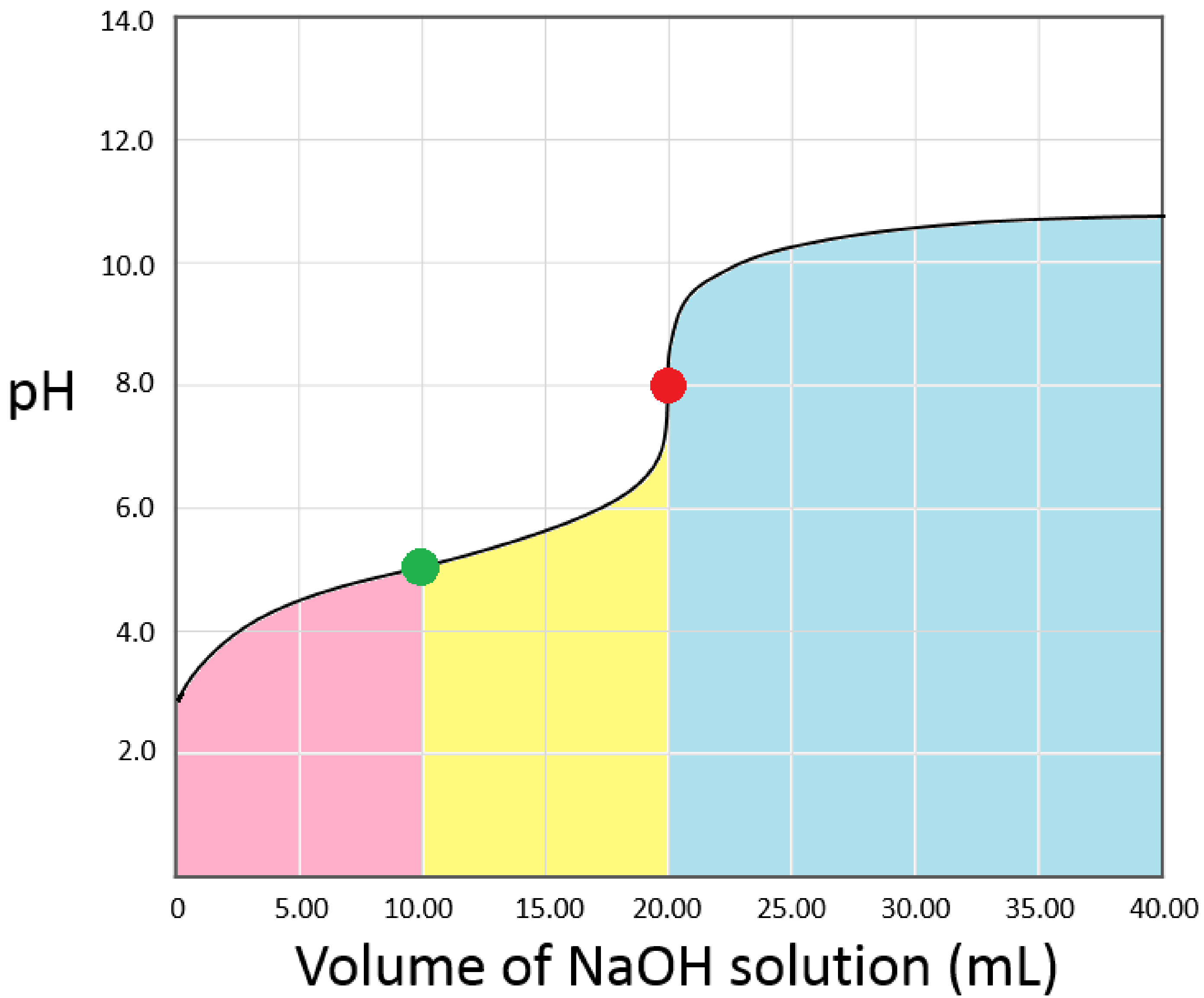


pH Range	Color	Name
0.1-1.8		Crystal Violet
1.0-2.0		Cresol Red
1.2-2.8		Thymol Blue
2.7-4.0		2,4-Dinitrophenol
3.0-4.6		Bromophenol Blue
3.1-4.4		Methyl Orange
3.8-5.4		Bromocresol Green
4.2-6.3		Methyl Red
5.0-6.4		Eriochrome Black T
5.2-6.8		Bromocresol Purple
6.2-7.6		Bromothymol Blue
6.8-8.4		Phenol Red
6.8-8.6		m-Nitrophenol
8.3-10.0		Phenolphthalein
9.3-10.5		Thymolphthalein

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



Before ½ Way Point

[HA] > [A$^-$]

Half Way Point

[HA] = [A$^-$]

After ½ Way Pt, before Eq. Pt

[A$^-$] > [HA]

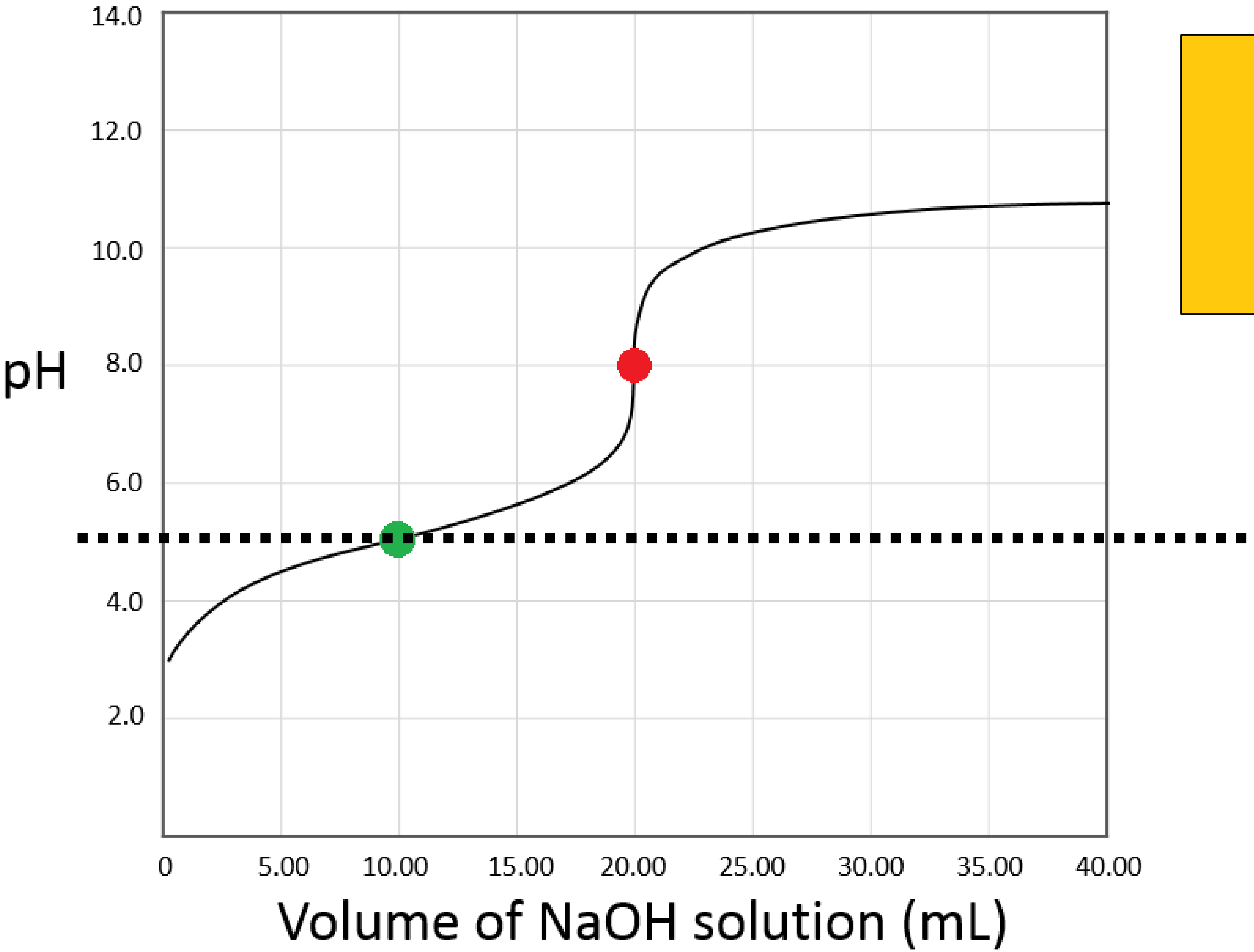
Equivalence Point

[HA] = 0 mol A$^-$ = mol OH$^-$ added

Over Shoot Past Eq. Pt.

Excess [OH$^-$] , [A$^-$]

Effective Buffer Region



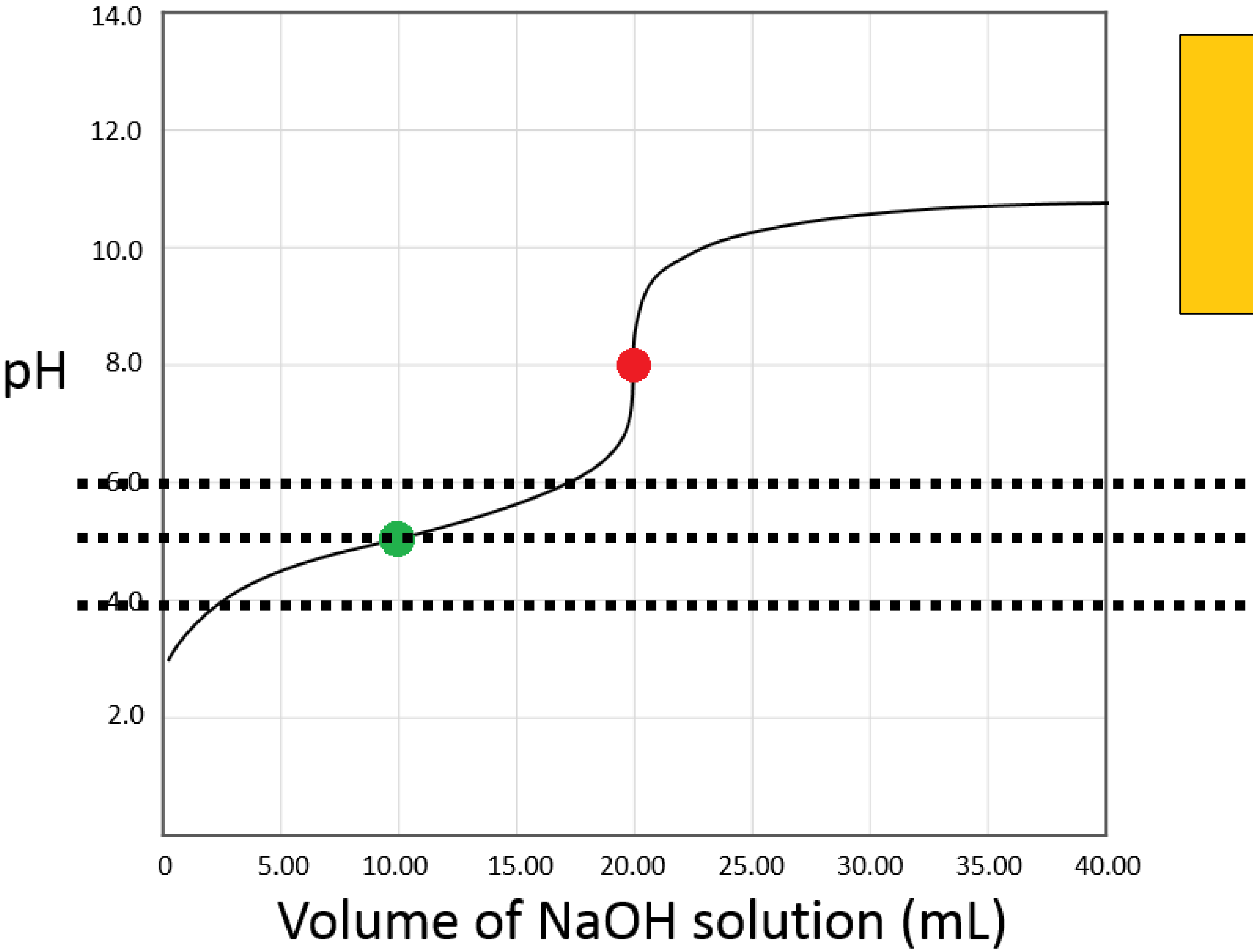
Buffer Region

pH = +/- 1 from pKa

pKa = pH @ ½ Way Point

pH @ ½ Way Point = 5

Effective Buffer Region



Buffer Region

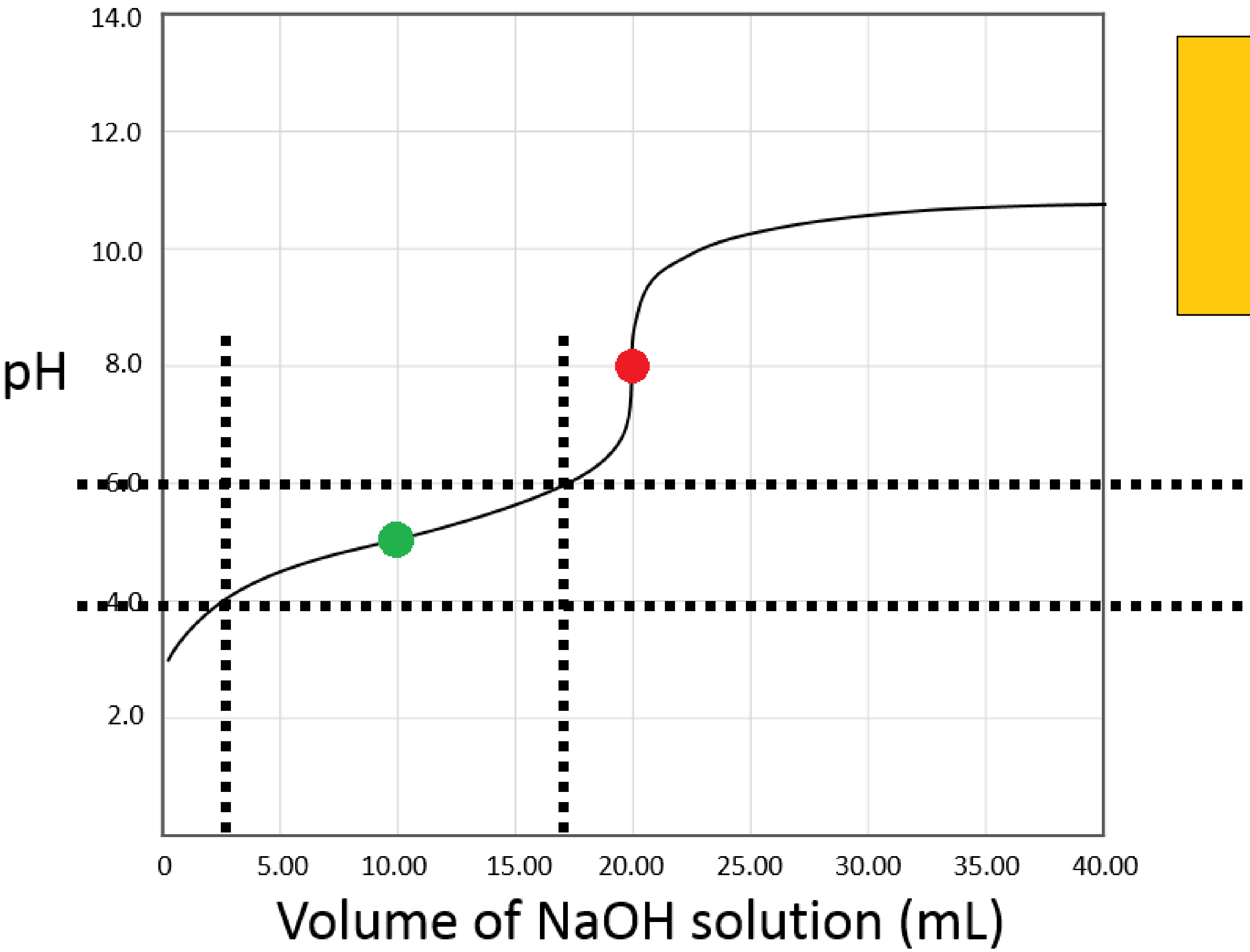
pH = +/- 1 from pKa

pKa = pH @ ½ Way Point

pH @ ½ Way Point = 5

+/- 1 pH = 4 – 6

Effective Buffer Region



Buffer Region

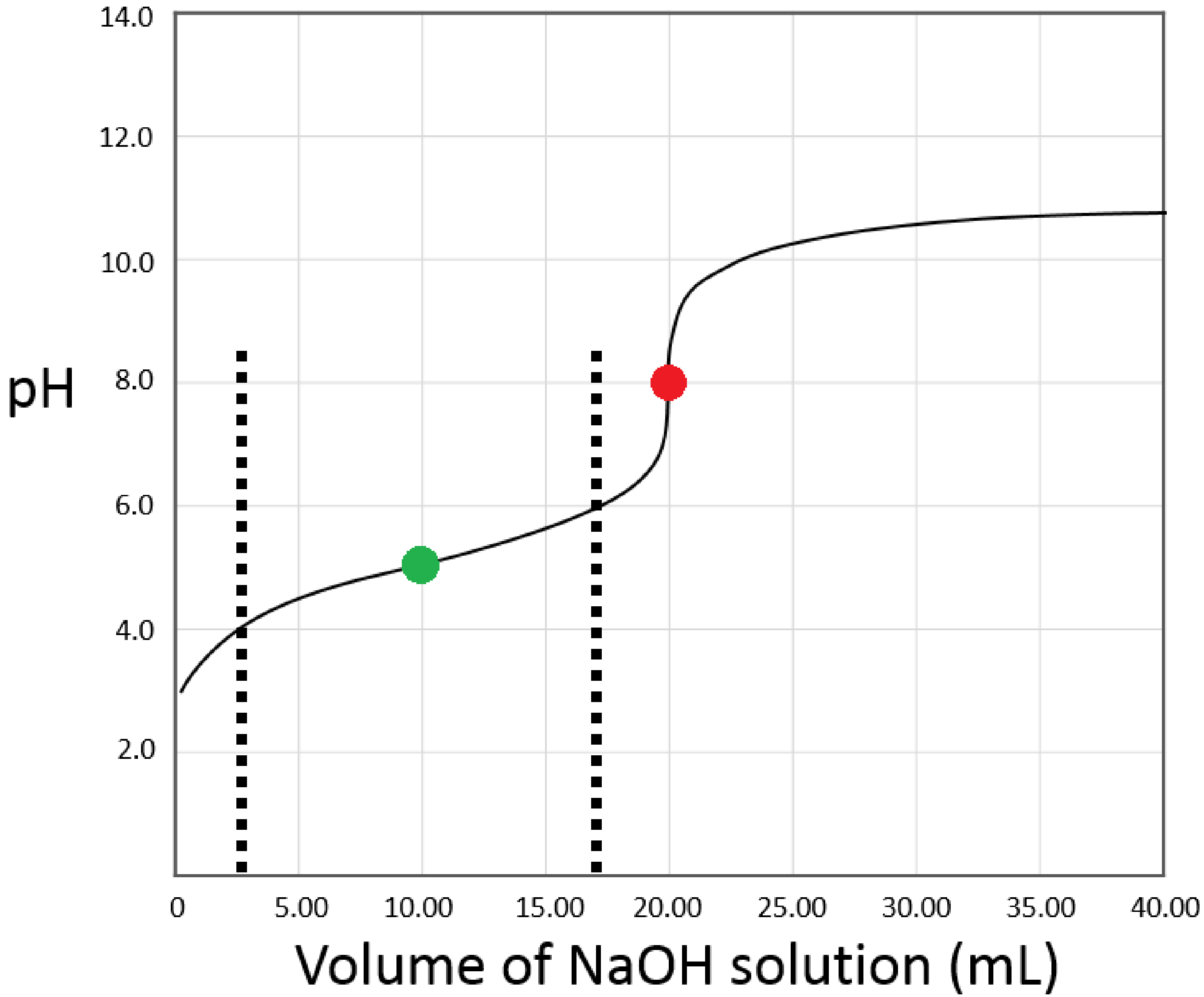
pH = +/- 1 from pKa

pKa = pH @ ½ Way Point

pH @ ½ Way Point = 5

+/- 1 pH = 4 – 6

Effective Buffer Region



Buffer Region

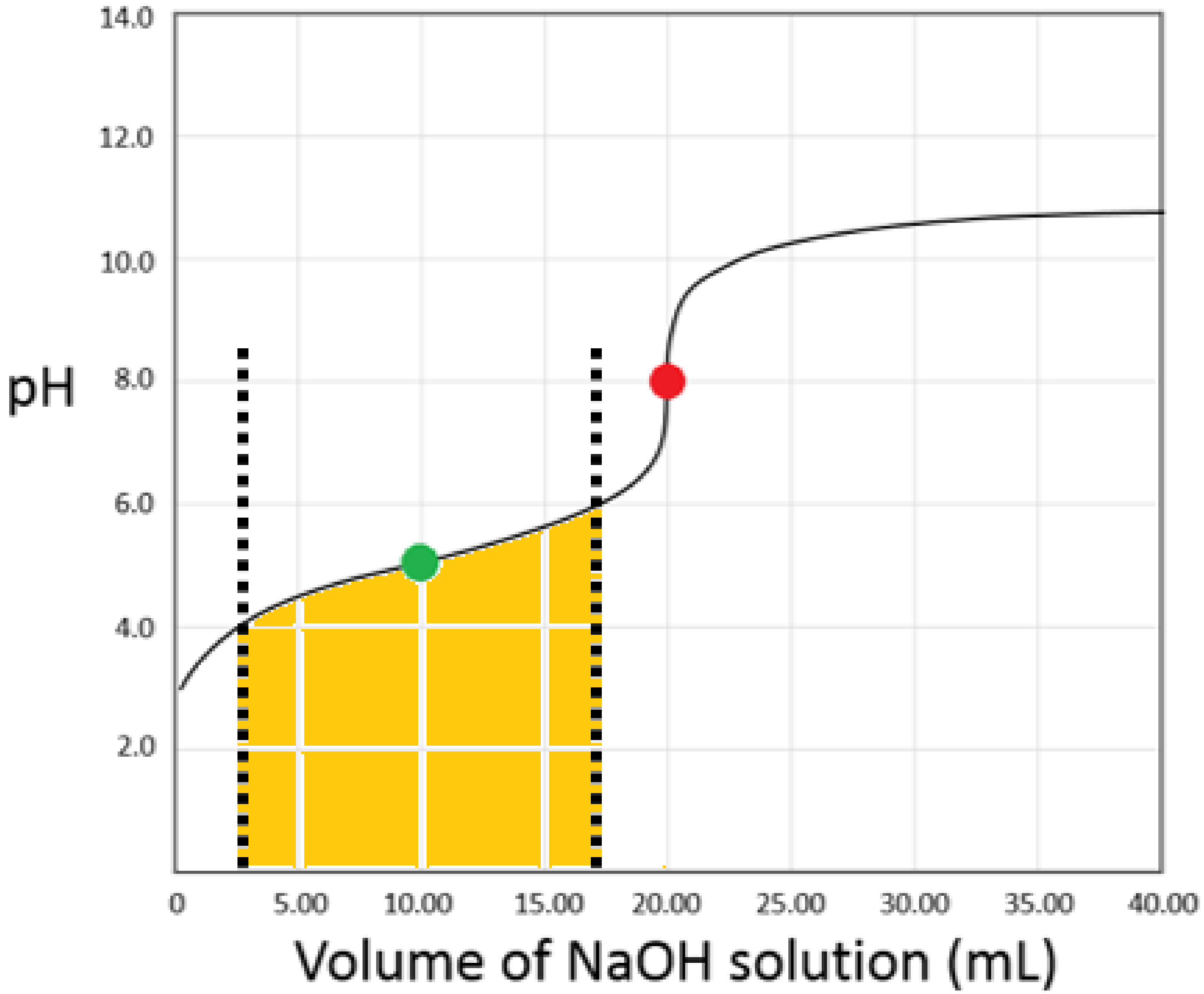
pH = +/- 1 from pKa

pKa = pH @ ½ Way Point

pH @ ½ Way Point = 5

+/- 1 pH = 4 – 6

Effective Buffer Region



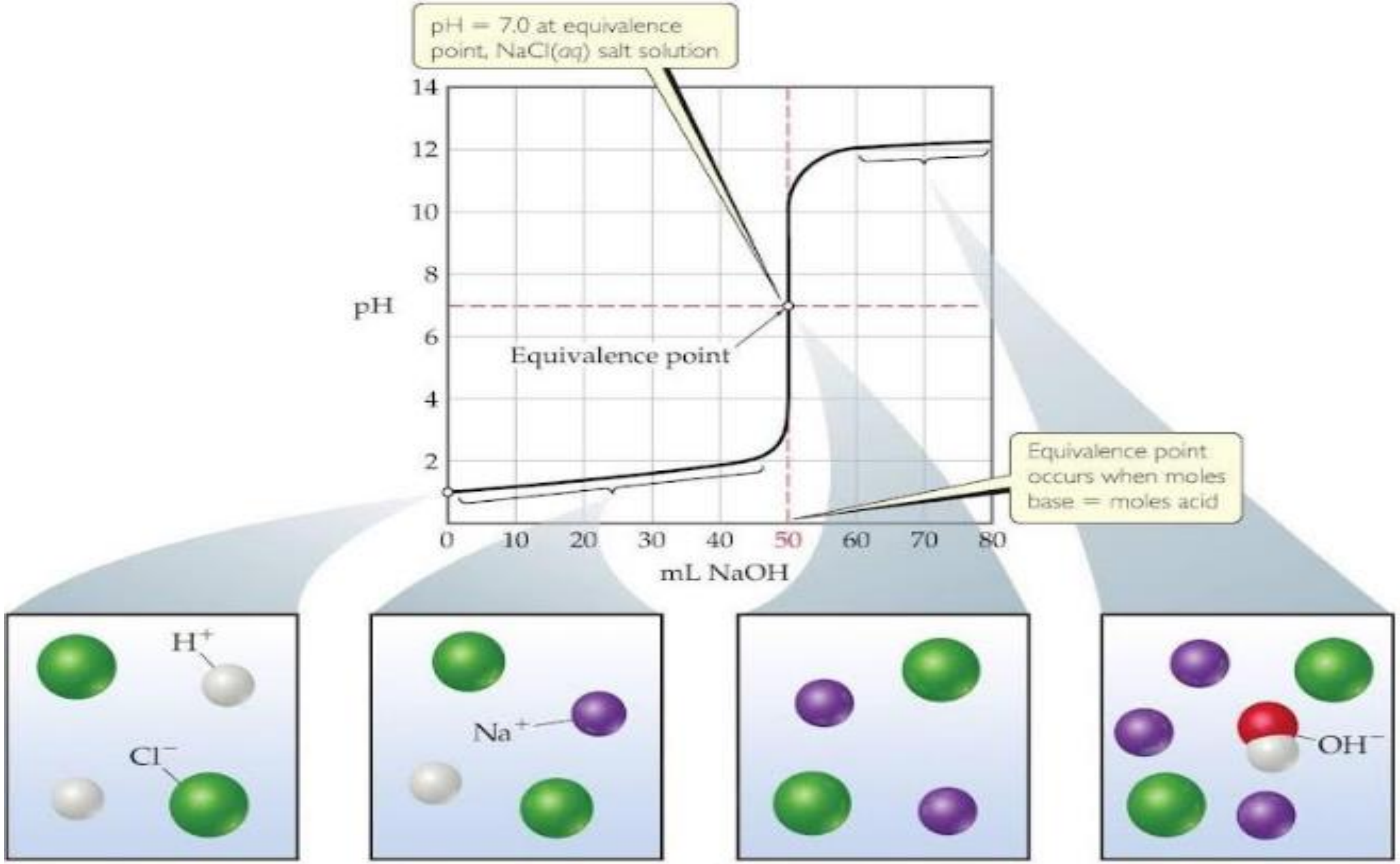
Buffer Region

pH = +/- 1 from pKa

pKa = pH @ ½ Way Point

pH @ ½ Way Point = 5

+/- 1 pH = 4 – 6



Only HCl(aq) present before titration

H^+ consumed as OH^- added, forming H_2O. Still have HCl. Some conjugate is formed. BUFFER

H^+ completely neutralized by OH^-. Only conjugate left

No H^+ left to react with excess OH-, now there is conjugate and excess OH^-

YouTube Link to Presentation

https://youtu.be/okVYe933E4k