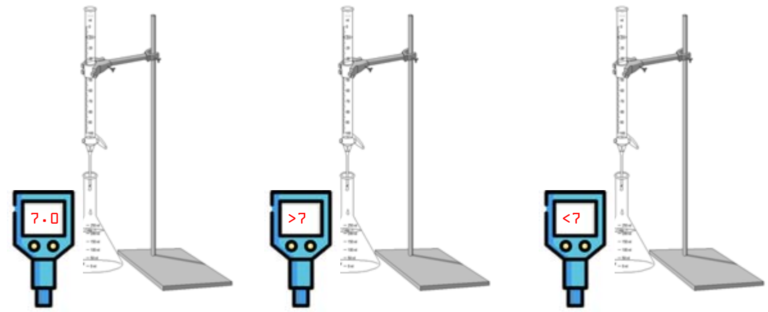
Weak Acid-Strong Base Titrations

At equivalence point,

strong acid + strong base | weak acid + strong base | strong acid + weak base



Qualitative Analysis

weak acid + strong base → basic salt + water

$HC_2H_3O_{2\,(aq)}$ + $NaOH_{(aq)}$ → $NaC_2H_3O_{2\,(aq)}$ + $H_2O_{(l)}$

$HC_2H_3O_{2\,(aq)}$ + $NaOH_{(aq)}$ → $Na^+_{(aq)}$ + $C_2H_3O_2^-{}_{(aq)}$ + $H_2O_{(l)}$

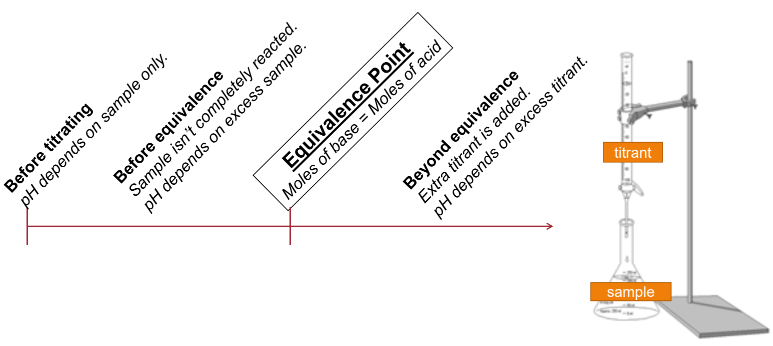
Na^+ does not have acidic properties
But $C_2H_3O_2$ is a **weak base**
∴ solution will be slightly basic
at the equivalence point.

Quantitative Analysis

Remember,
all titrations need to be analyzed in two steps:

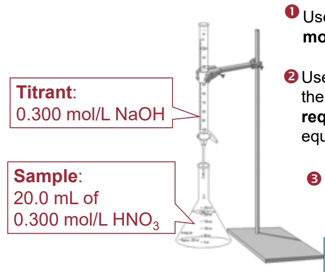
1. As **stoichiometry** problems:
   - How many **MOLES** of acid/base are in the solution? Which one is in excess, and how will that affect pH?
2. As **equilibrium** problems
   - In the case of **weak** acids or bases, what **CONCENTRATION** of acid/base will dissociate? This determines pH.

All titrations can be analyzed at multiple points:



Example 2. $HC_2H_3O_{2\,(aq)}$ + $NaOH_{(aq)}$ → $NaC_2H_3O_{2\,(aq)}$ + $H_2O_{(l)}$

a) Use stoichiometry to calculate the volume of NaOH that will be required to react completely with the sample of $HC_2H_3O_2$.



❶ Use n = c × v to find **moles of $C_2H_3O_2$**.

n_{acid} = 0.300 mol/L x 20.00 ml
$\mathbf{n_{acid}}$ **= 6.00 mmol acid**

❷ Use mole ratio to find the **amount of NaOH required** to reach the equivalence point.

$n_{NaOH} = 6.00 \text{ mmol } HC_2H_3O_2 \times \frac{1 \text{ mol NaOH}}{1 \text{ mol } HC_2H_3O_2}$
$\mathbf{n_{NaOH}}$ **= 6.00 mmol NaOH**

❸ Use the concentration to convert the amount of NaOH to a **volume**.

$V_{NaOH} = \frac{6.00 \text{ mmol}}{0.300 \text{ mol/L}} = \mathbf{20.0 \text{ mL}}$

The reaction will have reached its equivalence point once 20.0 mL of base has been added.

b) Before the titrant is added, what is the pH of the solution?

❶ **Stoichiometry**: How many moles of acid are present?

No base has been added, therefore no acid has reacted yet. The solution contains the original amount of $HC_2H_3O_2$.

❷ Consider all species in the solution. Which one controls the pH?

$HC_2H_3O_2$, H^+, $C_2H_3O_2^-$, H_2O

Even though $HC_2H_3O_2$ is a weak acid, its K_a is much higher than the K_w of water ∴ it controls the pH:

$$HC_2H_3O_{2\,(aq)} \rightleftharpoons H^+_{(aq)} + C_2H_3O_2^-{}_{(aq)}$$

❸ **Equilibrium**: What is the concentration of H^+?

$HC_2H_3O_2$ is a weak acid ∴ it only partially dissociates. Use the K_a to find the concentration of H^+ at equilibrium.

	$HC_2H_3O_2$	H^+	$C_2H_3O_2^-$
I	0.300	0	0
C	- x	+ x	+ x
E	0.300 – x	x	x

$$K_a = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} \xrightarrow{\text{sub in}} 1.8 \times 10^{-5} = \frac{(x^2)}{(0.300-x)}$$

$0.300/K_a > 100$ ∴ use simplifying assumption

$$1.8 \times 10^{-5} \cong \frac{(x^2)}{(0.300)}$$

$x \cong 2.3 \times 10^{-3}$ mol/L = $[H^+]$

x/0.300 = 0.77% ∴ assumption was valid

❹ Calculate pH

pH = -log [H^+]

= - log (2.3×10^{-3})

pH = 2.64

Before any base is added, the $HC_2H_3O_2$ solution has a pH of **2.64**.

c) At the equivalence point: After 20.0mL of titrant is added to the sample, what is the pH?

❶ **Stoichiometry**: How many moles of acid/base are present?

At the equivalence point, exactly 6.00 mmol of NaOH has been added, which reacts with the 6.00 mmol of acid initially present.

❷ Consider all species in the solution. Which one controls the pH?

All the H^+ and OH^- have been consumed.

Entities in solution: $Na^+{}_{(aq)}$, $C_2H_3O_2^-{}_{(aq)}$, and $H_2O_{(l)}$

Na^+ does not affect pH

$C_2H_3O_2^-$ is a weak base and CAN affect pH. It reacts with water:

$$C_2H_3O_2^- + H_2O \rightleftharpoons HC_2H_3O_2 + \mathbf{OH^-}$$

To find the K_b of this weak conjugate base, use the K_a of its acid:

$K_w = K_a \times K_b$

$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}}$

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

Even though the K_b for $C_2H_3O_2^-$ is small, it is still much larger than the K_w for water.

Therefore, the $C_2H_3O_2^-$ will control the pH.

❸ **Equilibrium**: What is the concentration of OH^-?

$$[C_2H_3O_2^-] = \frac{6.00\text{ mmol}}{20.0\text{ mL}+20.0\text{ mL}} = 0.150\text{ mol/L}$$

	$C_2H_3O_2^-$	H_2O	$HC_2H_3O_2$	OH^-
I	0.150	-	0	0
C	- x	-	+ x	+ x
E	0.150 – x	-	x	x

$$K_b = \frac{[C_2H_3O_2^-][OH^-]}{[HC_2H_3O_2]}$$

$$5.6 \times 10^{-10} = \frac{(x^2)}{(0.150-x)} \cong \frac{(x^2)}{(0.150)}$$

$0.150/K_b > 100$ ∴ use simplifying assumption

$x \cong 9.2 \times 10^{-6}$ mol/L = $[OH^-]$

x/0.150 = 0.0061% ∴ assumption was valid

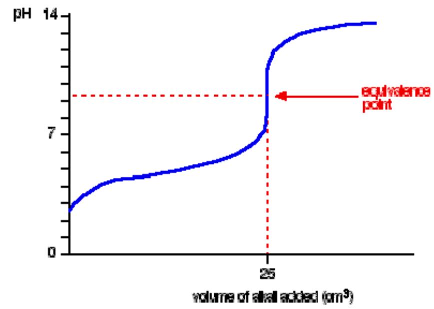
❹ Calculate pOH and pH

$pOH = -\log [OH^-]$
$= -\log (9.2 \times 10^{-6})$
$pOH = 5.04$

$pH = 14.00 - pOH$
$= 14.00 - 5.04$
pH = 8.96

In general, at the equivalence point of a titration between a weak acid and a strong base, the pH will be **slightly basic**.

A typical pH curve for a weak acid-strong base titration



Homework

- Pg. 554 #1, 2
- Pg. 557 #4-6, 8