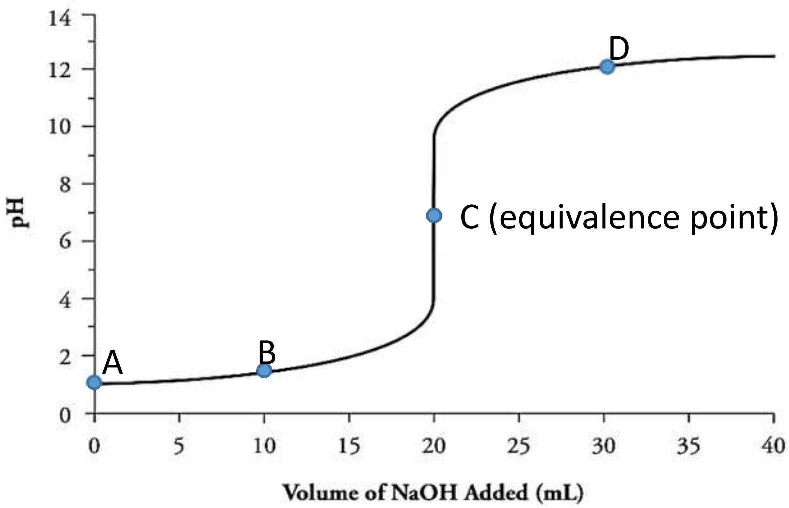
AP Chemistry — Name ____________________________________
Ms. Ye — Date ________________________Block ______

1. Strong Acid-Strong Base Titration

The graph shows the pH changes as **0.100 M NaOH** is added to a **20.00 mL solution of 0.100 M HCl.**



Molecular Equation:
HCl (aq) + NaOH (aq) → NaCl (aq) + H_2O (l)

Net Ionic Equation:
H^{+1} (aq) + OH^{-1} (aq) → H_2O (l)

**Since strong acids and strong bases both completely dissociate in solution, the pH calculations are more straightforward since every mole of OH^- added will react with one mole of H^+ to form water.

A. At point A, none of the base has been added yet. Calculate the **initial pH** of the solution at point A (Hint: HCl is a strong acid). Verify that this matches with the point on the graph.

B. At point B, 10.00 mL of the NaOH has been added. To calculate the pH at point B, you will need to apply the Molarity formula and simple stoichiometry.

i. Calculate the number of **moles of HCl** that is **initially** in the beaker

ii. Calculate the number of **moles of NaOH** that was added

iii. Calculate the number of **moles of HCl** that is **still unreacted** after the addition of NaOH

iv. Determine the **new volume** of the solution after the addition of the NaOH.

v. Use your answers from parts iii and iv above to determine the new Molarity of HCl

vi. Calculate the pH of the solution at point B. Verify that it matches up with the point on the graph.

C. At point C, a total of 20.00mL of NaOH has been added to the solution. To calculate the pH at point C, you will need to apply the Molarity formula and simple stoichiometry again

i. Determine the number of **moles of HCl** that is **initially** in the beaker (use answer from part B, i)

ii. Calculate the number of **moles of NaOH** that was added

iii. Look at your answers for parts i and ii above. What do you know about the acidity/basicity of a solution if the above conditions are true?

iv. Determine the pH of the solution at point C. Verify that it matches up with the C on the graph.

v. Notice that point C is labeled as the equivalence point. Explain in terms of amount of HCl and NaOH why this is the equivalence point.

D. At point D, a total of 30 mL of NaOH has been added. To calculate the pH at point D, you will need to apply the Molarity formula and simple stoichiometry again.

i. Determine the number of **moles of HCl** that is **initially** in the beaker (use answer from part B, i)

ii. Calculate the number of **moles of NaOH** that was added

iii. Calculate the number of **moles of NaOH** that is **still unreacted** after the addition of NaOH

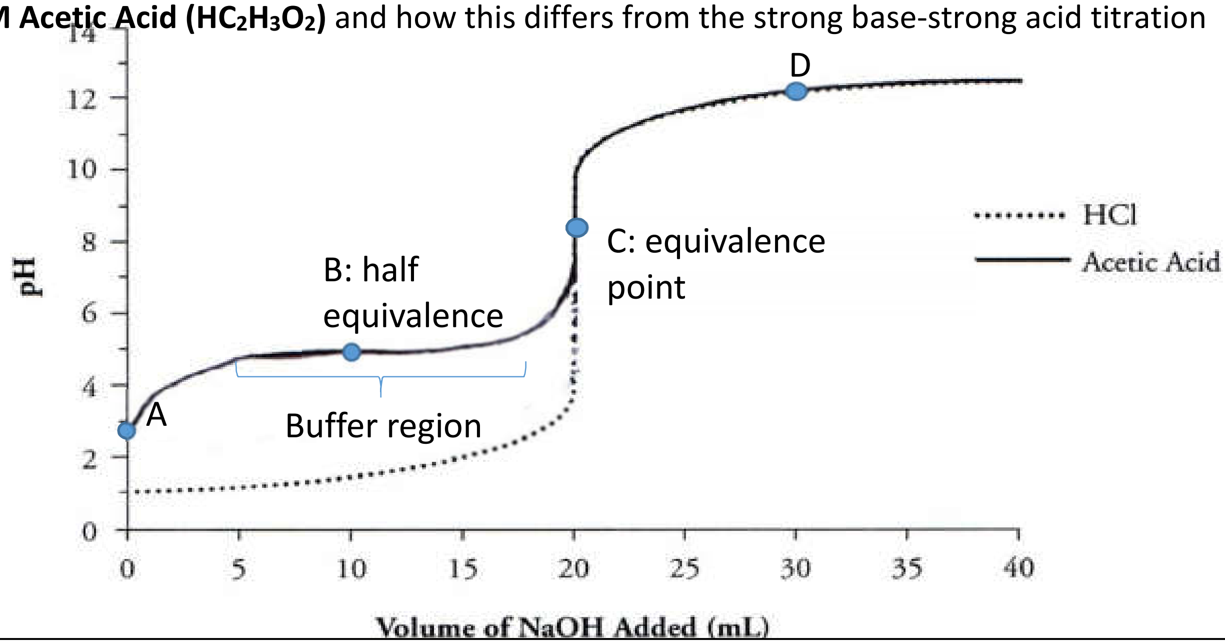
iv. Determine the **new volume** of the solution after the addition of the NaOH.

v. Use your answers from parts iii and iv above to determine the new Molarity of NaOH

vi. Now, calculate the pH of the solution at point D (Hint: calculate pOH first). Verify that this matches up with the point on the graph.

2. **Weak Acid-Strong Base Titration**

The graph below shows the pH changes as **0.100 M NaOH** is being added to a **20.00 mL solution of 0.100 M Acetic Acid ($HC_2H_3O_2$)** and how this differs from the strong base-strong acid titration



Molecular Equation:	**Net Ionic Equation:**
$HC_2H_3O_2$ (aq) + NaOH (aq) → $NaC_2H_3O_2$ (aq) + H_2O (l)	$HC_2H_3O_2$ (aq) + OH^{-1} (aq) → $C_2H_3O_2^{-1}$ (aq) + H_2O (l)

***Since weak acids do not completely dissociate in solution, pH calculations are a little more complicated…

1. Visually speaking, what are some key differences between a strong acid-strong base titration curve and a weak acid-strong base titration curve?

2. At point A, none of the base has been added yet. Calculate the initial pH of the solution at point A (Hint: Acetic Acid is a weak acid, so set up an equilibrium calculation using Ka). Verify that this matches with the point on the graph. Ka for acetic acid = 1.8×10^{-5}

3. Any point on the curve **between point A and point C** represent the "**buffered region**". You could set up another ICE table, or you can apply the Molarity Formula and stoichiometry, then use the Henderson-Hasselbalch formula to calculate the pH in the buffered region:

Note: $pK_a = -\log K_a$

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$

Ka for acetic acid = 1.8×10^{-5}

To calculate the pH of the solution when 5 mL of the NaOH has been added:

i. Calculate the number of **moles of $HC_2H_3O_2$** that is **initially** in the beaker

ii. Calculate the number of **moles of NaOH** that was added. This value will be the same as the number of **moles of $C_2H_3O_2^{-1}$**, the conjugate base, that is formed.

iii. Calculate the number of **moles of $HC_2H_3O_2$** that is **still unreacted** after the addition of NaOH

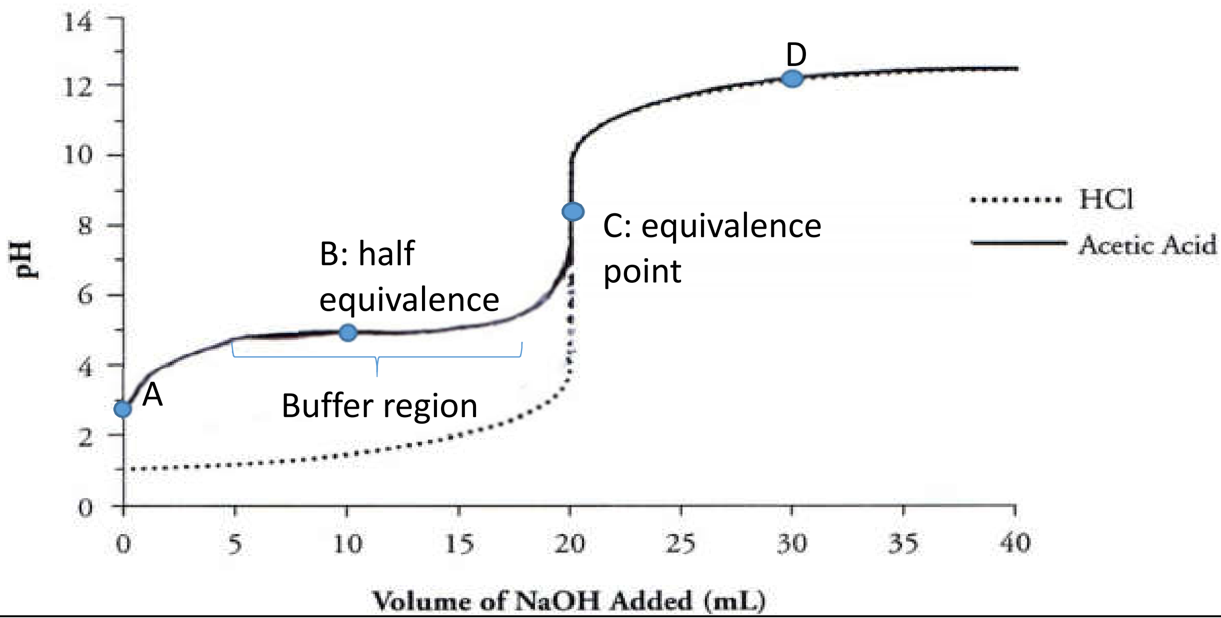
iv. Determine the **new volume** of the solution after the addition of the NaOH.

v. Use your answers from parts ii-iv above to determine the **molarity of undissociated $HC_2H_3O_2$ (HA)** that and the **molarity of the conjugate base $C_2H_3O_2^{-1}$ (A-)** that has formed.

vi. Plug in values into the Henderson-Hasselbalch equation to solve for pH.

4. Point B is known as the "half equivalence point", meaning half the volume of base that is needed to reach the equivalence point has been added. At the **half-equivalence point**, the amount of still undissociated acid **(HA)** and the amount of conjugate base that has already been formed (**A-)** are **equal** to each other.

   Use the Henderson-Hasselbalch equation to calculate the pH at the half equivalence point (B).



Molecular Equation:	**Net Ionic Equation:**
$HC_2H_3O_2$ (aq) + NaOH (aq) → $NaC_2H_3O_2$ (aq) + H_2O (l)	$HC_2H_3O_2$ (aq) + OH^{-1} (aq) → $C_2H_3O_2^{-1}$ (aq) + H_2O (l)

5. Point C is at **the equivalence point** (moles of base added = moles of acid). Because the neutralization of a weak acid produces its anion, which is a weak base, we expect the **pH at the equivalence point to be greater than 7**.

   To calculate the pH at the equivalence point:

   i. Determine the number of **moles of $HC_2H_3O_2$** that is initially in the beaker (you can use your answer from the previous problem). This value will be the same as the number of **moles of $C_2H_3O_2^{-1}$**, the conjugate base, that is present at the equivalence point.

   ii. Calculate the **new volume** of the solution after the addition of the NaOH at the equivalence point

   iii. Determine the concentration of **$C_2H_3O_2^{-1}$** at the equivalence point.

   iv. **$C_2H_3O_2^{-1}$** is a weak base. Set up a Kb expression to calculate the concentration of OH^{-1} in solution at the equivalence point (you can use an ICE table to help you). Hint: Kw = Ka x Kb

   v. Calculate the pOH, and therefore pH, of the solution at the equivalence point.

6. Point D is beyond the equivalence point. Since NaOH is a strong base and a stronger base than the acetate ion, the pH will solely be based on the OH^{-1} concentration.

To calculate the pH when 30 mL of NaOH has been added:

i. Determine the number of **moles of $HC_2H_3O_2$** that is initially in the beaker (you can use your answer from the previous problem).

ii. Calculate the number of **moles of NaOH** that was added.

iii. Calculate the number of **moles of NaOH** that is **still unreacted** after the addition of NaOH

iv. Determine the Determine the **new volume** of the solution after the addition of the NaOH.

v. Use your answers above to calculate the **molarity of OH^{-1}** at point D

vi. Calculate the pOH and then pH of the solution.

<u>**Other:**</u>

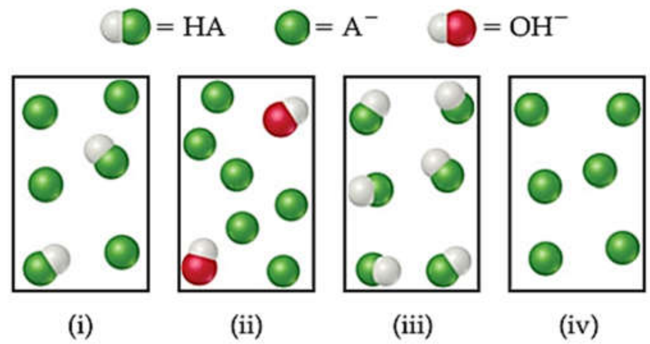
- **Strong Base-Strong Acid**

- **Strong Acid-Weak Base**

- **Titration of Polyprotic Acids**

Titrations Problem Set

1. The following drawings represent solutions at various stages of the titration of a weak acid, HA, with NaOH. (The Na^+ ions have been omitted for clarity). To which of the following regions of the titration curve does each drawing correspond:



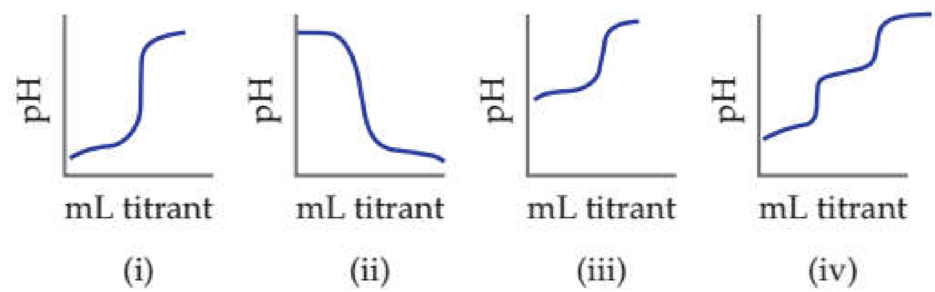
   a. before addition of NaOH

   b. after addition of NaOH but before equivalence point

   c. at equivalence point

   d. after equivalence point

2. Match the following descriptions of titration curves with the diagram



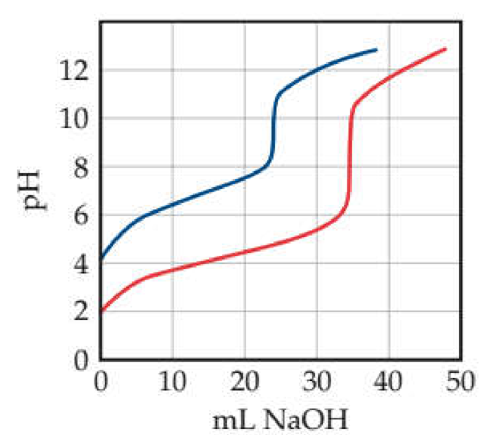
   a. strong acid added to strong base

   b. strong base added to weak acid

   c. strong base added to strong acid

   d. strong base added to polyprotic acid

3. Equal volumes of two acids are titrated with 0.10 M NaOH resulting in the two titration curves shown in the following figure.



   a. Which curve corresponds to the more concentrated acid solution? Explain.

   b. Which corresponds to the acid with the larger K_a? Explain.

4. How does titration of a 0.10 M strong, monoprotic acid with a 0.10 M strong base differ from titration of a 0.10 M weak, monoprotic acid with a 0.10 M strong base with respect to the following:
   a. quantity of base required to reach the equivalence point

   b. pH at the beginning of the titration

   c. pH at the equivalence point

   d. pH after addition of a slight excess of base

5. Predict whether the equivalence point of each of the following titrations is less than, greater than, or equal to pH 7:
   a. formic acid titrated with NaOH

   b. calcium hydroxide titrated with perchloric acid

   c. pyridine titrated with nitric acid

6. Sketch the titration curve for the titration of a generic weak base B with a strong acid. The titration reaction is: **$B + H^+ \leftrightarrow BH^+$**

On this curve, indicate the points that correspond to the following:

a. the stoichiometric (equivalence point)
b. the region with maximum buffering
c. pH = pK_a
d. pH depends only on [B]
e. pH depends only on [BH^+]
f. pH depends only on amount of excess strong acid

7. Assume that 30.0 mL of a 0.10 M solution of a weak base B that accepts one proton is titrated with a 0.10 M solution of the monoprotic strong acid HX.

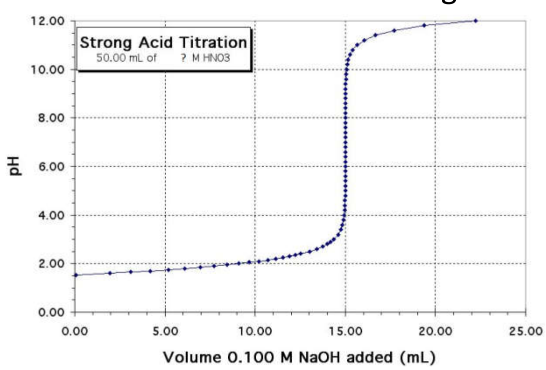
a. How many moles of HX have been added at the equivalence point?

b. What is the predominant form of B at the equivalence point?

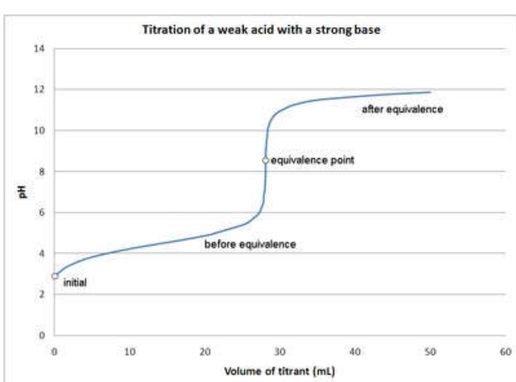
c. How can the pH be determined at the equivalence point?

d. Which indicator, phenolphthalein ($K_a = 10^{-8}$) or methyl red ($K_a = 10^{-5}$), is likely to be the better indicator for this titration?

8. 50.00 mL of an unknown concentration of HNO_3 were titrated according to the curve below. Determine its concentration through the results.



9. A 0.250 M solution of weak acid, HA, is titrated with 0.150 M KOH, generating the following titration curve. Determine the K_a of the weak acid.



10. Calculate the initial pH, the pH at the halfway point, the pH at the equivalence point, and the pH after the addition of 250.0 mL of titrant for each of the following titrations:

a. 100.0 mL of 0.10 M $HC_7H_5O_2$ ($K_a = 6.4 \times 10^{-5}$) titrated by 0.10 M NaOH

Initial pH

pH at halfway point

pH at equivalence point

pH afer 250.0 mL of titrant

b. 100.0 mL of 0.10 M $C_2H_5NH_2$ (K_b = 5.6 x 10^{-4}) titrated by 0.20 M HNO_3

Initial pH

pH at halfway point

pH at equivalence point

pH afer 250.0 mL of titrant

c. 100.0 mL of 0.50 M HCl titrated by 0.25 M NaOH

Initial pH

pH at halfway point

pH at equivalence point

pH afer 250.0 mL of titrant