Acid-Base Titration Curves Using a pH Meter

Introduction:

In this experiment you will use a pH sensor to collect volume and pH data as you titrate two acids with sodium hydroxide.

You will obtain titration curves for the following combinations of acids and bases (exact concentrations will be labeled on the reagent bottles and should be written in your data table):

1) hydrochloric acid, HCl*(aq)* with sodium hydroxide, NaOH*(aq)*;
2) acetic acid, CH_3COOH*(aq)* with sodium hydroxide, NaOH*(aq)*.

The recorded volume and pH values will generate titration curves that will be used to compare features of the strong acid curve versus the weak acid curve. You will determine the equivalence point volume and pH for both curves. You will estimate the pK_a and the K_a for a weak acid from its titration graph. Refer to Sections 14.2, 14.3, and 14.7 of Openstax Chemistry for information on pH calculations, relative strengths of acids and bases, and acid-base titrations.

Equations to use for the calculations and Explanations:

In an acid-base neutralization reaction, an acid reacts with a base to produce a salt and water:

$$\underset{\text{Acid}}{HA(aq)} + \underset{\text{Base}}{MOH(aq)} \rightarrow \underset{\text{Salt}}{MA(aq)} + H_2O(l) \qquad \text{Equation 1}$$

At the ***equivalence point*** for an acid-base neutralization reaction, the amount of base added is equal to the amount of acid initially present; thus, the acid has been completely neutralized.

When a weak acid solution is initially present, the following ionization reaction will occur:

$$HA(aq) \leftrightarrows H^+(aq) + A^-(aq) \qquad \text{Equation 2}$$

The equilibrium constant for the ionization of the weak acid, K_a, is: $K_a = \frac{[H^+][A^-]}{[HA]}$ Equation 3

At the volume half-way to the equivalence point during the titration of a weak acid by a strong base, one-half of the weak acid, HA, has been converted to its conjugate base, A^-. Thus, at this half-equivalence point, $[HA] = [A^-]$, and Equation 3 simplifies to: $K_a = [H^+]$.

By taking the negative log of both sides, this expression becomes:

$$pK_a = \text{pH at the the half-equivalence point} \qquad \text{Equation 4}$$

The equivalence point occurs at the midpoint of the region where the pH rises rapidly. The pK_a can be determined by estimating the pH at the volume halfway to the equivalence point. Figure 1b on page 2 shows the location of the equivalence point and half-equivalence point on a weak acid curve. The K_a for a weak acid can then be found from Equation 5:

$$K_a = 10^{-pK_a} \qquad \text{Equation 5}$$

Finally, the absolute % difference can be calculated for the weak acid ionization constant:

$$\text{Absolute \% difference} = \left|\frac{\text{experimental } K_a - \text{theoretical } K_a}{\text{theoretical } K_a}\right| x100\% \qquad \text{Equation 6}$$

Analyzing Titration Curves:

Figure 1a. Distribution of drops to yield a Titration with smooth curves.

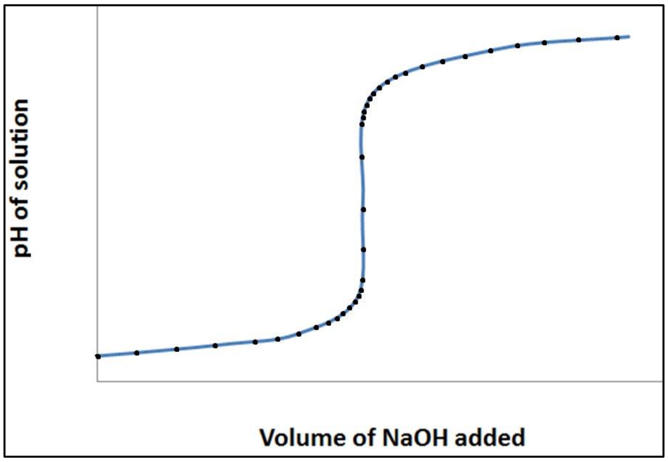
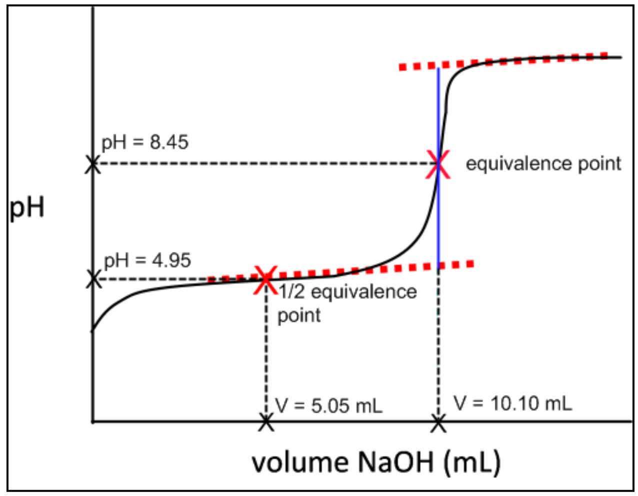


Figure 1b. Acid-Base Titration curve for WEAK monoprotic acid.



Materials:

2 – 150 mL beakers
25 mL buret
buret clamp
Hot/Stir plate
250 mL beaker
10.00 mL volumetric pipet
pipet pump
3-finger clamp
pH probe
Chromebook
GoLink
magnetic stir bar
KimWipes
pH calibration solutions (pH 4 and pH 7)
~ 0.1 M NaOH (record exact concentrations for all solutions)
~ 0.1 M HCl
~ 0.1 M CH_3COOH
ruler

Procedure: **This lab will be performed in two weeks. You will collect data for the HCl-NaOH titration the first week. You will collect data for the CH_3COOH-NaOH titration and work on post-lab calculations the second week.**

> ******Caution: Sodium hydroxide will attack your skin and is very effective at destroying the tissue of the eyeballs. Make sure you are wearing your goggles at all times and that you rinse off any sodium hydroxide immediately!******

1. Obtain about 15 mL of hydrochloric acid and 50 mL of NaOH in separate beakers.
2. Calculate the volume of base needed for your titration and show your professor the answer. Note: you should assume that 10.00 mL of acid is present for the titration since that is the amount you pipet into the titration beaker.
3. Clean and condition the buret with base – refer to the “Using a buret to deliver solution” technique. You should also review the “Performing a Titration” technique. After conditioning, fill the buret with NaOH and adjust the level of NaOH so that is initially at (or very close to) 0.00 mL.
4. Add 50 mL of deionized water into a 250 mL beaker. Pipet 10.00 mL of HCl into the beaker.
5. Assemble the Chromebook, GoLink, and pH probe system – refer to the “Using and calibrating a pH probe” technique. Calibrate the pH probe using the pH 4 and pH 7 buffer solutions. **Allow some space between your titration equipment and the computer!**

a. Click the Mode button in the lower left hand corner of Graphical Analysis. Choose "Event Based" in the Mode drop down menu.

b. Select "Events with Entry". Change Event Name to "Volume". Enter Units as "mL". Click "Done". Your x-axis should read Volume (mL).

c. Click the  plot picture above "Events with Entry". Select "Edit Graph Options". Give the plot an appropriate title. Change appearance to "Both" to show both the data points and the line for the curve. Click on the autoscaling button for the x-axis and change it to manual scaling. Enter x-axis range: 0 to 16. Click on the autoscaling button for the y-axis and change it to manual scaling. Enter y-axis range: 0 to 14.

6. Clamp the pH probe above the acid solution using a 3 finger clamp. Lower the pH probe into the acid solution, and adjust its position toward the side of the beaker, so that the sensor does not come into contact with the stirring bar. Begin stirring at a medium rate.

   Note: Stirring too rapidly could create a vortex around the sensor and possibly affect your pH measurements.

7. **Before adding any NaOH**, click **"Collect"**. Once the pH reading has stabilized, click the "**Keep**" button (top middle). A Keep Point window will pop up. Enter the total volume of NaOH added. Click "Keep Point". **Do NOT click the Stop button until you have collected all data points!** You will need to collect 30-40 data points for a good graph.

8. Add approximately 1 mL of base. When the pH stabilizes, click the "**Keep**" button. The pH readings may fluctuate; unless you are near the equivalence point, you can click "Keep" about 20-30 secs after adding base. Click "**Keep**" after each addition of NaOH.

9. When your volume of base is within 2 mL of your calculated equivalence point, the pH values will begin increasing more with less volume of base added. **Add volume in smaller increments – eventually adding dropwise – before and after the equivalence point.** You want to generate more data points in this region and plot a good curve before and after the equivalence point (see Figure 1a). You also need to wait longer for the pH to stabilize for readings near the equivalence point.

10. **After the equivalence point (about 2 mL after your calculated volume), the pH values will change by smaller increments.** You can gradually revert back to adding the larger 1 mL increments. Continue adding base in 1 mL increments of base until you've added a total of 15 mL.

11. When you have finished collecting data, click the **"Stop"** button. Make sure there is a line connecting your data points. You may need to click the plot picture in the bottom left corner and select "Both" under the appearance option. **Have your instructor approve your graph before exporting or printing.**

12. To print copies of the HCl titration curve, click the page icon in the upper left corner of the Graphical Analysis window.

    a. **Export** → Select ".CSV".

    b. **Decimal Format** → Select 12.3 and click "Download CSV"

    c. **Select My Drive** to save your data → Enter a name for your file at the bottom of the screen (xxxx.csv). Click "Save".

    d. **Click the page icon again:**

    e. **Export** → Select "Graph Image"

    f. **Select My Drive** to save your data → Enter a name for your file at the bottom of the screen (xxxx.csv). Click "Save".

g. **From the desktop computers on the side tables, open Chrome and login with your MEID and password. Login to your student email account to access Google. Click the 9 dot icon in the upper right and select "Drive". You should see both files (data and graph) in there. Click the print icon in the upper right. Print the graph in landscape so you have more space to draw lines and write values.**

h. **Share your file with group member →** Click the More actions icon (3 vertical dots) in the upper right corner; share the file with group members (type all members' email addresses including your own) and click send.

13. During week 2, repeat the above steps for a second titration using CH_3COOH instead of HCl. For the CH_3COOH titration, the pH may initially change by more than 0.3 units for the 1st two mL of base added, but should level out in the buffer region

14. The equivalence point occurs at the exact middle of the region where the pH rises sharply. Chances are there is no data point exactly at the equivalence point so it must be found graphically. Using a ruler and a pencil draw straight lines at the top and bottom of the the titration curve as shown in Figure 1b. The equivalence point occurs at the middle of the vertical line between the top and bottom lines you drew. Measure the distance between the top and bottom lines (parallel to the y-axis, not your graph) then divide by 2 to find the exact middle of the vertical line Refer to your graphs and data tables to estimate the volume and the pH at the equivalence point for both curves. **Mark the equivalence point, and write the corresponding pH value and the estimated volume in mL at the equivalence point on both curves.**

15. For the acetic acid plot, locate and **mark the half-equivalence point, and write the calculated volume in mL and the estimated pK_a value on the weak acid curve**. Refer to Figure 1b on page 2 for an example.

    Note: The equivalence point pH and volume (and the half-equivalence point pH) are estimated from your plots and data tables. The half-equivalence point volume is ½ of your estimated equivalence point volume. These values usually will not match specific data points on your curves.

Waste Disposal: Pour the solutions in the sink with running tap water.

Clean-Up: Rinse all glassware with lots of tap water and then a final rinse with DI water. Wipe your entire bench with a damp paper towel. Put all equipment back where you found it.

Acid-Base Titration Curves Pre-Lab Questions and Calculations

1. What is the difference between the equivalence point and the end point in a titration?

2. What substances are in solution at the equivalence point in a titration of HCl with NaOH?

3. What substances are in solution at the end point in a titration of HCl with NaOH?

4. What weak acid is used in this experiment?

5. How many data points should be collected to generate the best titration curve for each reaction in this lab?

6. In the expressions "**pH**" and "**pKa**", what does the lower-case "p" stand for?

7. In a titration of a weak acid with a strong base, **the pH of the solution** = **the pKa of the weak acid** at which point in the titration?

Name: ______________________________ Partners: ________________________

Acid-Base Titration Curves Lab Report

Data and Calculations

Table 1: Titration Volumes and pH values. Duplicate this table in your formal lab report.

HCl-NaOH titration data	
[HCl] = [NaOH] =	
NaOH volumes, mL	pH
0.00	

CH_3COOH-NaOH titration data	
[CH_3COOH] = [NaOH] =	
NaOH volumes, mL	pH
0.00	

Results:

Table 2: Results of titration. Duplicate this table in your formal lab report. Report the experimental pH and volume measurements that you wrote on your plots in this table.

	Equivalence point volume	Equivalence point pH	Half equivalence point volume	Half equivalence point pH
HCl-NaOH				
CH_3COOH-NaOH				

Conclusion: Summarize the results of the experiment. Remember to address the purpose of the experiment. State your calculated K_a value and percent error for acetic acid.

Group Formal Lab Report: Include sections in the correct order.

1. **Title, name, date**
2. **Data**
   a. All data including solution concentrations, volume and pH readings for both titrations. Be sure to label your data tables.
   b. Both graphs appropriately marked (see Figure 1b on page 2); you must write and show measurements on these graphs! Be sure to title/label each graph, and print large copies of your graphs so that you can write and label the following data points on them:
      i. **Mark the equivalence point, the equivalence point volume, and the equivalence point pH on both curves.** (Refer to step 14 in the procedure section on page 4.)
      ii. For the acetic acid plot, **mark the half-equivalence point, the half-equivalence point volume and estimated pH/pK_a value.** (Refer to step 15 in the procedure section on page 4.).
3. **Results**: Duplicate Results Table 2 in your report.
4. **Calculations**:
   a. Using the estimated pK_a value from your acetic acid-sodium hydroxide curve, show your calculation of the experimental K_a value for acetic acid.
   b. Given the theoretical K_a value for $CH_3COOH(aq)$ is **1.8×10^{-5}**, calculate the absolute percentage difference between the experimental and theoretical values.
5. **Conclusion**

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Post-Lab Discussion Questions – Do not include these in your lab report! These questions will not be graded as part of your lab report grade. You will be responsible for the information in these questions and should able to answer these or similar questions on the *post-lab quiz at the start of next week's lab period.*

1. Restate the purpose of the experiment
2. A student obtained a wet buret from the cart but failed to rinse it with a small amount of the base before starting a titration. Will more or less titrant (base) be required to neutralize the acid? Explain your answer.
3. A student failed to notice a bubble in the tip of the buret before starting a titration. Will more or less titrant (base) be required to neutralize the acid? Explain your answer.
4. Compare the initial pH values for both titrations. **Explain why** the pH of the HCl(aq) solution is initially lower, higher, or approximately equal to the pH of the CH_3COOH(aq) solution.
5. What is the pH at the equivalence point for your HCl(aq)-NaOH(aq) titration curve? What is the pH at the equivalence point for your CH_3COOH(aq)-NaOH(aq) titration curve? For each titration, **explain why** the pH at the equivalence point is either acidic, basic, or neutral by indicating which **substances are present in solution** that result in the observed pH.
6. Compare the pH values for the HCl(aq) and CH_3COOH(aq) titration curves past the equivalence point. **Explain why** this region is similar or different for the two acids.
7. Use the concentrations of HCl (10.00 mL) and NaOH used in this experiment to calculate the pH at each of the following volumes of base in your titration. Assume no change in concentrations with the added water.
   a. 0.00 mL b. 5.00 mL c. equivalence point (at the calculated volume) d. 14.00 mL
8. Use the concentrations of CH_3COOH (10.00 mL, $K_a = 1.8 \times 10^{-5}$) and NaOH used in this experiment to calculate the pH at each of the following volumes of base in your titration. Assume no change in concentrations with the added water.
   a. 0.00 mL b. 5.00 mL c. equivalence point (at the calculated volume) d. 14.00 mL
9. Discuss at least 2 sources of error in this experiment. How did they affect your results and how would you correct them if you were to repeat the experiment?