26. An Acid-Base Titration

Driving Questions

Many foods and household products contain acids and bases. Knowing if a sample is acidic or basic is only part of the question. How do you determine the actual amount of acid or base dissolved in a solution?

Background

Titration is a common quantitative laboratory method used to determine the concentration of a reactant. A reagent of known concentration, called the titrant, is used to react with a measured volume of another reactant, called the analyte.

When a basic solution is added to an acidic solution of unknown concentration, hydroxide ions (OH^-) from the basic solution react with hydronium ions (H_3O^+) from the acidic solution to form neutral water and a salt. The type of salt formed depends on the acid and base used. This type of reaction is called a neutralization reaction.

$$\text{acid} + \text{base} \rightarrow \text{water} + \text{salt}$$

$$HY(aq) + XOH(aq) \rightarrow H_2O(l) + XY(aq)$$

$$HBr(aq) + KOH(aq) \rightarrow H_2O(l) + KBr(aq)$$

Materials and Equipment

- Data collection system
- Drop counter
- pH sensor
- Magnetic stirrer
- Micro stir bar
- Beaker (2), 250-mL
- Beaker (2), 50-mL
- Graduated cylinder, 100-mL
- Volumetric pipet or graduated cylinder, 10-mL
- Buret , 50-mL
- Ring stand
- Right-angle clamp
- Buret clamp
- Funnel
- Transfer pipet
- Waste container
- Wash bottle filled with distilled (deionized) water
- Buffer solution pH 4, 25 mL
- Buffer solution pH 10, 25 mL
- Distilled (deionized) water, 200 mL
- Hydrochloric acid (HCl) solution, 10 mL
- Acetic acid ($HC_2H_3O_2$) solution, 10 mL
- Standardized sodium hydroxide (NaOH) solution, 120 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide, hydrochloric acid, and acetic acid are corrosive irritants. Avoid contact with the eyes and wash hands after handling.
- Be sure that all acids and bases are neutralized before disposal down the drain.
- When mixing acids with water, always add the acid to the water, not the other way around, as the solutions may get hot enough to boil.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Place 100 mL of distilled water and 10 mL of HCl into a 250-mL beaker and place it on the magnetic stirrer with the pH sensor in place.	Assemble the titration apparatus, rinse and then fill the buret with NaOH solution, and calibrate the pH sensor.	Write down the exact starting volumes of HCl and NaOH as well as the exact concentration of the NaOH solution. Start recording data.	Thoroughly clean the equipment and then repeat the procedure using the acetic acid solution.	Allow the NaOH to drip into the beaker until a pH of 12. Close the stopcock and stop recording data. Record the final volume of NaOH.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect a pH sensor to the data collection system. �(2.1)

3. ☐ Place 25 mL of pH 4 buffer solution in one 50-mL beaker and 25 mL of pH 10 buffer solutions in a second 50-mL beaker. Use these solutions to calibrate the pH sensor. �(3.6)

4. ☐ Using the terms “accuracy” and “precision,” explain why is it necessary to calibrate the pH sensor?

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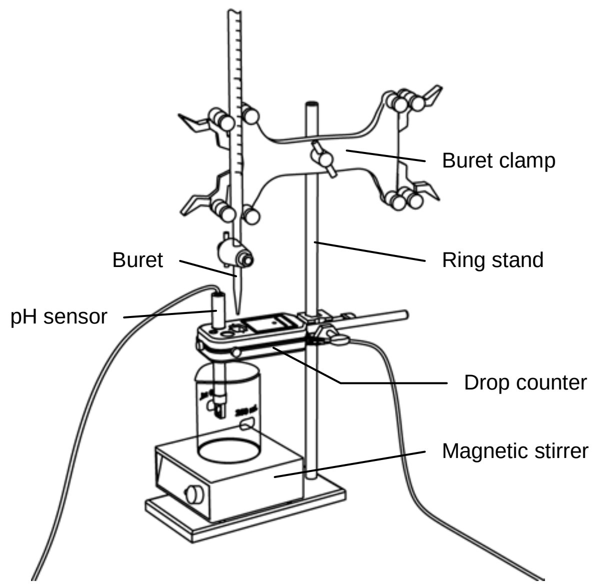
5. ☐ Connect a drop counter to the data collection system. �(2.2)

6. ☐ Display pH versus Drop Count (drops) on a graph. �(7.1.1)

7. ☐ Assemble the titration apparatus, using the steps below and the illustration as a guide.



   a. Assemble the ring stand.
   b. Position the magnetic stirrer on (or next to) the base of the ring stand.
   c. Place a waste container on the magnetic stirrer.
   d. Use the buret clamp to attach the buret to the ring stand.
   e. Position the drop counter over the waste container and attach it to the ring stand using the right-angle clamp.
   f. Place the pH sensor through one of the slots in the drop counter.

8. ☐ Rinse the buret with several milliliters of the standardized NaOH solution. Follow the steps below to complete this step.
   a. Ensure that the stopcock is closed and use a transfer pipet to rinse the inside of the buret with several milliliters of the standardized NaOH solution.
   b. Open the stopcock on the buret and drain the rinse NaOH into the waste container.
   c. Repeat this process two more times.

9. ☐ Why is it necessary to rinse the buret with the standardized NaOH solution?

10. ☐ Make sure the stopcock on the buret is in the "off" position, and then use a funnel to fill the buret with about 50 mL of the standardized NaOH solution (titrant).

11. ☐ Drain a small amount of the titrant through the drop counter into the waste beaker to remove any air in the tip of the buret.

12. ☐ Why is it important to remove air from the tip of the buret?

13. ☐ Practice adjusting the stopcock on the buret so that the titrant goes through the drop counter in distinguishable drops that fall at about 2 to 3 drops per second.

Note: Good control of the stopcock is important. If you accidently open the stopcock too far and the NaOH flows out (as opposed to drops out), you will have to start over.

14. ☐ Why will it be necessary to start your titration over again if you accidently allow the titrant to flow out of the stopcock instead of drop?

15. ☐ Close the stopcock and then remove the waste container.

Data Collection

Table 1: Titration data

Measurement	Hydrochloric Acid (HCl) Trial	Acetic Acid ($HC_2H_3O_2$) Trial
Concentration of the standard NaOH solution (M)		
Volume of acid used (mL)		
Initial volume of NaOH in the buret (mL)		
Final volume of NaOH in the buret (mL)		

16. ☐ Record the concentration of the standardized NaOH solution in Table 1 above (HCl Trial).

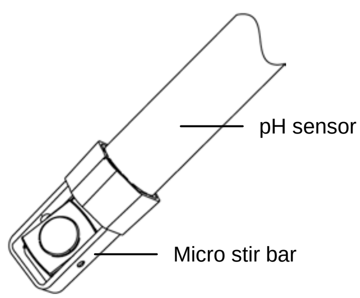
17. ☐ Using the 100-mL graduated cylinder, measure 100.0 mL of distilled water and add it to a 250-mL beaker.

18. ☐ Using the 10-mL graduated cylinder or a 10-mL volumetric pipet, measure 10.0 mL of HCl, and add it to the 100.0 mL of distilled water.

Caution: Always add acid to water.

19. ☐ Record the exact volume of acid used in Table 1 above (HCl Trial).

20. ☐ Add the micro stir bar to the end of the pH sensor.



21. ☐ Position the 250-mL beaker on the magnetic stirrer with the pH sensor submerged in the acidic solution.

22. ☐ Ensure the bulb of the pH sensor is fully submerged, and then turn on the magnetic stirrer and begin stirring at a slow-to-medium speed.

23. ☐ Why is it necessary to stir the solution during a titration?

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24. ☐ Determine the initial volume of the titrant (NaOH solution) in the buret to a precision of 0.01 mL, and record this in the HCl column in Table 1 above.

25. ☐ Start recording data. �(6.2)

26. ☐ Carefully open the stopcock on the buret so that 2 to 3 drops per second are released.

27. ☐ Continue recording data until the pH value reaches 12. If needed, rescale the axes so that you can see the changes taking place. �(7.1.2)

28. ☐ What substances are being formed in the beaker? What type of reaction is occurring?

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29. ☐ Write the chemical reaction that is occurring in the beaker.

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30. ☐ Close the stopcock when the pH of the solution reaches 12.

31. ☐ Stop recording data. �(6.2)

32. ☐ Name the data run "HCl". �(8.2)

33. ☐ Determine the final volume of the titrant in the buret and record the volume to 0.01 mL in the HCl column in Table 1 above.

34. ☐ Turn off the magnetic stirrer.

35. ☐ Remove the beaker and dispose of its contents according to the teacher's instructions.

36. ☐ Place the waste container under the pH sensor and use the wash bottle to thoroughly clean the micro stir bar and the pH sensor.

37. ☐ Dispose of this waste according to the teacher's instructions.

38. ☐ Perform a titration of acetic acid by repeating the steps in the Set Up and Collect Data sections above, this time substituting acetic acid. Take into account the following differences when you repeat the steps:

- ♦ Record the data collected in the acetic acid column in Table 1 above.
- ♦ Use 10.0 mL of acetic acid.
- ♦ Name the data run "Acetic acid".

39. ☐ Save your data file and clean up according to the teacher's instructions. �(11.1)

Data Analysis

1. ☐ Determine the total volume of NaOH used during each titration. Record the total volume used in table 2 below.

Total volume NaOH used = Final volume NaOH – Initial volume NaOH

Table 2: Volume of NaOH used in each titration

	HCl Trial (drops)	**$HC_2H_3O_2$ Trial (drops)**
Final volume of NaOH (mL)		
Initial volume of NaOH (mL)		
Total volume NaOH used (mL)		

2. ☐ Use the pH versus Drop Count (drops) graph to determine the total number of drops used in each trial. Follow the steps below to complete this on your data collection system.

   a. Display the run of data you want to analyze. �(7.1.7)

   b. Find the final drop count by finding the coordinates of the last data point collected. �(9.1)

   c. Record the final drop count for each trial in Table 3 below.

Table 3: Final drop count at the end of each titration

	HCl Trial	**$HC_2H_3O_2$ Trial**
Final drop count		

3. ☐ Create a calculation to convert drop count to volume (mL) for each trial. Follow the steps below to do this on your data collection system.

   a. Write the mathematical equation that can be used to convert drop count to volume. The general equation is given below, but you need to replace "total volume of titrant used" and "final drop count" with the numerical values determined above. Write the mathematical equation for each trial in Table 4 below.

$$\text{calcvolume} = \left[\text{Drop Count}\right] * \left(\text{total volume of titrant used / final drop count}\right)$$

Note: In the equation above "calcvolume" stands for calculated volume. You will have a different calculation for each trial so the two calculated volumes need to have different names.

   b. Enter the equations you determined above into the data collection system. �(10.3)

Table 4: Calculations for converting NaOH drop counts to volumes

Mathematical equation for the HCl trial:
Mathematical equation for the $HC_2H_3O_2$ trial:

4. ☐ Determine the pH and volume of NaOH at the equivalence point for each trial. Follow the steps below to do this on your data collection system.

   a. Change the units on the x-axis to the calculated volume for the run of data your want to analyze. �(7.1.9)

   b. Display the run of data you want to analyze. �(7.1.7)

   c. Find the coordinates of the equivalence point. The equivalence point is the data point with the greatest slope. �(9.3)

   d. Record the pH and Volume of NaOH at the equivalence point in Table 5 below.

Table 5: pH at the equivalence point and volume of NaOH used to reach the equivalence point

	HCl Trial	**$HC_2H_3O_2$ Trial**
pH at the equivalence point		
Volume of NaOH at the equivalence point (mL)		

5. ☐ Calculate the molar concentration of each of the acid solutions. Use the following steps as a guide and record your work for each step in the tables provided.

   a. Determine the number of moles of NaOH added using the volume of NaOH at the equivalence point and the molarity of the standardized NaOH solution.

   b. Convert from moles of NaOH to moles of acid using the balanced chemical equation.

   c Use the moles of acid and the starting volume of acid to determine the molarity of the acid.

Table 6: Calculating the molar concentration of the hydrochloric acid (HCl) solution

Name of Calculation	**HCl Trial** Show your work below
Moles of NaOH at the equivalence point (mol)	
Balanced chemical equation	
Moles of acid in solution (mol)	
Concentration of acid solution (M)	

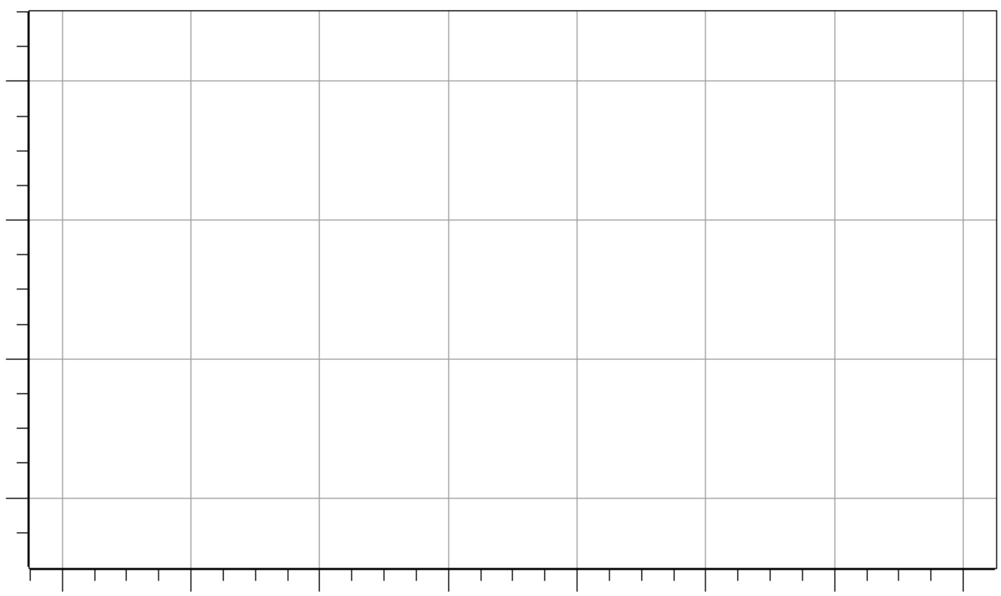
Table 7: Calculating the molar concentration of the acetic acid ($HC_2H_3O_2$) solution

Name of Calculation	**Acetic Acid Trial** Show your work below
Moles of NaOH at the equivalence point (mol)	
Balanced chemical equation	
Moles of acid in solution (mol)	
Concentration of acid solution (M)	

6. ☐ On your data collection system, create a graph of pH versus Volume of NaOH (mL) with both runs of data displayed on the same set of axes. �(7.1.3)

Note: Use either of the calculated volumes on the y-axis. This graph is for comparison purposes only.

7. ☐ Sketch or print a copy of the graph of pH versus Volume of NaOH (mL) with both runs of data on one set of axes. Label each run of data as well as the overall graph, the x-axis, the y-axis, and include numbers on the axes. �(11.2)



Analysis Questions

1. **What is the significance of the point on the titration curve where the slope is the steepest?**

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2. **What trend did you notice, if any, in the slope of the titration curve between the start of the titration and the equivalence point? Propose an explanation for any trend you observed.**

3. **What trend did you notice, if any, in the slope of the titration curve between the equivalence point and the point where the titration was stopped? Propose an explanation for the trend you observed.**

4. **What is the likelihood that the concentration of acid and base is exactly equal at the experimentally determined equivalence point? Explain your reasoning.**

5. **What, if any, difference do you notice between the start of the titration and the equivalence point in the titration curves for the two different acids? Explain any difference that may exist. (You may assume the concentrations of the two acid solutions are the same.)**

6. **What is the difference in pH at the equivalence points between the two acids? Explain.**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **How can the concentration of an unknown sodium hydroxide solution be determined?**

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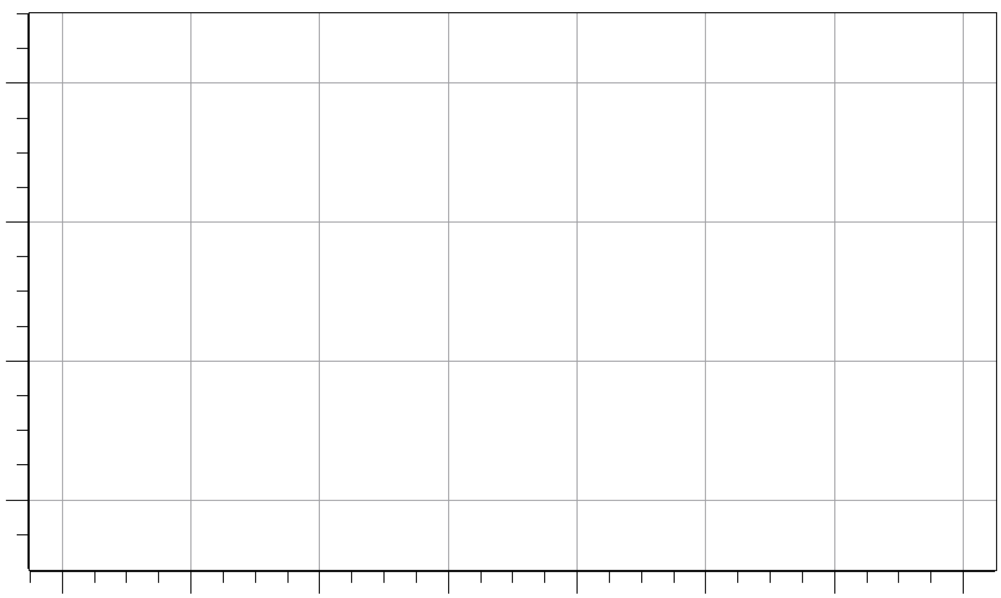
2. **Sketch the titration curves for a strong acid (HCl), a weak acid (acetic acid), and an acid that is weaker than acetic acid below. Label the curve for each acid as well as the overall graph, the x-axis, the y-axis, and include numbers on the axes.**

Sketch of an Acid Weaker than Acetic Acid



3. **Explain the difference between the strength and the concentration of an acidic solution.**

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Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **For the titration of an acid with a base, the pH will start ________ and finish ________.**

   A. low; low
   B. high; low
   C. low; high
   D. high; high

2. **On a titration curve, the equivalence point is:**

   A. The point with the smallest slope
   B. The point with the greatest slope
   C. The point with a slope of zero
   D. When the pH is equal to zero

3. **If the hydronium ion concentration in an aqueous solution increased, what would happen to the hydroxide ion concentration and the pH of the solution?**

   A. Hydroxide ion concentration would increase; pH would decrease
   B. Hydroxide ion concentration would decrease; pH would increase
   C. Hydroxide ion concentration would decrease; pH would decrease
   D. Hydroxide ion concentration would increase; pH would increase

4. **What is a reaction between an acid and a base called?**

   A. A pH reaction
   B. A titration reaction
   C. An s-shaped curve
   D. A neutralization reaction

5. **Why are titrations performed?**

   A. To determine the concentration of known solutions
   B. To determine the pH of known solutions
   C. To determine the type of molecules in a solution
   D. To differentiate an acid from a base

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Acid-base reactions are extremely important and are present in many areas, from acid rain to the chemistry of the blood. An acid is a substance that when dissolved in water, causes the hydronium ion (H_3O^+) concentration to ________________________ and the hydroxide ion (OH^-) concentration to ________________________. A base does exactly the opposite. A solution with equal concentrations of H_3O^+ ions and OH^- ions is known as ________________________. A solution containing more H_3O^+ ions than OH^- ions is considered ________________________ and has a pH ________________________ than 7. A solution containing fewer H_3O^+ ions than OH^- ions is considered ________________________ and has a pH ________________________ than 7. When an acid and base react, they form a ________________________ and water. This is called a ________________________ reaction.

2. A ________________________ is a common quantitative laboratory method used to determine the concentration of a reactant. A reactant with a known concentration, called the ________________________, is added to a known volume of a second reactant, called the ________________________. In a titration setup, the titrant is placed in the ________________________ and the analyte is placed in the ________________________. As the titrant is added to the analyte, the pH of the solution in the beaker changes as the ratio of H_3O^+ ions and OH^- ions change. The point in the titration at which the amount of titrant added reacts exactly with the amount of analyte present is known as the ________________________. On a titration curve, the equivalence point can be identified as the point with the ________________________ slope. The volume of the titrant added is multiplied by the ________________________ of the titrant to determine the number of moles in the titrant. The number of analyte moles can be determined using the ________________________ between the reactants as indicated in the balanced chemical equation. Finally, the number of analyte moles is ________________________ by the starting volume of the analyte to give the analyte concentration.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
acetic	analyte
acidic	beaker
basic	buret
decrease	divided
greater	equivalence point
increase	greatest
less	molarity
neutral	mole ratio
neutralization	multiplied
salt	smallest
single replacement	titrant
sugar	titration