Investigating Acid-Base Titrations

A titration is a laboratory process used to determine the volume of a solution needed to react with a given amount of another solution. One of the most common titrations performed in a Chemistry lab is an acid-base titration. In the Initial Investigation, you will be assigned an acid solution to titrate with a solution of the strong base sodium hydroxide, NaOH. The concentration of the NaOH solution is given and you will determine the concentration of the acid solution.

Your assigned acid may be strong, such as hydrochloric acid, HCl, or weak, such as acetic acid, CH_3COOH. When titrating a strong acid, the main objective is to determine the *equivalence point* of the titration. Near the equivalence point, the pH increases very rapidly, as shown in Figure 1. The graph of a strong acid-strong base titration is analyzed as accurately as possible to determine the exact amount of NaOH needed to neutralize all the acid,

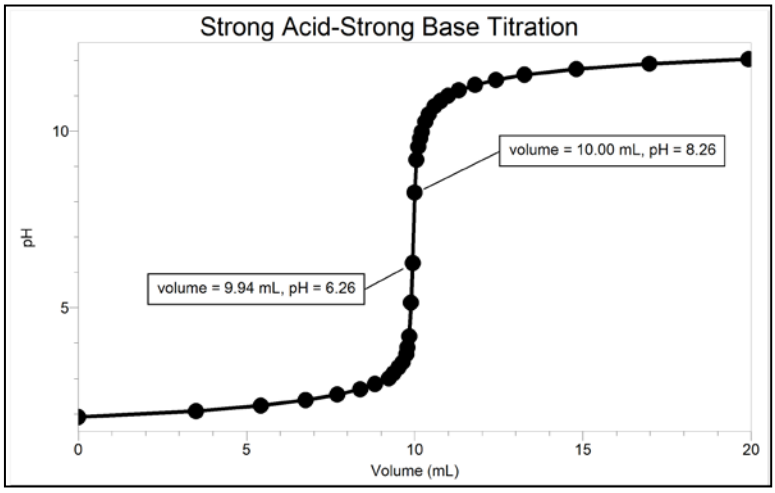

Figure 1

In the case of titrating a weak acid, a second objective is to determine an *equilibrium constant*. In reacting with a base, a weak acid will establish an equilibrium that can be evaluated mathematically, and is abbreviated as K_a. A K_a value is a unique quantity, which helps identify the acid. A weak acid may also have more than one K_a, depending on how many dissociation steps it undergoes in releasing ionizable hydrogen to form H_3O^+ ions.

After completing the Initial Investigation, you will be given a weak acid solution of unknown identity and concentration to test by titration. It will be helpful to use reference sources to find out more about acids and bases, acid-base titrations, and weak acid equilibria before planning and conducting your investigation.

PRE-LAB ACTIVITY

1. If you are given equal volumes of 0.25 M hydrochloric acid solution and 0.25 M acetic acid solution, will one acid require more of a sodium hydroxide solution, at a specific molar concentration, to be neutralized? Explain your answer.

2. In the scenario posed in #1 above, will the pH values at the equivalence points of the titrations be the same? Explain your answer.

3. If you are given a structural drawing, or 3-D model, of a compound and told that it is an acid, what features of the structure could you use to determine if the acid is strong or weak?

INITIAL INVESTIGATION

In the Initial Investigation, you will conduct a titration between a solution of sodium hydroxide, NaOH, and an acid solution to which your group has been assigned. Your instructor will provide you with the molar concentration of the NaOH solution; the molar concentration of the acid will be unknown.

1. Obtain and wear goggles.

2. Obtain about 25 mL of the acid solution assigned to your group. Measure out 10 mL of the acid solution and 50 mL of distilled water to a 250 mL beaker. **DANGER:** *Hydrochloric acid causes severe skin burns, eye damage, and respiratory inflammation.*

3. Place the beaker on a magnetic stirrer and add a stirring bar. If no magnetic stirrer is available, stir the reaction mixture with a stirring rod during the titration.

4. Connect a pH Sensor to LabQuest or a computer interface. In the data-collection program, choose New from the File menu.

5. Set up the data-collection mode for Events with Entry.
   - In Logger *Pro*, choose Data Collection from the Experiment menu. In the Data Collection dialog box, choose Events with Entry from the Mode list. Enter the Column Name (Volume), Short Name (Vol.), and the Units (mL). Click Done.
   - In LabQuest App, tap Mode on the Meter screen. Change the Mode to Events with Entry. Enter the Name (Volume) and Units (mL). Select OK.

6. Use a utility clamp to suspend the pH Sensor on the ring stand (see Figure 2). Position the pH Sensor so that its tip is immersed in the acid solution but is not struck by the stirring bar. Gently stir the beaker of acid solution.

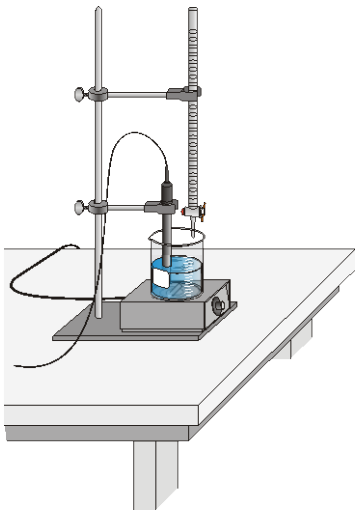

Figure 2

7. Rinse and fill a 50.0 mL buret with ~0.1 M NaOH solution. Your instructor will provide you with the specific molar concentration of the NaOH solution. Attach the buret to the ring stand using a buret clamp (see Figure 2). **WARNING:** *Sodium hydroxide causes skin and eye irritation.*

8. It can be helpful to conduct a first titration run in a so-called "quick and dirty" manner, where the NaOH solution is added 1 mL at a time to get a rough idea about how the titration curve will develop. This will provide some good information from which to plan a second, more accurate titration. Keep the following tips in mind:
   - Determine an initial pH reading, before adding any NaOH solution.
   - For a more accurate titration, add NaOH solution in small increments, raising the pH of the mixture by about 0.15–0.25 units at a time, until you are near an equivalence point.
   - Near an equivalence point, it is good to add NaOH solution drop by drop.
9. When the titration is complete, dispose of the reaction mixture as directed.

PLANNING FOR THE FINAL INVESTIGATION

As you analyze and discuss the data from your Initial Investigation, consider the following points:

- At the *equivalence point*, equimolar amounts of the acid and NaOH have been mixed. What is the most accurate way to determine the equivalence point?
- Calculate the number of moles of NaOH used to neutralize the acid.
- Calculate the molar concentration of the acid solutions.

In the Final Investigation, you will be given a new, unknown, weak acid solution. In planning to test the unknown acid solution, consider the following:

- What is the best method for calculating the K_a of a weak acid, using titration data?
- If an unknown acid has more than one equivalence point, is there reason to expect a specific K_a (K_{a1} or K_{a2}, or possibly K_{a3}) to be a better value to identify the acid?
- How important is the concentration of the NaOH solution to achieving good results? Is there reason to use a solution of NaOH that is similar to that of your unknown weak acid?
- Can suitably accurate results be achieved by titrating the unknown weak acid solution with a weak base solution, such as ammonium hydroxide?

FINAL INVESTIGATION

As you carry out your approved plan, consider the following questions:

- What is the optimum number of data-collection runs needed to achieve the best data?
- What is the best volume of the unknown to titrate to achieve the best data?
- What sampling and measuring techniques should be used to achieve the best data?

ANALYZING RESULTS

When preparing your report, include

- A statement of the results: What was the identity and the molar concentration of the unknown weak acid assigned to your group?
- A description of the procedure that you used in the investigation, including any changes that were made to the method that was used during the Initial Investigation

- An analysis of the graphs and supporting calculations, including any K_a values

Additional items to consider including in your report

- A comparison of your results with the results from other groups testing different weak acids
- Recommended modifications to the procedure that would increase accuracy, save time, or ensure that liquids are handled more efficiently and safely
- A discussion of any unanticipated difficulties your group faced in testing the unknown and/or determining its identity and molar concentration