Acid-Base Titration

Goals

- To practice the titration method of analysis and to use the method to analyze a vinegar solution.

Terms to Know

Titration - The process of adding a measured amount of a solution of known concentration to a sample of another solution for purposes of determining the concentration of the solution or the amount of some species in the solution.

Titrant - The solution measured from the buret in a titration.

Buret - A narrow, cylindrical-shaped, precisely calibrated piece of glassware. A device used to measure the volume of titrant delivered in a titration.

End Point - The stage of a titration when just enough titrant has been added to make the indicator change.

Indicator - A chemical, added to a titration mixture, which changes color at the end point of the titration.

Introduction

A titration is the process of adding a measured volume of a solution of one chemical species to a sample of a solution containing another species for the purpose of determining the concentration of the dissolved species in one of the solutions. A species in the solution of known concentration reacts with another species in the unknown solution. The addition and measurement of the volume of the added solution is done by use of a buret. (See Fig. 29-1.) A titration is usually carried out by placing a measured sample of the unknown solution in a flask, filling the buret with the known solution (called the titrant), and then slowly delivering the titrant to the flask until the necessary amount has been added to the unknown solution.

The point at which the necessary amount has been added is called the end point of the titration. The end point is often detected by placing a small amount of a chemical called an indicator in the reaction flask. The indicator is chosen so that it will react with the titrant when the end point is reached. The reaction of the indicator produces a colored product; the appearance of the color signals the end point of the titration. Some indicators are colored to begin with and react at the end point to produce a different colored product, so the change in color indicates the end point. Other indicators change from a colorless form to a colored form at the end point.

Once the end point has been found, the volume of titrant used can be determined from the buret. Using this volume, the concentration of the known solution and the stoichiometric factor from the balanced equation, we can deduce the number of moles of species in the solution being analyzed. If the molarity of the unknown solution is to be calculated, it is necessary to measure the volume of the original sample of unknown solution before it was titrated. Then, the molarity can be found by dividing the calculated number of moles by this volume. As an example, consider the following case. Determine the molarity of a hydrochloric acid solution if 30.21 mL of a 0.200 *M* sodium hydroxide solution is needed to titrate a 25.00-mL sample of the acid solution. First, the chemical reaction involved is:

$$OH^-_{(aq)} + H_3O^+_{(aq)} \rightleftharpoons 2\ H_2O$$

Note that one mole of acid reacts with one mole of base. The number of moles of hydroxide ion needed to react can be found from the volume used and the molarity. The titration required 30.21 mL of 0.200 *M* NaOH to react with the acid. The number of moles of hydroxide ion is found by multiplying the volume of sodium hydroxide solution in liters by the molarity. The calculations are:

First the number of moles of OH^- used are found as the product of the volume and molarity: $V_b M_b$

$$\frac{30.21\ \text{mL} \times 0.200\ \text{mol OH}^-}{1000\ \text{mL}} = 0.006042\ \text{mol OH}^-$$

Next the number of moles of hydronium ion is found by multiplying by the molar ratio obtained from the equation for the titration reaction.

$$0.006042\ \text{mol OH}^- \times \frac{1\ \text{mol H}_3\text{O}^+}{1\text{mol OH}^-} = 0.006042\ \text{mol H}_3\text{O}^+$$

Finally, the molarity of the acid solution can be found by dividing the number of moles of hydronium ion by the original volume of the acid solution in liters.

$$\frac{0.006042\ \text{mol H}_3\text{O}^+}{25.00\ \text{mL}} \times \frac{1000\ \text{mL}}{1\ \text{L}} = 0.242\ M\ \text{H}_3\text{O}^+$$

If the acid and base in a titration react in a one-to-one molar ratio, as is the case in the above example, the calculations can be simplified by using the equation:

$$M_a = \frac{M_b\ V_b}{V_a}$$

where V_b is the volume of the base used in the titration, V_a is the volume of the original acid solution, M_b is the molarity of the base solution, and M_a is the molarity of the acid solution. Using this simple equation for the example given above, the molarity of the acid solution is:

$$M_a = \frac{0.200\ M_b \times 30.21\ \text{mL}}{25.00\ \text{mL}} = 0.242\ M$$

How to use the buret

A buret is a piece of glass tubing calibrated to deliver measured volumes of solution. A 50-mL buret is calibrated to deliver between 0 and 50 mL. Each etched line on the buret corresponds to a 0.1-mL increment of volume. By interpolation, the buret can be read to the nearest 0.01 mL. These instructions apply to a Mohr buret as pictured in Figure 29-1. If you use a buret with a glass or plastic stopcock, disregard the reference to the rubber tubing and bead but follow the other instructions.

1. Cleaning

Place some water in the buret and allow it to run out through the tip by squeezing the rubber tube around the glass bead (or opening the stopcock). If you notice water drops adhering to the sides of the buret as it is drained, the buret needs cleaning. Clean the buret using tap water and a small amount of detergent. Use a buret brush to scrub the inside of the buret. Rinse the buret four or five times with tap water and allow some water to run out of the tip each time. Finally, rinse the buret three or four times with 10 mL portions of deionized water. By rotating the buret, allow the water to rinse the entire buret and be sure to rinse the tip by allowing some water to pass through.

2. Filling

When filling a buret, try not to splash or spill any titrant. Clean up any spills. Use a paper towel to dry the outside of the buret. Rinse the clean buret two or three times with less than 5 mL portions of the solution with which it is to be filled. Be sure to rinse the tip each time. Fill the buret to a level just above the 0.00-mL mark. Fill the tip by bending the rubber to point the tip upward and then gently squeeze the tube to allow the liquid to displace the air (or open the stopcock and remove any air bubbles). Adjust the meniscus to a position somewhat below the 0.00-mL mark.

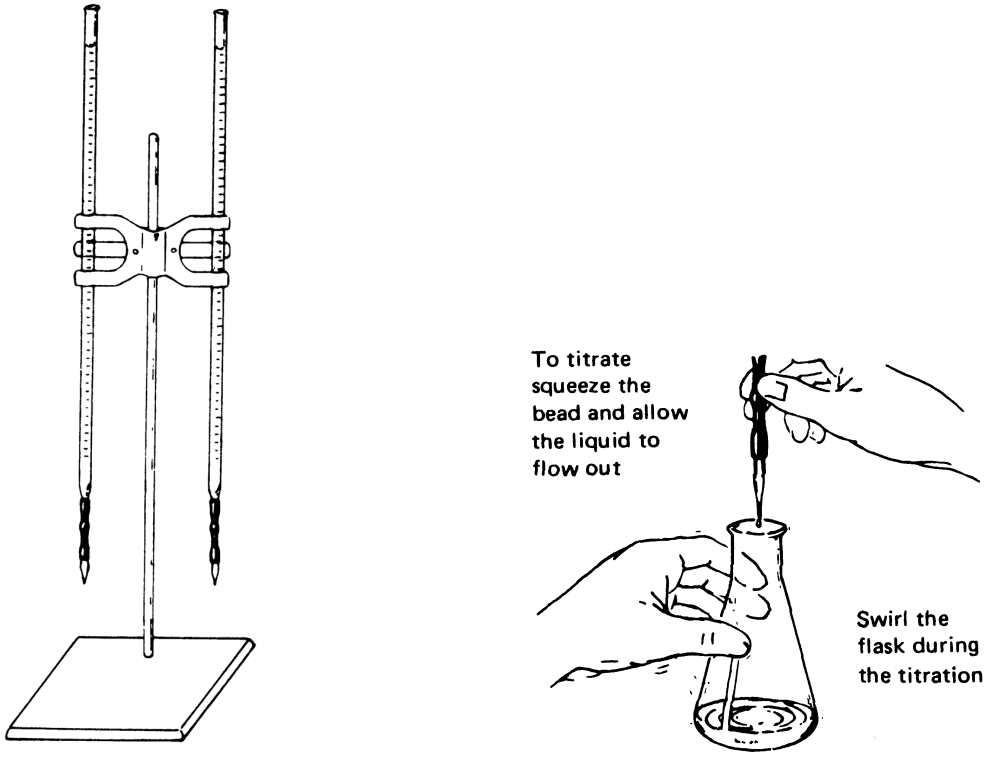

Figure 29-1 Burets and the titration process

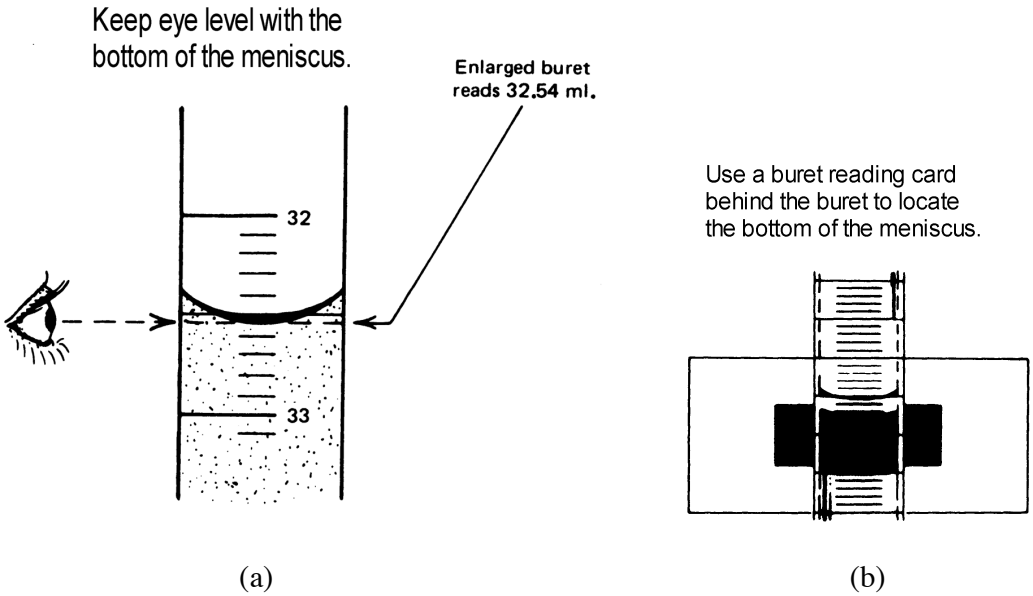

Figure 29-2 Reading a buret

3. Reading

The position of the bottom of the meniscus is read to the nearest 0.01 mL. The buret can be read directly to the nearest 0.1 mL, but you must interpolate to read to the nearest 0.01 mL. To interpolate, you imagine that the distance between lines is made up of 10 equally spaced parts. Then decide with which part the bottom of the meniscus coincides. A buret reading card can be used to aid you in reading the position of the meniscus. (See Fig. 29-2.) When reading the buret, make sure your eye is level with the bottom of the meniscus.

4. Titration Method

Be sure to record the initial and final buret readings when you do a titration. Place the sample of solution to be titrated in a flask. After recording the initial volume of the buret, allow the titrant to flow into the flask by pinching the rubber tube around the glass bead (or opening the stopcock). Let the titrant flow rapidly at first, and then add smaller and smaller volume increments as the end point is approached. When you are close to the end point, add one drop or less at a time. A fraction of a drop can be added by allowing a portion of a drop to form on the tip, touching the tip to the inside of the flask, and then washing down the sides of the flask with a small amount of deionized water from a wash bottle. During the titration, mix the solutions in the flask by swirling but do not splash the solutions out of the flask. (See Fig. 29-1b.)

5. Cleaning Up

Drain the solution from the buret and rinse thoroughly with tap water. Remember to rinse the tip. Try not to spill any of the solutions on the desk or your clothing. If you do spill the solutions, clean them up. If any solutions spill on your clothing, tell your instructor. Burets can be stored corked and filled with deionized water.

Safety

Act in accordance with the laboratory safety rules of Cabrillo College.
Wear safety glasses at all times.
Avoid contact* with all chemical reagents and dispose of reactions using appropriate waste container.

Materials:

Reagent Central solutions include:

Experimental Procedure

1. Analysis of Acetic Acid in Vinegar

In this experiment you will titrate a vinegar solution using a standardized sodium hydroxide solution. You need a clean, dry 100-mL beaker, a 250-mL beaker, a 250-mL erlenmeyer flask, a 50-mL buret, a buret clamp, and a ring stand. Set up a buret on a ring stand as shown in Fig. 29-1 but use only one buret.

Obtain about a little less than 100 mL of a standardized sodium hydroxide solution in the 100-mL beaker. (DANGER: NaOH is very caustic.) Write down the molarity of this solution. Be very careful not to splash or spill this solution. Sodium hydroxide solutions are especially dangerous if splashed in your eyes. Always pour such solutions in a buret by removing the buret from the clamp and holding the buret in a piece of paper towel well below your eye level. Never raise the beaker of solution above your eye level. Do not put a funnel in the buret to fill it.

Rinse and fill your buret with the sodium hydroxide solution according to the instructions given in the discussion section.

You will find vinegar solution in a bottle fitted with a precision 10.0-mL pump. As demonstrated by your instructor, pump a 10.0-mL sample of vinegar into a clean 250-mL flask. Add 2 or 3 drops of phenolphthalein indicator to the flask and dilute to about 50 mL volume using deionized water.
Take the initial volume reading of the buret. Titrate the acid solution sample with the sodium hydroxide solution until the end point is reached. As you add base, you will notice a slight pink color at the point at which the base solution enters the acid solution. As you approach the end point, you may see the entire solution momentarily become pink as you swirl it. When this occurs, slow down the rate of addition of the base and carefully approach the end point. When the addition of a single drop of base makes the solution in the flask turn a very light pink and remain so for one minute or longer, you have reached the end point. The sides of the flask may be washed down with small amounts of deionized water at any time. Once the end point has been reached, take the final volume reading.

Rinse the 250-mL flask with deionized water. Pump another 10.0 mL of acid into the flask and titrate the acid with the base. You may have to refill the buret with some sodium hydroxide solution. Record the titration data in your laboratory notebook. **Repeat the titration procedure a total of three times.**

Rinse the flask and carry out a third titration. When you are finished be sure to rinse out your buret with water and remember to rinse the tip of the buret so that it does not contain base solution. Test the tip using red litmus paper. If the paper turns blue rinse your buret and tip with more water.

Use the volumes of the acid and base solutions used from the data table for the calculations. The acid/base reaction involved is:

$$HC_2H_3O_{2(aq)} + OH^-_{(aq)} \rightleftharpoons H_2O_{(l)} + C_2H_3O_2^-{}_{(aq)}$$

Calculate the molarity of acetic acid in vinegar for each titration. If your results are within 10% of one another, calculate the average molarity. If your results do not seem close enough, consult your instructor.

2. The Percent By Mass Acetic Acid In Vinegar

From density of vinegar, which is 1.00 g/mL, it is possible to calculate the percent by mass of acetic acid in vinegar. This is done by carrying out the following sequence of calculations. (AA is an abbreviation for acetic acid, $HC_2H_3O_2$)

$$\frac{\text{moles AA} \xrightarrow{\text{molar mass AA}} \text{grams AA}}{\text{L vinegar} \longrightarrow \text{mL vinegar} \xrightarrow[\text{density water}]{} \text{g vinegar}} \times 100 = \%\text{AA}$$

Using your experimental value for the molarity of acetic acid in vinegar, calculate the percent by mass acetic acid in vinegar.

Questions for Analysis

Answer the following questions in your laboratory notebook:

1. Explain the function and purpose of an indicator in a titration.

2. If you are titrating an acid with a base, tell how each of the following factors will affect the calculated molarity of the acid. That is, explain whether the calculated molarity would be greater than it should be, less than it should be, or not changed, and explain why.

    a. The end point is exceeded by adding too much base.
    b. The volume of acid is measured incorrectly so that it is smaller than the value used in the calculations.
    c. Deionized water is used to wash down the sides of the flask during the titration.

3. A sample of vinegar is titrated with a sodium hydroxide solution to find the molarity of acetic acid. If 18.82 mL of a 0.430 *M* NaOH solution is required to titrate 10.00 mL of vinegar solution, what is the molarity of acetic acid in the vinegar?