Measuring the Acidity of Fruit Juices with Titration

Chemistry 283

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Introduction

All foods, beverages, pharmaceuticals, biofuels, and vitamins contain acids or bases, or a mixture of acids and bases. While there are times when knowing if a solution is acidic, basic, or neutral is sufficient, often the exact concentration is important. For example, fruit juices get their sweet taste from sugars and their sour taste from weak acids, such as citric acid. If the juice contains too much sugar, it will taste bland, but too much acid and the juice will taste sour. The food industry uses titrations to determine the amount of acid content in its products.

Guiding Questions

1. How do the structure and initial concentration of an Acid and Base influence the pH of the resultant solution during a titration?
2. How much acid is present in common fruit juices?

Background

The main acids present in fruits and fruit juices are citric acid (in citrus fruits), tartaric acid (in grapes), and malic acid (in apples). All of these are characterized as weak acids. Figure 1 below shows the structures of these common acids.

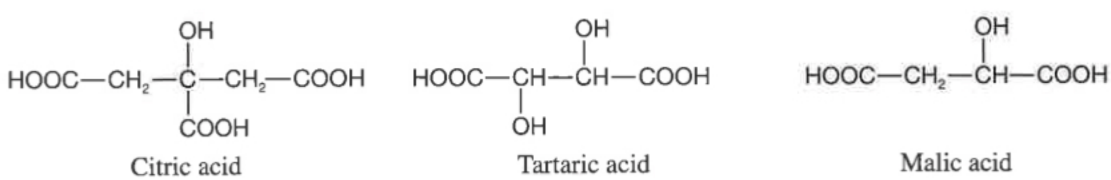
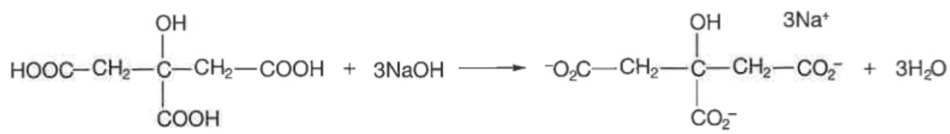


Figure 1: Organic acids in fruits and fruit juices

The amount of citric acid in citrus fruit juices can be determined by titration with a standard solution of sodium hydroxide. A standard solution is one whose concentration is accurately known, usually to three significant figures. Citric acid is a tricarboxylic acid and has three ionizable or "active" hydrogen atoms in its structure. One mole of citric acid therefore reacts with three moles of sodium hydroxide via the acid-base neutralization reaction shown in the equation below:



Citric acid — Citrate ion

Acid-base titrations are an extremely useful technique to determine the concentration of an acid or base in a sample. In titrating beverages such as orange juice, apple juice, and sodas that contain weak acids, the juice is called the analyte and a strong base is used as the titrant.

In the titration procedure, a sodium hydroxide solution of known molarity is carefully added using a buret to a measured volume of fruit juice containing an indicator. The exact volume of sodium hydroxide that must be added to reach the indicator endpoint is measured and then used to calculate the concentration of citric acid in the juice.

Earlier we conducted titrations using an indicator to assess the equivalence point of the reaction of a strong acid and strong base. While useful, indicators are not as precise as using pH meters.

A sample setup for a titration is shown in Figure 2, where a buret containing the titrant is clamped to the support stand and a beaker or flask containing the analyte is set atop a stir plate. If a pH probe is inserted into the solution, a titration curve can be constructed by plotting the pH of the solution on the y-axis versus the volume of titrant added on the x-axis. The shape of the titration curve may be used to distinguish strong and weak acids in the analyte, and also permits graphical analysis of the equivalence point. At the equivalence point, moles of added titrant are stoichiometrically related to moles of analyte in the sample.

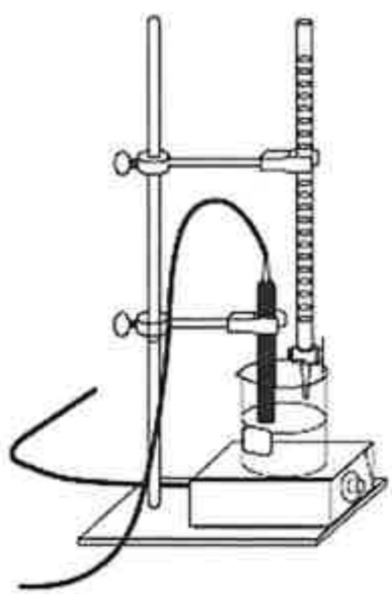


Figure 2: Titration equipment set up.

Choosing a suitable indicator for a titration is important for accurate results. Indicators signify the endpoint of a titration when a sudden change in the color of the analyte solution occurs. Indicators have different pH transition ranges and exhibit different colors in acidic versus basic solutions. The color changes arise because indicators are weak acids for which the acid form HIn and the conjugate base form In^- have different colors. An appropriate indicator for a titration is one whose color change occurs close to the theoretical pH of the equivalence point. Examples of indicators provided in this activity are shown in the table:

Indicator	pH Range	Color Change
Bromthymol blue	6.0 – 7.6	Yellow to blue
Phenolphthalein	8.2 – 10.0	Colorless to pink
Thymol blue	8.0 – 9.6	Yellow to blue
	1.2 – 2.8	Red to yellow

Experiment Overview

The purpose of this project is to conduct acid-base titrations and determine the concentration of acid in common beverages such as orange juice or pineapple juice. The beverages contain weak acids, which will be titrated with a strong base, sodium hydroxide.

Pre-experimental Questions

Answer the following questions in your notebook.

1. Using the structural formula of citric acid shown in Figure 1, determine the molecular formula of citric acid and calculate its molar mass (g/mole).
2. A 10.0 mL sample of pineapple juice was titrated with 0.100 M sodium hydroxide solution. The average volume of NaOH required to reach the endpoint was 12.8 mL.
   (a) Calculate the number of moles of sodium hydroxide required to reach the endpoint.
   (b) Using the mole ratio for the neutralization reaction shown in Equation 1, determine the number of moles of citric acid in 10.0 mL of pineapple juice.
   (c) Multiply the number of moles of citric acid by its molar mass to calculate the mass of citric acid in 10.0 mL of the juice.
   (d) The concentration of acid in juices is usually expressed in grams of acid per 100 mL of juice. What is the concentration of citric acid in pineapple juice?
3. Write a balanced chemical equation for the neutralization reaction of (a) hydrochloric acid and (b) acetic acid with sodium hydroxide.

4. The titration curves for hydrochloric acid and acetic acid with sodium hydroxide are shown below in Figure 3. Distinguish between the strong and weak acid in terms of the initial pH, the pH at the equivalence point, and the overall shape of the titration curve.

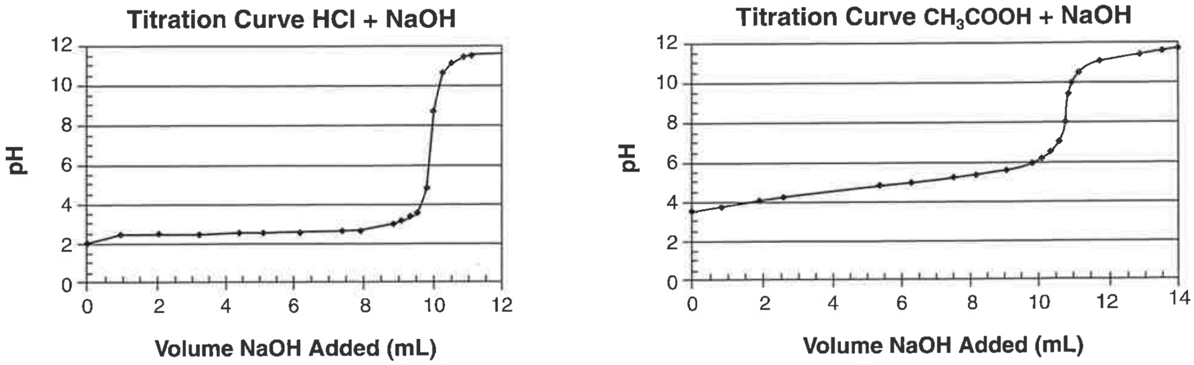


Figure 3: Standard Titration Curves

Procedures

Part 1

1. Label three medium test tubes B, P and T for the names of three indicators–bromthymol blue, phenolphthalein, and thymol blue-that will be studied in this activity.
2. Using a 10 mL graduated cylinder, measure and pour 2.0 mL of 0.1 M acetic acid into each test tube.
3. Add 1-2 drops of each indicator to the appropriate test tube.
4. Observe and record the initial indicator color in each test tube.
5. Rinse the graduated cylinder with distilled water and dry the cylinder.
6. Measure 3.0 mL of 0.1 M sodium hydroxide in the graduated cylinder. Using a graduated pipet, add the NaOH solution in 1 mL increments to the acetic acid solution in test tube B. Observe and record the indicator color as the base is added.
7. Note the approximate volume of NaOH that has been added when the indicator color changes.
8. Repeat steps 6-7 two times using the acetic acid-indicator solutions in test tubes P and T.
9. Rinse the test tubes with distilled water and dry them.
10. Using a clean, 10 mL graduated cylinder, measure and pour 2.0 mL of 0.1 M hydrochloric acid into each test tube B, P and T. Repeat steps 3-8 to determine the initial and final color changes for HCl and NaOH with various indicators.

Part 2

1. Choose a suitable indicator for determining the endpoint in the neutralization of a weak acid with a strong base. Explain your reasoning based on the evidence obtained above as well as the titration curve data discussed in Pre-Experiment Question 4.

2. Would you expect any differences in the choice of an appropriate indicator for the titration of a strong acid such as HCl? Why or why not?

3. Acidic beverages generally contain weak acids, such as citric acid in citrus fruit juices, tartaric or malic acids in other fruit juices, phosphoric acid in colas, and carbonic acid in seltzers. Write balanced chemical equations and determine the mole ratio for the reaction of each acid with sodium hydroxide. Note: Use the molecular formulas of the weak acids (it is not necessary to draw their chemical structures).

4. The titrant used in a titration experiment is a standard solution. Explain what this means, identify the titrant, and obtain the known molarity from your instructor.

5. Review the setup shown in Figure 2 for a titration procedure.

   - The buret should be cleaned and then rinsed with the titrant before beginning the titration. Explain why this is necessary.
   - Is it necessary to know the precise volume of beverage that will be titrated? Explain.
   - Choose the type of volumetric glassware (flask, graduated cylinder or pipet, etc.) to measure the beverage(s) that will be titrated in this experiment. Explain the choice.
   - It's helpful to occasionally rinse the sides of the beaker or flask with distilled water during the titration procedure. Explain why it is not necessary to know the volume of rinse water.

6. Examine a buret and explain how to "read" the volume of titrant in the buret. What precision (number of significant figures) is allowed in these measurements?

7. What data must be measured and plotted to obtain the titration curve for an acidic beverage? What is an appropriate volume interval for obtaining this data during the titration? Explain your reasoning.

8. Write a detailed, step-by-step procedure for titrating a beverage to determine the concentration of weak acid, if present. Include the reagents needed, the glassware and equipment that will be used, and the appropriate measurements and observations that must be made.

9. Review the hazards of the chemicals used in the procedure and write appropriate safety precautions that must be followed during the experiment.

10. Carry out a "rough" titration to estimate the volume of beverage to be used in the experiment. Pour 5 mL of juice into a test tube, add 1-2 drops of indicator, and note the initial color. Add the titrant in 1 mL increments using a graduated pipet until the endpoint color is observed. Keep the test tube to be used as a "color standard" for the titration.

11. Choose an amount of beverage to be titrated that will require at least 10 mL but less than 20 mL of titrant. Explain why this range of titrant is optimum.

12. Carry out the titration to obtain the titration curve data. Record the results in an appropriate data table.
13. Repeat the titration as needed to check the reproducibility of the endpoint measurement. Record results.

Analysis

1. Plot the data and explain the titration curve results, including the initial pH and the pH at the equivalence point.
2. Determine the molar concentration of acid in the beverage sample based on its ingredient label and/or the most probable acid it contains.
3. Calculate the mass of acid contained in a serving size of the beverage.