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Acidity of Beverages

AP* Chemistry Big Idea 1, Investigation 4

An Advanced Inquiry Lab

Introduction

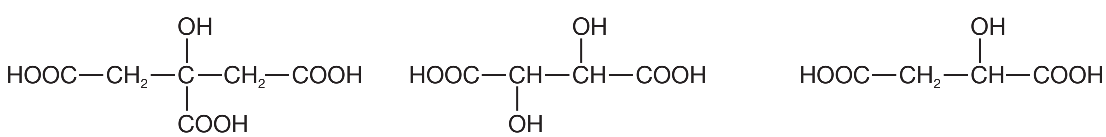
Common beverages may be either *acidic* or *basic*. Fruit juices, for example, get their sweet taste from sugars and their sour or tart taste from weak acids such as citric acid. If the juice contains too much sugar, it will taste bland, but too much acid and the juice will taste sour. The concentration of acids in various consumer beverages may be determined by titration with sodium hydroxide.

Concepts

- Acids and bases
- Titration
- Indicators
- pH
- Equivalence point
- Neutralization

Background

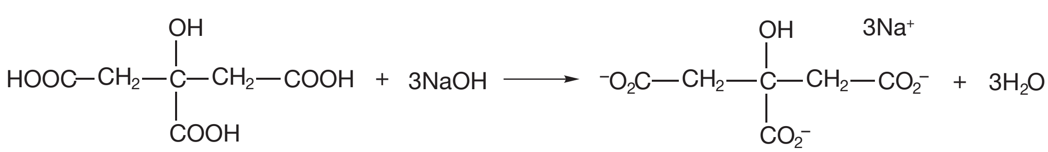
The main acids present in fruits and fruit juices are citric acid (in citrus fruits), tartaric acid (in grapes), and malic acid (in apples). All of these are characterized as weak acids.



Citric acid　　Tartaric acid　　Malic acid

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*—it 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 Equation 1.



Citric acid　　Citrate ion

Equation 1

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.

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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 a-top 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.

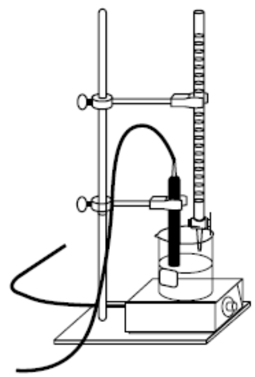


Figure 2.

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 following table, along with their colors and pH ranges.

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 1.2–2.8	Yellow to blue Red to yellow

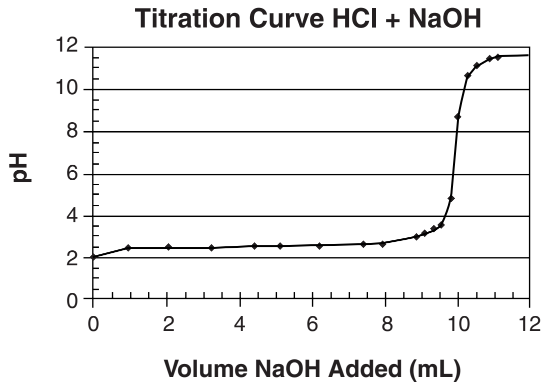
Experiment Overview

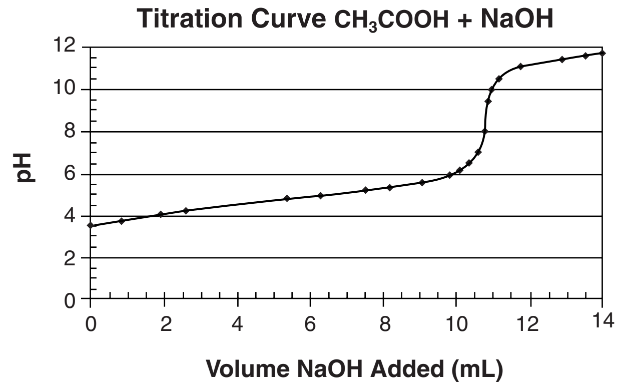
The purpose of this advanced inquiry lab is to conduct acid–base titrations and determine the concentration of acid in common beverages such as orange juice or pineapple juice. The beverages contain weak acids, which will be titrated with a strong base, sodium hydroxide. The lab begins with an introductory activity to determine the proper indicator to use in the titration of acetic acid, a characteristic weak acid. The results provide a model for guided-inquiry design of a titration procedure to obtain titration curve data and calculate the molar concentration of acid in a beverage. The titration curve will be analyzed and the amount of acid in a typical serving size or bottle may also be determined. The identity of the acid in the beverage may be derived by reviewing the titration curve and reference information, and by consulting the ingredients label.

Pre-Lab Questions *(Answer in a laboratory notebook or on a separate sheet of paper.)*

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. 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.





Materials (for each lab group)

Acetic acid, CH_3COOH, 0.10 M, 6 mL

Hydrochloric acid, HCl, 0.10 M, 6 mL (optional)

Sodium hydroxide, NaOH, 0.10 M

Samples, light-colored fruit juices or soda, 45-mL

Water, distilled or deionized

Beaker, 150-mL

Beral-type pipets, graduated

Buret, 50-mL

Graduated cylinders, 10-mL and 100-mL

Indicators, 1–2 mL each

- Bromthymol blue
- Phenolphthalein
- Thymol blue

Magnetic stirrer and stir bar or stirring rod

pH meters or pH paper (if meters are not available)

Support stand and buret clamp

Test tubes, medium, 3

Test tube rack

Safety Precautions

Dilute sodium hydroxide and acid solutions are irritating to skin and eyes. Avoid contact of all chemicals with eyes and skin. All food-grade items that have been brought into the lab are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the chemistry laboratory. Do not remove any remaining food items from the lab after they have been used in the lab. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab.

Introductory Activity

Indicators for Titration of a Weak Acid

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. *(Optional)* 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.

Guided-Inquiry Design and Procedure

Titration Curves and the Concentration of Acids in Fruit Juices

Form a working group with other students and discuss the following questions.

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-Lab 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. It is not necessary to use the pH meter for the additional trials. Record results.

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

AP Chemistry Review Questions

Integrating Content, Inquiry and Reasoning

1. Why is phenolphthalein an appropriate indicator for titration of a strong acid with a strong base? Explain based on the pH at the equivalence point and the transition range for phenolphthalein.

2. A 10.00-mL sample of HCl solution was transferred to an Erlenmeyer flask and diluted by adding about 40 mL of distilled water. Phenolphthalein indicator was added, and the solution was titrated with 0.215 M NaOH until the indicator just turned pink. The exact volume of NaOH required was 22.75 mL. Calculate the concentration of HCl in the original 10.00-mL sample.

3. One student accidentally "overshot" the endpoint and added 23.90 mL of 0.215 M NaOH. Is the calculated concentration of HCl likely to be too high or too low as a result of this error?

4. Acid–base indicators are large organic molecules that behave as weak acids. The distinguishing characteristic of indicators is that the acid (HIn) and conjugate base (In^-) forms are different colors.

$$\underset{(Color\ A)}{HIn(aq)} + H_2O(l) \rightarrow \underset{(Color\ B)}{In^-(aq)} + H_3O^+(aq)$$

The color of an indicator solution depends on pH and the relative amount of HIn and In^- at a given pH. Consider the following indicators and their acidic and basic colors, as well as the pH transition range for each.

Indicator	**HIn**	**In^-**	**pH Transition**
Alizarin*	Yellow	Red	5.5–6.8
	Red	Purple	11.0–12.4
Bromthymol blue	Yellow	Blue	6.0–7.6
Phenolphthalein	Colorless	Pink	8.2–10.0

**Alizarin has two ionizable hydrogen atoms and three color forms, H_2In, HIn^-, and In^{2-}.*

a. The intermediate or transition color of bromthymol blue is green. What are the relative proportions of HIn and In^- when bromthymol blue is green? Explain.

b. A colorless solution was tested with phenolphthalein, bromthymol blue and alizarin. The solution was colorless with phenolphthalein, yellow with bromthymol blue and orange with alizarin. What is the pH of the solution? Explain.