Microscale Titration of Vinegar

Introduction

Vinegar, aspirin, antacids—many common substances that we use every day are acids or bases. The composition or purity of these products can be determined by microscale titration.

Concepts

- Titration
- Neutralization
- Concentration

Background

Vinegar is a dilute aqueous solution of acetic acid produced by the fermentation of apple juice (cider vinegar), grapes (wine vinegar), or barley malt (malt vinegar). Federal regulations require that vinegar contain at least 4% acetic acid by mass. If the amount of acetic acid is less than 4%, the acidity level may not be high enough to prevent the growth of bacteria in pickled or canned foods.

The amount of acetic acid in vinegar can be determined by microscale titration with a standard solution of sodium hydroxide. Acetic acid, a weak acid, reacts with sodium hydroxide, a strong base, via the neutralization reaction shown in Equation 1.

$$CH_3COOH(aq) + NaOH(aq) \rightarrow NaCH_3COO(aq) + H_2O(l)$$

Equation 1

In a microscale titration, the exact number of drops of sodium hydroxide of known molarity needed to react completely with a measured number of drops of vinegar will be counted. When all of the acid has been neutralized, the number of moles of acid ($moles_a$) must be equal to the number of moles of base ($moles_b$), as shown in Equation 2.

$$moles_a = moles_b$$ *Equation 2*

Molarity is defined as moles of solute per liter of solution (a unit of volume). Rearranging the units in the definition of molarity provides an equation for the number of moles of solute (Equation 3).

$$moles = molarity \times volume = M \times V$$ *Equation 3*

Combining Equations 2 and 3 gives Equation 4, which can be used to calculate the molarity of acetic acid in vinegar (M_a) based on titration with a standard base solution (M_b).

$$M_a \times V_a = M_b \times V_b$$ *Equation 4*

Since volume appears on both sides of Equation 4, any units may be substituted in Equation 4, as long as they are identical for both the acid and base. Thus, volume may be measured in liters, milliliters, or even drops from a pipet. Equation 5 will be used to calculate the molar concentration of acetic acid (M_a) in vinegar in this experiment.

$$(M_a)(Drops_a) = (M_b)(Drops_b)$$ *Equation 5*

Materials *(for each student group)*

- Phenolphthalein solution, 0.05%, 1 mL
- Sodium hydroxide solution, NaOH, 0.50 M, 15 mL
- Vinegar, about 10 mL
- Water, distilled or deionized
- Beakers, 50-mL, 2
- Marker or labeling pen
- Pipets, Beral-type, microtip, 3
- Reaction plate, 24-well
- Wash bottle

Safety Precautions

Dilute sodium hydroxide solution is irritating to skin and eyes and can cause skin burns. Phenolphthalein is an alcohol-based solution and is flammable. It is moderately toxic by ingestion. Keep away from flames and other ignition sources. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please consult current Material Safety Data Sheets for additional safety, handling, and disposal information.

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Procedure

1. Obtain a 24-well reaction plate and place it on top of a piece of white paper.
2. Label two 50-mL beakers "V" and "B," respectively. Obtain about 10 mL of vinegar (V) and 20 mL of 0.50 *M* sodium hydroxide (base, B) in the corresponding beakers. Record the brand of vinegar used in a data table.
3. Label two microtip pipets "V" and "B" and place them in their respective beakers.
4. Using pipet V, add 15 drops of white vinegar into well A1. *Note:* For best results, hold the pipet in a nearly vertical position. This will help ensure equal-sized drops.
5. Using a clean pipet, add 1 drop of phenolphthalein indicator to the vinegar.
6. Using pipet B, slowly add the sodium hydroxide solution one drop at a time to the vinegar sample in well A1.
7. Count the exact number of drops of sodium hydroxide required to give the solution a faint red color that does not fade with mixing and that lasts at least 20 seconds. Record the number of drops of NaOH in a data table.
8. Repeat steps 4–7 four more times using separate wells on the reaction plate. Record the results for each trial in a data table.
9. Drain the microtip pipets and discard them in the trash.
10. Rinse the beakers and the reaction plate with water.

Questions

1. Use Equation 5 to calculate the molarity of the vinegar solution for each trial 1–5.
2. Calculate the average molarity of the vinegar solution. Use the range of values calculated for Trials 1–5 to estimate the error (e.g., 0.78 ±0.05 *M*).
3. The mass–volume percent acetic acid in vinegar is given by the following equation:

$$\%\text{ acetic acid} = \frac{\text{g (acetic acid)}}{\text{mL (vinegar)}} \times 100\% \qquad \textit{Equation 6}$$

   Carry out the following steps to calculate the percent acetic acid in vinegar.

   a. Calculate the molar mass of acetic acid.

   b. Use the molar mass of acetic acid and the molarity of the vinegar solution to calculate the number of grams of acetic acid in one liter of vinegar.

   c. Use Equation 6 to convert the number of grams of acetic acid in one liter of vinegar to percent. *Note:* Convert one liter to milliliters.

4. Explain why the procedure described in this activity could not be used to analyze red wine vinegar. How could the proce dure be modified to analyze this type of vinegar?

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The waste solutions may be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry

Content Standard B: Physical Science, chemical reactions

Tips

- Microscale titration is a convenient alternative to traditional titration experiments using burets and pipets. We recommend a classic titration to illustrate the use of volumetric glassware and to teach students the importance of good laboratory technique. Microscale titration provides a fast and effective way to apply the principles of titration to the analysis of consumer products such as aspirin, antacids or fruit juices.
- The advantages of microscale titration are that the amount of chemicals and the time needed for preparation are greatly reduced, disposal problems are minimized, and the procedure itself is fast and easy to perform. Students can repeat the titration several times, which improves both the accuracy and precision of the analysis.
- The most important variable that affects the reliability of microscale titration experiments is the reproducibility of the drop size. Reproducible drop volumes are easily achieved using microtip pipets (Flinn Catalog No. AP1517). The best way to deliver same-size drops is to hold the pipet vertically above the reaction well. With such small volumes being used, it is critical to expel any air bubbles in the pipet before counting drops.
- To determine the average volume of a drop of liquid, fill a 10-mL graduated cylinder to the 1.00-mL mark, then add water dropwise. Measure and record the volume of water in the graduated cylinder after 10, 20, 30, and 40 drops of water have been added. Average the volume of 10 drops of water and then divide by 10 to calculate the average volume of one drop.
- Percent composition of a solution is usually stated in mass percent, grams of solute divided by grams of solution, times 100. Mass percent is equal to mass–volume percent (Equation 6) if the density of the solution is exactly equal to one. This approximation is true (within two significant figures) for vinegar (density = 1.007 g/mL).
- The phenolphthalein solution used in this experiment is very dilute to ensure more accurate results and avoid staining of the reaction plates. The 0.05% solution may be conveniently prepared by 1:10 dilution of commercially available 0.5% phenolphthalein.
- Sodium hydroxide solution may be standardized by titration with potassium hydrogen phthalate (KHP).
- Two biochemical processes are involved in the production of vinegar. In the first stage, natural sugars in fruits and grains are converted to alcohol by the action of *Saccharomyces* yeast (step 1). This is an anaerobic process—it occurs in the absence of oxygen. The second stage involves further oxidation of alcohol to acetic acid by *Acetobacter* bacteria (step 2). This is an aerobic process and thus requires exposure to oxygen in air.

$$\underset{\text{sugar}}{C_6H_{12}O_6} \rightarrow \underset{\text{alcohol}}{2CH_3CH_2OH} + 2CO_2 \qquad \textit{Step 1}$$

$$\underset{\text{alcohol}}{CH_3CH_2OH} + O_2 \rightarrow \underset{\text{acetic acid}}{CH_3COOH} + H_2O \qquad \textit{Step 2}$$

Sample Data Table *(Student data will vary.)*

Brand of Vinegar	**White Cider Vinegar**
Titration Trial	**Number of Drops of NaOH Added**
1	*24 drops*
2	*27 drops*
3	*24 drops*
4	*26 drops*
5	*26 drops*

Answers to Questions *(Student answers will vary.)*

1. Use Equation 5 to calculate the molarity of the vinegar solution for each trial 1–5.

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

Trial 1: M_a = (0.50 M)(24 drops)/(15 drops) = 0.80 M
Trial 2: M_a = (0.50 M)(27 drops)/(15 drops) = 0.90 M
Trial 3: M_a = (0.50 M)(24 drops)/(15 drops) = 0.80 M
Trial 4: M_a = (0.50 M)(26 drops)/(15 drops) = 0.87 M
Trial 5: M_a = (0.50 M)(26 drops)/(15 drops) = 0.87 M

2. Calculate the average molarity of the vinegar solution. Use the range of values calculated for Trials 1–5 to estimate the error (e.g., 0.78 ±0.05 M).

$$\text{Average molarity} = \frac{(0.80\ M + 0.90\ M + 0.80\ M + 0.87\ M + 0.87\ M)}{5} = 0.85\ M$$

Molarity range (Trials 1–5) = 0.80–0.90 M
Estimated error = 0.85 ±0.05 M

Note to teacher: *Error is normally reported as the average deviation (sum of the differences between each individual result and the average, divided by the number of results).*

3. The mass–volume percent acetic acid in vinegar is given by the following equation:

$$\%\ \text{acetic acid} = \frac{\text{g (acetic acid)}}{\text{mL (vinegar)}} \times 100\% \qquad \textit{Equation 6}$$

Carry out the following steps to calculate the percent acetic acid in vinegar.

a. Calculate the molar mass of acetic acid.

Molar mass ($C_2H_4O_2$) = (2 × 12.01) + (4 × 1.008) + (2 × 16.00) = 60.05 g/mole

b. Use the molar mass of acetic acid and the molarity of the vinegar solution to calculate the number of grams of acetic acid in one liter of vinegar.

$$\text{Mass (acetic acid)} = \frac{0.85\ \text{moles}}{1\ \text{L vinegar}} \times \frac{60.05\ \text{g}}{1\ \text{mole}} = 51\ \text{g/L}$$

c. Use Equation 6 to convert the number of grams of acetic acid in one liter of vinegar to percent. *Note:* Convert one liter to milliliters.

$$\text{Percent acetic acid in vinegar} = \frac{51\ \text{g}}{\text{L}} \times \frac{1\ \text{L}}{1000\ \text{mL}} \times 100\% = 5.1\%$$

4. Explain why the procedure described in this activity could not be used to analyze red wine vinegar. How could the procedure be modified to analyze this type of vinegar?

The red color would mask the color of the phenolphthalein endpoint. The procedure could be modified to provide a different means of detecting the endpoint. This could be done by measuring the actual pH at the equivalence point or using a different indicator that would provide a more visible color change at a pH of about 9.

Materials for *Microscale Titration of Vinegar* are available from Flinn Scientific, Inc.

Catalog No.	Description
P0115	Phenolphthalein Indicator Solution, 100 mL
S0074	Sodium Hydroxide Pellets, 100 G
V0001	Vinegar, 1 L

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.