

A Student Titrated A 50.0 ML Of 0.15 M Glycolic Acid With 0.50 M NaOH. Answer The Following Questions.

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Titration is a fundamental technique in analytical chemistry used to determine the concentration of an unknown solution by reacting it with a standard solution of known concentration. In this scenario, a student is titrating a glycolic acid solution with sodium hydroxide (NaOH) to find out various properties such as the acid's concentration or the amount of titrant needed. This process involves several steps, calculations, and understanding of chemical principles, including molarity, molality, pH, and acid-base reactions.

This article explores the detailed process involved in this titration, including the calculations for determining the molarity of glycolic acid, the stoichiometry of the reaction, and related concepts for a comprehensive understanding.

Understanding the Titration Setup

Before diving into calculations, it's essential to understand the key components involved in this titration:

Glycolic Acid ($\text{HC}_2\text{H}_2\text{O}_3$)

- A weak organic acid with the formula $\text{C}_2\text{H}_4\text{O}_3$.
- It has a single acidic hydrogen atom, making it a monoprotic acid.
- The initial concentration is given as 0.15 M, and the volume is 50.0 mL.

Sodium Hydroxide (NaOH)

- A strong base with the formula NaOH.
- Concentration is 0.50 M, used as titrant.

Purpose of Titration

- To determine the molarity of glycolic acid.
- To find the amount of acid neutralized by a known amount of NaOH.

- To analyze the reaction's stoichiometry and pH changes during titration.

Calculating the Moles of Glycolic Acid

The first step in the titration process is to find out how many moles of glycolic acid are present in the initial solution.

Given Data

- Volume of glycolic acid solution, $V_{\text{acid}} = 50.0\text{ mL} = 0.0500\text{ L}$
- Concentration of glycolic acid, $M_{\text{acid}} = 0.15\text{ M}$

Calculation

The number of moles of glycolic acid can be calculated using the formula:

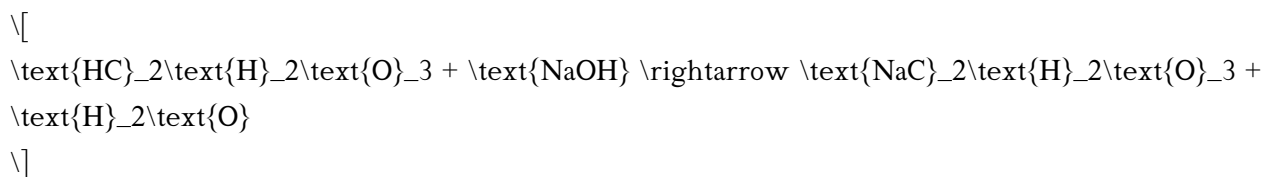
$$\text{moles of acid} = M_{\text{acid}} \times V_{\text{acid}}$$

$$\text{moles of glycolic acid} = 0.15\text{ mol/L} \times 0.0500\text{ L} = 0.0075\text{ mol}$$

This indicates that the initial amount of glycolic acid in the solution is 0.0075 moles.

Understanding the Acid-Base Reaction

The titration involves a neutralization reaction between glycolic acid and sodium hydroxide:



Since glycolic acid is monoprotic, it reacts with NaOH in a 1:1 molar ratio. This is crucial for stoichiometric calculations.

Reaction Stoichiometry

- 1 mole of glycolic acid reacts with 1 mole of NaOH.
- Therefore, the amount of NaOH needed to neutralize the acid depends directly on the initial moles of glycolic acid.

Calculating the Volume of NaOH Used

Suppose during the titration, the student records the volume of NaOH solution used to reach the equivalence point. Let's assume, for example, that the student used 15.0 mL of 0.50 M NaOH to neutralize all the glycolic acid.

Given Data for NaOH

- Concentration of NaOH, $M_{\text{base}} = 0.50 \text{ M}$
- Volume of NaOH used, $V_{\text{NaOH}} = 15.0 \text{ mL} = 0.0150 \text{ L}$

Calculating Moles of NaOH

$$\begin{aligned} \text{moles of NaOH} &= M_{\text{base}} \times V_{\text{NaOH}} = 0.50 \text{ mol/L} \times 0.0150 \text{ L} = \\ &0.0075 \text{ mol} \end{aligned}$$

Since the molar ratio is 1:1,

$$\begin{aligned} \text{moles of glycolic acid} &= \text{moles of NaOH} = 0.0075 \text{ mol} \end{aligned}$$

which matches the initial moles of glycolic acid calculated earlier, confirming the titration's accuracy.

Determining the Concentration of Glycolic Acid

Knowing the amount of NaOH needed to neutralize the acid allows us to find the concentration of glycolic acid.

Calculation

$$M_{\text{acid}} = \frac{\text{moles of acid}}{\text{volume of acid in liters}}$$

$$M_{\text{acid}} = \frac{0.0075 \text{ mol}}{0.0500 \text{ L}} = 0.15 \text{ M}$$

This confirms the initial concentration, illustrating the titration process's validity.

pH Calculations at Different Stages

Understanding pH changes during titration provides insights into the acid-base behavior.

Initial pH of Glycolic Acid Solution

Since glycolic acid is weak, its initial pH can be calculated using the acid dissociation constant (K_a). If K_a is known, the pH can be estimated.

Assuming K_a for glycolic acid is approximately (1.4×10^{-4}) :

$$\text{Initial concentration of } \text{HC}_2\text{H}_3\text{O}_3 = 0.15 \text{ M}$$

Using the approximation for weak acids:

$$\text{pH} = -\log\left(\sqrt{K_a \times C}\right)$$

$$\text{pH} = -\log\left(\sqrt{1.4 \times 10^{-4} \times 0.15}\right)$$

$$\text{pH} = -\log\left(\sqrt{2.1 \times 10^{-5}}\right) = -\log(4.58 \times 10^{-3}) \approx 2.34$$

At the Equivalence Point

- The solution contains the salt sodium glycolate, which is the conjugate base of a weak acid.
- The pH at this point generally exceeds 7 due to the hydrolysis of the conjugate base.

Beyond the Equivalence Point

- Excess NaOH increases the pH, which can be calculated using the molarity of remaining base.

Conclusion and Summary

This titration process demonstrates key concepts in acid-base chemistry, including stoichiometry, molarity calculations, and pH estimation. By knowing the initial concentration and volume of glycolic acid, and measuring the volume of NaOH needed to reach the equivalence point, students can accurately determine the molarity of glycolic acid in their solution.

Summary of Essential Steps:

- Convert given volumes and concentrations to moles.
- Use molar ratios to find the amount of titrant needed.
- Confirm the molarity of the unknown solution.
- Calculate pH at various stages for a comprehensive understanding.

This practical application of titration not only reinforces theoretical knowledge but also develops skills in experimental data analysis, precision, and critical thinking vital for a future chemist.

Further Applications:

- Determining the purity of acids.
- Analyzing buffer solutions.
- Studying weak acid and weak base equilibria.

By mastering these concepts, students gain a solid foundation for more complex chemical analysis and laboratory techniques essential in research, industry, and academia.

Frequently Asked Questions

What is the purpose of titrating glycolic acid with NaOH in this

experiment?

The purpose is to determine the concentration of the glycolic acid solution by neutralizing it with a known concentration of NaOH and calculating the acid's molarity based on the titration data.

How do you calculate the amount of NaOH needed to completely neutralize the glycolic acid?

Use the molarity and volume of the glycolic acid to find moles of acid, then apply the molar ratio from the balanced equation to find moles of NaOH required, and convert this to volume based on its molarity.

What is the balanced chemical equation for the titration of glycolic acid with NaOH?

The balanced equation is: $\text{C}_2\text{H}_4\text{O}_3$ (glycolic acid) + NaOH $\rightarrow$ $\text{C}_2\text{H}_3\text{O}_3\text{Na}$ + H_2O .

How do you determine the equivalence point in this titration experiment?

The equivalence point is typically identified using a pH indicator that changes color at the neutralization point or by using a pH meter to observe the sharp change in pH during titration.

Why is it important to know the initial concentration of glycolic acid in this titration?

Knowing the initial concentration allows for accurate calculation of unknown concentrations or purity of the acid, and helps in preparing standard solutions or formulations.

What role does the molarity of NaOH play in calculating the amount of glycolic acid in the sample?

The molarity of NaOH, combined with the volume used at the equivalence point, allows calculation of the moles of acid in the sample, enabling determination of its concentration.

What are common indicators used in acid-base titrations like this one, and how do they work?

Indicators such as phenolphthalein or methyl orange are commonly used; they change color at specific pH levels corresponding to the equivalence point, signaling when titration is complete.

How can you ensure accuracy and precision in this titration experiment?

By properly calibrating burettes, accurately measuring volumes, performing multiple titrations to get consistent results, and carefully observing the endpoint, you can improve accuracy and precision.

Additional Resources

Titration of Glycolic Acid with Sodium Hydroxide: An In-Depth Analysis

Titration is a fundamental analytical technique used in chemistry to determine the concentration of an unknown solution by reacting it with a solution of known concentration. In this detailed review, we explore the process of titrating a 50.0 mL sample of 0.15 M glycolic acid with 0.50 M sodium hydroxide (NaOH). This experiment not only exemplifies core principles of acid-base chemistry but also provides insights into practical laboratory techniques, calculations, and the significance of understanding titration curves. Let's delve into each aspect comprehensively.

Understanding the Components: Glycolic Acid and Sodium Hydroxide

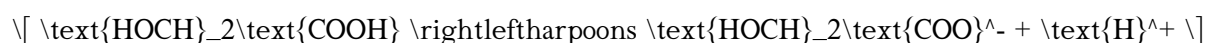
Glycolic Acid: Properties and Significance

Glycolic acid, chemically known as hydroxyacetic acid, is a small, naturally occurring alpha hydroxy acid (AHA) characterized by its simple structure: $\text{CH}_2(\text{OH})\text{COOH}$. Its unique features include:

- **Molecular Weight:** Approximately 76.05 g/mol.
- **Weak Acid Behavior:** Glycolic acid is a weak monoprotic acid, meaning it donates only one proton per molecule during dissociation.
- **Applications:** Widely used in skincare, chemical peeling, and as a precursor in organic synthesis due to its ability to penetrate skin and exfoliate effectively.

Reactivity in Titration:

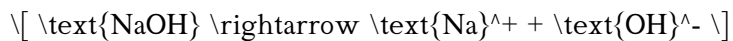
Because glycolic acid is weak, it doesn't fully dissociate in aqueous solution. Its dissociation equilibrium can be represented as:



Understanding this equilibrium is crucial for interpreting titration data.

Sodium Hydroxide: The Titrant

NaOH is a strong base and readily dissociates in water:



The high molarity (0.50 M) ensures that a relatively small volume is needed to neutralize the acid, facilitating precise titration.

The Titration Process: Step-by-Step

Preparation and Setup

Before initiating titration, ensure:

- The solutions are prepared accurately, with proper molarity.
- Equipment (burette, pipette, flask) is clean and calibrated.
- The glycolic acid solution (50.0 mL) is accurately measured using a pipette.
- The NaOH solution is filled in the burette, with initial volume recorded precisely.

Performing the Titration

1. Pipetting the Acid:

- Transfer 50.0 mL of 0.15 M glycolic acid into a clean conical flask.
- Add a few drops of a suitable indicator, such as phenolphthalein, which changes color at the endpoint of the titration.

2. Titrant Addition:

- Slowly add NaOH from the burette to the acid solution, swirling constantly.
- As the endpoint approaches (color change in indicator), add NaOH more carefully, dropwise.

3. Reaching the Endpoint:

- The endpoint is reached when the indicator displays a persistent color change (e.g., phenolphthalein turns from colorless to faint pink).
- Record the final volume of NaOH used.

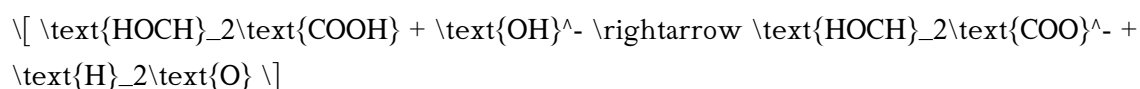
4. Repeat for Accuracy:

- Perform multiple titrations to ensure reproducibility.
- Calculate the average volume of NaOH used for consistent results.

Calculations: Determining the Acid Concentration and Titration Data

Fundamental Equation: Neutralization Reaction

Since glycolic acid is monoprotic:



The molar ratio of acid to base is 1:1.

Calculating Moles of NaOH Used

Suppose, for example, the average volume of NaOH used to reach the endpoint is V mL. The number of moles of NaOH is:

$$\text{moles NaOH} = \text{concentration} \times \text{volume in liters}$$

$$\text{moles NaOH} = 0.50 \, \text{mol/L} \times \frac{V \, \text{mL}}{1000}$$

Because of the 1:1 molar ratio, the moles of acid neutralized are equal to the moles of NaOH added.

Calculating the Concentration of Glycolic Acid

Given that the initial glycolic acid volume is 50.0 mL and its molarity is 0.15 M:

$$\left[\text{moles acid} = 0.15 \text{ mol/L} \times 0.050 \text{ L} = 0.0075 \text{ mol} \right]$$

The titration allows us to verify this value or determine the actual concentration if the initial concentration was unknown. The key calculation is:

$$\left[\text{Concentration of glycolic acid} = \frac{\text{moles acid}}{\text{volume of solution in liters}} \right]$$

Understanding the Titration Curve and Endpoint

The Titration Curve

Visualizing the titration involves plotting pH versus volume of NaOH added. For glycolic acid, the curve typically exhibits:

- A gradual increase in pH as NaOH is added.
- A sharp rise near the equivalence point, indicating rapid neutralization.
- A final plateau where excess NaOH causes pH to level off.

Significance of the Equivalence Point

The equivalence point is where the amount of acid equals the amount of base:

$$\left[\text{Moles acid} = \text{moles base} \right]$$

At this point, the solution is neutralized, and the pH reflects the nature of the resulting solution:

- For weak acid-strong base titrations, the pH at equivalence exceeds 7.
- The exact pH depends on the hydrolysis of the conjugate base.

Choosing the Indicator

Phenolphthalein is suitable because:

- It changes color around pH 8.2 to 10.0.

- The equivalence point for this titration (weak acid with strong base) occurs at a pH slightly above 7, making phenolphthalein an appropriate choice.

Implications and Practical Applications

Analytical Significance

Titrating glycolic acid with NaOH provides critical data:

- Concentration verification: Ensuring the prepared acid solution matches expected molarity.
- Purity assessment: Detecting impurities or degradation if titration results deviate.
- Standardization: Validating NaOH solution strength through titration with a primary standard.

Industrial and Commercial Relevance

Accurate titration techniques are vital in:

- Manufacturing skincare products containing glycolic acid, where precise concentration affects efficacy.
- Organic synthesis where exact reagent stoichiometry is essential.
- Quality control in chemical production.

Educational Importance

This titration exemplifies core principles:

- Acid-base reactions.
- Stoichiometric calculations.
- Indicator selection and titration endpoint detection.
- Data analysis and error minimization.

Advanced Considerations

Factors Affecting Titration Accuracy

To ensure reliable results, consider:

- Solution purity: Use deionized water and clean apparatus.
- Calibration: Regularly calibrate volumetric equipment.
- Temperature control: Conduct titrations at consistent temperatures, as pH and reaction rates are temperature-dependent.
- Indicator choice: Confirm that the indicator's transition pH aligns with the titration's equivalence point.

Potential Challenges and Solutions

- Indicator interference: Ensure the indicator does not react with the reagent.
- Over-titration: Add NaOH slowly near the endpoint to avoid overshooting.
- Incomplete reactions: Stir thoroughly and allow sufficient reaction time.

Conclusion: The Value of Precise Titration in Chemical Analysis

Titrating a 50.0 mL sample of 0.15 M glycolic acid with 0.50 M NaOH exemplifies a fundamental yet sophisticated laboratory technique. It underscores the importance of meticulous preparation, precise measurement, and keen observation. When executed properly, titration not only confirms the concentration of known solutions but also ensures quality and consistency in both academic and industrial settings.

This experiment illuminates the intricate balance of chemical reactions, the importance of understanding acid-base equilibria, and the practical skills necessary for analytical chemistry. As a cornerstone of quantitative analysis, titration remains an indispensable tool that bridges theoretical knowledge with real-world applications, reaffirming its status as a vital process in the chemist's toolkit.

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