What Volume (in Milliliters) Of 0. 130 M NaOH Should Be Added To A 0. 120 L Solution Of 0. 021 M Glycine

What Volume (in Milliliters) Of 0.130 M NaOH Should Be Added To A 0.120 L Solution Of 0.021 M Glycine is a common question in titration experiments and analytical chemistry, especially when preparing solutions or determining the amount of titrant needed to reach a specific pH or equivalence point. Understanding how to calculate this volume involves a thorough grasp of molarity, moles, and the acid-base chemistry of glycine, which is a zwitterionic amino acid capable of acting as both an acid and a base.

In this article, we will explore the step-by-step process to determine the volume of sodium hydroxide (NaOH) required to neutralize or titrate a given glycine solution. We will provide a detailed explanation of the relevant concepts, including the chemistry of glycine, the principles of titration, and the mathematical calculations involved.

Understanding the Chemistry of Glycine and NaOH

Glycine as an Amphoteric Compound

Glycine (NH_2CH_2COOH) is an amino acid that exhibits amphoteric behavior, meaning it can act as both an acid and a base. It has two relevant ionizable groups:
- The amino group ($-NH_2$), which can accept a proton.
- The carboxyl group (-COOH), which can donate a proton.

Depending on the pH of the solution, glycine exists predominantly in different forms:
- At low pH, it exists mainly as a cation ($NH_3^+CH_2COOH$).
- At neutral pH (~7), it exists as a zwitterion ($NH_3^+CH_2COO^-$).
- At high pH, it exists mainly as an anion ($NH_2CH_2COO^-$).

The relevant pKa values are:
- pKa_1 (carboxyl group): approximately 2.35
- pKa_2 (amino group): approximately 9.78

For titration purposes, when adding a strong base like NaOH, the primary reaction involves converting the zwitterionic form into the deprotonated form.

Calculating Moles of Glycine in Solution

Before determining the amount of NaOH needed, it is essential to calculate the number of moles of glycine present in the initial solution.

Given data:
- Volume of glycine solution, V_glycine = 0.120 L
- Concentration of glycine, C_glycine = 0.021 M

Step 1: Calculate moles of glycine:

$$
\text{Moles of glycine} = C_{glycine} \times V_{glycine}
$$

$$
= 0.021 \, \text{mol/L} \times 0.120 \, \text{L} = 0.00252 \, \text{mol}
$$

This is the total amount of glycine available for titration.

Understanding the Titration Process

What Happens During Titration?

When NaOH is added to the glycine solution, it primarily reacts with the protonated amino group, converting it into its neutral form:

$$
\text{NH}_3^+ + \text{OH}^- \rightarrow \text{NH}_2 + \text{H}_2\text{O}
$$

Depending on the pH and the amount of NaOH added, glycine can also undergo deprotonation of the carboxyl group, but typically, in the initial stages, the focus is on neutralizing the amino group.

Key Point: For the purpose of this calculation, we assume the titration involves converting the amino group from NH_3^+ to NH_2, which requires one mole of NaOH per mole of glycine.

Reaction Stoichiometry

The primary reaction in the titration of glycine with NaOH is:

$$
\text{NH}_3^+ \text{ group} + \text{OH}^- \rightarrow \text{NH}_2 \text{ group} + \text{H}_2\text{O}
$$

This indicates a 1:1 molar ratio between NaOH and glycine for the neutralization of the amino group.

Note: If the titration continues to higher pH levels, deprotonation of the carboxyl group might also be involved, but for simplicity, we focus on the initial neutralization step.

Calculating the Volume of NaOH Needed

Step 1: Determine Moles of NaOH Required

Since the molar ratio is 1:1, the moles of NaOH needed are equal to the moles of glycine:

$$
\text{Moles of NaOH} = \text{Moles of glycine} = 0.00252 \, \text{mol}
$$

Step 2: Use Molarity to Find Volume

Given NaOH molarity:
- $C_{NaOH} = 0.130$ M

The volume V_{NaOH} (in liters) needed is:

$$
V_{NaOH} = \frac{\text{Moles of NaOH}}{C_{NaOH}} = \frac{0.00252}{0.130} \approx 0.01938 \, \text{L}
$$

Step 3: Convert liters to milliliters:

$$
V_{NaOH} = 0.01938 \, \text{L} \times 1000 = 19.38 \, \text{mL}
$$

Therefore, approximately 19.38 mL of 0.130 M NaOH should be added to neutralize the glycine solution.

Additional Considerations and Practical Implications

Effect of pH and Endpoint Detection

In practical scenarios, titration is performed until a certain endpoint is reached, often indicated by a pH indicator or a pH meter. The calculated volume above assumes complete neutralization of the amino group. If the titration continues to deprotonate the carboxyl group, the volume of base needed will increase accordingly.

Buffering Capacity of Glycine

Glycine's buffering capacity is significant around its pKa values. When titrating, the pH change occurs most rapidly near these pKa points. Knowing the initial pH and desired final pH helps refine the volume calculation.

Adjustments for Experimental Conditions

Factors such as solution temperature, ionic strength, and measurement precision can influence the actual volume required. Always perform a preliminary titration to confirm calculations.

Summary of Key Steps

1. Calculate moles of glycine in the solution:
   - 0.120 L × 0.021 mol/L = 0.00252 mol

2. Determine moles of NaOH required (1:1 molar ratio):
   - 0.00252 mol

3. Calculate volume of NaOH solution needed:
   - Volume = Moles / Molarity = 0.00252 mol / 0.130 mol/L ≈ 0.01938 L
   - Converted to milliliters: ≈ 19.38 mL

In conclusion, to neutralize a 0.120 L solution of 0.021 M glycine with 0.130 M NaOH, approximately 19.38 milliliters of NaOH should be added. This calculation provides a theoretical starting point for laboratory procedures and helps in designing experiments involving amino acid titrations.

Final Thoughts

Understanding the relationship between molarity, moles, and volume is fundamental in analytical chemistry. Whether preparing solutions, conducting titrations, or analyzing biochemical reactions, precise calculations ensure accurate results. Always consider the specific chemistry of the compounds involved, the reaction stoichiometry, and practical factors to optimize your experimental procedures.

Frequently Asked Questions

How do you calculate the volume of 0.130 M NaOH needed to neutralize 0.120 L of 0.021 M glycine?

Use the neutralization formula: $M_1V_1 = M_2V_2$. Rearranged, $V_1 = (M_2 \times V_2) / M_1$. Substituting the values: $V_1 = (0.021 \text{ mol/L} \times 0.120 \text{ L}) / 0.130 \text{ mol/L} \approx 0.0194$ L or 19.4 mL.

Why is it important to know the molarity of NaOH and glycine when calculating the required volume?

Because the molarity determines the concentration of each solution, allowing you to accurately calculate the volume of NaOH needed to completely neutralize or react with the glycine based on their molar ratios.

What is the significance of the molar ratio in this titration scenario?

The molar ratio indicates the proportion in which the acid (glycine) and base (NaOH) react. For glycine, which is amphoteric, the ratio depends on the specific reaction, but in a basic titration, it generally involves a 1:1 molar ratio for neutralization.

How would the calculation change if the concentration of glycine was doubled to 0.042 M?

If glycine concentration doubles, the amount of glycine in moles doubles, requiring twice the amount of NaOH. The new volume of NaOH needed would be $V_1 = (0.042 \text{ mol/L} \times 0.120 \text{ L}) / 0.130 \text{ mol/L} \approx 0.0388$ L or 38.8 mL.

What assumptions are made when calculating the volume of NaOH needed in this titration?

Assumptions include that the reaction goes to completion, the solutions are ideal with no volume change upon mixing, and that the molarity values are accurate and precise.

Can this calculation be used if the glycine solution is at a different pH? Why or why not?

No, because the pH affects the ionization state of glycine and thus its reactivity with NaOH. The calculation assumes complete neutralization at a specific molarity, which is valid only if glycine’s form is known and consistent at the given pH.

Additional Resources

What Volume (in Milliliters) Of 0.130 M NaOH Should Be Added To A 0.120 L Solution Of 0.021 M Glycine

Understanding how much of a strong base like NaOH is required to neutralize or modify a glycine solution is fundamental in various biochemical and chemical laboratory procedures. When working with amino acids such as glycine, pH adjustments are often necessary—for example, in preparing buffers, performing titrations, or studying the amino acid's acid-base properties. This article provides a comprehensive analysis of calculating the volume of 0.130 M NaOH needed to react with a 0.120 L solution of 0.021 M glycine, exploring the underlying chemistry, detailed calculation steps, and practical considerations.

Understanding the Chemistry of Glycine and NaOH Titration

Glycine (NH_2CH_2COOH) is the simplest amino acid, featuring both amino ($-NH_2$) and carboxyl (-COOH) functional groups. These groups possess different acid-base properties:

- The carboxyl group ($pKa \approx 2.34$) can donate a proton, acting as an acid.
- The amino group ($pKa \approx 9.60$) can accept a proton, acting as a base.

When titrating glycine with NaOH, the primary reaction involves the deprotonation of the carboxyl group:

$NH_2CH_2COOH + OH^- \rightarrow NH_2CH_2COO^- + H_2O$

At this stage, the glycine molecule transitions from its neutral form to its zwitterionic form or further into its deprotonated form, depending on the amount of base added.

Key Points:

- The initial solution contains neutral glycine molecules.
- NaOH reacts primarily with the carboxyl group first, converting it to its carboxylate form.
- Excess NaOH may also deprotonate the amino group if enough base is added, but for typical titrations, the focus is on neutralizing the carboxyl group.

Calculating the Required Volume of NaOH

The calculation process involves understanding molar relationships, stoichiometry, and applying basic titration principles.

Step 1: Determine moles of glycine in the solution

Given data:

- Volume of glycine solution: $V_{glycine} = 0.120\, \text{L}$
- Concentration of glycine: $C_{glycine} = 0.021\, \text{M}$

Number of moles of glycine:

$$
n_{glycine} = C_{glycine} \times V_{glycine}
$$

$$
n_{glycine} = 0.021\, \text{mol/L} \times 0.120\, \text{L} = 0.00252\, \text{mol}
$$

Step 2: Determine the molar equivalence point

Since the primary reaction involves the deprotonation of the carboxyl group, which is a 1:1 molar ratio:

$$
\text{Glycine} + \text{OH}^- \rightarrow \text{Glycine}^{-} + \text{H}_2\text{O}
$$

To neutralize all glycine molecules' carboxyl groups, you need the same number of moles of NaOH:

$$
n_{NaOH} = n_{glycine} = 0.00252\, \text{mol}
$$

Step 3: Calculate the volume of NaOH solution needed

Given:

- NaOH molarity: $C_{NaOH} = 0.130\, \text{M}$

Number of moles needed:

$$
n_{NaOH} = C_{NaOH} \times V_{NaOH}
$$

Rearranged to find V_{NaOH}:

$$
V_{NaOH} = \frac{n_{NaOH}}{C_{NaOH}} = \frac{0.00252\, \text{mol}}{0.130\, \text{mol/L}} \approx 0.0194\, \text{L}
$$

Convert to milliliters:

$$
V_{NaOH} \approx 0.0194\, \text{L} \times 1000\, \text{mL/L} = 19.4\, \text{mL}
$$

Therefore, approximately 19.4 mL of 0.130 M NaOH should be added to fully neutralize the glycine's carboxyl groups in the given solution.

Additional Considerations in the Titration Process

While the above calculation provides a theoretical volume for neutralization of the carboxyl groups, real-world titrations and pH adjustments often involve more nuanced factors.

pKa Values and pH Changes

- The first equivalence point corresponds to deprotonation of the carboxyl group (~pH 4.7–5.0), considering the amino group remains protonated.
- The second equivalence point involves deprotonation of the amino group (~pH 9.6), which requires more NaOH and results in a higher pH.

Implication: If the goal is to reach a specific pH or to fully deprotonate both groups, the volume of NaOH needed must be adjusted accordingly.

Buffer Capacity and Titration Curves

- Glycine acts as a zwitterion at its isoelectric point (~pH 6.0), where both functional groups are partially charged.
- The titration curve features two buffering regions, making precise volume calculations dependent on the desired pH.

Practical Features and Limitations

Understanding the theoretical calculation is essential, but laboratory practices involve practical considerations:

Features:

- Precision in measurements: Use of calibrated pipettes and burettes ensures accurate volume measurements.
- Monitoring pH: Employing a pH meter allows for real-time pH adjustments during titration.
- Standardization of solutions: Ensuring NaOH solution is standardized avoids errors due to concentration inaccuracies.

Limitations:

- Assumption of 100% reaction efficiency: In practice, reaction may be incomplete, especially if impurities or CO_2 absorption occurs.
- Temperature effects: pKa values can vary with temperature, influencing titration endpoints.
- Over-titration risks: Excess NaOH can lead to an increase in pH beyond the desired point, affecting data accuracy.

Summary and Final Remarks

To conclude, the amount of 0.130 M NaOH required to neutralize a 0.120 L solution of 0.021 M glycine is approximately 19.4 milliliters. This calculation assumes complete reaction of the glycine's carboxyl groups without further deprotonation of the amino group. Adjustments may be necessary depending on the specific pH target, experimental conditions, and whether the goal is partial or complete deprotonation.

Key takeaways:

- The molar relationship between glycine and NaOH is 1:1 for the neutralization of the carboxyl group.
- The calculation hinges on accurate molarity and volume measurements.
- Real-world titrations require considerations of pH, buffer capacity, and operational precision.

Final thoughts:

Understanding the quantitative aspects of titration not only aids in achieving precise experimental outcomes but also enhances comprehension of amino acid chemistry and acid-base interactions. Whether preparing buffer solutions, conducting titrations, or studying amino acid properties, mastering these calculations is vital for both educational and research purposes.

Pros of this approach:

- Provides a clear, step-by-step methodology.
- Incorporates fundamental chemical principles.
- Offers practical insights for laboratory work.

Cons:

- Assumes ideal reaction conditions.
- Does not account for potential experimental errors or side reactions.
- Focuses mainly on the first deprotonation stage; further titration considerations are external to this calculation.

In summary, by understanding the molar relationships and applying basic titration calculations, one can accurately determine the volume of NaOH needed for glycine solutions, facilitating precise experimental control in biochemical and analytical chemistry contexts.

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