A 50.0 ML Solution Of 1.50 M NaOH Is Being Titrated With 2.00 M HCl. What Will Be The Total Volume Of

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Introduction

In the realm of analytical chemistry, titration is a fundamental technique used to determine the concentration of an unknown solution. When titrating strong acids with strong bases—such as hydrochloric acid (HCl) with sodium hydroxide (NaOH)—the reaction proceeds to completion, allowing precise calculations of unknown quantities.

This particular scenario involves titrating a 50.0 mL solution of 1.50 M NaOH with 2.00 M HCl. The question posed is: What will be the total volume of the solution at the equivalence point? Understanding this calculation is essential for chemists and students alike, as it forms the basis for many laboratory procedures and theoretical analyses.

Through this article, we'll explore the principles underlying titration, the stoichiometric relationships involved, and step-by-step calculations to arrive at the total volume of the titration mixture at the equivalence point. Additionally, we’ll discuss how this knowledge applies in practical laboratory settings and its importance in chemical analysis.

Understanding the Titration Process

What is Titration?

Titration is a technique that involves adding a solution of known concentration (the titrant) to a solution of unknown concentration (the analyte) until the reaction reaches its endpoint. The endpoint signifies the completion of the reaction, often detected visually via a color change in an indicator or through instrumentation.

Strong Acid–Strong Base Titrations

When titrating strong acids and strong bases—like HCl and NaOH—the reaction proceeds to form water and a neutral salt:

$$ \text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} $$

This reaction has a 1:1 molar ratio, simplifying calculations.

Initial Data and Basic Concepts

The problem provides the following data:

- Volume of NaOH solution (analyte): 50.0 mL
- Concentration of NaOH: 1.50 M
- Concentration of HCl (titrant): 2.00 M

Our goal is to determine the total volume of the solution at the equivalence point—that is, after adding enough HCl to completely neutralize the NaOH.

Step-by-Step Calculation of the Equivalence Point Volume

1. Calculate the moles of NaOH present initially

Using molarity and volume:

$$ \text{Moles of NaOH} = M_{NaOH} \times V_{NaOH} $$

Convert volume to liters:

$$ V_{NaOH} = 50.0 \text{ mL} = 0.0500 \text{ L} $$

Calculate:

$$ \text{Moles of NaOH} = 1.50 \text{ mol/L} \times 0.0500 \text{ L} = 0.0750 \text{ mol} $$

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2. Determine the volume of HCl required to reach equivalence

Since the reaction ratio is 1:1:

$$ \text{Moles of HCl needed} = \text{Moles of NaOH} = 0.0750 \text{ mol} $$

Using the concentration of HCl:

$$ V_{HCl} = \frac{\text{Moles of HCl}}{M_{HCl}} = \frac{0.0750 \text{ mol}}{2.00 \text{ mol/L}} $$

Calculate:

$$ V_{HCl} = 0.0375 \text{ L} = 37.5 \text{ mL} $$

This is the volume of HCl required to fully neutralize the NaOH.

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3. Calculate the total volume at the equivalence point

Total volume is the sum of the initial NaOH solution volume and the added HCl volume:

$$ V_{total} = V_{NaOH} + V_{HCl} $$

$$ V_{total} = 50.0 \text{ mL} + 37.5 \text{ mL} = 87.5 \text{ mL} $$

Therefore, the total volume of the solution at the equivalence point is 87.5 mL.

Additional Considerations

pH at the Equivalence Point

Since the titration involves a strong acid and a strong base, the pH at the equivalence point is neutral (~7). However, in practical settings, slight deviations may occur due to impurities or measurement errors.

Practical Applications

- Standardization: Titration is often used to determine unknown concentrations of acids or bases in commercial products, environmental samples, or biological fluids.
- Quality Control: Accurate calculation of titration volumes ensures consistency in manufacturing processes.
- Educational Purposes: Demonstrates fundamental principles of stoichiometry and acid-base reactions.

Summary of Key Points

- The initial moles of NaOH are calculated from its concentration and volume.
- The required volume of HCl to reach the equivalence point is determined using molarity and the mole ratio.
- The total volume at the equivalence point is the sum of the initial NaOH volume and the added HCl volume.
- This calculation assumes ideal behavior, complete reaction, and no volume change upon mixing (which is valid for dilute solutions).

Conclusion

In conclusion, titrating 50.0 mL of 1.50 M NaOH with 2.00 M HCl requires 37.5 mL of HCl to reach the equivalence point. The total volume of the solution at this point is 87.5 mL. Understanding this calculation not only enhances comprehension of titration procedures but also reinforces fundamental concepts in stoichiometry and solution chemistry.

Accurate determination of titration volumes is crucial for various applications, from academic experiments to industrial processes. Mastery of these calculations enables chemists to analyze solutions precisely, ensuring quality and consistency in chemical analyses and product development.

Keywords: titration, NaOH, HCl, molarity, equivalence point, solution volume, stoichiometry, strong acid-base reaction, chemical analysis, laboratory techniques

Frequently Asked Questions

What is the process involved in titrating 1.50 M NaOH with 2.00 M HCl?

The process involves slowly adding HCl to the NaOH solution until neutralization occurs, indicated by a pH endpoint, to determine the amount of NaOH present.

How do you calculate the volume of HCl needed to completely neutralize 50.0 mL of 1.50 M NaOH?

Using the molarity and volume: $M1V1 = M2V2$. Rearranged to find V2: $V2 = (M1 \times V1) / M2 = (1.50 \text{ mol/L} \times 50.0 \text{ mL}) / 2.00 \text{ mol/L} = 37.5 \text{ mL}$.

What is the total volume of the solution after titration if HCl is added until neutralization?

The total volume will be the initial NaOH volume plus the volume of HCl added: 50.0 mL + 37.5 mL = 87.5 mL.

What is the significance of knowing the total volume after titration?

It helps in calculating the concentration of the unknown solution, verifying titration accuracy, and understanding the reaction's stoichiometry.

Can the titration be performed with a different concentration of HCl, and how would that affect the total volume?

Yes, using a different HCl concentration would change the volume needed for neutralization; a more concentrated HCl would require less volume, affecting the total final volume accordingly.

What are common indicators used in titrating NaOH with HCl, and how do they work?

Indicators like phenolphthalein or methyl orange are used; phenolphthalein turns pink at pH 8.3-10 (endpoint for strong acid-strong base titration), signaling neutralization completion.

Additional Resources

A 50.0 mL solution of 1.50 M NaOH is being titrated with 2.00 M HCl. What will be the total volume of titrant needed to reach the equivalence point? This question encapsulates fundamental concepts of titration chemistry, specifically involving strong acid-strong base reactions. Understanding the precise volume of titrant required is essential in analytical chemistry for determining unknown concentrations, preparing standard solutions, and conducting various laboratory analyses. In this comprehensive review, we will delve into the principles behind titration, the calculation methods involved, and the factors influencing the titration process to provide a clear understanding of solving such problems.

Understanding the Basics of Titration

What is Titration?

Titration is an analytical technique used to determine the concentration of an unknown solution by reacting it with a solution of known concentration. The process involves gradually adding the titrant to the analyte until the reaction reaches its equivalence point—a stage where the exact amount of titrant has reacted completely with the analyte. The volume of titrant used at this point allows for the calculation of the unknown concentration or, in some cases, the amount of substance present.

Types of Titration

While titration can be performed with various chemical reactions, the most common types include:
- Acid-Base Titration: Involving acids and bases, such as NaOH and HCl.
- Redox Titration: Involving oxidation-reduction reactions.
- Complexometric Titration: Involving complex formation.
- Precipitation Titration: Involving formation of a precipitate.

The problem under discussion involves an acid-base titration, specifically a strong base (NaOH) with a strong acid (HCl), which simplifies the analysis due to their complete dissociation in aqueous solutions.

Analyzing the Given Data

Initial Parameters

- Volume of NaOH solution, V_{NaOH} = 50.0 mL = 0.050 L
- Concentration of NaOH, C_{NaOH} = 1.50 M
- Concentration of HCl, C_{HCl} = 2.00 M

The goal is to find the total volume of HCl required to reach the equivalence point.

Calculating Moles of NaOH

The first step is to determine the number of moles of NaOH present in the initial solution. This is achieved via the formula:

$$ \text{moles of NaOH} = C_{NaOH} \times V_{NaOH} $$

$$ = 1.50\, \text{mol/L} \times 0.050\, \text{L} = 0.075\, \text{mol} $$

This quantity of NaOH will react completely with an equivalent amount of HCl at the equivalence point, thanks to the 1:1 molar ratio in the acid-base reaction.

Understanding the Reaction and Its Stoichiometry

Reaction Equation

The neutralization reaction between NaOH and HCl can be written as:

$$ \text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} $$

Since it's a 1:1 molar ratio, the moles of HCl needed to neutralize the NaOH are equal to the moles of NaOH present.

Calculating the Volume of HCl Needed

Using the molar relationship:

$$ \text{moles of HCl} = \text{moles of NaOH} = 0.075\, \text{mol} $$

Now, applying the concentration of HCl:

$$ V_{HCl} = \frac{\text{moles of HCl}}{C_{HCl}} = \frac{0.075\, \text{mol}}{2.00\, \text{mol/L}} = 0.0375\, \text{L} $$

Converting to milliliters:

$$ V_{HCl} = 0.0375\, \text{L} \times 1000\, \text{mL/L} = 37.5\, \text{mL} $$

Therefore, 37.5 mL of HCl is required to reach the equivalence point for the titration.

Interpreting the Results and Practical Considerations

Total Volume of Titrant Needed

The total volume of HCl necessary to fully neutralize the NaOH solution is 37.5 mL. This value is crucial for analytical purposes, such as calculating the unknown concentration in titrations or preparing solutions.

Features and Advantages of Precise Titration Calculations

- Accuracy: Ensures precise determination of unknown concentrations.
- Efficiency: Helps in minimizing reagent waste by knowing the exact volume required.
- Standardization: Assists in preparing standard solutions for various experiments.

Limitations and Potential Errors

- Indicator Choice: Selecting an appropriate indicator is vital; for strong acid-strong base titrations, phenolphthalein is commonly used.
- Measurement Precision: Volumetric measurements can introduce errors; using calibrated burettes is recommended.
- Reaction Completeness: Any side reactions or incomplete reactions can affect the results.
- Temperature Effects: Variations in temperature can influence reaction dynamics and volume measurements.

Features and Pros/Cons of Using Molarity in Titration Calculations

Features:
- Molarity provides a straightforward way to relate moles of solute to volume.
- Enables easy calculation of unknown quantities through stoichiometry.
- Widely used in laboratory settings due to its simplicity.

Pros:
- Simplifies complex reactions into manageable calculations.
- Facilitates standardization across experiments.

- Useful for both qualitative and quantitative analyses.

Cons:
- Sensitive to measurement errors in volume and concentration.
- Assumes complete dissociation and reaction, which may not hold for weak acids/bases.
- Does not account for activity coefficients at high concentrations or non-ideal solutions.

Additional Factors Influencing Titration Outcomes

Temperature

Temperature variations can cause volume expansion or contraction, impacting titration accuracy. Maintaining a constant temperature during titration is crucial.

Indicator Selection

Choosing the appropriate indicator ensures a clear and sharp endpoint. For strong acid-strong base titrations, phenolphthalein is suitable because it changes color around pH 8.2–10.

Solution Purity and Preparation

Impurities or incorrect preparation of solutions can lead to inaccurate molarity values and erroneous results.

Equipment Calibration

Regular calibration of burettes and pipettes ensures measurement precision, reducing systematic errors.

Conclusion

In summary, determining the total volume of titrant required in this titration involves understanding the fundamental principles of stoichiometry,

molarity, and reaction mechanisms. With the given data:
- Moles of NaOH: 0.075 mol
- Moles of HCl needed: 0.075 mol (due to 1:1 reaction)
- Volume of 2.00 M HCl required: 37.5 mL

This calculation exemplifies the practical application of molarity and stoichiometry in analytical chemistry. Accurate titration relies on precise measurements, proper indicator selection, and awareness of factors that might influence the reaction. Mastery of these concepts enables chemists to perform reliable analyses, develop standard solutions, and interpret experimental data effectively.

In essence, understanding the detailed process behind titration calculations provides a solid foundation for mastering analytical techniques and enhances experimental accuracy in various chemical investigations.

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