A Solution Of 0.312 M KOH Is Used To Titrate 15.0 Ml Of A 0.186 M H3PO4 Solution. What Volume, In Millilitres,

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Understanding titration calculations is fundamental in chemistry, especially when determining unknown concentrations or volumes of solutions in various chemical processes. In this article, we will explore a practical example involving the titration of phosphoric acid (H_3PO_4) with potassium hydroxide (KOH). Specifically, we will analyze how to calculate the volume of 0.312 M KOH required to completely titrate 15.0 mL of 0.186 M H_3PO_4 solution.

Introduction to Titration and Its Significance

Titration is a laboratory technique used to determine the concentration of an unknown solution by reacting it with a solution of known concentration. It is a precise method that involves slowly adding a titrant to a analyte until the reaction reaches its equivalence point, where the amount of titrant added is stoichiometrically equivalent to the analyte.

Key concepts in titration include:

- Molarity (M): A measure of concentration expressed as moles of solute per liter of solution.
- Equivalence point: The point at which the reactants have reacted in stoichiometrically equivalent amounts.
- Indicator: A chemical that signals the endpoint of the titration, usually by changing color.

Understanding the Given Data

Let's review the data provided for this titration problem:

- Concentration of KOH (titrant): 0.312 M
- Volume of KOH used (unknown): To be determined
- Concentration of H_3PO_4 (analyte): 0.186 M
- Volume of H_3PO_4 solution: 15.0 mL

The goal is to determine the volume of KOH solution (in mL) needed to completely titrate the given amount of phosphoric acid.

Understanding the Chemistry of Phosphoric Acid and Potassium Hydroxide

Before performing calculations, it's essential to understand the chemical reaction involved:

Reaction Equation

Phosphoric acid (H_3PO_4) is a triprotic acid, meaning it can donate three protons (H^+) per molecule. The reaction with potassium hydroxide (KOH), a strong base, can be represented as:

$H_3PO_4 + 3KOH \rightarrow K_3PO_4 + 3H_2O$

Key points:

- Each molecule of H_3PO_4 reacts with 3 molecules of KOH.
- The reaction proceeds in a 1:3 molar ratio (H_3PO_4:KOH).

Calculating Moles of Phosphoric Acid

The first step is to determine the number of moles of H_3PO_4 present in the 15.0 mL solution.

Formula:

$$
\text{Moles of } H_3PO_4 = \text{Concentration} \times \text{Volume (in liters)}
$$

Convert volume from mL to liters:

$$
15.0\, \text{mL} = 0.0150\, \text{L}
$$

Calculate:

$$
\text{Moles of } H_3PO_4 = 0.186\, \text{mol/L} \times 0.0150\, \text{L} = 0.00279\, \text{mol}
$$

Determining Moles of KOH Needed

Based on the balanced chemical equation, 1 mol of H_3PO_4 reacts with 3 mol of

KOH:

$$
\text{Moles of KOH} = 3 \times \text{Moles of } H_3PO_4
$$

Therefore:

$$
\text{Moles of KOH} = 3 \times 0.00279\, \text{mol} = 0.00837\, \text{mol}
$$

This is the total amount of KOH required to neutralize the phosphoric acid.

Calculating the Volume of KOH Solution Required

Knowing the moles of KOH needed, and its molarity, we can find the volume required:

$$
\text{Volume of KOH} = \frac{\text{Moles of KOH}}{\text{Concentration of KOH}}
$$

Substitute the known values:

$$
\text{Volume of KOH} = \frac{0.00837\, \text{mol}}{0.312\, \text{mol/L}} \approx 0.02683\, \text{L}
$$

Convert liters to milliliters:

$$
0.02683\, \text{L} \times 1000 = 26.83\, \text{mL}
$$

Result:

Approximately 26.83 mL of 0.312 M KOH solution are required to titrate 15.0 mL of 0.186 M H_3PO_4.

Final Answer

The volume of 0.312 M KOH needed to titrate 15.0 mL of 0.186 M H_3PO_4 is approximately 26.83 mL.

Additional Insights and Considerations

1. Significance of Stoichiometry in Titration

Understanding the molar ratios in chemical reactions is crucial for accurate titration calculations. In this case, the triprotic nature of phosphoric acid means each molecule reacts with three hydroxide ions, emphasizing the importance of balanced equations.

2. Importance of Precise Measurements

To achieve accurate titration results, precise measurements of volumes and concentrations are necessary. Errors in measurement can lead to significant deviations in calculated volumes.

3. Titration Endpoints and Indicators

In practical lab scenarios, indicators such as methyl orange or phenolphthalein are used to signal the endpoint, which must be accurately identified to avoid over- or under-titration.

4. Applications of Titration Calculations

Titration calculations are vital in various industries, including pharmaceuticals, environmental testing, food chemistry, and manufacturing, where precise concentration determination is essential.

5. Variations and Complexities

While this example involves a straightforward triprotic acid and strong base reaction, real-world titrations can involve weak acids/bases, polyprotic acids, or complex ions, necessitating more advanced calculations and considerations.

Summary of Key Steps for Titration Calculations

To summarize, the essential steps in titration calculations are:

1. Determine the moles of the analyte (H_3PO_4) using its concentration and volume.
2. Use the balanced chemical equation to find the molar ratio and calculate the required moles of titrant (KOH).
3. Calculate the volume of titrant needed using its concentration.

Applying this systematic approach ensures accurate and reliable results in titration experiments.

Conclusion

Titration remains a fundamental technique in analytical chemistry, allowing precise determination of solution concentrations and volumes. By understanding the chemical reactions involved, molar relationships, and proper calculation methods, chemists can accurately determine the volume of titrant needed for complete neutralization. In this specific example, approximately 26.83 mL of 0.312 M KOH is required to titrate 15.0 mL of 0.186 M H_3PO_4, exemplifying the practical application of stoichiometry in laboratory settings.

Remember: Always double-check calculations, ensure proper solution preparation, and carefully identify titration endpoints to achieve the most accurate and reproducible results in your experiments.

Frequently Asked Questions

What is the balanced chemical equation for the reaction between KOH and H3PO4?

The balanced equation is 3KOH + H3PO4 → K3PO4 + 3H2O.

How do you calculate the moles of H3PO4 in 15.0 mL of 0.186 M solution?

Moles of H3PO4 = concentration × volume in liters = 0.186 mol/L × 0.015 L = 0.00279 mol.

What is the molar ratio between KOH and H3PO4 in the titration?

The molar ratio is 3:1, meaning 3 moles of KOH react with 1 mole of H3PO4.

How do you determine the volume of KOH solution required to completely titrate the H3PO4?

Use the molar ratio to find moles of KOH needed (0.00279 mol H3PO4 × 3 = 0.00837 mol KOH), then divide by KOH concentration: 0.00837 mol / 0.312 mol/L ≈ 0.02683 L or 26.83 mL.

What is the final volume of KOH needed in millilitres to titrate the given H3PO4 solution?

Approximately 26.83 mL of 0.312 M KOH solution is required.

Why is it important to know the molarity of both

solutions in titration calculations?

Knowing the molarity allows accurate calculation of the volume needed to react completely, ensuring precise titration results.

Additional Resources

Titration of Phosphoric Acid with Potassium Hydroxide: A Detailed Analysis

Titrations are fundamental in analytical chemistry, enabling precise determination of unknown concentrations of solutions through the controlled addition of a titrant of known concentration. In this comprehensive review, we explore a specific titration scenario involving phosphoric acid (H_3PO_4) and potassium hydroxide (KOH), providing insights into the calculations, chemical principles, and practical considerations involved. The problem at hand states that a 0.312 M KOH solution is used to titrate 15.0 mL of a 0.186 M H_3PO_4 solution, and the goal is to determine the volume of KOH required to complete the titration.

Understanding the Chemical Context

The Nature of Phosphoric Acid (H_3PO_4)

Phosphoric acid is a triprotic acid, meaning it can release three protons (H^+) per molecule during dissociation:

$$ \mathrm{H_3PO_4} \rightleftharpoons \mathrm{H^+} + \mathrm{H_2PO_4^-} $$

$$ \mathrm{H_2PO_4^-} \rightleftharpoons \mathrm{H^+} + \mathrm{HPO_4^{2-}} $$

$$ \mathrm{HPO_4^{2-}} \rightleftharpoons \mathrm{H^+} + \mathrm{PO_4^{3-}} $$

This multistep dissociation affects the titration process because different equivalence points correspond to the neutralization of each acidic proton.

The Titrant: Potassium Hydroxide (KOH)

Potassium hydroxide is a strong base that dissociates completely in aqueous solution:

$$ \mathrm{KOH} \rightarrow \mathrm{K^+} + \mathrm{OH^-} $$

Given its known concentration (0.312 M), it serves as an ideal titrant for acid-base titrations, offering high accuracy and straightforward calculations.

Fundamental Principles and Key Equations

Stoichiometry of the Titration

The core concept involves the molar relationship between the acid and the base, governed by their balanced chemical equation. For phosphoric acid, which is triprotic, the overall neutralization can be represented as:

$$ \mathrm{H_3PO_4} + 3\, \mathrm{KOH} \rightarrow \mathrm{K_3PO_4} + 3\, \mathrm{H_2O} $$

This indicates that each mole of H_3PO_4 reacts with three moles of KOH.

Calculating Moles of H_3PO_4

Given:
- Volume of H_3PO_4 solution, $V_{H_3PO_4} = 15.0\, \mathrm{mL} = 0.015\, \mathrm{L}$
- Concentration of H_3PO_4, $C_{H_3PO_4} = 0.186\, \mathrm{M}$

Number of moles:
$$ n_{H_3PO_4} = C_{H_3PO_4} \times V_{H_3PO_4} = 0.186\, \mathrm{mol/L} \times 0.015\, \mathrm{L} = 2.79 \times 10^{-3}\, \mathrm{mol} $$

Determining Moles of KOH Needed

Since 1 mole of H_3PO_4 requires 3 moles of KOH:
$$ n_{KOH} = 3 \times n_{H_3PO_4} = 3 \times 2.79 \times 10^{-3} = 8.37 \times 10^{-3}\, \mathrm{mol} $$

Calculating the Volume of KOH Required

Using the Concentration of KOH

Given:
- Concentration of KOH, $C_{KOH} = 0.312\, \mathrm{M}$

The volume of KOH solution needed:
$$ V_{KOH} = \frac{n_{KOH}}{C_{KOH}} = \frac{8.37 \times 10^{-3}\, \mathrm{mol}}{0.312\, \mathrm{mol/L}} $$

Calculating:
$$ V_{KOH} = 0.02686\, \mathrm{L} = 26.86\, \mathrm{mL} $$

Rounding to a practical precision, approximately 26.9 mL of KOH solution is required to fully titrate 15.0 mL of the phosphoric acid solution.

Practical Considerations and Experimental

Aspects

Choice of Indicators

For triprotic acids like phosphoric acid, the titration process can involve multiple equivalence points. Common indicators include:
- Methyl orange: suitable for the first and second equivalence points.
- Phenolphthalein: suitable for the third equivalence point, when the solution turns faintly basic.

In an ideal educational setting, a pH meter could provide a more precise endpoint detection, especially due to multiple equivalence points.

Significance of Accurate Measurements

- Ensuring the proper calibration of volumetric glassware (burettes, pipettes).
- Precise measurement of solution volumes.
- Consistent stirring during titration to avoid concentration gradients.
- Multiple titration trials to confirm reproducibility and accuracy.

Potential Sources of Error

- Parallax errors during reading burette measurements.
- Imprecise endpoint detection, especially with color indicators.
- Impurities in reagents affecting titration accuracy.
- Incomplete dissociation or secondary reactions.

Broader Implications and Applications

Analytical Chemistry Significance

The process exemplifies a classic acid-base titration, fundamental in:
- Determining unknown concentrations in unknown samples.
- Quality control in manufacturing processes involving phosphates and bases.
- Environmental analysis, such as measuring phosphate levels in water samples.

Educational Value

This scenario provides opportunities to:
- Reinforce understanding of molarity and stoichiometry.
- Explore the behavior of polyprotic acids.
- Understand the importance of equivalence point detection.

Extensions to Related Fields

- Phosphoric acid titrations are relevant in agriculture (fertilizer analysis), biochemistry, and industrial manufacturing.
- The methodology can be adapted for other triprotic acids or polyprotic systems.

Summary and Final Calculations Recap

- Moles of H_3PO_4 in solution: 2.79×10^{-3} mol
- Moles of KOH needed (triprotic neutralization): 8.37×10^{-3} mol
- Volume of 0.312 M KOH required: 26.9 mL

This comprehensive analysis underscores the importance of understanding the chemical principles, stoichiometry, and practical aspects of titration procedures to accurately determine solution concentrations.

Conclusion

The titration of phosphoric acid with potassium hydroxide exemplifies core principles of analytical chemistry, combining theoretical stoichiometry with practical laboratory considerations. By carefully calculating the molar relationships and considering real-world factors, chemists can achieve precise and reliable measurements. The volume of approximately 26.9 mL of 0.312 M KOH is needed to completely neutralize 15.0 mL of 0.186 M H_3PO_4, illustrating the power of titration as an analytical tool. This detailed understanding not only aids in academic settings but also extends to industrial and environmental applications, reinforcing the significance of accurate chemical analysis in various scientific domains.

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