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Understanding how to prepare and analyze solutions of weak acids like acetic acid is fundamental in chemistry, especially in fields such as analytical chemistry, biochemistry, and environmental science. In this article, we will explore the detailed process of preparing a specific acetic acid solution, discuss the principles behind its behavior in water, and delve into the calculations necessary to understand its properties, including pH, pKa, and related equilibria.

Introduction to Acetic Acid and Its Importance

Acetic acid (HOAc), also known as ethanoic acid, is a common weak acid with the chemical formula CH_3COOH . It is well known as the main component of vinegar, giving it its characteristic sour taste and pungent smell. Beyond culinary uses, acetic acid plays a vital role in industrial processes, chemical syntheses, and biological systems.

Understanding the properties of acetic acid, particularly its dissociation in water, is crucial for various applications:

- Buffer solutions: Acetic acid and acetate form an effective buffer system.
- Titration and analytical chemistry: It is used in titrations to determine concentration and purity.
- Environmental chemistry: Its behavior influences soil and water chemistry.

Preparation of the Acetic Acid Solution

Step 1: Calculating the Mass of Acetic Acid Needed

Given:

- Moles of acetic acid (HOAc): 0.020 mol
- Molar mass of acetic acid: approximately 60.05 g/mol

Calculation:

$$\begin{aligned} \text{Mass of HOAc} &= \text{moles} \times \text{molar mass} = 0.020 \text{ mol} \times 60.05 \text{ g/mol} \\ &= 1.201 \text{ g} \end{aligned}$$

Thus, to prepare the solution, approximately 1.201 grams of acetic acid should be measured.

Step 2: Dissolving in Water

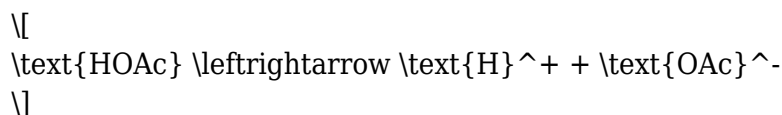
The process involves:

1. Measuring the Water: Determine the desired total volume of the solution. For simplicity, assume 1 liter (L) of solution, which is common in laboratory preparations.
2. Adding Acetic Acid: Carefully transfer the 1.201 grams of acetic acid into a volumetric flask.
3. Dilution: Add distilled water to reach exactly 1 liter, ensuring thorough mixing.

Understanding the Properties of the Prepared Solution

pKa and Acid Dissociation Equilibrium

Acetic acid has a pKa value of approximately 4.8, indicating that at pH 4.8, half of the acetic acid molecules are dissociated into acetate ions (CH_3COO^-) and hydrogen ions (H^+):



This equilibrium is pivotal for buffer capacity and pH calculations.

Calculating the Initial Concentration

Given the total moles of acetic acid (0.020 mol) and total volume (1 L):

$$\text{Initial concentration} = \frac{0.020 \text{ mol}}{1 \text{ L}} = 0.020 \text{ M}$$

This low concentration classifies the solution as a dilute weak acid solution.

Analyzing the pH of the Acetic Acid Solution

Step 1: Applying the Acid Dissociation Constant (Ka)

The acid dissociation constant (Ka) relates to pKa as:

$$\text{pKa} = -\log_{10} \text{Ka}$$

Given pKa = 4.8,

$$\text{Ka} = 10^{-4.8} \approx 1.58 \times 10^{-5}$$

Step 2: Setting Up the Equilibrium Expression

Assuming initial concentration of acetic acid is 0.020 M, and let x be the concentration of dissociated H⁺ ions at equilibrium:

$$\text{Ka} = \frac{[\text{H}^+][\text{OAc}^-]}{[\text{HOAc}]} \approx \frac{x^2}{0.020 - x}$$

Since acetic acid is weak and dilute, x is small compared to 0.020, so:

$$\text{Ka} \approx \frac{x^2}{0.020}$$

Rearranged:

$$x^2 = \text{Ka} \times 0.020 = 1.58 \times 10^{-5} \times 0.020 = 3.16 \times 10^{-7}$$

$$x = \sqrt{3.16 \times 10^{-7}} \approx 5.62 \times 10^{-4} \text{ M}$$

This x value is the concentration of H⁺ ions, and the pH is:

$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (5.62 \times 10^{-4}) \approx 3.25$$

Result: The pH of the 0.020 M acetic acid solution is approximately 3.25.

Buffer Capacity and the Role of Acetic Acid

Acetic acid's weak nature means it doesn't fully dissociate, but it still influences the solution's pH significantly. When mixed with its conjugate base (acetate), it forms a buffer system capable of resisting pH changes upon addition of small amounts of acid or base.

Buffer System Components

- Weak acid: Acetic acid (HOAc)
- Conjugate base: Acetate ion (OAc^-)

The prepared solution's pH can be fine-tuned or predicted using the Henderson-Hasselbalch equation:

$$\text{pH} = \text{pKa} + \log_{10} \left(\frac{[\text{A}^-]}{[\text{HA}]}\right)$$

In the initial pure acetic acid solution, the ratio of acetate to acetic acid is minimal, leading to a lower pH.

Practical Applications of the Prepared Acetic Acid Solution

This specific 0.020 M acetic acid solution has various practical uses:

- Calibration of pH meters: As a standard weak acid solution.
- Buffer preparation: For experiments requiring pH around 4.8.
- Titration experiments: To determine the concentration of unknown bases.
- Educational demonstrations: Illustrating weak acid dissociation and buffer systems.

Safety Precautions and Handling

While acetic acid is relatively safe in dilute solutions, precautions are necessary:

- Wear protective gloves and goggles.
- Handle with care to avoid spills.
- Use fume hoods if working with concentrated acetic acid.

Conclusion

Preparing a solution of acetic acid by dissolving 0.020 moles in water to give 1 liter involves careful calculation and understanding of its chemical properties. The resulting solution exhibits a pH around 3.25, influenced by its pKa of 4.8 and its weak acid dissociation. Such solutions are vital in laboratories for buffer preparation, titrations, and educational purposes, exemplifying fundamental principles of acid-base chemistry.

Understanding these concepts enables chemists and students to manipulate solution conditions precisely, facilitating a broad range of scientific experiments and applications. Proper preparation, analysis, and application of weak acid solutions like acetic acid form the backbone of many chemical processes and research endeavors.

Keywords: acetic acid solution, HOAc, pKa, weak acid, buffer system, pH calculation, solution preparation, titration, chemistry experiments, dilute acids, laboratory techniques

Frequently Asked Questions

What is the significance of dissolving 0.020 moles of acetic acid in water for preparing a solution?

Dissolving 0.020 moles of acetic acid in water creates a specific molarity of the solution, allowing for precise pH and acidity control, which is essential in various chemical and biological applications.

How does the pKa value of acetic acid (4.8) relate to the pH of the prepared solution?

Since the pKa of acetic acid is 4.8, the pH of the solution will be close to this value when dissolved in water, especially if the solution is dilute, indicating a weak acid equilibrium between dissociation and undissociated molecules.

What is the expected pH of a solution prepared by dissolving 0.020 moles of acetic acid in 1 liter of water?

The pH can be estimated using the acid dissociation constant (K_a) and the initial concentration. For 0.020 M acetic acid, the pH is approximately 2.9 to 3.0, reflecting its weak acidic nature.

Why is acetic acid classified as a weak acid, and how does this affect its dissociation in water?

Acetic acid is classified as a weak acid because it does not fully dissociate in water; only a small fraction of acetic acid molecules release protons, establishing an equilibrium that results in a higher pH compared to strong acids.

How can the concentration of acetic acid in the solution be calculated from the given data?

Since 0.020 moles of acetic acid are dissolved in 1 liter of water, the concentration (molarity) of the solution is 0.020 M, calculated by dividing the moles by the volume in liters.

Additional Resources

Acetic Acid Solution Preparation: A Detailed Expert Review

In the realm of chemistry, the preparation of solutions with precise concentrations is fundamental to both academic experiments and industrial processes. Among the myriad of compounds used for various purposes, acetic acid (HOAc) stands out due to its wide applications ranging from food preservation to chemical synthesis. This article offers an in-depth exploration of the process of preparing a specific acetic acid solution—dissolving 0.020 moles of acetic acid in water to produce a solution with a concentration of 1 molar (1 M). We will analyze the underlying principles, calculations, and considerations involved, providing a comprehensive understanding suitable for both students and professionals.

Understanding Acetic Acid and Its Properties

What is Acetic Acid?

Acetic acid, with the chemical formula CH_3COOH , is a weak organic acid characterized by its distinctive sour taste and pungent smell. It exists naturally in vinegar, where it imparts the characteristic flavor. Chemically, acetic acid is classified as a weak acid because it does not completely dissociate in aqueous solution.

Acetic Acid's Acid Strength and pKa

- pKa of Acetic Acid: 4.8

This value indicates the acid's strength; the lower the pKa, the stronger the acid. Acetic acid's pKa of 4.8 suggests moderate acidity, meaning it partially dissociates in water, establishing an equilibrium between undissociated molecules and ions.

- Dissociation in Water:



The extent of dissociation influences the pH and other properties of the solution.

Preparation of a 1 M Acetic Acid Solution

Target Concentration and Moles

To prepare a 1 M solution, the molarity (M) is defined as:

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Given:

- Moles of acetic acid: 0.020 mol
- Desired molarity: 1 mol/L

Using the formula:

$$\text{Volume of solution} = \frac{\text{moles of solute}}{\text{molarity}} = \frac{0.020 \text{ mol}}{1 \text{ mol/L}} = 0.020 \text{ L}$$

which equals 20 milliliters.

Therefore, dissolving 0.020 mol of acetic acid in water and adjusting the final volume to exactly 20 mL yields a 1 M solution.

Step-by-Step Preparation Process

Materials Needed

- Pure acetic acid (glacial acetic acid): for accurate measurement
- Distilled or deionized water: to ensure no impurities interfere
- Volumetric flask (20 mL capacity): for precise volume measurement
- Analytical balance: to weigh acetic acid accurately
- Pipette or syringe: for transferring liquids
- Stirring rod or magnetic stirrer: to homogenize the solution

Procedure

1. Calculate the required mass of acetic acid:

The molar mass of acetic acid is approximately 60.05 g/mol.

$$\begin{aligned} \text{Mass} &= \text{moles} \times \text{molar mass} = 0.020 \text{ mol} \times 60.05 \text{ g/mol} \\ &\approx 1.201 \text{ g} \end{aligned}$$

2. Weigh the acetic acid:

Using an analytical balance, weigh approximately 1.201 grams of glacial acetic acid.

3. Transfer to volumetric flask:

Carefully transfer the weighed acetic acid into a 20 mL volumetric flask.

4. Add water:

Add distilled water gradually to the flask, swirling gently to dissolve the acetic acid completely. It's best to add water until the level approaches, but does not yet reach, the calibration mark.

5. Dilute to the mark:

Carefully add water until the bottom of the meniscus aligns precisely with the 20 mL calibration line on the flask.

6. Mix thoroughly:

Cap the flask and invert several times or use a stirrer to ensure homogeneity.

Important Considerations and Precautions

Purity and Safety

- Use high-purity acetic acid to ensure the desired concentration accuracy.
- Acetic acid, especially in glacial form, is corrosive and can cause burns; handle with appropriate protective gear.

Temperature Effects

- The volume of solutions can vary with temperature; perform measurements at room temperature (around 20-25°C) for consistency.

- Be aware that the density of water and acetic acid may slightly change with temperature, affecting calculations.

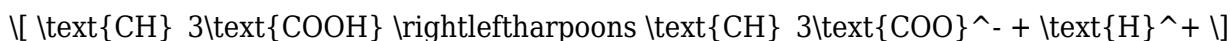
Accuracy and Precision

- Use calibrated instruments for weighing and volume measurement.
- Repeat measurements if necessary to confirm accuracy.

Understanding the Chemistry Behind the Dissolution Process

Dissociation and pH of the Solution

When acetic acid dissolves in water, it establishes an equilibrium:



Because acetic acid is weak, only a small fraction dissociates. The degree of dissociation (α) can be approximated using the acid dissociation constant (K_a):

$$K_a = 10^{-\text{pKa}} = 10^{-4.8} \approx 1.58 \times 10^{-5}$$

The concentration of free H^+ ions (which determines pH) can be calculated considering the initial concentration and dissociation:

$$\text{Initial concentration of acetic acid} = 1 \text{ M}$$

$$\begin{aligned} \text{At equilibrium:} \quad & \\ \begin{cases} [\text{CH}_3\text{COOH}] \approx 1 - \alpha \\ [\text{CH}_3\text{COO}^-] = \alpha \\ [\text{H}^+] = \alpha \end{cases} \end{aligned}$$

Using the approximation:

$$K_a = \frac{\alpha^2}{1 - \alpha} \approx \alpha^2$$

$$\alpha^2 = K_a \rightarrow \alpha = \sqrt{K_a} \approx \sqrt{1.58 \times 10^{-5}} \approx 4.0 \times 10^{-3}$$

Thus,

$$[\text{H}^+] \approx 4.0 \times 10^{-3} \text{ M}$$

and the pH:

$$\text{pH} = -\log [\text{H}^+] \approx -\log (4.0 \times 10^{-3}) \approx 2.4$$

This pH value confirms the weak acidity of the solution.

Applications and Significance of the Prepared Solution

Educational Purposes:

This precise preparation method serves as an excellent demonstration of molarity, solution preparation, and acid-base chemistry in academic settings.

Industrial and Laboratory Uses:

- Calibration of pH meters
- As a standard solution for titrations
- In chemical syntheses requiring controlled acidity

Research and Development:

Accurate solutions of acetic acid are pivotal in experiments exploring fermentation processes, enzyme activity, and material synthesis.

Conclusion: Evaluating the Solution's Efficacy and Reliability

Preparing a 1 M acetic acid solution by dissolving 0.020 moles in water is a straightforward yet precise process demanding attention to detail and understanding of fundamental chemistry principles. The key steps involve accurate measurement, careful dilution, and thorough mixing, ensuring the final solution's concentration aligns with theoretical expectations.

This method exemplifies best practices in solution preparation—balancing accuracy, safety, and reproducibility—making it invaluable for students, researchers, and industry professionals alike. Whether used for educational demonstrations or sophisticated research, the prepared acetic acid solution stands as a testament to meticulous laboratory technique and chemical understanding.

In summary:

- Precise calculation of moles and volume is essential for target concentration.
- Handling acetic acid safely is paramount due to its corrosive nature.
- Understanding dissociation and pH provides insights into solution behavior.
- Proper techniques ensure reliable, reproducible results crucial for scientific and industrial applications.

By mastering these principles, practitioners can confidently prepare and utilize acetic acid solutions tailored to their specific needs, exemplifying the importance of precision and knowledge in the art of solution chemistry.

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