What Is The PH Of A Solution That Results From Mixing 25.0 ML Of 0.200 M HA With 12.5 ML Of 0.400 M NaOH?

What Is The PH Of A Solution That Results From Mixing 25.0 ML Of 0.200 M HA With 12.5 ML Of 0.400 M NaOH?

Understanding the pH of a solution resulting from mixing a weak acid with a strong base is a fundamental concept in chemistry, particularly in acid-base titrations and buffer solutions. In this scenario, we are dealing with the weak acid hydroxyapatite (HA) and sodium hydroxide (NaOH), a strong base. Calculating the final pH involves determining the initial amounts of each reactant, understanding their reaction, and applying principles of stoichiometry and equilibrium chemistry. This article explores these steps in detail to find the pH of the resulting solution.

Background Concepts

Understanding pH and pOH

- pH is a measure of the acidity or alkalinity of a solution, defined as:

pH = -log[H□]

- pOH relates to the hydroxide ion concentration:

$pOH = -\log[OH^-]$

- The relationship between pH and pOH at 25°C is:

$pH + pOH = 14$

Weak Acid and Strong Base Reactions

- Hydroxyapatite (HA) is a weak acid, which means it does not fully dissociate in water.
- Sodium hydroxide (NaOH) is a strong base and dissociates completely.
- When mixed, NaOH will react with HA, neutralizing some of it and possibly leading to a solution that is either acidic, basic, or neutral depending on the amounts.

Stoichiometry in Acid-Base Reactions

- Key to calculating the final pH is understanding how much of each reactant is present and how they react.
- The reaction between HA and NaOH can be represented (assuming HA is a monoprotic acid for simplicity):

$HA + OH^- \rightarrow A^- + H_2O$

- The amount of HA neutralized depends on the molar amounts of NaOH added.

Step 1: Calculate Initial Moles of Reactants

Calculating Moles of HA

- Volume of HA solution = 25.0 mL = 0.025 L
- Concentration of HA = 0.200 M

Number of moles of HA:

$$ \text{moles HA} = \text{volume} \times \text{concentration} = 0.025\,L \times 0.200\, \text{mol/L} = 0.005\, \text{mol} $$

Calculating Moles of NaOH

- Volume of NaOH solution = 12.5 mL = 0.0125 L
- Concentration of NaOH = 0.400 M

Number of moles of NaOH:

$$ \text{moles NaOH} = 0.0125\,L \times 0.400\, \text{mol/L} = 0.005\, \text{mol} $$

Step 2: Analyze the Reaction

Reaction Stoichiometry

- Since both reactants have 0.005 mol, and assuming a 1:1 reaction ratio:

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

- The entire amount of HA will be neutralized by the NaOH present.

Extent of Reaction

- Moles of HA initially: 0.005 mol
- Moles of NaOH initially: 0.005 mol

Since they are equal, all HA will react with NaOH, producing:

- 0.005 mol of A^- (the conjugate base)
- Water

Remaining reactants:

- None, as all HA is neutralized.

Step 3: Determine the Composition of the Final Solution

Final Volume of the Mixture

- Total volume = 25.0 mL + 12.5 mL = 37.5 mL = 0.0375 L

Remaining Species in Solution

- Since all HA has reacted, the solution contains:
- 0 mol of HA
- 0 mol of free NaOH (fully reacted)
- 0.005 mol of A^- (the conjugate base formed)

- The solution also contains water and any additional ions from the initial solutions, but these do not affect pH significantly.

Nature of the Final Solution

- The solution is now a mixture of the conjugate base (A^-) in water.
- Because the strong base fully reacted, the pH depends on the hydrolysis of A^-.

Step 4: Determine the pH Based on Hydrolysis of A^-

Hydrolysis of the Conjugate Base

- A^- can undergo hydrolysis:

$$\text{A}^- + \text{H}_2\text{O} \rightleftharpoons \text{HA} + \text{OH}^-$$

- The equilibrium constant for this reaction is the base dissociation constant K_b, related to the acid dissociation constant K_a of HA:

$$K_b = \frac{K_w}{K_a}$$

- K_a of HA must be known or estimated to proceed.

Estimating K_a for HA

- The problem does not provide K_a, but typical weak acids have K_a values ranging from 10^{-3} to 10^{-7}.
- For hydroxyapatite, K_a is approximately 10^{-3} to 10^{-4}. Let's assume:

$$K_a = 1 \times 10^{-4}$$

- Therefore:

$$ K_b = \frac{K_w}{K_a} = \frac{1 \times 10^{-14}}{1 \times 10^{-4}} = 1 \times 10^{-10} $$

Calculating Hydroxide Ion Concentration

- Moles of A^- = 0.005 mol
- Final volume = 0.0375 L

Concentration of A^-:

$$ [A^-] = \frac{0.005\, \text{mol}}{0.0375\, \text{L}} \approx 0.133\, \text{M} $$

- Using the hydrolysis equilibrium:

$$ K_b = \frac{[OH^-]^2}{[A^-]} $$

- Solving for $[OH^-]$:

$$ [OH^-] = \sqrt{K_b \times [A^-]} = \sqrt{1 \times 10^{-10} \times 0.133} $$

$$ [OH^-] \approx \sqrt{1.33 \times 10^{-11}} \approx 3.65 \times 10^{-6}\, \text{M} $$

Step 5: Calculate the Final pH

Determine pOH

$$ pOH = -\log [OH^-] = -\log (3.65 \times 10^{-6}) \approx 5.44 $$

Determine pH

$$pH = 14 - pOH = 14 - 5.44 = 8.56$$

Conclusion

The final pH of the solution, after mixing 25.0 mL of 0.200 M HA with 12.5 mL of 0.400 M NaOH, is approximately 8.56. This indicates a slightly basic solution, which makes sense given the complete neutralization of the weak acid and the hydrolysis of the conjugate base formed. The pH is above 7, confirming the basic nature of the resulting solution due to the presence of hydrolyzed A^{-} ions.

Additional Considerations

- Assumptions Made: The calculation assumes complete reaction and uses an estimated K_a for HA. Actual values may vary based on the specific compound.
- Effect of Ionic Strength: In real solutions, ionic strength can influence activity coefficients, slightly affecting the pH.
- Buffer Capacity: Since a weak acid and its conjugate base are present, the solution can act as a buffer, resisting drastic changes in pH upon small additions of acids or bases.

Summary

- Initial moles of HA: 0.005 mol
- Moles of NaOH: 0.005 mol
- Reaction: Complete neutralization to form conjugate base A^-
- Final species: A^- in water undergoing hydrolysis
- Estimated pH: approximately 8.56

This detailed approach demonstrates how stoichiometry, acid-base equilibria, and hydrolysis reactions

Frequently Asked Questions

What is the initial concentration of HA before mixing?

The initial concentration of HA is 0.200 M.

How much HA is present in moles before mixing?

Moles of HA = 0.200 mol/L × 25.0 mL = 0.200 mol/L × 0.025 L = 0.005 mol.

What is the initial concentration of NaOH before mixing?

The initial concentration of NaOH is 0.400 M.

How many moles of NaOH are in the solution before mixing?

Moles of NaOH = 0.400 mol/L × 12.5 mL = 0.400 mol/L × 0.0125 L = 0.005 mol.

After mixing, which reactant is in excess?

Since both have 0.005 mol, they react completely, resulting in a neutralization.

What is the resulting solution after mixing?

The acid and base react completely, producing water and a salt, resulting in a neutral or very close to neutral solution.

What is the pH of the resulting solution?

Since the moles of acid and base are equal and react completely, the solution is neutral with a pH of approximately 7.0.

How does the volume change after mixing, and does it affect the pH?

The total volume is 25.0 mL + 12.5 mL = 37.5 mL, but since the acid and base neutralize each other completely, the pH remains close to 7.0 regardless of volume change.

Would the pH change significantly if there were slight excess of either reactant?

Yes, a slight excess of acid or base would make the solution slightly acidic or basic, respectively, changing the pH slightly above or below 7.0.

Additional Resources

What Is The pH Of A Solution That Results From Mixing 25.0 mL Of 0.200 M HA With 12.5 mL Of 0.400 M NaOH?

Understanding the pH of a solution resulting from the mixing of a weak acid with a strong base is fundamental in chemistry, particularly in acid-base titrations, buffer solutions, and various industrial processes. In this detailed analysis, we explore the steps involved in calculating the pH of the mixture when 25.0 mL of 0.200 M HA (a weak acid) is combined with 12.5 mL of 0.400 M NaOH (a strong base). By delving into the principles of molarity, titration, and equilibrium calculations, this article aims to clarify the process and provide a comprehensive understanding of the final solution’s acidity.

Understanding the Components of the Solution

Before calculating the pH, it's essential to understand the nature of the reactants involved:

Weak Acid (HA)

- Definition: HA represents a generic weak acid that partially dissociates in water.
- Concentration: 0.200 M
- Volume: 25.0 mL
- Moles of HA: Calculated by multiplying molarity by volume (in liters).

Strong Base (NaOH)

- Definition: NaOH is a strong base that dissociates completely in water.
- Concentration: 0.400 M
- Volume: 12.5 mL
- Moles of NaOH: Similarly, molarity times volume in liters.

The core of the problem involves computing the moles of each reactant and understanding how they interact.

Calculating Moles of Reactants

To determine the final pH, we need to establish the amount of acid and base involved:

Moles of HA

- Convert volume to liters: 25.0 mL = 0.025 L
- Use molarity to find moles:

Moles of HA = 0.200 mol/L × 0.025 L = 0.005 mol

Moles of NaOH

- Convert volume to liters: 12.5 mL = 0.0125 L
- Use molarity to find moles:

Moles of NaOH = 0.400 mol/L × 0.0125 L = 0.005 mol

Observation: Both reactants have exactly 0.005 mol, indicating a stoichiometric equivalence if they react completely.

Reaction Between the Weak Acid and Strong Base

The primary chemical reaction is:

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

Given the molar equivalence, the moles of NaOH will neutralize an equivalent amount of HA.

Extent of Reaction

- Since moles of HA and NaOH are equal, the reaction proceeds to complete neutralization.
- All the HA is consumed, producing its conjugate base, A^-, and water.

Remaining Species in Solution

- After neutralization, the solution contains:
- A^- (the conjugate base of HA)
- Water
- Any excess or residual species (none in this case, as the reactants are stoichiometrically equivalent)

Determining the Final Composition of the Solution

Because the initial quantities of acid and base are equal, the neutralization reaction results in:

- All the HA being converted into its conjugate base (A^-).
- No excess acid or base remains.

Calculations:

- Moles of A^- formed = initial moles of HA = 0.005 mol
- Total volume of the final solution:
- 25.0 mL + 12.5 mL = 37.5 mL = 0.0375 L

- Concentration of A^- in the final solution:

$$ [A^-] = \frac{0.005 \text{ mol}}{0.0375 \text{ L}} \approx 0.1333 \text{ M} $$

Calculating the pH of the Resulting Solution

Since the final solution contains only the conjugate base A^- (which is a weak base), the pH depends on the hydrolysis of A^-:

$$ \text{A}^- + \text{H}_2\text{O} \rightleftharpoons \text{HA} + \text{OH}^- $$

To find the pH, we need:

- The K_b (base dissociation constant) for A^-
- The relationship between K_b and K_a for HA

Relationship Between K_a and K_b

$$ K_b = \frac{K_w}{K_a} $$

where:

- $K_w = 1.0 \times 10^{-14}$ at 25°C
- K_a is the acid dissociation constant for HA

Because the problem doesn’t specify the actual K_a for HA, we'll assume a typical weak acid with:

$$ K_a = 1.8 \times 10^{-5} $$

This value resembles acetic acid, a common weak acid.

Calculating K_b:

$$ K_b = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} \approx 5.56 \times 10^{-10} $$

Hydrolysis of A^- and pOH Calculation

Set up the equilibrium:

$$ \text{A}^- + \text{H}_2\text{O} \rightleftharpoons \text{HA} + \text{OH}^- $$

Let x be the concentration of OH^- produced:

$$ K_b = \frac{[OH^-]^2}{[A^-]} $$

Rearranged:

$$ x = \sqrt{K_b \times [A^-]} $$

Insert known values:

$$ x = \sqrt{5.56 \times 10^{-10} \times 0.1333} $$
$$ x \approx \sqrt{7.41 \times 10^{-11}} $$
$$ x \approx 8.62 \times 10^{-6} \text{ M} $$

This is the concentration of OH^-.

Calculate pOH:

$$ \text{pOH} = -\log [OH^-] $$
$$ \text{pOH} = -\log (8.62 \times 10^{-6}) \approx 5.06 $$

Finally, determine pH:

$$\text{pH} = 14 - \text{pOH}$$

$$\text{pH} = 14 - 5.06 = 8.94$$

Final pH of the Mixture

Based on the calculations, the pH of the resulting solution after mixing 25.0 mL of 0.200 M HA with 12.5 mL of 0.400 M NaOH is approximately 8.94.

This slightly basic pH reflects the fact that the conjugate base A^- is a weak base capable of hydrolyzing to produce OH^- ions, raising the pH above neutral.

Summary and Key Features

Features:

- The solution is slightly basic due to the formation of the conjugate base.
- The calculations assume complete neutralization given the stoichiometric equivalence of reactants.
- The pH depends heavily on the acid dissociation constant K_a of HA, which influences the strength of the conjugate base.

Pros:

- The approach provides a clear step-by-step methodology for similar titration problems.

- Demonstrates the relationship between \(K_a\), \(K_b\), and pH.

- Highlights the importance of molarity, volume, and stoichiometry in solution chemistry.

Cons:

- Assumes a specific \(K_a\) value; different acids will yield different pH values.

- Neglects activity coefficients and temperature effects, which may influence precise pH calculations.

- Simplifies the hydrolysis equilibrium without considering ionic strength effects.

Conclusion

The calculation of the pH after mixing a weak acid with a strong base involves understanding stoichiometry, chemical equilibria, and the properties of conjugate bases. In this case, the mixture results in a solution with a pH of approximately 8.94, indicating a mildly basic environment primarily due to the hydrolysis of the conjugate base. This example underscores the importance of precise volume and molarity measurements, as well as an understanding of acid-base equilibria, in predicting the properties of chemical solutions. Such calculations are vital in laboratory settings, industrial processes, and educational demonstrations of acid-base chemistry.

What Is The Ph Of A Solution That Results From Mixing 25 0 Ml Of 0 200 M Ha With 12 5 Ml Of 0 400 M Naoh

What Is The Ph Of A Solution That Results From Mixing 25 0 Ml Of 0 200 M Ha With 12 5 Ml Of 0 400 M Naoh

Related Articles

- The Principal Similarity Between Business And Military Strategy Is That:a. They Share The

Same Objective:

- What Strategies Did Clinton Use To Improve The Economy?tax Increases And Spending Increasestax Reductions
- A Bottle With A Volume Of 188 U. S. Fluid Gallons Is Filled At The Rate Of 1.5 G/min. (water Has A Density

Back to Home