What Is The Ph At The Equivalence Point For The Titration Of 0.20 M Nitrous Acid By 0.20 M Sodium Hydroxide?

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Understanding the pH at the equivalence point of a titration between nitrous acid (HNO_2) and sodium hydroxide (NaOH) is fundamental in analytical chemistry. This specific titration involves a weak acid (nitrous acid) being neutralized by a strong base (sodium hydroxide), resulting in a pH that reflects the properties of the resulting solution. The equivalence point is the moment when the amount of added titrant (NaOH) exactly neutralizes the analyte (HNO_2), leading to a solution primarily composed of the conjugate base (NO_2^-). Determining the pH at this stage involves understanding the acid-base chemistry, the dissociation constants, and the resulting hydrolysis reactions.

In this comprehensive article, we will explore what the pH at the equivalence point is for this specific titration, delve into the chemical principles involved, and provide step-by-step calculations to arrive at the precise pH value. We will also discuss the significance of this pH in the context of titration curves and analytical chemistry. Whether you're a student preparing for exams or a chemistry enthusiast seeking a deeper understanding, this guide aims to clarify the concepts thoroughly.

Understanding the Chemistry of Nitrous Acid and Sodium Hydroxide

Properties of Nitrous Acid (HNO_2)

Nitrous acid is a weak, diprotic acid with the chemical formula HNO_2. It exists in solution as an equilibrium between the undissociated acid and its ions:

$$ \text{HNO}_2 \rightleftharpoons \text{H}^+ + \text{NO}_2^- $$

The acid dissociation constant (Ka) for nitrous acid is approximately:

$$ K_a \approx 4.5 \times 10^{-4} $$

This value indicates that nitrous acid is only partially dissociated in aqueous solution, making it a weak acid.

Its conjugate base, nitrite ion (NO_2^-), can undergo hydrolysis, which significantly influences the pH at various stages of titration.

Properties of Sodium Hydroxide (NaOH)

Sodium hydroxide is a strong base that dissociates completely in water:

$$ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- $$

Because of its complete dissociation, NaOH readily neutralizes acids, including weak acids like HNO_2, to produce their conjugate bases and water.

Overview of the Titration Process

Initial Solution: Nitrous Acid

At the start, the solution contains only nitrous acid at a concentration of 0.20 M. Its pH can be calculated based on its dissociation equilibrium:

$$ \text{HNO}_2 \rightleftharpoons \text{H}^+ + \text{NO}_2^- $$

Using the Ka value and initial concentration, we can determine the initial pH.

During Titration: Addition of NaOH

As NaOH is added, it reacts with HNO_2:

$$ \text{HNO}_2 + \text{OH}^- \rightarrow \text{NO}_2^- + \text{H}_2\text{O} $$

This neutralization converts the weak acid into its conjugate base, NO_2^-. The titration curve will show a typical S-shape, with the pH rising gradually until reaching the equivalence point.

At the Equivalence Point

The equivalence point is reached when all the acid has been neutralized:

$$ \text{HNO}_2 + \text{NaOH} \rightarrow \text{NaNO}_2 + \text{H}_2\text{O} $$

At this stage, the solution contains only the sodium nitrite ($NaNO_2$), which dissociates into Na^+ and NO_2^- ions.

Determining the pH at the Equivalence Point

Since the titration involves a weak acid and a strong base, the pH at the equivalence point is not neutral (pH 7). Instead, it is governed by the hydrolysis of the conjugate base (NO_2^-). This makes the pH basic, as NO_2^- acts as a weak base in water.

Step-by-Step Calculation of pH at the Equivalence Point

Step 1: Recognize the Dominant Species at Equivalence Point
At the equivalence point, the solution contains only the conjugate base NO_2^-, coming from the neutralization of the weak acid. The pH depends on the hydrolysis of NO_2^-:

$$ \text{NO}_2^- + \text{H}_2\text{O} \rightleftharpoons \text{HNO}_2 + \text{OH}^- $$

Step 2: Write the Hydrolysis Equilibrium Expression
The equilibrium constant for hydrolysis (Kb) of NO_2^- can be derived from the Ka of HNO_2:

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

where $K_w = 1.0 \times 10^{-14}$ at 25°C.

Calculating K_b:

$$ K_b = \frac{1.0 \times 10^{-14}}{4.5 \times 10^{-4}} \approx 2.22 \times 10^{-11} $$

Step 3: Determine the Concentration of NO_2^- at Equivalence Point
Since the initial concentration of HNO_2 was 0.20 M and the titration is 1:1, the concentration of NO_2^- at equivalence is also 0.20 M.

Step 4: Set Up the Hydrolysis Equation
Let x be the concentration of OH^- produced by hydrolysis:

$$ \text{NO}_2^- + \text{H}_2\text{O} \rightleftharpoons \text{HNO}_2 + \text{OH}^- $$

The expression:

$$ K_b = \frac{[\text{OH}^-]^2}{[\text{NO}_2^-]} $$

Substituting known values:

$$ 2.22 \times 10^{-11} = \frac{x^2}{0.20} $$

Solve for x:

$$ x^2 = 2.22 \times 10^{-11} \times 0.20 = 4.44 \times 10^{-12} $$

$$ x = \sqrt{4.44 \times 10^{-12}} \approx 6.66 \times 10^{-6} \, \text{M} $$

This is the concentration of OH^- ions.

Step 5: Calculate the pOH and then the pH

$$ \text{pOH} = -\log [\text{OH}^-] $$

$$ \text{pOH} = -\log (6.66 \times 10^{-6}) \approx 5.18 $$

Then,

$$ \text{pH} = 14 - \text{pOH} = 14 - 5.18 = 8.82 $$

Final Result: pH at the Equivalence Point

Based on the calculations, the pH at the equivalence point for the titration of 0.20 M nitrous acid with 0.20 M sodium hydroxide is approximately 8.82.

This basic pH confirms that the conjugate base (NO_2^-) hydrolyzes to produce hydroxide ions, resulting in a solution that is slightly alkaline at the equivalence point.

Additional Insights and Practical Significance

Why Is the pH at the Equivalence Point Not Neutral?

In titrations involving a weak acid and a strong base, the resulting solution contains the conjugate base of the weak acid. This conjugate base is weakly basic, which causes the pH at the equivalence point to be greater than 7. Conversely, titrations involving a weak base and a strong acid would produce a pH less than 7 at the equivalence point.

Implications for Acid-Base Titration Curves

Understanding the pH at the equivalence point helps in:
- Accurately determining the endpoint of a titration using indicators.
- Interpreting titration curves for weak acid-strong base systems.
- Calculating the dissociation constants and properties of weak acids and their conjugates.

Key Points to Remember

- The pH at the equivalence point reflects the hydrolysis of the conjugate base.
- For nitrous acid titration with NaOH, the pH is approximately 8.82.
- The initial concentration and Ka value influence the pH at various stages.

Conclusion

The pH at the equivalence point for the titration of 0.20 M nitrous acid with 0.20 M sodium hydroxide is

Frequently Asked Questions

What is the pH at the equivalence point for titrating 0.20 M nitrous acid with 0.20 M sodium hydroxide?

The pH at the equivalence point is approximately 8.6 because nitrous acid (a weak acid) is neutralized by a strong base, resulting in a slightly basic solution.

Why is the pH at the equivalence point for this titration above 7?

Because the titration involves a weak acid (nitrous acid) being neutralized by a strong base (NaOH), the resulting solution contains the conjugate base (nitrite ion), which is slightly basic, raising the pH above 7.

How do you determine the pH at the equivalence point in this titration?

You calculate the concentration of the conjugate base formed at the equivalence point and use its hydrolysis to find the pH, typically employing the Kb of the conjugate base and the water ionization constant.

What is the role of the conjugate base in this titration's pH calculation?

The conjugate base (nitrite ion) hydrolyzes in water, producing hydroxide ions that make the solution slightly basic, which determines the pH at the equivalence point.

Is the pH at the equivalence point for titrating a weak acid with a strong base always above 7?

Not always, but for weak acid-strong base titrations like this one, the pH at equivalence is typically above 7 due to the basic nature of the conjugate base.

What is the approximate pKa of nitrous acid, and how does it relate to the titration?

The pKa of nitrous acid is approximately 3.3. It indicates the acid strength and helps predict the pH changes during titration, especially near the equivalence point.

How does the molarity of the acid and base affect the pH at the equivalence point?

Since both are 0.20 M and are titrated in equal amounts, the pH at equivalence is primarily determined by the hydrolysis of the conjugate base, not the initial concentrations.

What experimental methods can be used to determine the pH at the equivalence point?

A pH meter can be used to accurately measure the pH during titration, with the equivalence point identified by the steepest change in pH.

Why is understanding the pH at the equivalence point important in titration analysis?

Knowing the pH at the equivalence point allows for accurate determination of the analyte's concentration and understanding of the acid-base properties involved.

Can the pH at the equivalence point be estimated without calculations?

Yes, for weak acid-strong base titrations, the pH at equivalence typically ranges between 8 and 9, allowing for a rough estimate based on similar titrations.

Additional Resources

What Is The pH At The Equivalence Point For The Titration Of 0.20 M Nitrous Acid By 0.20 M Sodium Hydroxide? is a common question in analytical chemistry, especially when understanding titration curves involving weak acids and strong bases. This scenario provides a clear illustration of acid-base neutralization, the concept of equivalence points, and how to determine the resulting pH at this critical juncture. Whether you're a student preparing for an exam or a chemistry enthusiast seeking to deepen your understanding, this comprehensive guide will walk you through the principles, calculations, and implications involved in this titration process.

Understanding the Basics: Acid-Base Titration

Before diving into the specifics of nitrous acid titration, it's essential to understand the fundamental concepts of acid-base titrations:

- Titrant and analyte: The titrant (here, sodium hydroxide, NaOH) is added gradually to the analyte (nitrous acid, HNO_2) until the reaction reaches its equivalence point.
- Equivalence point: The point at which stoichiometrically equivalent amounts of acid and base have reacted, resulting in a neutralization.
- pH at equivalence point: The pH value when the titration reaches the equivalence point, which depends on the nature of the acid and base involved.

The Chemistry of Nitrous Acid and Sodium Hydroxide

Nitrous acid (HNO_2) is a weak, monoprotic acid with a known acid dissociation constant (Ka). Its behavior in water involves partial dissociation:

$HNO_2 \rightleftharpoons H^+ + NO_2^-$

Sodium hydroxide (NaOH) is a strong base that dissociates completely in water:

$NaOH \rightarrow Na^+ + OH^-$

When titrated, the NaOH neutralizes the HNO_2, converting it into its conjugate base, NO_2^-.

Step 1: Recognizing the Titration Dynamics

In titrating a weak acid like nitrous acid with a strong base (NaOH), the following stages occur:

1. Initial phase: The solution contains only the weak acid; pH is determined by the acid's dissociation.
2. Buffer region: As base is added, the acid is partially neutralized, forming its conjugate base, creating a buffer solution.
3. Approaching equivalence point: The acid is mostly converted into its conjugate base.
4. At the equivalence point: All the acid has been neutralized, forming the conjugate base (NO_2^-), which influences the pH.
5. Beyond equivalence: Excess strong base raises the pH sharply.

Our focus is on the pH at the equivalence point, where all of the nitrous acid has been converted into NO_2^-.

Step 2: Calculating the Equivalence Point Volume

Given that both solutions are 0.20 M:

- Volume of nitrous acid (HNO_2): Let's assume 50 mL for simplicity.
- Volume of NaOH needed to reach the equivalence point:

$$V_{NaOH} = \frac{C_{HNO_2} \times V_{HNO_2}}{C_{NaOH}} = \frac{0.20\, M \times 50\, mL}{0.20\, M} = 50\, mL$$

So, at 50 mL of NaOH added, the titration reaches the equivalence point.

Step 3: What Is Present at the Equivalence Point?

At this stage:

- All HNO_2 has been converted to NO_2^-.
- The solution contains mainly the conjugate base NO_2^-, along with some water and possibly residual ions.
- The pH is determined by the hydrolysis (reactive interaction with water) of NO_2^-.

Step 4: Determining the pH at the Equivalence Point

Since the conjugate base NO_2^- is the dominant species, the pH is influenced by its hydrolysis:

$NO_2^- + H_2O \rightleftharpoons HNO_2 + OH^-$

The hydrolysis equilibrium's extent depends on the base hydrolysis constant, Kb, related to the acid dissociation constant, Ka, of nitrous acid:

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

Where:

- $K_w = 1.0 \times 10^{-14}$ (at 25°C)
- K_a for nitrous acid is approximately 4.5×10^{-4}

Thus:

$$ K_b = \frac{1.0 \times 10^{-14}}{4.5 \times 10^{-4}} \approx 2.2 \times 10^{-11} $$

Step 5: Calculating the pH at the Equivalence Point

The hydrolysis of NO_2^- will generate OH^- ions, raising the pH above 7. To find the pH:

Step 5.1: Determine the concentration of NO_2^- at the equivalence point

The initial concentration of HNO_2 was 0.20 M, and the volume was 50 mL. After neutralization with 50 mL of NaOH, the concentration of NO_2^- formed is:

$$ C_{NO_2^-} = \frac{\text{moles of HNO}_2}{\text{total volume}} $$

Total volume after titration:

$$ 50\, mL + 50\, mL = 100\, mL = 0.1\, L $$

Moles of HNO_2 initially:

$$ 0.20\, M \times 0.050\, L = 0.010\, \text{moles} $$

All converted to NO_2^-, so:

$$ C_{NO_2^-} = \frac{0.010\, \text{moles}}{0.1\, L} = 0.10\, M $$

Step 5.2: Set up hydrolysis equilibrium

Let x be the concentration of OH^- produced:

$$ K_b = \frac{[OH^-]^2}{[NO_2^-]_{initial} - [OH^-]} $$

Assuming $x \ll [NO_2^-]$:

$$ K_b \approx \frac{x^2}{0.10} $$

$$ x^2 = K_b \times 0.10 = 2.2 \times 10^{-11} \times 0.10 = 2.2 \times 10^{-12} $$

$$ x = \sqrt{2.2 \times 10^{-12}} \approx 1.48 \times 10^{-6}\, M $$

Step 5.3: Calculate pOH and pH

$$ pOH = -\log x \approx -\log (1.48 \times 10^{-6}) \approx 5.83 $$

$$ pH = 14 - pOH \approx 14 - 5.83 = 8.17 $$

Final Answer:

The pH at the equivalence point for the titration of 0.20 M nitrous acid by 0.20 M sodium hydroxide is approximately 8.17.

This slightly basic pH results from the hydrolysis of the conjugate base NO_2^-, demonstrating how weak acids produce a basic equivalence point when titrated with a strong base.

Additional Considerations and Variations

- Effect of initial concentrations: Higher or lower initial concentrations of nitrous acid will influence the pH at the equivalence point, mainly due to changes in the hydrolysis equilibrium.
- Temperature dependence: The value of K_a and K_b is temperature-dependent; thus, pH calculations may vary accordingly.
- Indicator choice: Since the pH at the equivalence point is slightly above 7, suitable indicators include phenolphthalein, which changes color around pH 8.2–10, providing an accurate endpoint.

Summary

Understanding what is the pH at the equivalence point for the titration of 0.20 M nitrous acid by 0.20 M sodium hydroxide involves grasping the principles of acid-base chemistry, calculating the hydrolysis of the conjugate base, and applying equilibrium concepts. The key takeaway is that the pH at the equivalence point in this case is approximately 8.17, reflecting the weak acid's conjugate base's basic nature. Recognizing these nuances is fundamental in analytical chemistry, enabling precise titrations and better interpretation of titration curves.

References

- Atkins, P., & de Paula, J. (2010). Physical Chemistry. Oxford University Press.
- Zumdahl, S. S., & Zumdahl, S. A. (2014). Chemistry: An Atoms First Approach. Cengage Learning.
- Lippincott's Illustrated Reviews: Biochemistry, 6th Edition, for basics on pH and buffer solutions.

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