Calculate The Ph Of 0.20 M Sodium Benzoate, C6h5coona. Ka(c6h5cooh) = 6.5 X 10-5

Calculate The pH Of 0.20 M Sodium Benzoate, C6H5COONa. Ka(C6H5COOH) = 6.5 x 10^-5

Understanding how to calculate the pH of a solution like sodium benzoate is fundamental in chemistry, especially in the study of acids and bases. Sodium benzoate, C6H5COONa, is the sodium salt of benzoic acid and exhibits basic properties when dissolved in water. Given its molarity and the acid dissociation constant (Ka) of benzoic acid, we can determine the pH of a 0.20 M sodium benzoate solution. This article provides a comprehensive step-by-step guide to calculating that pH, including the relevant chemical principles, equations, and considerations.

Understanding Sodium Benzoate and Its Properties

What is Sodium Benzoate?

Sodium benzoate is an organic sodium salt derived from benzoic acid. It is widely used as a preservative in food and beverages due to its antimicrobial properties. When dissolved in water, sodium benzoate dissociates completely into sodium ions (Na^+) and benzoate ions ($C6H5COO^-$).

Acid-Base Behavior of Sodium Benzoate

Although sodium benzoate itself is a salt, it can influence the pH of its solution through the hydrolysis of the benzoate ion. Since benzoate is the conjugate base of benzoic acid, it can accept a proton from water, making the solution slightly basic.

Key Concepts for pH Calculation

Understanding the Acid Dissociation Constant (Ka)

Ka is an equilibrium constant that measures the strength of an acid in solution. For benzoic acid:

$C6H5COOH \rightleftharpoons C6H5COO^- + H^+$

Given: Ka = 6.5 x 10^-5

This value indicates that benzoic acid is a weak acid, dissociating only slightly in water.

Conjugate Base Hydrolysis

The sodium salt provides the conjugate base (benzoate ion), which can react with water:

$C6H5COO^- + H_2O \rightleftharpoons C6H5COOH + OH^-$

This hydrolysis reaction causes the solution to be basic, and calculating the concentration of hydroxide ions (OH^-) is key to finding the pH.

Step-by-Step Calculation of the pH

Step 1: Recognize the Type of Solution

Since sodium benzoate is the salt of a weak acid, its aqueous solution will be basic due to hydrolysis of the benzoate ion.

Step 2: Write the Hydrolysis Equilibrium Expression

The hydrolysis reaction:

$C6H5COO^- + H_2O \rightleftharpoons C6H5COOH + OH^-$

The equilibrium expression for this reaction involves the base dissociation constant (Kb), related to Ka through the water ion product (Kw):

Kw = Ka x Kb

Given:
- Ka for benzoic acid = 6.5 x 10^-5
- Kw = 1.0 x 10^-14 at 25°C

Calculate Kb for benzoate:

K_b = Kw / Ka = (1.0 x 10^-14) / (6.5 x 10^-5) ≈ 1.54 x 10^-10

Step 3: Set Up the Equilibrium Expression

Let's denote:

- Initial concentration of benzoate, $[C6H5COO^-]_0$ = 0.20 M
- Change in concentration during hydrolysis = x (amount of benzoate converted to benzoic acid and hydroxide)

At equilibrium:

- $[C6H5COO^-]$ = 0.20 - x ≈ 0.20 M (since x is small)
- $[OH^-]$ = x

Using the Kb expression:

$K_b = [OH^-]^2 / [C6H5COO^-]$

Plugging in the known values:

$1.54 \times 10^{-10} = x^2 / 0.20$

Solve for x:

$x^2 = 1.54 \times 10^{-10} \times 0.20 = 3.08 \times 10^{-11}$

$x = \sqrt{(3.08 \times 10^{-11})} \approx 5.55 \times 10^{-6}$ M

This x represents the concentration of OH^- ions in solution.

Step 4: Calculate the pOH

$pOH = -\log[OH^-] = -\log(5.55 \times 10^{-6}) \approx 5.26$

Step 5: Determine the pH

$pH = 14 - pOH = 14 - 5.26 = 8.74$

Thus, the pH of the 0.20 M sodium benzoate solution is approximately 8.74.

Additional Considerations and Assumptions

Assumption of Negligible Change in Concentration

In the calculations, we assume that the change in benzoate concentration (x) is small compared to the initial concentration (0.20 M), which is valid here as x is very small.

Temperature Dependence

This calculation assumes standard temperature (25°C). Changes in temperature can affect Ka, Kb, and Kw, thereby influencing the pH.

Effect of Ionic Strength

In more concentrated solutions or in the presence of other ions, ionic strength can influence activity coefficients, slightly altering the calculation. For dilute solutions like this, the approximation is generally valid.

Summary and Final Thoughts

Calculating the pH of sodium benzoate solutions involves understanding the hydrolysis of the conjugate base and applying equilibrium principles. Given the molarity of 0.20 M and the Ka of benzoic acid (6.5×10^{-5}), the solution is mildly basic, with a pH approximately 8.74. This reflects the typical behavior of salt solutions derived from weak acids, demonstrating the importance of conjugate base hydrolysis in determining solution pH.

Practical Applications of pH Calculations in Chemistry

Accurate pH calculations are essential in various fields including:

- Pharmaceutical formulations
- Food preservation and safety
- Environmental chemistry and water quality analysis
- Industrial manufacturing processes

Understanding the principles demonstrated here can help chemists, students, and professionals develop better insights into solution chemistry and acid-base equilibria.

Conclusion

By carefully analyzing the hydrolysis of sodium benzoate and applying equilibrium concepts, we determined that a 0.20 M solution has a pH of approximately 8.74. This process underscores the significance of knowing Ka, Kb, and the relationships between conjugate acids and bases in calculating solution pH. Whether for academic purposes or practical applications, mastering these calculations enhances our understanding of chemical equilibria and solution behavior.

Frequently Asked Questions

What is the pH of a 0.20 M sodium benzoate solution given that the Ka of benzoic acid is 6.5 x 10^-5?

To find the pH, first recognize that sodium benzoate is the conjugate base of benzoic acid. Using the Kb for benzoate: Kb = Kw / Ka = 1.0 x 10^-14 / 6.5 x 10^-5 ≈ 1.54 x 10^-10. Assuming x is the concentration of OH- produced: x^2 / 0.20 ≈ 1.54 x 10^-10, so x ≈ √(3.08 x 10^-11) ≈ 5.55 x 10^-6 M. pOH = -log(5.55 x 10^-6) ≈ 5.26, thus pH ≈ 14 - 5.26 ≈ 8.74.

How does the pH of sodium benzoate solution relate to the Ka of benzoic acid?

Since sodium benzoate is the conjugate base of benzoic acid, its pH depends on the hydrolysis of the benzoate ion. A higher Ka (or lower pKa) of benzoic acid results in a more acidic conjugate base, but since sodium benzoate is a salt, it typically produces a basic solution with pH above 7.

What role does the Ka of benzoic acid play in

calculating the pH of sodium benzoate?

The Ka of benzoic acid helps determine the Kb for its conjugate base, sodium benzoate. Knowing Kb allows calculation of the hydroxide ion concentration and thus the pH of the solution.

Can you explain the steps to calculate the pH of a 0.20 M sodium benzoate solution?

Yes. First, calculate Kb = Kw / Ka. Then, set up an equilibrium expression for hydrolysis: C: benzoate + H2O ⇌ benzoic acid + OH−. Assume x is the concentration of OH−. Write the Kb expression: Kb = x^2 / initial concentration. Solve for x, then find pOH = −log(x), and finally pH = 14 − pOH.

If the concentration of sodium benzoate increases, how does the pH change?

Increasing the concentration of sodium benzoate increases the amount of hydrolysis, leading to a higher concentration of OH− ions and thus a higher pH, making the solution more basic.

What is the significance of the given Ka value in determining the buffer capacity of benzoate solutions?

The Ka value indicates the acid strength of benzoic acid; in the context of sodium benzoate, it helps assess how effectively the salt can resist pH changes when acids or bases are added, thus determining its buffer capacity.

How would the pH change if you dilute the sodium benzoate solution from 0.20 M to 0.10 M?

Diluting the solution decreases the concentration of benzoate ions, reducing the extent of hydrolysis and slightly lowering the pH. However, since the hydrolysis is weak, the pH remains above 7 but will decrease slightly with dilution.

Additional Resources

Calculate the pH of 0.20 M Sodium Benzoate, C_6H_5COONa, given that Ka (C_6H_5COOH) = 6.5×10^{-5}

Understanding how to calculate the pH of 0.20 M sodium benzoate is fundamental in acid-base chemistry, especially when dealing with salts derived from weak acids and strong bases. Sodium benzoate (C_6H_5COONa) is the sodium salt of benzoic acid, and its solution's pH is influenced by the hydrolysis of the benzoate ion ($C_6H_5COO^-$) in water. This guide provides a comprehensive step-by-step approach to determining the pH of such a solution using principles of equilibrium chemistry, including the relationship between Ka and Kb, hydrolysis reactions, and the equilibrium calculations involved.

Introduction to Sodium Benzoate and Its Hydrolysis

Sodium benzoate is a common preservative and a salt formed from benzoic acid (a weak acid) and sodium hydroxide (a strong base). When dissolved in water, sodium benzoate dissociates completely into sodium ions (Na^+) and benzoate ions ($C_6H_5COO^-$):

$$ \mathrm{C_6H_5COONa} \rightarrow \mathrm{Na}^+ + \mathrm{C_6H_5COO}^- $$

The sodium ion (Na^+), being a spectator ion, does not affect the pH significantly. However, the benzoate ion can undergo hydrolysis:

$$ \mathrm{C_6H_5COO}^- + \mathrm{H_2O} \rightleftharpoons \mathrm{C_6H_5COOH} + \mathrm{OH}^- $$

This hydrolysis produces hydroxide ions, making the solution slightly basic. Calculating the pH involves understanding this equilibrium and the relationships between the acid dissociation constant (Ka) of benzoic acid and the base hydrolysis constant (Kb) of benzoate.

Step 1: Understanding the Relationship Between Ka and Kb

Since benzoate is the conjugate base of benzoic acid, their dissociation constants are related by the ion-product constant of water (Kw):

$$ K_a \times K_b = K_w $$

Where:
- K_a = acid dissociation constant of benzoic acid = 6.5×10^{-5}
- K_b = base hydrolysis constant of benzoate (unknown)
- K_w = ion product of water at 25°C = 1.0×10^{-14}

Rearranged to find K_b:

$$ K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{6.5 \times 10^{-5}} $$

Calculating:

$$ K_b = \frac{1.0 \times 10^{-14}}{6.5 \times 10^{-5}} \approx 1.54 \times 10^{-10} $$

This K_b value characterizes the hydrolysis equilibrium of benzoate.

Step 2: Setting Up the Hydrolysis Equilibrium

The hydrolysis of benzoate ion can be represented as:

$$ \mathrm{C_6H_5COO}^- + \mathrm{H_2O} \rightleftharpoons \mathrm{C_6H_5COOH} + \mathrm{OH}^- $$

Let's define:
- x = concentration of OH^- produced at equilibrium

Initially, the concentration of benzoate is 0.20 M (from the salt dissociation). When hydrolysis occurs, some of the benzoate ions react to produce hydroxide and benzoic acid:

Species	Initial (M)	Change (M)	Equilibrium (M)
$\mathrm{C_6H_5COO}^-$	0.20	$-x$	$0.20 - x$
OH^-	0	$+x$	x
$\mathrm{C_6H_5COOH}$	0	$+x$	x

Applying the expression for K_b:

$$K_b = \frac{[\mathrm{C_6H_5COOH}][\mathrm{OH}^-]}{[\mathrm{C_6H_5COO}^-]}$$

$$K_b = \frac{x \times x}{0.20 - x} \approx \frac{x^2}{0.20}$$

Since K_b is very small (~1.54×10^{-10}), we can assume $x \ll 0.20$, simplifying:

$$\frac{x^2}{0.20} \approx 1.54 \times 10^{-10}$$

$$x^2 = 0.20 \times 1.54 \times 10^{-10}$$

$$x^2 = 3.08 \times 10^{-11}$$

$$x = \sqrt{3.08 \times 10^{-11}}$$

$$x \approx 5.55 \times 10^{-6} \text{ M}$$

This is the concentration of hydroxide ions at equilibrium.

Step 3: Calculating pOH and pH

With $[\mathrm{OH}^-] = 5.55 \times 10^{-6}$ M, calculate the pOH:

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

$$\mathrm{pOH} = -\log (5.55 \times 10^{-6})$$

$$\mathrm{pOH} \approx 5.26$$

Now, find the pH:

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

$$\mathrm{pH} = 14 - 5.26 = 8.74$$

Final Result: The pH of 0.20 M Sodium Benzoate

Therefore, the pH of a 0.20 M sodium benzoate solution is approximately 8.74. This indicates a slightly basic solution, consistent with the hydrolysis of the benzoate ion.

Additional Insights and Considerations

Factors Affecting pH Calculations
- Temperature: The value of \(K_w \) changes with temperature, affecting \(K_b \) and ultimately the pH.
- Concentration: Very dilute solutions may require more precise calculations considering activity coefficients.
- Presence of other ions: Additional ions can shift equilibrium positions.

Practical Applications
- Buffer Systems: Sodium benzoate acts as a buffer in certain formulations.
- Food Preservation: Understanding its pH helps in assessing its preservative effectiveness.

Summary of Steps to Calculate pH of Sodium Benzoate Solution

1. Identify the relevant acid dissociation constant \(K_a \) of benzoic acid.
2. Calculate the conjugate base's \(K_b \) using \(K_w / K_a \).
3. Set up the hydrolysis equilibrium expression for benzoate in water.
4. Assume \(x \ll \) initial concentration to simplify the quadratic equation.
5. Solve for hydroxide ion concentration \([\mathrm{OH}^-] \).
6. Calculate pOH and then pH from the hydroxide concentration.

Conclusion

Calculating the pH of 0.20 M sodium benzoate involves understanding the principles of acid-base equilibria, conjugate relationships, and hydrolysis reactions. By accurately determining \(K_b \) from \(K_a \), setting up the equilibrium expression, and making justified assumptions, you can derive the pH efficiently and precisely. This process exemplifies fundamental concepts in solution chemistry and highlights the importance of equilibrium calculations in practical scenarios involving weak acids and their conjugate bases.

Calculate The Ph Of 0 20 M Sodium Benzoate C6h5coona Ka C6h5cooh 6 5 X 10 5

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