Determine If The Solution Formed By Each Salt Is Acidic, Basic, Or Neutral. (K(NH3) = 1.76 X 10-5, Ka

Determine If The Solution Formed By Each Salt Is Acidic, Basic, Or Neutral. (K(NH3) = 1.76 X 10-5, Ka

Understanding whether a salt solution is acidic, basic, or neutral is a fundamental concept in chemistry, particularly in the study of salts and their hydrolysis behavior. This knowledge is crucial for various applications, including pharmaceutical formulations, environmental chemistry, and industrial processes. This article provides an in-depth explanation of how to determine the nature of solutions formed by different salts, emphasizing the role of equilibrium constants such as Kb for bases and Ka for acids, with particular focus on salts involving ammonia (NH_3) and related ions.

Introduction to Salt Hydrolysis and Solution pH

Salts are compounds formed from the neutralization of an acid with a base. When dissolved in water, salts can undergo hydrolysis — a process where the ions derived from the salt interact with water, leading to a change in hydrogen ion (H^+) or hydroxide ion (OH^-) concentration. This process influences whether the resulting solution is acidic, basic, or neutral.

Hydrolysis depends on the nature of the ions present:
- Cations that are conjugate acids of weak bases tend to produce acidic solutions.
- Anions that are conjugate bases of weak acids tend to produce basic solutions.
- Ions from strong acids and strong bases generally do not hydrolyze, resulting in a neutral solution.

Understanding Key Concepts and Constants

Before analyzing specific salts, it's essential to understand the constants involved:

Acid Dissociation Constant (Ka)

- Describes the strength of an acid in solution.
- For a weak acid (HA):
$HA \rightleftharpoons H^+ + A^-$
$K_a = [H^+][A^-] / [HA]$

Base Dissociation Constant (Kb)

- Describes the strength of a base in solution.
- For a weak base (B):
$B + H_2O \rightleftharpoons BH^+ + OH^-$
$K_b = [BH^+][OH^-] / [B]$

Relationship between Ka and Kb for conjugate acid-base pairs:
$K_a \times K_b = K_w = 1.0 \times 10^{-14}$ at 25°C

This relationship helps determine the acidity or basicity of a solution based on the ions present.

Ammonia and Its Ion

- Ammonia (NH_3) is a weak base with Kb = 1.76×10^{-5}.
- Its conjugate acid is NH_4^+ (ammonium ion).

Understanding the behavior of ammonia and its derivatives is vital when analyzing salts containing NH_4^+ or NH_3.

Analyzing Different Salts and Their Hydrolysis Behavior

The key to predicting whether a salt solution is acidic, basic, or neutral lies in analyzing its constituent ions and their hydrolysis tendencies.

1. Salts of Strong Acid and Strong Base

- Examples: NaCl, KBr, Na_2SO_4
- These salts do not hydrolyze in water because their ions are from strong acids and bases.
- Result: Solutions are neutral (pH ≈ 7).

2. Salts of Weak Acid and Strong Base

- Examples: CH_3COONa (sodium acetate), Na_2CO_3
- The conjugate base (e.g., CH_3COO^-) tends to accept protons from water, leading to basic solutions.
- Result: pH > 7 (alkaline).

3. Salts of Strong Acid and Weak Base

- Examples: NH_4Cl, NH_4NO_3
- The conjugate acid (NH_4^+) donates protons to water, producing an acidic solution.
- Result: pH < 7 (acidic).

4. Salts of Weak Acid and Weak Base

- Examples: NH_4CH_3COO, where both ions are weak conjugates.
- The pH depends on the relative strengths of the conjugate acid and base.
- Usually, such solutions are slightly acidic or basic, depending on which ion is stronger.

Case Study: Salts Involving Ammonia (NH_3)

Given the specific Kb for ammonia ($K(NH_3) = 1.76 \times 10^{-5}$), analyzing salts containing ammonium (NH_4^+) or ammonia itself offers insights into their solution behavior.

1. Ammonium Salt (e.g., NH_4Cl)

- NH_4Cl is formed from ammonia (weak base) and hydrochloric acid (strong acid).
- Upon dissolution, it produces NH_4^+ and Cl^-.
- NH_4^+ can donate a proton to water, forming H_3O^+, which makes the solution acidic.

Calculation of acidity:

Using the conjugate acid (NH_4^+) dissociation:

$NH_4^+ + H_2O$ ⍰ $NH_3 + H_3O^+$

The acid dissociation constant (Ka) for NH_4^+ can be derived from Kb of NH_3:

$Ka(NH_4^+) = Kw / Kb(NH_3)$
$= 1.0 \times 10^{-14} / 1.76 \times 10^{-5}$
$\approx 5.68 \times 10^{-10}$

Since Ka is small but non-zero, NH_4^+ is a weak acid, and the solution is acidic (pH < 7).

Conclusion: Salts like NH_4Cl produce acidic solutions because their cation is a conjugate acid of a weak base.

2. Ammonia Salt (e.g., NH_4OH)

- NH_4OH is not a typical salt but a weak base (ammonia in water).
- When dissolved, it produces NH_3 and OH^-, resulting in a basic solution.
- The Kb for NH_3 is given as 1.76×10^{-5}, indicating a weak base.

pH calculation:

Using Kb and concentration, we can determine the pOH and pH.

Summary:

Salt Type	Solution pH	Explanation
Ammonium salt (e.g., NH_4Cl)	< 7	Conjugate acid of weak base, hydrolyzes to produce H_3O^+
Ammonia (NH_3) in water	> 7	Weak base, hydrolyzes to produce OH^-

Practical Steps to Determine the Nature of a Salt Solution

To systematically determine whether a salt solution is acidic, basic, or neutral, follow these steps:

1. Identify the ions present in the salt.
2. Determine if the ions are from strong or weak acids/bases:
    - Strong acid ⍰ conjugate base is negligible; no hydrolysis.
    - Strong base ⍰ conjugate acid is negligible; no hydrolysis.
    - Weak acid or weak base ⍰ potential hydrolysis and pH change.
3. Calculate or compare the relevant equilibrium constants (Ka or Kb):
    - If Ka > Kb, solution tends to be acidic.
    - If Kb > Ka, solution tends to be basic.
    - If Ka ≈ Kb, solution tends to be neutral.

4. Use the relationship $K_a \times K_b = K_w$ to find the missing constant if needed.
5. Estimate or calculate pH based on hydrolysis equilibrium expressions.

Note: For salts involving polyprotic acids or bases, or more complex ions, additional steps may be needed involving multiple equilibria.

Sample Calculations and Examples

Let's work through a sample problem to illustrate the process:

Example 1: Is Sodium Acetate ($NaCH_3COO$) solution basic, acidic, or neutral?

- Sodium acetate contains Na^+ and CH_3COO^-.
- Na^+ is from a strong base ($NaOH$) and does not hydrolyze.
- CH_3COO^- is from acetic acid (weak acid), and its conjugate base tends to accept protons from water.

Hydrolysis of CH_3COO^-:

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

The K_b for acetate can be calculated:

$K_b(CH_3COO^-) = K_w / K_a(CH_3COOH)$
$= 1.0 \times 10^{-14} / 1.8 \times 10^{-5} \approx 5.56 \times 10^{-10}$

Since K_b is

Frequently Asked Questions

Given the K_b value for ammonia as 1.76×10^{-5}, how can we determine if the solution formed by ammonium salt is acidic, basic, or neutral?

By calculating the pK_a of the ammonium ion and comparing it to 7.0: if $pK_a < 7$, the solution is acidic; if $pK_a > 7$, it's basic; and if $pK_a \approx 7$, it's neutral.

What is the significance of the K_b value of 1.76×10^{-5} for ammonia when determining the nature of its salt solution?

This K_b value indicates the strength of ammonia as a base; it helps in calculating the pOH and pH of the salt solution, thereby determining if the solution is acidic, basic, or neutral.

How do you calculate the pH of a salt solution derived from ammonia and a

strong acid?

First, identify the salt's hydrolysis reaction, then calculate the concentration of H^+ or OH^- produced, using the Ka or Kb values, to find the pH. For ammonium salts, since NH_4^+ is a weak acid, the solution is typically slightly acidic.

If a salt contains the ammonium ion, will its solution generally be acidic, basic, or neutral?

Since ammonium ion (NH_4^+) is a weak acid, solutions of salts containing NH_4^+ tend to be slightly acidic.

How does the value of Ka for the conjugate acid relate to the basicity or acidity of the salt solution?

A higher Ka indicates a stronger acid, leading to a more acidic solution; conversely, a lower Ka suggests weaker acidity and potentially a neutral or basic solution if the conjugate base is strong.

What is the process to determine whether a salt solution is neutral, acidic, or basic using Kb and Ka values?

Calculate the pKa of the conjugate acid or the pKb of the conjugate base. Compare these to 7: $pKa < 7$ indicates acidity, $pKa > 7$ indicates basicity, and $pKa \approx 7$ indicates neutrality.

Why is it important to know Kb and Ka values when analyzing the pH of salt solutions?

Because these equilibrium constants determine the extent of hydrolysis of the salt's ions in water, which directly affects whether the solution is acidic, basic, or neutral.

Can the solution formed by a salt with $K(NH_3) = 1.76 \times 10^{-5}$ be neutral? Why or why not?

Generally, salts derived from weak bases like ammonia tend to produce slightly basic solutions due to hydrolysis, so unless other factors intervene, the solution is unlikely to be neutral.

Additional Resources

Determine If The Solution Formed By Each Salt Is Acidic, Basic, Or Neutral (K(NH3) = 1.76 × 10-5, Ka)

Introduction

Salts are a fundamental component of chemistry, representing compounds formed by the combination of acids and bases. When salts dissolve in water, they can produce solutions that are acidic, basic, or neutral, depending on their constituent ions and their interactions with water molecules. Determining the nature of these solutions is essential in various fields, including analytical chemistry, environmental science, and industrial processes.

One particularly interesting case involves salts derived from weak acids and weak bases, which can produce solutions with varying pH levels. The salt in focus here involves the ammonium ion (NH4+) and possibly other ions, with given equilibrium constants such as the base dissociation constant (Kb) for ammonia (NH3) being 1.76 × 10-5. The goal is to analyze whether the solution formed by such salts is acidic, basic, or neutral by

understanding the underlying chemistry, especially the behavior of ammonium ions in aqueous solutions.

This comprehensive review aims to elucidate the principles necessary to determine the solution's nature, considering the relevant constants, the interactions between ions and water, and the broader implications of these findings.

Section 1: Understanding Salts and Their Dissociation in Water

1.1 What Are Salts?

Salts are ionic compounds formed from the neutralization of acids and bases. They typically consist of cations derived from bases and anions derived from acids. When dissolved in water, salts dissociate into their constituent ions, which then interact with the solvent to influence the solution's pH.

1.2 Dissociation of Salts in Aqueous Solutions

The dissociation process depends on the nature of the ions:

- Strong acids and bases dissociate completely.
- Weak acids and bases dissociate partially, establishing equilibrium between their undissociated form and ions.

For example:

- Sodium chloride (NaCl), from a strong acid (HCl) and strong base (NaOH), yields neutral solutions.
- Ammonium chloride (NH_4Cl), from a weak base (NH_3) and a strong acid (HCl), produces an acidic solution.
- Sodium acetate (CH_3COONa), from a weak acid (acetic acid) and a strong base (NaOH), results in a basic solution.

1.3 The Role of Ion Hydrolysis in pH Determination

The pH of a salt solution is significantly affected by hydrolysis — the reaction of ions with water:

- Cations that are conjugate acids of weak bases tend to hydrolyze to produce H^+ ions, making the solution acidic.
- Anions that are conjugate bases of weak acids tend to hydrolyze to produce OH^- ions, making the solution basic.
- If neither ion hydrolyzes significantly, the solution remains neutral.

Understanding these interactions is key to predicting the pH of the solution formed by a particular salt.

Section 2: Analyzing the Specific Salt: Ammonium-Based Compounds

2.1 The Ammonium Ion (NH_4^+) and Its Hydrolysis Behavior

The ammonium ion (NH_4^+) originates from ammonia (NH_3), a weak base. When NH_4^+ is present in water, it can act as an acid:

$$
\mathrm{NH_4^+} + \mathrm{H_2O} \rightleftharpoons \mathrm{NH_3} + \mathrm{H_3O^+}
$$

This hydrolysis releases hydrogen ions (H_3O^+), lowering the pH and thus making the solution acidic.

2.2 The Relationship Between K_b and K_a for NH_4^+

The acidity or basicity of ions can be quantified using their equilibrium constants:

- K_a: Acid dissociation constant, for acids donating protons.
- K_b: Base dissociation constant, for bases accepting protons.

For conjugate acid-base pairs:

$$
K_a \times K_b = K_w
$$

where K_w is the ionization constant of water (1.0×10^{-14}) at 25°C).

Given:

$$
K_b(\mathrm{NH_3}) = 1.76 \times 10^{-5}
$$

then:

$$
K_a(\mathrm{NH_4^+}) = \frac{K_w}{K_b(\mathrm{NH_3})} = \frac{1.0 \times 10^{-14}}{1.76 \times 10^{-5}} \approx 5.68 \times 10^{-10}
$$

This very small K_a indicates that NH_4^+ is a weak acid, capable of releasing H^+ ions into water but to a limited extent.

2.3 Implications for Salt Solutions

If the salt contains NH_4^+ as the cation, the solution will tend to be slightly acidic because of hydrolysis, unless the anion exerts a stronger basic influence or other factors intervene.

Section 3: The Significance of K(NH3) in Hydrolysis

3.1 Clarifying K(NH3)

In the context of the question, K(NH3) likely refers to the equilibrium constant for ammonia's base dissociation (K_b), which is given as:

$$
K_b(\mathrm{NH_3}) = 1.76 \times 10^{-5}
$$

This constant quantifies ammonia's ability to accept a proton:

$$
\mathrm{NH_3} + \mathrm{H_2O} \rightleftharpoons \mathrm{NH_4^+} + \mathrm{OH^-}
$$

3.2 Connecting K(NH3) to the Behavior of the Salt

The strength of ammonia as a base, reflected in its K_b, influences the acidity of its conjugate acid, NH_4^+. A small K_b indicates weak basicity, thus the conjugate acid (NH_4^+) is weak but still capable of hydrolysis, producing H^+ ions.

Section 4: Determining the Nature of the Solution

4.1 General Approach

To determine whether the solution is acidic, neutral, or basic, analyze the hydrolysis tendencies of the ions:

- Cation (e.g., NH_4^+): Tends to hydrolyze to produce H^+.
- Anion (e.g., Cl^-): If from a strong acid, generally inert; if from a weak acid, may hydrolyze to produce OH^-.

Given the information, the focus is on salts containing the ammonium ion, with the knowledge of K_b for ammonia.

4.2 Calculating the pH of the Solution

The hydrolysis of NH_4^+ can be represented as:

$$
\mathrm{NH_4^+} + \mathrm{H_2O} \rightleftharpoons \mathrm{NH_3} + \mathrm{H_3O^+}
$$

The equilibrium constant for this process (K_a) is:

$$
K_a = 5.68 \times 10^{-10}
$$

The initial concentration of NH_4^+ (from the salt) influences the extent of hydrolysis and the resulting pH.

Step-by-step calculation approach:

1. Define the initial concentration of the salt, say $[\mathrm{NH_4^+}]_0 = C$.

2. Set up the hydrolysis equilibrium:

$$
\mathrm{NH_4^+} \rightleftharpoons \mathrm{NH_3} + \mathrm{H^+}
$$

with equilibrium concentration $[\mathrm{H^+}] = x$.

3. Apply the equilibrium expression:

$$
K_a = \frac{[\mathrm{NH_3}][\mathrm{H^+}]}{[\mathrm{NH_4^+}]} \approx \frac{x \times x}{C - x} \approx \frac{x^2}{C}
$$

assuming $x \ll C$.

4. Solve for x:

$$
x = \sqrt{K_a \times C}
$$

5. Calculate pH:

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