

# Acid–Base Properties of Salts

Why are some salt solutions acidic or basic, and how do you calculate their pH?

●●○ Intermediate

Acids & Bases

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**Before you start:** it helps to understand [Weak Acids and Ka](#) and [pH and the pH Scale](#).

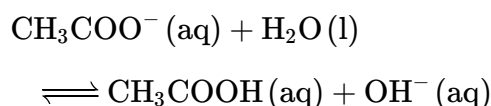
## What is it?

A **salt** is the ionic compound formed when an acid neutralizes a base. You might expect every salt solution to be neutral, but many are not:

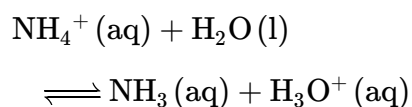
- Sodium chloride solution has pH 7.
- Sodium ethanoate (sodium acetate) solution is **basic**.
- Ammonium chloride solution is **acidic**.

The reason is that some ions react with water. This reaction is called **hydrolysis**.

- The **conjugate base of a weak acid** (such as  $\text{CH}_3\text{COO}^-$  or  $\text{F}^-$ ) takes a proton from water, making  $\text{OH}^-$ :



- The **conjugate acid of a weak base** (such as  $\text{NH}_4^+$ ) gives a proton to water, making  $\text{H}_3\text{O}^+$ :



- The conjugates of **strong** acids and bases ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) are far too weak to react with water: they are **neutral**.

### KEY IDEA

Look at where the salt came from. **The “parent” that is stronger wins.** Strong acid + strong base gives a neutral salt; strong acid + weak base gives an **acidic** salt; weak acid + strong base gives a **basic** salt.

## Why does it matter?

- **Titration end points.** At the equivalence point of a weak acid–strong base titration, the solution contains only the salt, so the pH is **above 7**. This decides which indicator to use.
- **Everyday chemistry.** Baking soda and washing soda solutions are basic; ammonium salts in fertilizers make soil more acidic.
- **Medicine and biology.** Many drugs are given as salts, and their pH in solution affects how they are absorbed.

## How does it work?

### 1. Predicting acidic, basic or neutral

| Salt made from            | Example                    | Ion that hydrolyses                               | Solution                   |
|---------------------------|----------------------------|---------------------------------------------------|----------------------------|
| Strong acid + strong base | NaCl, KNO <sub>3</sub>     | none                                              | <b>neutral</b> , pH 7      |
| Strong acid + weak base   | NH <sub>4</sub> Cl         | NH <sub>4</sub> <sup>+</sup>                      | <b>acidic</b> , pH below 7 |
| Weak acid + strong base   | CH <sub>3</sub> COONa, NaF | CH <sub>3</sub> COO <sup>−</sup> , F <sup>−</sup> | <b>basic</b> , pH above 7  |

(For a salt of a weak acid **and** a weak base, compare  $K_a$  of the cation with  $K_b$  of the anion.)

### 2. $K_a \times K_b = K_w$

For any conjugate acid–base pair in water:

$$K_a \times K_b = K_w = 1.0 \times 10^{-14} \text{ at } 25^\circ \text{C}$$

So the **weaker** the acid, the **stronger** its conjugate base. You can find  $K_b$  for CH<sub>3</sub>COO<sup>−</sup> from  $K_a$  for ethanoic acid, and  $K_a$  for NH<sub>4</sub><sup>+</sup> from  $K_b$  for ammonia.

### 3. Calculating the pH of a salt solution

Treat the hydrolysing ion as a weak base (or weak acid) and use the same method as for weak acids:

1. Find  $K_b$  (or  $K_a$ ) of the ion from  $K_a K_b = K_w$ .
2. Set up the equilibrium:  $x = [\text{OH}^-]$  (or  $[\text{H}_3\text{O}^+]$ ), and  $x \approx \sqrt{KC}$  if  $x$  is small.
3. Convert to pH.

## ∞ THINK OF IT LIKE THIS

Think of a tug of war between two teams, the parent acid and the parent base. If both teams are strong, they cancel and the rope doesn't move (neutral). If one is strong and the other weak, the strong side's partner (the conjugate ion of the weak side) still pulls a little: the solution leans towards the weak parent's opposite.

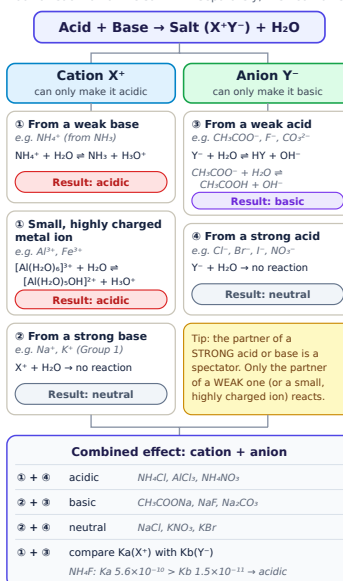
## 🔍 MORE PRECISELY

Small, highly charged metal ions such as  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  also make solutions acidic: the hydrated ion, e.g.  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ , releases a proton from one of its water molecules. The relationship  $K_a K_b = K_w$  can also be written  $\text{p}K_a + \text{p}K_b = 14.00$  at 25 °C.  $K_w$  increases with temperature, so neutral pH is slightly below 7 in hot water.

## Visualise it

### pH of a salt solution: a summary

Look at each ion of the salt  $\text{X}^+\text{Y}^-$  separately, then combine.

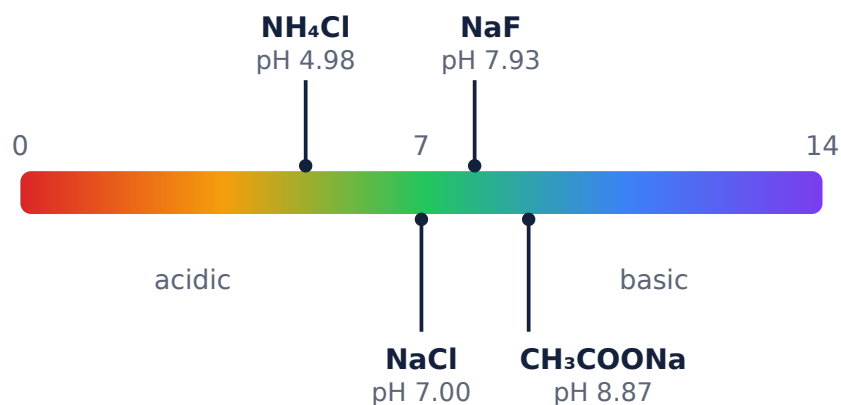


Summary: judge each ion of the salt separately, then combine their effects.

Applying the chart to four solutions gives these pH values:

## pH of salt solutions

Parent acid + parent base decide the pH



0.20 M  $\text{NH}_4\text{Cl}$  · 0.10 M  $\text{NaCl}$  · 0.050 M  $\text{NaF}$  · 0.10 M  $\text{CH}_3\text{COONa}$

The parent acid and base decide whether a salt solution is acidic, neutral or basic.

## Worked example

### WORKED EXAMPLE: Acidic, basic or neutral?

**Question:** Predict whether solutions of (a)  $\text{KNO}_3$  (b)  $\text{NH}_4\text{NO}_3$  (c)  $\text{Na}_2\text{CO}_3$  (d)  $\text{KF}$  are acidic, basic or neutral.

**Step 1** (a) From  $\text{HNO}_3$  (strong) and  $\text{KOH}$  (strong): **neutral**.

**Step 2** (b)  $\text{NH}_4^+$  comes from  $\text{NH}_3$  (weak base);  $\text{NO}_3^-$  is neutral: **acidic**.

**Step 3** (c)  $\text{CO}_3^{2-}$  comes from a weak acid;  $\text{Na}^+$  is neutral: **basic**.

**Step 4** (d)  $\text{F}^-$  comes from  $\text{HF}$  (weak acid): **basic**.

### WORKED EXAMPLE: Finding $K_b$ from $K_a$

**Question:** Find  $K_b$  for the ethanoate ion, given  $K_a(\text{CH}_3\text{COOH}) = 1.8 \times 10^{-5}$ .

$$\begin{aligned} K_b &= \frac{K_w}{K_a} \\ &= \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} \\ &= 5.6 \times 10^{-10} \end{aligned}$$

 **WORKED EXAMPLE:** pH of a basic salt

**Question:** Calculate the pH of 0.10 mol/L sodium ethanoate.

**Step 1**  $\text{CH}_3\text{COO}^-$  is a weak base with  $K_b = 5.6 \times 10^{-10}$ . Let  $x = [\text{OH}^-]$ :

$$\begin{aligned}x &\approx \sqrt{K_b C} \\&= \sqrt{5.6 \times 10^{-10} \times 0.10} \\&= 7.48 \times 10^{-6} \text{ mol/L}\end{aligned}$$

**Step 2** Check:  $x$  is far below 5 % of 0.10 mol/L, so the approximation holds.

**Step 3** pOH and pH:

$$\begin{aligned}\text{pOH} &= -\log(7.48 \times 10^{-6}) \\&= 5.13 \\ \text{pH} &= 14.00 - 5.13 = 8.87\end{aligned}$$

 **WORKED EXAMPLE:** pH of an acidic salt

**Question:** Calculate the pH of 0.20 mol/L ammonium chloride. ( $K_b(\text{NH}_3) = 1.8 \times 10^{-5}$ )

**Step 1**  $K_a(\text{NH}_4^+) = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10}$

**Step 2** Let  $x = [\text{H}_3\text{O}^+]$ :

$$\begin{aligned}x &\approx \sqrt{5.6 \times 10^{-10} \times 0.20} \\&= 1.058 \times 10^{-5} \text{ mol/L}\end{aligned}$$

**Step 3**  $\text{pH} = -\log(1.058 \times 10^{-5}) = 4.98$

## Common mistake

 **COMMON MISTAKE:** Assuming every salt is neutral

“Salt” does not mean “neutral”. Only salts of a **strong** acid and a **strong** base give pH 7. Check the parents of both ions.

 **COMMON MISTAKE:** Using  $K_a$  of the parent acid directly

The base in a sodium ethanoate solution is  $\text{CH}_3\text{COO}^-$ , not ethanoic acid. Convert first:  $K_b = K_w / K_a$ .

 **COMMON MISTAKE:** Forgetting to convert pOH to pH

For a basic salt, the calculation gives  $[\text{OH}^-]$  and pOH. Finish with  $\text{pH} = 14.00 - \text{pOH}$ .

 **NOTATION NOTE**

- Hydrolysis is shown with equilibrium arrows ( $\rightleftharpoons$ ) because only a small fraction of the ions react.
- Units:  $K_a$  and  $K_b$  are written without units (they are ratios of concentrations relative to 1 mol/L).

## Remember this

 **REMEMBER THIS**

- Strong acid + strong base  $\rightarrow$  neutral salt; strong acid + weak base  $\rightarrow$  acidic; weak acid + strong base  $\rightarrow$  basic.
- Conjugates of strong acids and bases ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) don't hydrolyse.
- $K_a \times K_b = K_w = 1.0 \times 10^{-14}$  at 25 °C.
- pH of a salt: find  $K$  of the hydrolysing ion, then  $x \approx \sqrt{KC}$ , then pH.

## References

- Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

Practise this topic with flashcards and a quiz at [chemistryclarity.com/chemistry/acid-base-properties-of-salts/](https://chemistryclarity.com/chemistry/acid-base-properties-of-salts/)