

pH and the pH Scale

What is pH and how do you calculate it?

●●○ Intermediate

Acids & Bases

Last reviewed 3 October 2026

Before you start: it helps to understand [What Are Acids and Bases?](#) and [Molarity and Solution Stoichiometry](#).

What is it?

pH is a number that tells you how acidic or basic a solution is. It is based on the concentration of hydronium ions, H_3O^+ :

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

where $[\text{H}_3\text{O}^+]$ is the concentration in mol/L.

At 25 °C:

- **pH < 7:** acidic
- **pH = 7:** neutral
- **pH > 7:** basic (also called alkaline)

KEY IDEA

The pH scale is **logarithmic**: each change of 1 pH unit means a **10-fold** change in $[\text{H}_3\text{O}^+]$. A solution at pH 3 has 1000 times more H_3O^+ than one at pH 6.

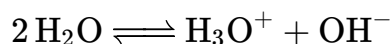
Why does it matter?

- **Living things depend on it.** Human blood is kept between about pH 7.35 and 7.45; a change of a few tenths can be dangerous.
- **Chemistry depends on it.** The speed and outcome of many reactions, and how well many substances dissolve, change with pH.
- **Everyday life depends on it.** Soil pH affects which crops grow, swimming pools and drinking water are kept within set pH ranges, and many food and cleaning products are designed around their pH.

How does it work?

1. Water always contains a little H_3O^+ and OH^-

Water reacts with itself very slightly:



At 25 °C, the product of the two concentrations is always the same constant, K_w :

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$$

In pure water both concentrations are 1.0×10^{-7} M, so the pH is 7.00. Adding acid raises $[\text{H}_3\text{O}^+]$ and lowers $[\text{OH}^-]$, and adding base does the opposite.

2. pOH and the link between pH and pOH

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

and, at 25 °C,

$$\text{pH} + \text{pOH} = 14.00$$

3. Strong acids and bases

A strong acid ionizes completely, so $[\text{H}_3\text{O}^+]$ equals the acid's concentration (for acids that give one H^+ , such as HCl and HNO_3). Likewise, for a strong base, $[\text{OH}^-]$ comes straight from its concentration, **remembering how many OH^- each formula unit releases** (2 for $\text{Ca}(\text{OH})_2$).

4. Going back from pH to concentration

$$[\text{H}_3\text{O}^+] = 10^{-\text{pH}}$$

THINK OF IT LIKE THIS

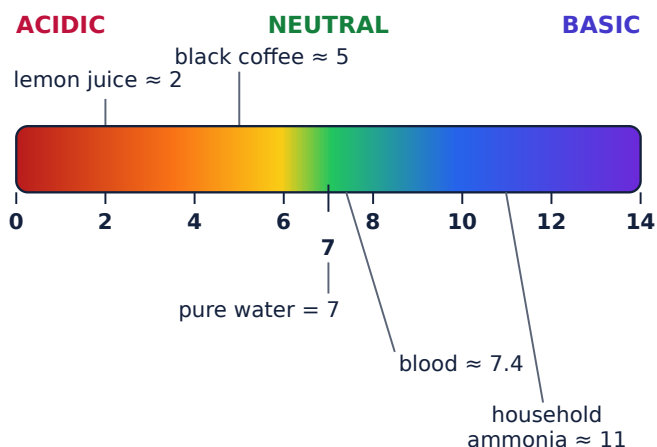
Think of prices that each have one more zero: 10, 100, 1,000, 10,000. Each step is ten times the last. The pH scale counts those zeros: each step **down** in pH means ten times more H_3O^+ . So pH 4 isn't twice as acidic as pH 8. It has **10,000 times** more H_3O^+ .

MORE PRECISELY

K_w changes with temperature, so neutral water has pH 7.00 only at 25 °C (at higher temperatures, neutral pH is a little lower). pH can also be below 0 or above 14 for very concentrated acids or bases. For very dilute acids, the H_3O^+ from water itself can't be ignored: 1×10^{-8} M HCl is slightly acidic, not pH 8. Strictly, pH is defined using *activity* rather than concentration, but concentration works well for dilute solutions.

Visualise it

The pH scale (at 25 °C)



Each step of 1 pH unit = a 10× change in $[\text{H}_3\text{O}^+]$.
Everyday values are approximate. Colour is a guide only.

The pH scale. Each step is a 10× change in $[\text{H}_3\text{O}^+]$.

Worked example

WORKED EXAMPLE: pH of a strong acid

Question: What is the pH of 0.050 M hydrochloric acid?

Step 1 HCl is a strong acid, so $[\text{H}_3\text{O}^+] = 0.050 \text{ M}$.

Step 2 $\text{pH} = -\log(0.050) = 1.30$

WORKED EXAMPLE: pH of a strong base

Question: What is the pH of 0.020 M calcium hydroxide, $\text{Ca}(\text{OH})_2$?

Step 1 Each $\text{Ca}(\text{OH})_2$ releases **two** OH^- ions: $[\text{OH}^-] = 2 \times 0.020 = 0.040 \text{ M}$

Step 2 $\text{pOH} = -\log(0.040) = 1.40$

Step 3 $\text{pH} = 14.00 - 1.40 = 12.60$

WORKED EXAMPLE: Concentration from pH

Question: A solution has pH 4.50. What is $[\text{H}_3\text{O}^+]$?

$[\text{H}_3\text{O}^+] = 10^{-4.50} = 3.2 \times 10^{-5} \text{ M}$

Common mistake

COMMON MISTAKE: Thinking the pH scale is linear

pH 4 is **not** twice as acidic as pH 8. Each pH unit is a factor of 10, so the difference is $10^4 = 10,000$ times.

COMMON MISTAKE: Forgetting the number of OH⁻ ions

For Ca(OH)₂ or Ba(OH)₂, [OH⁻] is **twice** the concentration of the base. Using 0.020 M instead of 0.040 M in the example gives pH 12.30 instead of 12.60.

COMMON MISTAKE: Mixing up pH and pOH

For a base, you usually calculate **pOH** first from [OH⁻], then convert: pH = 14.00 – pOH. Reporting the pOH as the pH is a very common slip.

NOTATION NOTE

- [H⁺] and [H₃O⁺] are used interchangeably in pH calculations.
- **Significant figures:** the number of decimal places in a pH equals the number of significant figures in the concentration. 0.050 M (2 s.f.) gives pH 1.30 (2 decimal places).
- “log” here means the base-10 logarithm (the “log” key on a calculator, not “ln”).

Remember this

REMEMBER THIS

- pH = $-\log[\text{H}_3\text{O}^+]$; $[\text{H}_3\text{O}^+] = 10^{-\text{pH}}$.
- At 25 °C: pH < 7 acidic, = 7 neutral, > 7 basic; pH + pOH = 14.00.
- 1 pH unit = 10× change in [H₃O⁺].
- **Strong acids/bases:** concentration of H₃O⁺ or OH⁻ comes straight from the formula (count the OH⁻!).

References

1. 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.

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