Objectives

- **Describe** the self-ionization of water.
- **Define** pH, and give the pH of a neutral solution at 25°C.
- **Explain** and use the pH scale.
- **Given** $[H_3O^+]$ or $[OH^-]$, **find** pH.
- **Given** pH, **find** $[H_3O^+]$ or $[OH^-]$.

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Hydronium Ions and Hydroxide Ions

Self-Ionization of Water

- In the **self-ionization of water,** two water molecules produce a hydronium ion and a hydroxide ion by transfer of a proton.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

- In water at 25°C, $[H_3O^+] = 1.0 \times 10^{-7}$ M and $[OH^-] = 1.0 \times 10^{-7}$ M.
- *The ionization constant of water, K_w,* is expressed by the following equation.

$$K_w = [H_3O^+][OH^-]$$

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Hydronium Ions and Hydroxide Ions, *continued*

Self-Ionization of Water, *continued*

- At 25°C,

$$K_w = [H_3O^+][OH^-] = (1.0 \times 10^{-7})(1.0 \times 10^{-7}) = 1.0 \times 10^{-14}$$

- *K_w increases as temperature increases*

Temperature (°C)	K_w
0	1.2×10^{-15}
10	3.0×10^{-15}
25	1.0×10^{-14}
50	5.3×10^{-14}

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Hydronium Ions and Hydroxide Ions, *continued*

Neutral, Acidic, and Basic Solutions

- Solutions in which $[H_3O^+] = [OH^-]$ is *neutral.*
- Solutions in which the $[H_3O^+] > [OH^-]$ are *acidic.*
  - $[H_3O^+]$ **>** 1.0×10^{-7} *M*
- Solutions in which the $[OH^-] > [H_3O^+]$ are *basic.*
  - $[OH^-] > 1.0 \times 10^{-7}$ *M*

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Chapter menu Resources

Hydronium Ions and Hydroxide Ions, *continued*
Calculating $[H_3O^+]$ and $[OH^-]$

- Strong acids and bases are considered completely ionized or dissociated in weak aqueous solutions.

$$\underset{1\text{ mol}}{NaOH(s)} \xrightarrow{H_2O} \underset{1\text{ mol}}{Na^+(aq)} + \underset{1\text{ mol}}{OH^-(aq)}$$

- 1.0×10^{-2} M NaOH solution has an $[OH^-]$ of 1.0×10^{-2} M
- The $[H_3O^+]$ of this solution is calculated using K_w.

$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

$$[H_3O^+] = \frac{1.0\times10^{-14}}{[OH^-]} = \frac{1.0\times10^{-14}}{1.0\times10^{-2}} = 1.0\times10^{-12}\text{ M}$$

End of Slide

Hydronium Ions and Hydroxide Ions, *continued*
Calculating $[H_3O^+]$ and $[OH^-]$

- If the $[H_3O^+]$ of a solution is known, the $[OH^-]$ can be calculated using K_w.

$$[HCl] = 2.0 \times 10^{-4}\text{ M}$$
$$[H_3O^+] = 2.0 \times 10^{-4}\text{ M}$$
$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

$$[OH^-] = \frac{1.0\times10^{-14}}{[H_3O^+]} = \frac{1.0\times10^{-14}}{2.0\times10^{-4}} = 5.0\times10^{-10}\text{ M}$$

End of Slide

Some Strong Acids and Some Weak Acids

Acid	Formula	K_a of acid	Conjugate base	Formula
Hydronium ion	H_3O^+	5.53×10^1	water	H_2O
Hydrogen sulfate ion	HSO_4^-	1.23×10^{-2}	sulfate ion	SO_4^{2-}
Phosphoric acid	H_3PO_4	7.52×10^{-3}	dihydrogen phosphate ion	$H_2PO_4^-$
Formic acid	HCOOH	1.82×10^{-4}	formate ion	$HCOO^-$
Benzoic acid	C_6H_5COOH	6.46×10^{-5}	benzoate ion	$C_6H_5COO^-$
Acetic acid	CH_3COOH	1.75×10^{-5}	acetate ion	CH_3COO^-
Carbonic acid	H_2CO_3	4.30×10^{-7}	hydrogen carbonate ion	HCO_3^-
Dihydrogen phosphate ion	$H_2PO_4^-$	6.31×10^{-8}	monohydrogen phosphate ion	HPO_4^{2-}
Hypochlorous acid	HOCl	2.95×10^{-9}	hypochlorite ion	ClO^-
Ammonium ion	NH_4^+	5.75×10^{-10}	ammonia	NH_3
Hydrogen carbonate ion	HCO_3^-	4.68×10^{-11}	carbonate ion	CO_3^{2-}
Monohydrogen phosphate ion	HPO_4^{2-}	4.47×10^{-13}	phosphate ion	PO_4^{3-}
Water	H_2O	1.81×10^{-16}	hydroxide ion	OH^-
Conjugate acid	Formula	K_a of acid	Base	Formula

Increasing acid strength ↑ Increasing base strength ↓

Concentrations and K_w

Solution	$[H_3O^+]$ (M)	$[OH^-]$ (M)	$K_w = [H_3O^+][OH^-]$
Pure water	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-14}
0.10 M strong acid	1.0×10^{-1}	1.0×10^{-13}	1.0×10^{-14}
0.010 M strong acid	1.0×10^{-2}	1.0×10^{-12}	1.0×10^{-14}
0.10 M strong base	1.0×10^{-13}	1.0×10^{-1}	1.0×10^{-14}
0.010 M strong base	1.0×10^{-12}	1.0×10^{-2}	1.0×10^{-14}
0.025 M strong acid	2.5×10^{-2}	4.0×10^{-13}	1.0×10^{-14}
0.025 M strong base	4.0×10^{-13}	2.5×10^{-2}	1.0×10^{-14}

Hydronium Ions and Hydroxide Ions, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$

Sample Problem A

A 1.0×10^{-4} M solution of HNO_3 has been prepared for a laboratory experiment.

a. Calculate the $[H_3O^+]$ of this solution.

b. Calculate the $[OH^-]$.

End of Slide

Hydronium Ions and Hydroxide Ions, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$, *continued*

Sample Problem A Solution

Given: Concentration of the solution = 1.0×10^{-4} M HNO_3

Unknown: **a.** $[H_3O^+]$
b. $[OH^-]$

Solution:

- HNO_3 is a strong acid

a. $HNO_3(l) + H_2O(l) \rightarrow H_3O^+(aq) + NO_3^-(aq)$

1 mol **1 mol** **1 mol** **1 mol**

End of Slide

Hydronium Ions and Hydroxide Ions, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$, *continued*

Sample Problem A Solution, *continued*

a.

b. $[H_3O^+][OH^-] = 1.0 \times 10^{-14}$

End of Slide

Hydronium Ions and Hydroxide Ions, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$, *continued*

Sample Problem A Solution, *continued*

a.

1.0×10^{-4} M H_3O^+

b.

1.0×10^{-10} M

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The pH Scale

- The **pH** of a solution is defined as the negative of the common logarithm of the hydronium ion concentration, $[H_3O^+]$.

$$pH = -\log [H_3O^+]$$

  - example: a neutral solution has a $[H_3O^+] = 1\times10^{-7}$
  - The logarithm of 1×10^{-7} is −7.0.

$$pH = -\log [H_3O^+] = -\log(1 \times 10^{-7}) = -(-7.0) = 7.0$$

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pH Values as Specified $[H_3O^+]$

Solution	$[H_3O^+]$ (M)	pH
1.00 L of H_2O	1.00×10^{-7}	7.00
0.100 mol HCl in 1.00 L of H_2O	1.00×10^{-1}	1.00
0.0100 mol HCl in 1.00 L of H_2O	1.00×10^{-2}	2.00
0.100 mol NaCl in 1.00 L of H_2O	1.00×10^{-7}	7.00
0.0100 mol NaOH in 1.00 L of H_2O	1.00×10^{-12}	12.00
0.100 mol NaOH in 1.00 L of H_2O	1.00×10^{-13}	13.00

The pH Scale

- The **pOH** of a solution is defined as the negative of the common logarithm of the hydroxide ion concentration, $[OH^-]$.

$$pOH = -\log [OH^-]$$

  - example: a neutral solution has a $[OH^-] = 1\times10^{-7}$
  - The pH = 7.0.

- The negative logarithm of K_w at 25°C is 14.0.

$$pH + pOH = 14.0$$

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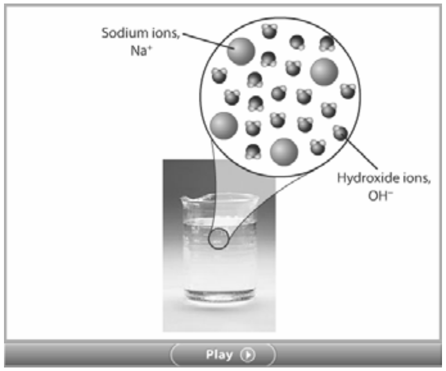
pOH



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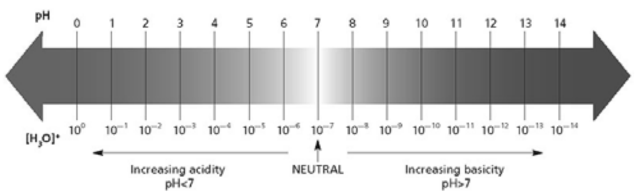
Chapter 15 Section 1 Aqueous Solutions and the Concept of pH

The pH Scale



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Chapter 15 Section 1 Aqueous Solutions and the Concept of pH

Approximate pH Range of Common Materials

Material	pH	Material	pH
Gastric juice	1.0–3.0	Bread	5.0–6.0
Lemons	2.2–2.4	Rainwater	5.4–5.8
Vinegar	2.4–3.4	Potatoes	5.6–6.0
Soft drinks	2.0–4.0	Milk	6.3–6.6
Apples	2.9–3.3	Saliva	6.5–7.5
Grapefruit	3.0–3.3	Pure water	7.0
Oranges	3.0–4.0	Blood	7.3–7.5
Cherries	3.2–4.0	Eggs	7.6–8.0
Tomatoes	4.0–4.4	Sea water	8.0–8.5
Bananas	4.5–5.7	Milk of magnesia	10.5

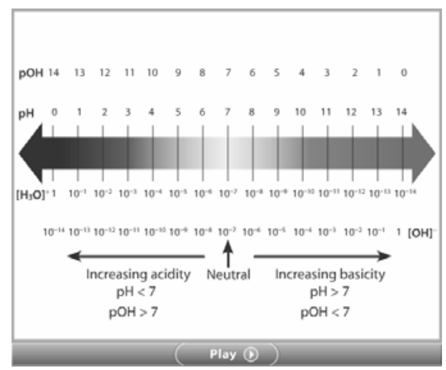
Chapter 15 Section 1 Aqueous Solutions and the Concept of pH

$[H_3O^+]$, $[OH^-]$, pH and pOH of Solutions

Solution	General condition	At 25°C
Neutral	$[H_3O^+] = [OH^-]$ pH = pOH	$[H_3O^+] = [OH^-] = 1 \times 10^{-7}$ M pH = pOH = 7.0
Acidic	$[H_3O^+] > [OH^-]$ pH < pOH	$[H_3O^+] > 1 \times 10^{-7}$ M $[OH^-] < 1 \times 10^{-7}$ M pH < 7.0 pOH > 7.0
Basic	$[H_3O^+] < [OH^-]$ pH > pOH	$[H_3O^+] < 1 \times 10^{-7}$ M $[OH^-] > 1 \times 10^{-7}$ M pH > 7.0 pOH < 7.0

Chapter 15 Visual Concepts

Comparing pH and pOH



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Calculations Involving pH

- There must be as many significant figures to the right of the decimal as there are in the number whose logarithm was found.
  - example: $[H_3O^+] = 1 \times 10^{-7}$

    one significant figure

    pH = 7.0

Using Logarithms in pH Calculations

It is easy to find the pH or the $[H_3O^+]$ of a solution by using a scientific calculator. Because calculators differ, check your manual to find out which keys are used for log and antilog functions and how to use these functions.

1. Calculating pH from $[H_3O^+]$

Use the definition of pH:

$$pH = -\log [H_3O^+]$$

- Take the logarithm of the hydronium ion concentration.
- Change the sign (+/–).
- The result is the pH.

2. Calculating $[H_3O^+]$ from pH

If you rearrange $pH = -\log [H_3O^+]$ to solve for $[H_3O^+]$, the equation becomes

$$[H_3O^+] = 10^{-pH}$$

- Change the sign of the pH (+/–)
- Raise 10 to the negative pH power (take the antilog).
- The result is $[H_3O^+]$.

Calculations Involving pH, *continued*

Calculating pH from $[H_3O^+]$, *continued*

Sample Problem B

What is the pH of a 1.0×10^{-3} M NaOH solution?

Calculations Involving pH, *continued*

Calculating pH from $[H_3O^+]$, *continued*

Sample Problem B Solution

Given: Identity and concentration of solution = 1.0×10^{-3} M NaOH

Unknown: pH of solution

Solution: concentration of base → concentration of OH^- → concentration of H_3O^+ → pH

$$[H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

$$pH = -\log [H_3O^+] = -\log(1.0 \times 10^{-11}) = \boxed{11.00}$$

Calculations Involving pH, *continued*

Calculating pH from $[H_3O^+]$, *continued*

- pH = −log $[H_3O^+]$
- log $[H_3O^+]$ = −pH
- $[H_3O+]$ = antilog (−pH)
- $[H_3O^+] = 10^{-pH}$
- The simplest cases are those in which pH values are integers.

Calculations Involving pH, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$ from pH, *continued*

Sample Problem D

Determine the hydronium ion concentration of an aqueous solution that has a pH of 4.0.

Calculations Involving pH, *continued*

Calculating $[H_3O^+]$ and $[OH^-]$ from pH, *continued*

Sample Problem D Solution

Given: pH = 4.0

Unknown: $[H_3O^+]$

Solution:

$$[H_3O^+] = 10^{-pH}$$

$$[H_3O^+] = \boxed{1 \times 10^{-4}\ M}$$

Calculations Involving pH, *continued*

pH Calculations and the Strength of Acids and Bases

TABLE 5 *Relationship of $[H_3O^+]$ to $[OH^-]$ and pH (at 25°C)*

Solution	$[H_3O^+]$	$[OH^-]$	pH
1.0×10^{-2} M KOH	1.0×10^{-12}	1.0×10^{-2}	12.00
1.0×10^{-2} M NH_3	2.4×10^{-11}	4.2×10^{-4}	10.63
Pure H_2O	1.0×10^{-7}	1.0×10^{-7}	7.00
1.0×10^{-3} M HCl	1.0×10^{-3}	1.0×10^{-11}	3.00
1.0×10^{-1} M CH_3COOH	1.3×10^{-3}	7.5×10^{-12}	2.87

- The pH of solutions of weak acids and weak bases must be measured experimentally.
- The $[H_3O^+]$ and $[OH^-]$ can then be calculated from the measured pH values.

pH of Strong and Weak Acids and Bases

Solution	$[H_3O^+]$	$[OH^-]$	pH
1.0×10^{-2} M KOH	1.0×10^{-12}	1.0×10^{-2}	12.00
1.0×10^{-2} M NH_3	2.4×10^{-11}	4.2×10^{-4}	10.62
Pure H_2O	1.0×10^{-7}	1.0×10^{-7}	7.00
1.0×10^{-3} M HCl	1.0×10^{-3}	1.0×10^{-11}	3.00
1.0×10^{-1} M CH_3COOH	1.3×10^{-3}	7.7×10^{-12}	2.88

pH Values of Some Common Materials