Chapter 10

Acids & Bases

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CHAPTER OUTLINE

- General Properties
- Arrhenius Acids & Bases
- Brønsted-Lowery Acids & Bases
- Strength of Acids & Bases
- Ionization of Water
- pH Scale

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GENRAL PROPERTIES OF ACIDS & BASES

- **Many common substances in our daily lives are acids and bases.**
- **Oranges, lemons and vinegar are examples of acids. In addition, our stomachs contain acids that help digest foods.**
- **Antacid tablets taken for heartburn and ammonia cleaning solutions are examples of bases.**

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GENRAL PROPERTIES OF ACIDS & BASES

- **General properties associated with acids include the following:**
  - **sour taste**
  - **change color of litmus from blue to red**
  - **react with metals to produce H_2 gas**
  - **react with bases to produce salt & water**

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GENRAL PROPERTIES OF ACIDS & BASES

- **General properties associated with bases include the following:**
  - **bitter taste**
  - **slippery, soapy feeling**
  - **change color of litmus from red to blue**
  - **react with acids to produce salt & water**

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ARRHENIUS ACIDS & BASES

- **The first modern definition of acids and bases was formulated by the Swedish chemist Svante Arrhenius in 1884.**

According to the Arrhenius definition,

- **Acids are substances that produce hydronium ions (H_3O^+) in aqueous solution.**

$$HCl\,(g) + H_2O\,(l) \longrightarrow H_3O^+\,(aq) + Cl^-\,(aq)$$

Commonly written as

$$HCl\,(g) \xrightarrow{H_2O} H^+\,(aq) + Cl^-\,(aq)$$

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ARRHENIUS ACIDS & BASES

According to the Arrhenius definition,

- **Bases are substances that produce hydroxide ion (OH^-) in aqueous solution.**

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

$$NH_3\ (aq) + H_2O\ (l) \longrightarrow NH_4^+\ (aq) + OH^-\ (aq)$$

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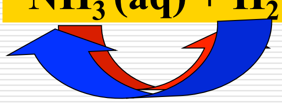
BRØNSTED-LOWRY ACIDS & BASES

- **The Arrhenius definition of acids and bases is**
  According to Brønsted-Lowry definition, an
  developed by Brønsted and Lowry in the early 20th century.

A substance that can act as a Brønsted-Lowry acid and base (such as water) is called amphiprotic.

Base **Acid**

$$NH_3\ (aq) + H_2O\ (l) \rightarrow NH_4^+\ (aq) + OH^-\ (aq)$$



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BRØNSTED-LOWRY ACIDS & BASES

- **In Brønsted-Lowry definition, any pair of molecules or ions that can be inter-converted by transfer of a proton is called conjugate acid-base pair.**

$$HCl\,(g) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + Cl^-\,(aq)$$

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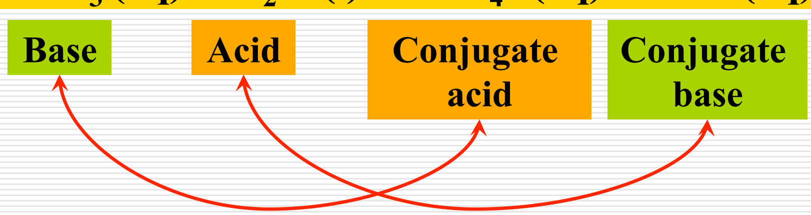
BRØNSTED-LOWRY ACIDS & BASES

$$NH_3\,(aq) + H_2O\,(l) \rightarrow NH_4^+\,(aq) + OH^-\,(aq)$$



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Example 1:

Identify the conjugate acid-base pairs for each reaction shown below:

$$H_2O + Cl^{-} \rightarrow HCl + OH^{-}$$

Acid — **Base** — **Conjugate acid** — **Conjugate base**

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Example 1:

Identify the conjugate acid-base pairs for each reaction shown below:

$$C_6H_5OH + C_2H_5O^{-} \rightarrow C_6H_5O^{-} + C_2H_5OH$$

Acid — **Base** — **Conjugate base** — **Conjugate acid**

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Example 2:

Write the formula for the conjugate acid for each base shown:

$HS^- + H^+ \rightarrow H_2S$

$NH_3 + H^+ \rightarrow NH_4^+$

$CO_3^{2-} + H^+ \rightarrow HCO_3^-$

Example 3:

Write the formula for the conjugate base for each acid shown:

$HI - H^+ \rightarrow I^-$

$CH_3OH - H^+ \rightarrow CH_3O^-$

$HNO_3 - H^+ \rightarrow NO_3^-$

ACID & BASE STRENGTH

- According to the Arrhenius definition, the strength of acids and bases is based on the amount of their ionization in water.
- Strong acids and bases are those that ionize completely in water.
- Strong acids and bases are strong electrolytes.

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

100	100	100
1M	1M	1M

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ACID & BASE STRENGTH

- **Weak** acids and bases are those that ionize partially in water.
- Weak acids and bases are weak electrolytes.

$$NH_3\ (aq) + H_2O\ (l) \rightleftharpoons NH_4^{+}\ (aq) + OH^{-}\ (aq)$$

100	~1	~1
1M	~0.01M	~0.01M

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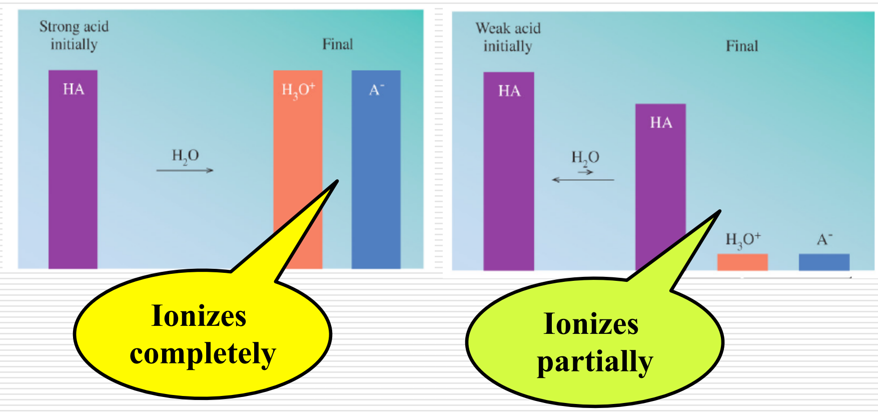
IONIZATION OF STRONG vs. WEAK ACIDS



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COMMON ACIDS

Strong Acids		Weak Acids	
HCl	Hydrochloric acid	$HC_2H_3O_2$	Acetic acid
HBr	Hydrobromic acid	H_2CO_3	Carbonic acid
HI	Hydroiodic acid	H_3PO_4	Phosphoric acid
HNO_3	Nitric acid	HF	Hydrofluoric acid
H_2SO_4	Sulfuric acid	HCN	Hydrocyanic acid
		H_2S	Hydrosulfuric acid

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COMMON BASES

Strong Bases		Weak Bases	
LiOH	Lithium hydroxide	NH_3	Ammonia
NaOH	Sodium hydroxide	$CO(NH_2)_2$	Urea
$Ca(OH)_2$	Calcium hydroxide		
KOH	Potassium hydroxide		
$Ba(OH)_2$	Barium hydroxide		

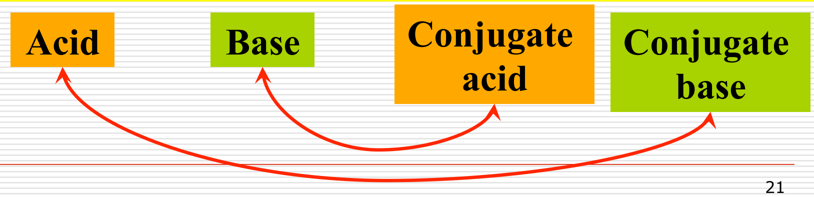
COMPARISON OF ACIDS & BASES

Characteristic	Acids	Bases
Reaction: Arrhenius	Produce H^+	Produce OH^-
Reaction: Brønsted–Lowry	Donate H^+	Accept H^+
Electrolytes	Yes	Yes
Taste	Sour	Bitter, chalky
Feel	May sting	Slippery
Litmus	Red	Blue
Phenolphthalein	Colorless	Pink
Neutralization	Neutralize bases	Neutralize acids

IONIZATION OF WATER

- Water can act both as an acid and a base.
- In pure water, one water molecule donates a proton to another water molecule to produce ions.

$$H_2O \quad + \quad H_2O \quad \leftrightarrow \quad H_3O^+ \quad + \quad OH^-$$



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IONIZATION OF WATER

- When the concentrations of H_3O^+ and OH^- are multiplied together, the ion product constant (K_w) is formed.
- An increase in the concentration of one of the ions will cause an equilibrium shift that causes a decrease in the other one.
- The number of ions produced in pure water is very small, as indicated below:

$$[H_3O^+] = [OH^-] = 1.0 \times 10^{-7}\ M$$

$$K_w = [H_3O^+][OH^-] = [1.0\times10^{-7}][1.0\times10^{-7}] = 1.0\times10^{-14}$$

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ACIDIC & BASIC SOLUTIONS

- When $[H_3O^+]$ is greater than $[OH^-]$ in a solution, it is acidic.
- For example, if $[H_3O^+]$ is 1.0 x 10^{-4} M, then $[OH^-]$ would be 1.0 x 10^{-10} M.

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{1.0 \text{ x } 10^{-14}}{1.0 \text{ x } 10^{-4}} = 1.0 \text{ x } 10^{-10} \text{ M}$$

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ACIDIC & BASIC SOLUTIONS

- When $[OH^-]$ is greater than $[H_3O^+]$ in a solution, it is basic.
- For example, if $[OH^-]$ is 1.0 x 10^{-6} M, then $[H_3O^+]$ would be 1.0 x 10^{-8} M.

$$[H_3O^+] = \frac{K_w}{[OH^-]} = \frac{1.0 \text{ x } 10^{-14}}{1.0 \text{ x } 10^{-6}} = 1.0 \text{ x } 10^{-8} \text{ M}$$

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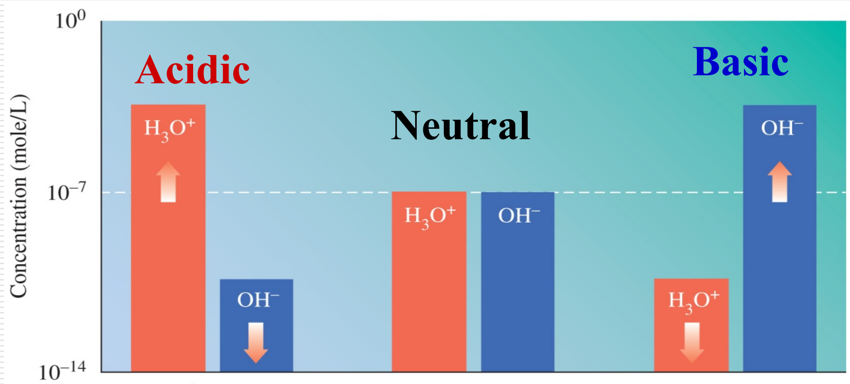
ACIDIC & BASIC SOLUTIONS



$[H_3O^+]>[OH^-]$ $[H_3O^+]=[OH^-]$ $[H_3O^+]<[OH^-]$

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Example 1:

Calculate the $[OH^-]$ in a solution with $[H_3O^+]=2.3\text{x}10^{-4}$ M. Classify the solution as acid or basic.

$$[OH^-]=\frac{K_w}{[H_3O^+]}=\frac{1.0\text{x}10^{-14}}{2.3\text{x}10^{-4}}=4.3\text{x}10^{-11}$$

Solution is acidic

$[H_3O^+] > 1.0\text{x}10^{-7}$

$[OH^-] < 1.0\text{x}10^{-7}$

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Example 2:

Calculate the $[H_3O^+]$ in a solution with $[OH^-]=3.8x10^{-6}$ M. Classify the solution as acid or basic.

$$[H_3O^+] = \frac{K_w}{[OH^-]} = \frac{1.0x10^{-14}}{3.8x10^{-6}} = 2.6x10^{-9}$$

Solution is basic

$[OH^-] > 1.0x10^{-7}$

$[H_3O^+] < 1.0x10^{-7}$

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Example 3:

Calculate the $[OH^-]$ in a solution with $[H_3O^+]=5.8x10^{-8}$ M. Classify the solution as acid or basic.

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{1.0x10^{-14}}{5.8x10^{-8}} = 1.7x10^{-7}$$

Solution is basic

$[H_3O^+] < 1.0x10^{-7}$

$[OH^-] > 1.0x10^{-7}$

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Example 4:

Calculate the $[H_3O^+]$ in a solution with $[OH^-]$=$1.3x10^{-2}$ M. Classify the solution as acid or basic.

$$[H_3O^+] = \frac{K_w}{[OH^-]} = \frac{1.0x10^{-14}}{1.3x10^{-2}} = 7.7x10^{-13}$$

Solution is basic

$[OH^-] > 1.0x10^{-7}$

$[H_3O^+] < 1.0x10^{-7}$

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pH SCALE

- **The acidity of a solution is commonly measured on a pH scale.**
- **The pH scale ranges from 0-14, where acidic solutions are less than 7 and basic solutions are greater than 7.**

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

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pH SCALE

Acidic solutions	**pH < 7**	**$H_3O^+ > 1x10^{-7}$**
Neutral solutions	**pH = 7**	**$H_3O^+ = 1x10^{-7}$**
Basic solutions	**pH > 7**	**$H_3O^+ < 1x10^{-7}$**

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Example 1:

The $[H_3O^+]$ of a liquid detergent is 1.4 ...
Calculate its pH.

pH = -log $[H_3O^+]$ = -log [1.4 ... -8.85)

Solution is basic

pH = 8.85

2 significant figures

The number of decimal places in a logarithm is equal to the number of significant figures in the measurement.

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Example 2:

The pH of … ffee is 5.3. Calculate its $[H_3O^+]$.

Solution is acidic

$[H_3O^+]$ = … (-pH) = 10^{-pH} = $10^{-5.3}$

1 significant figure

$[H_3O^+] = 5 \times 10^{-6}$

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Example 3:

The $[H_3O^+]$ of a solution is 3.5×10^{-3} M … its pH.

Solution is acidic

pH = -log $[H_3O^+]$ = -log [3.5x … .46)

2 significant figures

pH = 2.46

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Example 4:

The p... ato juice is 4.1. Calculate its $[H_3C$...

Solution is acidic

$[H_3C$ ... g (-pH) $= 10^{-pH} = 10^{-4.1}$

1 significant figure

$[H_3O^+] = 8 \times 10^{-5}$

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Example 5:

The $[OH^-]$ of a cleaning solution is 1.0×10^{-5} M. What is the pH of this solution?

Solution is basic

$K_w = [H_3O^+][O$...

2 sig figs

$[H_3O^+] = \frac{Kw}{[OH^-]} = \frac{\ldots x\ 10^{\ldots 14}}{1.0 \times 10^{-5}}$ ... 1.0×10^{-9} M

pH = −log[H3O+] = −log(1.0x10−9) = 9.00

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Example 6:

The pH … lution is 11.50. Calculate the $[H_3O$ … olution.

Solution is basic

$[H_3O^+]$ = antilog (-pH) = $10^{-pH} = 10^{-11.50}$

$[H_3O^+] = 3.2 \times 10^{-12}$

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THE END

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