

### Equilibrium Constants



$$K = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

When a chemical **reaction** reaches equilibrium, it means that the amount of reactants getting turned into products is equal to the amount of products being turned into the **reactants**.

### Lesson Objectives

By the end of this lesson, you should be able to:

- Differentiate between the **concentration** and strength of solutions.
- Compare the strength of acids and their conjugate bases.
- Explain that strong **acids** and bases fully dissociate and weak acids and bases partially dissociate.
- Explain how the acid-dissociation constant,  $K_a$ , and the base-dissociation constant,  $K_b$ , relate to the constant for the self-dissociation of water,  $K_w$ .
- Use the pH scale to characterize the acidity and **basicity** of solutions.

**Science Practice:** Use dissociation constants to compare strengths of acids and bases.

**Words to Know**

Write the letter of the definition next to the matching word as you work through the lesson. You may use the glossary to help you.

- |   |   |
|---|---|
| <u>B</u> weak acid  | A. an acid that dissociates completely in water   |
| <u>C</u> strong base                                      | B. an acid that does not dissociate completely in water   |
| <u>A</u> strong acid                                      | C. a base that dissociates completely in water  |
| <u>E</u> acid-dissociation equilibrium constant ( $K_a$ ) | D. a base the does not dissociate completely in water   |
| <u>F</u> base-dissociation equilibrium constant ( $K_b$ ) | E. the product of the concentrations of the products of dissociation of an acid over the concentration of the reactants (not including water) |
| <u>D</u> weak base  | F. the product of the concentrations of the products of dissociation of base over the concentration of the reactants (not including water)    |

## Instruction

## Equilibria of Acids and Bases

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## Lesson Question

What is the main difference between a strong acid and a weak base?

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## Acid or Acid Solution

Acids are compounds that donate **protons**.

Acids donate protons to water according to this general equation:



Chemists use acid solutions, which are acids dissolved in water.

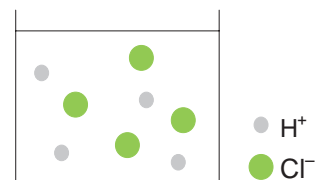
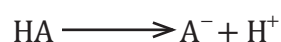
- Concentration is a measure of the quantity of acid dissolved in water and is designated by molarity (e.g., 0.10 M).
- Strength is an intrinsic characteristic of a particular acid and not related to **concentration**.

## Strong Acids and Bases

A **strong acid** dissociates completely when placed in water.



This is often written as :



## Instruction

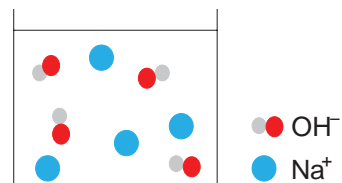
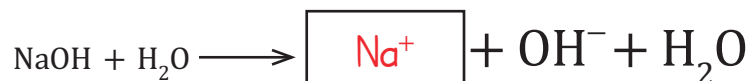
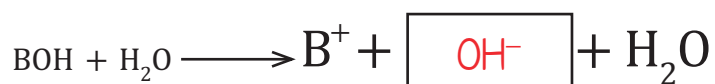
## Equilibria of Acids and Bases

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**Strong Acids and Bases**

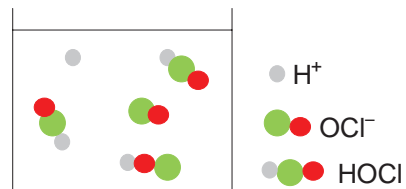
A **strong base** dissociates completely when placed in water.

**Weak Acids and Bases**

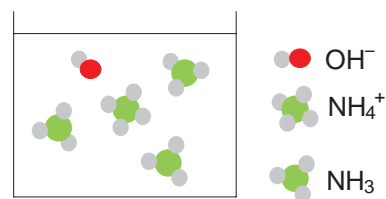
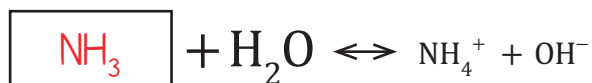
A **weak acid** **partially** dissociates when placed in water.



This is often written as :



A **weak base** partially dissociates when placed in water.



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### Equilibrium Conditions for Acids and Bases

Strong acids:

- do not undergo a reverse reaction.
- contain little or no HA in solution.



Weak

acids:

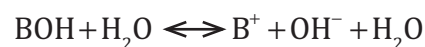
- partially dissociate.
- undergo forward and reverse reactions.
- contain a large amount of HA in solution.



Strong

bases:

- do not undergo a reverse reaction.
- contain little or no BOH in solution.



Weak bases:

- partially dissociate.
- undergo forward and reverse reactions.
- contain a large amount of B in solution.



### Dissociation Constants for Acids and Bases

Acid-dissociation constant

 $(K_a)$ 

:



$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

- Strong acids:
  - $K_a$  is large
  - Equilibrium favors products
- Weak acids:
  - $K_a$  is small
  - Equilibrium favors reactants

Base-dissociation constant

 $(K_b)$ 

:



$$K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$$

- Strong bases:
  - $K_b$  is large
  - Equilibrium favors products
- Weak bases:
  - $K_b$  is small
  - Equilibrium favors reactants

## Instruction

## Equilibria of Acids and Bases

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## Auto-Dissociation of Water

- Water functions as both an **acid** and a **base** and can react with itself.



- $K_w$  is the auto-constant for water.

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

$$K_w = (1 \times 10^{-7})(1 \times 10^{-7}) = 1 \times 10^{-14}$$

Relationship between  $K_a$  and  $K_b$ 

For any weak acid equilibrium:



$$K_a \times K_b = \frac{[\text{A}^-] [\text{H}^+]}{[\text{HA}]} \times \frac{[\text{HA}] [\text{OH}^-]}{[\text{A}^-]}$$

$$K_a \times K_b = \frac{\cancel{[\text{A}^-]} [\text{H}^+]}{[\text{HA}]} \times \frac{[\text{HA}] [\text{OH}^-]}{\cancel{[\text{A}^-]}}$$

$$K_a \times K_b = [\text{H}^+] [\text{OH}^-] = K_w = 1 \times 10^{-14}$$

The same holds for any weak base

**equilibrium**.

Because of this relationship, the larger  $K_a$  is, the smaller  $K_b$  must be. The smaller  $K_a$  is, the larger  $K_b$  must be. This means:

- The stronger the acid, the weaker its conjugate base. The weaker the acid, the stronger its

**conjugate** base.

- The stronger the base, the weaker its conjugate

**acid**. The weaker

the base, the stronger its conjugate acid.

## Instruction

## Equilibria of Acids and Bases

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**How to Calculate  $K_b$  from  $K_a$** 

The  $K_a$  for hydrocyanic acid, HCN, is  $4.9 \times 10^{-10}$ . What is  $K_b$  for the cyanide ion,  $\text{CN}^-$ ?

- Write the equation relating  $K_a$  and  $K_b$ .

$$K_a \times K_b = K_w$$

- Solve for  $K_b$ .

$$K_b = K_w / K_a$$

- Substitute the given values and solve.

$$K_b = K_w / K_a$$

$$K_b = 1 \times 10^{-14} / 4.9 \times 10^{-10}$$

$$K_b = \boxed{2.0 \times 10^{-5}}$$

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**A Return to pH**

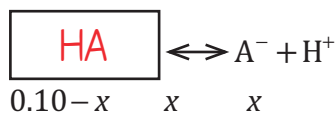
Calculate the pH of 0.10 M HCl solution.



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

$$\text{pH} = -\log(0.10) = 1.0$$

Calculate the pH of 0.10 M acetic acid solution.



$$0.10 - x \quad x \quad x$$

$$K_a = \frac{[\text{A}^-][\text{H}^+]}{[\text{HA}]} = \frac{x^2}{(0.10 - x)} = 1.8 \times 10^{-5}$$

Simplify by assuming that  $x$  is very small compared to 0.10:

$$\frac{\boxed{x^2}}{0.10} = 1.8 \times 10^{-5}$$

$$x^2 = 1.8 \times 10^{-6}$$

$$x = 1.34 \times 10^{-3}$$

$$\text{pH} = -\log[\text{H}^+] = -\log(1.34 \times 10^{-3}) = \boxed{2.9}$$

## Summary

## Equilibria of Acids and Bases

?

## Lesson Question

What is the main difference between a strong acid and a weak base?

✓

## Answer

(Sample answer) The main difference between a strong acid and a weak base is that a strong acid undergoes complete dissociation in water, whereas a weak base partially dissociates in water.

Slide

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## Strong and Weak Acids and Bases

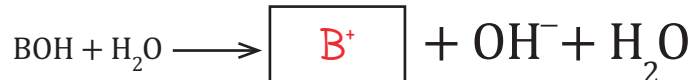
Strong acids dissociate completely in **water**:



Weak acids dissociate **partially** in water:



Strong bases dissociate completely in water:



Weak bases dissociate partially in water:



Slide

2

**Equilibrium Constants**

- $K_w$  is the auto-dissociation constant for water:

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

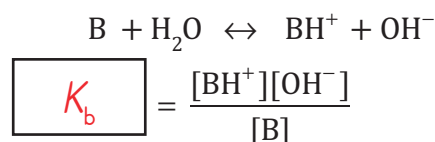
$$K_w = \left(1 \times 10^{-7}\right) \left(1 \times 10^{-7}\right) = 1 \times 10^{-14}$$



$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

- For any acid or base equilibrium system:

- an acid/conjugate **base** or base/conjugate acid pair exists.



- $K_a$  and  $K_b$  describe the **reactions** of the acid and base, respectively, with water.

**Relationship between  $K_a$  and  $K_b$** 

- For any acid or base **equilibrium** system, the product of  $K_a$  and  $K_b$  is equal to a constant,  $K_w$ .

$$K_a \times K_b = K_w = 1 \times 10^{-14}$$

- The stronger the acid, the weaker its conjugate base. The weaker the **acid**, the stronger its conjugate base.
- The stronger the base, the weaker its conjugate acid. The weaker the base, the stronger its **conjugate** acid.



# Summary

## Equilibria of Acids and Bases

*Use this space to write any questions or thoughts about this lesson.*