Chapter 16
Acids and Bases

Section 16.1
Acids and Bases

Models of Acids and Bases
- Arrhenius: Acids produce H⁺ ions in solution, bases produce OH⁻ ions.
- Brønsted-Lowry: Acids are proton (H⁺) donors, bases are proton acceptors.
  \[ \text{HCl} + \text{H}_2\text{O} \rightarrow \text{Cl}^- + \text{H}_3\text{O}^+ \]
  \text{acid} \quad \text{base}

- Conjugate base is everything that remains of the acid molecule after a proton is lost.
- Conjugate acid is formed when the proton is transferred to the base.

Concept Check
Which of the following represent conjugate acid-base pairs?
a) HCl, HNO₃
b) H₃O⁺, OH⁻
c) H₂SO₄, SO₄²⁻
d) HCN, CN⁻
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Acid Strength

Strong Acid
• Completely ionized or completely dissociated

\[ HA(aq) + H_2O(l) \rightarrow H_3O^+(aq) + A^-(aq) \]

Weak Acid
• Most of the acid molecules remain intact.

\[ HA(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + A^-(aq) \]

Behavior of Acids of Different Strengths in Aqueous Solution

A strong acid contains a relatively weak conjugate base.

Ways to Describe Acid Strength

<table>
<thead>
<tr>
<th>Property</th>
<th>Strong Acid</th>
<th>Weak Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid ionization reaction</td>
<td>forward reaction predominates</td>
<td>reverse reaction predominates</td>
</tr>
<tr>
<td>Strength of the conjugate base compared with that of water</td>
<td>( A^- ) is a much weaker base than ( H_2O )</td>
<td>( A^- ) is a much stronger base than ( H_2O )</td>
</tr>
</tbody>
</table>

Common Strong Acids
• Sulfuric acid, \( H_2SO_4 \)
• Hydrochloric acid, HCl
• Nitric acid, HNO\(_3\)
• Perchloric acid, HClO\(_4\)
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Acid Strength

- Oxyacid – acidic proton is attached to an oxygen atom
- Organic acid – have a carbon atom backbone and commonly contain the carboxyl group:

  ![Oxalic Acid](image)

  - Typically a weak acid

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Concept Check

Consider a 1.0 M solution of HCl.

Order the following from strongest to weakest base and explain:

- \( \text{H}_2\text{O}(l) \)
- \( \text{A}^-_{(aq)} \) (from weak acid HA)
- \( \text{Cl}^-_{(aq)} \)

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Let’s Think About It…

- How good is \( \text{Cl}^-_{(aq)} \) as a base?
- Is \( \text{A}^-_{(aq)} \) a good base?

The bases from strongest to weakest are:

\[ \text{A}^-, \text{H}_2\text{O}, \text{Cl}^- \]

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Concept Check

Acetic acid (\( \text{HC}_2\text{H}_3\text{O}_2 \)) and HCN are both weak acids. Acetic acid is a stronger acid than HCN.

Arrange these bases from weakest to strongest and explain your answer:

\[ \text{H}_2\text{O}, \text{Cl}^-, \text{CN}^-, \text{C}_2\text{H}_3\text{O}_2^- \]

Section 16.2

Let’s Think About It…

- \( \text{H}_2\text{O}(l) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq) \)

  - Acid + base → conjugate acid + conjugate base

  - At 25°C, \( K_w = 1.0 \times 10^{-14} \)

  The bases from weakest to strongest are:

\[ \text{Cl}^-, \text{H}_2\text{O}, \text{C}_2\text{H}_3\text{O}_2^-, \text{CN}^- \]

Section 16.3

Water as an Acid and a Base

Water as an Acid and a Base

- Water is amphoteric:
  - Behaves either as an acid or as a base.
- At 25°C:
  \[ K_w = [\text{H}^+][\text{OH}^-] = 1.0 \times 10^{-14} \]
- No matter what the solution contains, the product of [H⁺] and [OH⁻] must always equal 1.0 \times 10^{-14} at 25°C.
Three Possible Situations

• $[H^+] = [OH^-]$; neutral solution
• $[H^+] > [OH^-]$; acidic solution
• $[H^+] < [OH^-]$; basic solution

In each case, however, $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$.

Concept Check

In an acidic aqueous solution, which statement below is correct?

a) $[H^+] < 1.0 \times 10^{-7} \text{ M}$

b) $[H^+] > 1.0 \times 10^{-7} \text{ M}$

c) $[OH^-] > 1.0 \times 10^{-7} \text{ M}$

d) $[H^+] < [OH^-]$

Exercise

In an aqueous solution in which $[OH^-] = 2.0 \times 10^{-10} \text{ M}$, the $[H^+] = \ldots \text{ M}$, and the solution is ________.

a) $2.0 \times 10^{-10} \text{ M}$; basic

b) $1.0 \times 10^{-14} \text{ M}$; acidic

c) $5.0 \times 10^{-5} \text{ M}$; acidic

d) $5.0 \times 10^{-5} \text{ M}$; basic

$[H^+] = K_w/[OH^-] = 1.0 \times 10^{-14}/2.0 \times 10^{-10} = 5.0 \times 10^{-5} \text{ M}$. Since $[H^+]$ is greater than $[OH^-]$, the solution is acidic.

The pH Scale

• $pH = -\log[H^+]$

A compact way to represent solution acidity.

• $pH$ decreases as $[H^+]$ increases.

Significant figures:

• The number of decimal places in the log is equal to the number of significant figures in the original number.
Exercise

Calculate the pH for each of the following solutions.

a) \(1.0 \times 10^{-4} \text{ M } H^+\)

\[ \text{pH} = -\log[H^+] = -\log(1.0 \times 10^{-4} \text{ M}) = 4.00 \]

b) \(0.040 \text{ M } OH^-\)

\[ k_w = [H^+][OH^-] = 1.0 \times 10^{-14} \quad \text{So, } \quad [H^+] = \frac{1.0 \times 10^{-14}}{0.040} = 2.5 \times 10^{-13} \text{ M} \]

\[ \text{pH} = -\log[H^+] = -\log(2.5 \times 10^{-13}) = 12.60 \]

Exercise

The pH of a solution is 5.85. What is the \([H^+]\) for this solution?

\[ [H^+] = 1.4 \times 10^{-6} \text{ M} \]

\[ [H^+] = 10^{-5.85} = 1.4 \times 10^{-6} \text{ M} \]

Exercise

The pH of a solution is 5.85. What is the \([OH^-]\) for this solution?

\[ [OH^-] = 7.1 \times 10^{-9} \text{ M} \]

\[ 14.00 = 5.85 + \text{pOH}; \quad \text{pOH} = 8.15 \]

\[ [OH^-] = 10^{-8.15} = 7.1 \times 10^{-9} \text{ M} \]
Concept Check
Consider an aqueous solution of $2.0 \times 10^{-3} \ M \ HCl$. What is the \( \text{pH} \)?

\[
\text{pH} = 2.70
\]

\[
2.0 \times 10^{-3} \ M \ HCl \rightarrow 2.0 \times 10^{-3} \ M \ H^+ \text{ and } 2.0 \times 10^{-3} \ M \ Cl^-
\]

\[
\text{pH} = -\log(2.0 \times 10^{-3} \ M)
\]

\[
\text{pH} = 2.70
\]

Concept Check
Calculate the \( \text{pH} \) of a $1.5 \times 10^{-11} \ M$ solution of HCl.

\[
\text{pH} = 7.00
\]

Concept Check
Calculate the \( \text{pH} \) of a $1.5 \times 10^{-2} \ M$ solution of HNO\(_3\).

\[
\text{pH} = 1.82
\]

\[
\text{pH} = -\log(1.5 \times 10^{-2} \ M)
\]

\[
\text{pH} = 1.82
\]

Section 16.6
Buffered Solutions

- Buffered solution – resists a change in its pH when either an acid or a base has been added.
  - Presence of a weak acid and its conjugate base buffers the solution.

The Characteristics of a Buffer
1. The solution contains a weak acid HA and its conjugate base \( A^- \).
2. The buffer resists changes in pH by reacting with any added H\(^+\) or OH\(^-\) so that these ions do not accumulate.
3. Any added H\(^+\) reacts with the base \( A^- \).
   \[
   \text{H}^+(aq) + \text{A}^-(aq) \rightarrow \text{HA}(aq)
   \]
4. Any added OH\(^-\) reacts with the weak acid HA.
   \[
   \text{OH}^+(aq) + \text{HA}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{A}^-(aq)
   \]

Concept Check
If a solution is buffered with NH\(_3\) to which has been added NH\(_4\)Cl, what reaction will occur if a strong base such as NaOH is added?

a) NaOH + NH\(_3\) \rightarrow NaNH\(_2\)O
b) NaOH + NH\(_4^+\) \rightarrow Na\(^+\) + NH\(_3\) + H\(_2\)O
c) NaOH + Cl\(^-\) \rightarrow NaCl + OH\(^-\)
d) NaOH + H\(_2\)O \rightarrow NaH\(_2\)O\(_2\)