Arrhenius Base Definition

- A **base** is a substance that generates $\text{OH}^-$ when added to water.
- A **basic** solution is a solution with a significant concentration of $\text{OH}^-$ ions.
• Bases have a bitter taste.
• Bases feel slippery on your fingers.
• Bases turn litmus from red to blue.
• Bases react with acids.
• **Strong Base** = due to a completion reaction with water, generates close to one (or more) OH$^{-}$ for each formula unit of base added to water.

  – Metal hydroxides are strong bases.
Ammonia reacts with water in a reversible reaction, which forms ammonium and hydroxide ions.

\[
\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)
\]
• **Weak Base** = due to a reversible reaction with water, generates significantly less than one OH\(^{-}\) for each formula unit of base added to water.
  
  – Ammonia and ionic compounds that contain CO\(_3^{2-}\) or HCO\(_3^-\) are weak bases.
Ammonia Solution

In a typical ammonia solution, there are about 200 times as many uncharged ammonia molecules, NH₃, as ammonium ions NH₄⁺.

Ammonium ion, NH₄⁺, surrounded by the negatively charged oxygen ends of water molecules.

Hydroxide ion, OH⁻, surrounded by the positively charged hydrogen ends of water molecules.
Carbonate Bases

\[ \text{Na}_2\text{CO}_3(s) \rightarrow 2\text{Na}^+(aq) + \text{CO}_3^{2-}(aq) \]
\[ \text{CO}_3^{2-}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCO}_3^-(aq) + \text{OH}^-(aq) \]

\[ \text{NaHCO}_3(s) \rightarrow \text{Na}^+(aq) + \text{HCO}_3^-(aq) \]
\[ \text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq) + \text{OH}^-(aq) \]
### Arrhenius Bases

<table>
<thead>
<tr>
<th></th>
<th>Strong</th>
<th>Weak</th>
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<tbody>
<tr>
<td><strong>Ionic Compounds</strong></td>
<td>Metal hydroxides</td>
<td>Ionic compounds with CO$_3^{2-}$ and HCO$_3^-$</td>
</tr>
<tr>
<td><strong>Certain Uncharged molecules</strong></td>
<td>None</td>
<td>NH$_3$</td>
</tr>
</tbody>
</table>
• Acidic solutions have pH values less than 7, and the more acidic the solution is, the lower its pH.
• Basic solutions have pH values greater than 7, and the more basic the solution is, the higher its pH.
pH Range

Acidic solutions have pH values less than 7.

Basic solutions have pH values greater than 7.
Neutralization Reactions

- Reactions between Arrhenius acids and Arrhenius bases are called \textit{neutralization reactions}.

\[ \text{HNO}_3(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NaNO}_3(aq) \]
Aqueous Nitric Acid

Hydronium ions, $\text{H}_3\text{O}^+$, surrounded by the negatively charged oxygen ends of water molecules.

Nitrate ions, $\text{NO}_3^-$, surrounded by the positively charged hydrogen ends of water molecules.
Mixture of HNO$_3$ and NaOH Before Reaction

At the instant after nitric acid and sodium hydroxide solutions are mixed and before the reaction, four separate ions move throughout the solution, breaking and making attractions and constantly colliding with each other.

When a hydroxide ion, OH$^-$, collides with a hydronium ion, H$_3$O$^+$, an H$^+$ ion is transferred from the H$_3$O$^+$ to the OH$^-$, yielding two water molecules, H$_2$O.

Hydronium ion, H$_3$O$^+$

Hydroxide ion, OH$^-$

Sodium ion, Na$^+$

Nitrate ion, NO$_3^-$
The hydronium ion, $\text{H}_3\text{O}^+$, from the strong acid reacts with the hydroxide ion, $\text{OH}^-$, from the strong base to form water, $\text{H}_2\text{O}$.

This proton, $\text{H}^+$, is transferred to a hydroxide ion.

$$\text{H}_3\text{O}^+(aq) + \text{OH}^-(aq) \rightarrow 2\text{H}_2\text{O}(l)$$
Mixture of HNO₃ and NaOH After the Reaction

After the reaction between nitric acid and sodium hydroxide, hydroxide ions, OH⁻, and hydronium ions, H₃O⁺, have combined to form water, H₂O.

The sodium ions, Na⁺, and nitrate ions, NO₃⁻, remain in solution in the same form they were in before the reaction.

Sodium ion, Na⁺
Nitrate ion, NO₃⁻

http://preparatorychemistry.com/neutralization_flash.htm
Reaction between an Acid and a Hydroxide Base.

- The reaction has the double displacement form.
  \[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]
  - The positive part of the acid is H\(^+\).
- The hydroxide base can be soluble or insoluble.
- The products are water and a water-soluble ionic compound.
Reaction between an Acid and a Carbonate Base

• The reaction has the double displacement form.

\[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]

– The positive part of the acid is \( \text{H}^+ \).

• The products are water, carbon dioxide, and a water-soluble ionic compound. The \( \text{H}_2\text{O} \) and the \( \text{CO}_2 \) come from the decomposition of the initial product \( \text{H}_2\text{CO}_3 \).
Arrhenius Acid-Base Reactions?

\[
\text{NH}_3(aq) + \text{HF}(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{F}^-(aq)
\]
base  acid

\[
\text{H}_2\text{O}(l) + \text{HF}(aq) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-(aq)
\]
neutral  acid

\[
\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)
\]
base  neutral
Acid and Base Definitions

- **Acid**
  - Arrhenius: a substance that generates $\text{H}_3\text{O}^+$ in water
  - Brønsted-Lowry: a proton, $\text{H}^+$, donor

- **Base**
  - Arrhenius: a substance that generates $\text{OH}^-$ in water
  - Brønsted-Lowry: a proton, $\text{H}^+$, acceptor

- **Acid-Base Reaction**
  - Arrhenius: between an Arrhenius acid and base
  - Brønsted-Lowry: a proton ($\text{H}^+$) transfer
Brønsted-Lowry Acids and Bases

\[ \text{NH}_3(aq) + \text{HF}(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{F}^-(aq) \]

base \hspace{1cm} acid

\[ \text{H}_2\text{O}(l) + \text{HF}(aq) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-(aq) \]

base \hspace{1cm} acid

\[ \text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \]

base \hspace{1cm} acid
Why Two Definitions for Acids and Bases? (1)

• Positive Aspects of Arrhenius Definitions
  – All isolated substances can be classified as acids (generate $\text{H}_3\text{O}^+$ in water), bases (generate $\text{OH}^-$ in water), or neither.
  – Allows predictions, including (1) whether substances will react with a base or acid, (2) whether the pH of a solution of the substance will be less than 7 or greater than 7, and (3) whether a solution of the substance will be sour.

• Negative Aspects of Arrhenius Definitions
  – Does not include similar reactions ($\text{H}^+$ transfer reactions) as acid-base reactions.
Why Two Definitions for Acids and Bases? (2)

• Positive Aspects of Brønsted-Lowry Definitions
  – Includes similar reactions (H\(^+\) transfer reactions) as acid-base reactions.

• Negative Aspects of Brønsted-Lowry Definitions
  – Cannot classify isolated substances as acids (generate H\(_3\)O\(^+\) in water), bases (generate OH\(^-\) in water), or neither. The same substance can sometimes be an acid and sometimes a base.
  – Does not allow predictions of (1) whether substances will react with a base or acid, (2) whether the pH of a solution of the substance will be less than 7 or greater than 7, and (3) whether a solution of the substance will be sour.
Conjugate Acid-Base Pairs

Proton donor + Proton acceptor $\Leftrightarrow$ Proton acceptor + Proton donor

H$^+$
Brønsted-Lowry
Acids and Bases

\[
\text{NH}_3(aq) + \text{HF}(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{F}^-(aq)
\]
base      acid     acid      base

\[
\text{H}_2\text{O}(l) + \text{HF}(aq) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-(aq)
\]
base      acid     acid      base

\[
\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)
\]
base      acid     acid      base

\[
\text{H}_2\text{PO}_4^-(aq) + \text{HF}(aq) \rightleftharpoons \text{H}_3\text{PO}_4(aq) + \text{F}^-(aq)
\]
base      acid     acid      base
Amphoteric Substances

Can be a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in another?

\[
\begin{align*}
\text{HCO}_3^- (aq) + \text{HF} (aq) & \rightleftharpoons \text{CO}_2 (g) + \text{H}_2\text{O} (l) + \text{F}^- (aq) \\
\text{base} & \quad \text{acid} \\
\text{HCO}_3^- (aq) + \text{OH}^- (aq) & \rightleftharpoons \text{CO}_3^{2-} (aq) + \text{H}_2\text{O} (l) \\
\text{acid} & \quad \text{base} \\
\text{H}_2\text{PO}_4^- (aq) + \text{HF} (aq) & \rightleftharpoons \text{H}_3\text{PO}_4 (aq) + \text{F}^- (aq) \quad \text{base} \quad \text{acid} \\
\text{H}_2\text{PO}_4^- (aq) + 2\text{OH}^- (aq) & \rightarrow \text{PO}_4^{3-} (aq) + 2\text{H}_2\text{O} (l) \quad \text{acid} \quad \text{base}
\end{align*}
\]