Chapter 5
Acids, Bases, and Acid-Base Reactions

An Introduction to Chemistry
by Mark Bishop
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• An **acid** is a substance that generates hydronium ions, $\text{H}_3\text{O}^+$ (often described as $\text{H}^+$), when added to water.

• An **acidic solution** is a solution with a significant concentration of $\text{H}_3\text{O}^+$ ions.
• Acids have a sour taste.
• Acids turn litmus from blue to red.
• Acids react with bases.
When HCl dissolves in water, hydronium ions, $\text{H}_3\text{O}^+$, and chloride ions, $\text{Cl}^-$, ions form.

This proton, $\text{H}^+$, is transferred to a water molecule.
Solution of a Strong Acid

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

Chloride ions, $\text{Cl}^-$, surrounded by the positively charged hydrogen ends of water molecules.
Types of Acids

- Binary acids have the general formula of HX(aq)
  - HF(aq) and HCl(aq)
- Oxyacids have the general formula H\text{aX}_b\text{O}_c.
  - HNO\text{3} and H\text{2SO}_4
- Organic acids, which are also called carbon-based acids or carboxylic acids
  - HC\text{2H}_3\text{O}_2
Acetic Acid

H\_2\_C\_C\_O\_H

Acidic hydrogen

H\_C\_C\_O\_H

Acidic hydrogen

Double bond, four electrons shared by atoms

Acidic hydrogen
Monoprotic and Polyprotic Acids

• If each molecule of an acid can donate one hydrogen ion, the acid is called a **monoprotic acid**.
• If each molecule can donate two or more hydrogen ions, the acid is a **polyprotic acid**.
• A **diprotic acid**, such as sulfuric acid, H$_2$SO$_4$, has two acidic hydrogen atoms.
• Some acids, such as phosphoric acid, H$_3$PO$_4$, are **triprotic acids**.
Acetic acid reacts with water in a reversible reaction, which forms hydronium and acetate ions.

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

This proton, H\(^+\), is transferred to a water molecule. Indicates a reversible reaction. This proton, H\(^+\), may be transferred back to the acetate ion.
Solution of Weak Acid

In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules, $\text{HC}_2\text{H}_3\text{O}_2$, as acetate ions, $\text{C}_2\text{H}_3\text{O}_2^-$. 

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

Acetate ion, $\text{C}_2\text{H}_3\text{O}_2^-$, surrounded by the positively charged hydrogen ends of water molecules.
Strong and Weak Acids

- **Weak Acid** = due to a reversible reaction with water, generates significantly less than one \( \text{H}_3\text{O}^+ \) for each molecule of acid added to water.

- **Strong Acid** = due to a completion reaction with water, generates close to one \( \text{H}_3\text{O}^+ \) for each acid molecule added to water.
Strong and Weak Acids

For every 250 molecules of the weak acid acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, added to water, there are about

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

249 uncharged acetic acid molecules

For every 250 molecules of the strong acid hydrochloric acid, $\text{HCl}$, added to water, there are about

$$\text{HCl}(g) + \text{H}_2\text{O}(l) \rightarrow \text{Cl}^- (\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$$

Zero uncharged HCl molecules

250 chloride ions

250 hydronium ions
• There is an animation on the textbook’s website that will give you a better understanding of weak and strong acids.

https://preparatorychemistry.com/acids_Canvas.html
Sulfuric Acid

\[ \text{H}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{HSO}_4^-(aq) \]

\[ \text{HSO}_4^-(aq) + \text{H}_2\text{O}(l) \Leftrightarrow \text{H}_3\text{O}^+(aq) + \text{SO}_4^{2-}(aq) \]
### Acid Summary

<table>
<thead>
<tr>
<th></th>
<th>Strong</th>
<th>Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binary acid</strong></td>
<td>hydrochloric acid, HCl(aq)</td>
<td>Hydrofluoric acid</td>
</tr>
<tr>
<td><strong>Oxyacid</strong></td>
<td>nitric acid, HNO₃</td>
<td>other acids with ( H_aX_bO_c )</td>
</tr>
<tr>
<td><strong>Organic acid</strong></td>
<td>none</td>
<td>acetic acid, ( \text{HC}_2\text{H}_3\text{O}_2 )</td>
</tr>
</tbody>
</table>
• Large quantities of sulfur dioxide, \( \text{SO}_2 \), are formed and released into the air from burning sulfur-containing substances in coal in power plants and in metal ores in smelting, which involves heating of metal ores to extract metals.

• \( \text{SO}_2 \) forms sulfuric acid, \( \text{H}_2\text{SO}_4 \), in the atmosphere, which can dissolve in the clouds and form acid rain.

• Sulfuric acid forms hydronium ions.

\[
\begin{align*}
\text{H}_2\text{SO}_4 + \text{H}_2\text{O} & \rightarrow \text{H}_3\text{O}^+ + \text{HSO}_4^- \\
\text{HSO}_4^- + \text{H}_2\text{O} & \rightleftharpoons \text{H}_3\text{O}^+ + \text{SO}_4^{2-}
\end{align*}
\]
1995 SO2 Emissions
NO$_x$ and Nitric Acid

- The combination of air at high temperature, perhaps with a metal to act as a catalyst, leads to the formation of nitrogen monoxide, NO, and nitrogen dioxide, NO$_2$, often summarized as “NOx”.
- Transportation and industry are major sources of nitrogen oxides.
- The NO$_2$ forms nitric acid in the atmosphere, which is a strong acid.

\[
\text{HNO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{NO}_3^- 
\]
Acids and Acid Precursors

- Sulfur dioxide (SO$_2$) $\rightarrow$ sulfuric acid (H$_2$SO$_4$)
  - primarily from coal burning and smelting
- Nitrogen oxides (NO, NO$_2$) $\rightarrow$ nitric acid (HNO$_3$)
  - primarily from high-temperature combustion
- Formic and acetic acids (HCO$_2$H, CH$_3$CO$_2$H)
  - primarily from biomass burning, mostly in Africa and South America
- Carbonic acid (CO$_2$ $\rightarrow$ H$_2$CO$_3$)
  - from CO$_2$ in atmosphere, responsible for acidity of pristine precipitation
• The pH scale can be used to describe the acidity and basicity of dilute solutions of acid and base.

• Acidic solutions have pHs from 0 to 7.

• The lower the pH, the more acidic the solution, and a decrease in one pH unit is associated with an increase of 10-times the hydronium ion concentration.

• Therefore, small changes in pH reflect significant changes in $\text{H}_3\text{O}^+$ concentration.
Pristine Rain and Acid Rain

• Due to acids dissolved in natural rain, such as the carbonic acid that forms when CO$_2$ dissolves in water, pristine or unpolluted rain has a pH of about 5.6.

• Acid rain can have a pH close to 4.
Rain pH 1999

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu
• Lowering pH can damage freshwater ecosystems, forests, agriculture, human health, buildings, and other property.
• More acidic rain dissolves more toxic metals in the soil, which increases the level of these metals in water systems, leading to consumption of fish with elevated concentrations of toxic metals (Al, Pb, Cd, Hg, Cu, Zn).

• Corrosion of pipes results in excess levels of Cu, Zn, Pb in drinking water.
Damage to Buildings and Property

• Acids etch glass, damage roofing and other building materials, and damage plastics and paint (especially automotive paint).

• Carbonate stones (marble, limestone, etc.), cement, mortar are dissolved by acids:

\[
\text{CaCO}_3(\text{s}) + 2\text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})
\]
The statues on the left were transported by William Randolph Hearst to his home in San Simeon, California. Because it so rarely rains there, and because San Simeon is far from any major sources of pollution, these statues are in much better condition than the similar statues found elsewhere, such as the one on the right, that have been damaged by acid rain.
Effects on Metals

• Acid rain speeds the corrosion of metals.
Automobile Catalytic Converters

- Catalytic converters can convert up to 95% of the NO and NO\(_2\) back to nitrogen and oxygen.

\[
2\text{NO} \rightarrow \text{N}_2 + \text{O}_2 \quad \quad 2\text{NO}_2 \rightarrow \text{N}_2 + 2\text{O}_2
\]
Mitigation - Sulfur

- Switch from coal to natural gas (0.001% S)
- Switch to low-sulfur coal
- Power plant scrubbers can use CaO (lime), CaCO₃ (limestone), or Ca(OH)₂ (lime) to remove SO₂ from the stack gases.
• Due largely to the US EPA’s Acid Rain Program, the U.S. had a 33% decrease in $\text{SO}_2$ emissions between 1983 and 2002.
1995 $SO_2$ Emissions
2004 SO₂ Emissions
• Names have the general form of *hydro*(root)*ic acid*, such as hydrochloric acid.

• The formulas are usually followed by *(aq)*, such as HCl*(aq)*.
If enough H\(^+\) ions are added to a (root)ate polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.

- Nitrate, NO\(_3^-\), goes to nitric acid, HNO\(_3\).
- Sulfate, SO\(_4^{2-}\), goes to sulfuric acid, H\(_2\)SO\(_4\). (Note the -ur- in the name.)
- Phosphate, PO\(_4^{3-}\), goes to phosphoric acid, H\(_3\)PO\(_4\). (Note the -or- in the name.)
Chemical Nomenclature

• General procedure for naming compounds (See Table 5.5 in the text.)
  – **Step 1**: Decide what type of compound the name or formula represents.
  – **Step 2**: Apply the rules for writing the name or formula for that type of compound.
A base is a substance that generates OH\(^-\) when added to water.

A basic solution is a solution with a significant concentration of 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) \( \text{OH}^- \) 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.
In a typical ammonia solution, there are about 200 times as many uncharged ammonia molecules, \( \text{NH}_3 \), as ammonium ions \( \text{NH}_4^+ \).

Ammonium ion, \( \text{NH}_4^+ \), surrounded by the negatively charged oxygen ends of water molecules.

Hydroxide ion, \( \text{OH}^- \), surrounded by the positively charged hydrogen ends of water molecules.
Na$_2$CO$_3$(s) $\rightarrow$ 2Na$^+$ (aq) + CO$_3^{2-}$ (aq)
CO$_3^{2-}$ (aq) + H$_2$O(l) $\rightleftharpoons$ HCO$_3^-$ (aq) + OH$^-$ (aq)

NaHCO$_3$(s) $\rightarrow$ Na$^+$ (aq) + HCO$_3^-$ (aq)
HCO$_3^-$ (aq) + H$_2$O(l) $\rightleftharpoons$ H$_2$CO$_3$(aq) + OH$^-$ (aq)
<table>
<thead>
<tr>
<th></th>
<th>Strong</th>
<th>Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic Compounds</td>
<td>Metal hydroxides</td>
<td>Ionic compounds with CO$_3^{2-}$ and HCO$_3^-$</td>
</tr>
<tr>
<td>Certain Uncharged molecules</td>
<td>None</td>
<td>NH$_3$</td>
</tr>
</tbody>
</table>
Acidic and Basic Solutions

• The pH scale describes the acidity and basicity of dilute acid and base solutions.

• In pure water, there are proton transfers between water molecules that form hydronium ions and hydroxide ions.

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

• The reaction is reversible, and at equilibrium, the product of the hydronium ion and hydroxide ion concentrations expressed in mol/L is about \(10^{-14}\).

\[
[\text{H}_3\text{O}^+][\text{OH}^-] = 10^{-14}
\]
\([H_3O^+][OH^-] = 10^{-14}\]

• We consider acidic and basic solutions to be dilute if they have a concentrations of 1 mol/L or less.
• Because the product of the concentrations of \(H_3O^+\) and \(OH^-\) is \(10^{-14}\), as the concentration of \(H_3O^+\) decreases from 1 mol/L to \(10^{-14}\) mol/L, the concentration of \(OH^-\) increases from \(10^{-14}\) mol/L to 1 mol/L.
• See the table at the right.
\([\text{H}_3\text{O}^+][\text{OH}^-] = 10^{-14}\)

- When the \(\text{H}_3\text{O}^+\) concentration is greater than the \(\text{OH}^-\) concentration, the solution is acidic. (Note that even in a dilute solution of acid, there are some hydroxide ions.)
- When the \(\text{OH}^-\) concentration is greater than the \(\text{H}_3\text{O}^+\) concentration, the solution is basic.
- When the concentrations are equal, both \(10^{-7}\) mol/L, we say the solution is neutral in the acid/base sense.
To avoid the small numbers associated with describing acidic and basic solutions in terms of mol/L, pH is defined as:

\[
pH = \log_{10}[H_3O^+]
\]

- An acidic solution that has an H\(_3\)O\(^+\) concentration of 10\(^{-3}\) mol/L has a pH of 3 (\(-\log10^{-3} = 3\)).
- A basic solution that has an OH\(^-\) concentration of 10\(^{-3}\) mol/L, and therefore an H\(_3\)O\(^+\) concentration of 10\(^{-11}\) mol/L, has a pH of 11 (\(-\log10^{-11} = 11\)).
\[ [\text{H}_3\text{O}^+] [\text{OH}^-] = 10^{-14} \]

- Dilute acidic solutions with \( \text{H}_3\text{O}^+ \) concentrations of 1 to \( 10^{-6} \) mol/L have a pHs of 0 to 6.
- Dilute basic solutions with \( \text{OH}^- \) concentrations of \( 10^{-6} \) to 1 mol/L have \( \text{H}_3\text{O}^+ \) concentrations of \( 10^{-8} \) to \( 10^{-14} \) mol/L and pHs of 8-14.
- Neutral solutions with \( \text{H}_3\text{O}^+ \) and \( \text{OH}^- \) concentrations \( 10^{-7} \) mol/L have a pH of 7.
**pH Range**

Acidic solutions have pH values less than 7.

Basic solutions have pH values greater than 7.

- **pH**: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

- **More Acidic**
- **Neutral**
- **More Basic**

- **gastric juice**
- **lemon juice**
- **wine**
- **coffee**
- **milk**
- **pure water**
- **blood**
- **seawater**
- **detergents**
- **household ammonia**
- **bleach**
Reactions between Arrhenius acids and Arrhenius bases are called **neutralization reactions**.

\[
\text{HNO}_3(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{NaNO}_3(\text{aq})
\]
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.
Strong Acid and Strong Base Reaction

The hydronium ion, $H_3O^+$, from the strong acid reacts with the hydroxide ion, $OH^-$, from the strong base to form water, $H_2O$.

This proton, $H^+$, is transferred to a hydroxide ion.

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$$
Mixture of HNO$_3$ and NaOH After the Reaction

After the reaction between nitric acid and sodium hydroxide, hydroxide ions, OH$^-$, and hydronium ions, H$_3$O$^+$, have combined to form water, H$_2$O.

The sodium ions, Na$^+$, and nitrate ions, NO$_3^-$, remain in solution in the same form they were in before the reaction.

https://preparatorychemistry.com/neutralization_Canvas.html
Reaction between an Acid and a Hydroxide Base.

- If you have an Arrhenius acid combined with an Arrhenius base, they will react in an acid-base reaction.
- The reactions we will see have the double displacement form.
  \[ AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CB(aq) \]
  - 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 of an acid with a base containing the carbonate ion or the hydrogen carbonate ion has the double displacement form.

\[
AB(aq) + CD(aq \text{ or } s) \rightarrow H_2O(l) + CO_2(g) + CB(aq)
\]

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

• The products are water, carbon dioxide, and a water-soluble ionic compound. The H\(_2\)O and the CO\(_2\) come from the decomposition of the initial product H\(_2\)CO\(_3\).
Steps for Writing Acid-Base Equations

• Write the formulas for the given reactants separate by a “+” and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.

\[ \text{AB}(aq) + \text{CD}(aq \text{ or } s) \rightarrow \]
Steps for Writing Acid-Base Equations

• Follow these steps to determine the formulas for the products.
  – Divide the acid formula into H\(^+\) and whatever is left after all of the H\(^+\) ions are removed. For example, HNO\(_3\) is divided into H\(^+\) and NO\(_3^-\), and H\(_2\)SO\(_4\) is divided into H\(^+\) and SO\(_4^{2-}\).
  – Divide the base into its cation and whatever is left when the cations are removed. For example, NaOH is divided into Na\(^+\) and OH\(^-\), and K\(_2\)CO\(_3\) is divided into K\(^+\) and CO\(_3^{2-}\).
Steps for Writing Acid-Base Equations (cont.)

• Follow these steps to determine the formulas for the products. (cont.)
  – If the base includes the hydroxide ion, the first product will be water.
    \[ AB(aq) + CD(aq \text{ or s}) \rightarrow H_2O(l) + CB(aq) \]
  – If the base includes either the carbonate ion or the hydrogen carbonate ion, the first products will be water and carbon dioxide.
    \[ AB(aq) + CD(aq \text{ or s}) \rightarrow H_2O(l) + CO_2(g) + CB(aq) \]
• Follow these steps to determine the formulas for the products. (cont.)

– The formula for the second product is formed by combining the cation from the base and the anion from the acid. For example, Na\(^+\) combines with NO\(_3^-\) to form the CB formula, NaNO\(_3\)(aq). (Remember that even though the ions in ionic compounds dissolved in water are separated from each other, we describe them as together in the complete equation.)

\[
AB(aq) + CD(aq \text{ or s}) \rightarrow H_2O(l) + CB(aq)
\]

or

\[
AB(aq) + CD(aq \text{ or s}) \rightarrow H_2O(l) + CO_2(g) + CB(aq)
\]
Example 1

- Write the complete equation for the neutralization reaction that takes place when aqueous solutions of sulfuric acid, \( \text{H}_2\text{SO}_4 \), and sodium hydroxide, \( \text{NaOH} \), are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)
Example 1

Steps

• The acid-base reactions we will see are double displacement reactions.
  
  \[ \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \]

• Write the formulas for the given reactants separated by a “+” and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.
  
  \[ \text{H}_2\text{SO}_4(aq) + \text{NaOH}(aq) \rightarrow \]
Example 1

Steps

\[ \text{H}_2\text{SO}_4(aq) + \text{NaOH}(aq) \rightarrow \]

- Identify A, B, C, and D.
  - For the acid \( \text{H}_2\text{SO}_4 \), A is \( \text{H}^+ \) and B is \( \text{SO}_4^{2-} \).
  - For \( \text{NaOH} \), C is \( \text{Na}^+ \) and D is \( \text{OH}^- \).

- Write the formulas for the AD and CB products on the right side of the arrow. Remember to balance the charges when writing the formulas. \( \text{H}_2\text{O} \) will be followed by (l), and the ionic product will be followed by (aq).

\[ \text{H}_2\text{SO}_4(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{Na}_2\text{SO}_4(aq) \]
**Example 1**

**Steps**

\[
\text{H}_2\text{SO}_4(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{Na}_2\text{SO}_4(\text{aq})
\]

- If one of your products is \(\text{H}_2\text{CO}_3\), eliminate it and write \(\text{H}_2\text{O}(\text{l})\) and \(\text{CO}_2(\text{g})\) in its place.
- Balance the equation.

\[
\text{H}_2\text{SO}_4(\text{aq}) + 2\text{NaOH}(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{Na}_2\text{SO}_4(\text{aq})
\]
Example 2

- Write the complete equation for the neutralization reaction that takes place when aqueous solutions of hydrochloric acid, HCl(aq), and potassium carbonate, K₂CO₃, are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic anions.)
Steps

• The acid-base reactions we will see are double displacement reactions.

\[ AB + CD \rightarrow AD + CB \]

• Write the formulas for the given reactants separate by a “+” and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.

\[ \text{HCl(aq)} + \text{K}_2\text{CO}_3(\text{aq}) \rightarrow \]
Example 2

Steps

\[ \text{HCl(aq)} + \text{K}_2\text{CO}_3\text{(aq)} \rightarrow \]

- Identify A, B, C, and D.
  - For the acid HCl, A is H\(^+\) and B is Cl\(^-\).
  - For K\(_2\)CO\(_3\), C is K\(^+\) and D is CO\(_3^{2-}\).

- Write the formulas for the AD and CB products on the right side of the arrow. Remember to balance the charges when writing the formulas. The ionic product will be followed by (aq).

\[ \text{HCl(aq)} + \text{K}_2\text{CO}_3\text{(aq)} \rightarrow \text{H}_2\text{CO}_3\text{(l)} + \text{KCl(aq)} \]
Example 2
Steps

\[
\text{HCl(aq)} + \text{K}_2\text{CO}_3(\text{aq}) \rightarrow \text{H}_2\text{CO}_3(\text{aq}) + \text{KCl(\text{aq})}
\]

- If one of your products is H$_2$CO$_3$, eliminate it and write H$_2$O(l) and CO$_2$(g) in its place.

\[
\text{HCl(aq)} + \text{K}_2\text{CO}_3(\text{aq}) \\
\quad \rightarrow \text{H}_2\text{O(l)} + \text{CO}_2(\text{g}) + \text{KCl(\text{aq})}
\]

- Balance the equation.

\[
2\text{HCl(aq)} + \text{K}_2\text{CO}_3(\text{aq}) \\
\quad \rightarrow \text{H}_2\text{O(l)} + \text{CO}_2(\text{g}) + 2\text{KCl(\text{aq})}
\]
Arrhenius Acid-Base Reactions?

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

base \quad \text{acid}

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

neutral \quad \text{acid}

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

base \quad \text{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

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

\begin{align*}
\text{base} & \quad \text{acid} \\
\text{H}_2\text{O(l)} + \text{HF}(aq) & \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-(aq) \\
\text{base} & \quad \text{acid} \\
\text{NH}_3(aq) + \text{H}_2\text{O(l)} & \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \\
\text{base} & \quad \text{acid}
\end{align*}
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 H₃O⁺ 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 ⇌ Proton acceptor + Proton donor

H^+
Brønsted-Lowry Acids and Bases

\[
\begin{align*}
\text{NH}_3(aq) + HF(aq) & \rightleftharpoons \text{NH}_4^+(aq) + F^-(aq) \\
\text{base} & \quad \text{acid} & \quad \text{acid} & \quad \text{base} \\
\text{H}_2\text{O}(l) + HF(aq) & \rightleftharpoons \text{H}_3\text{O}^+(aq) + F^-(aq) \\
\text{base} & \quad \text{acid} & \quad \text{acid} & \quad \text{base} \\
\text{NH}_3(aq) + H_2\text{O}(l) & \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \\
\text{base} & \quad \text{acid} & \quad \text{acid} & \quad \text{base} \\
\text{H}_2\text{PO}_4^-(aq) + HF(aq) & \rightleftharpoons \text{H}_3\text{PO}_4(aq) + F^-(aq) \\
\text{base} & \quad \text{acid} & \quad \text{acid} & \quad \text{base}
\end{align*}
\]
Amphoteric Substances

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

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

\[ \text{base} \quad \text{acid} \]

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

\[ \text{acid} \quad \text{base} \]

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

\[ \text{base} \quad \text{acid} \]

\[ \text{H}_2\text{PO}_4^- (aq) + 2\text{OH}^- (aq) \rightarrow \text{PO}_4^{3-}(aq) + 2\text{H}_2\text{O}(l) \]

\[ \text{acid} \quad \text{base} \]