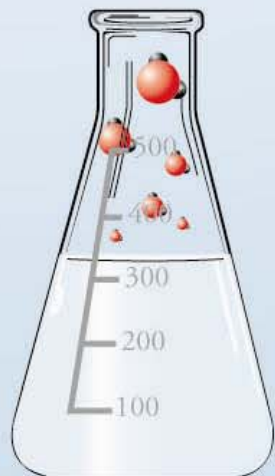


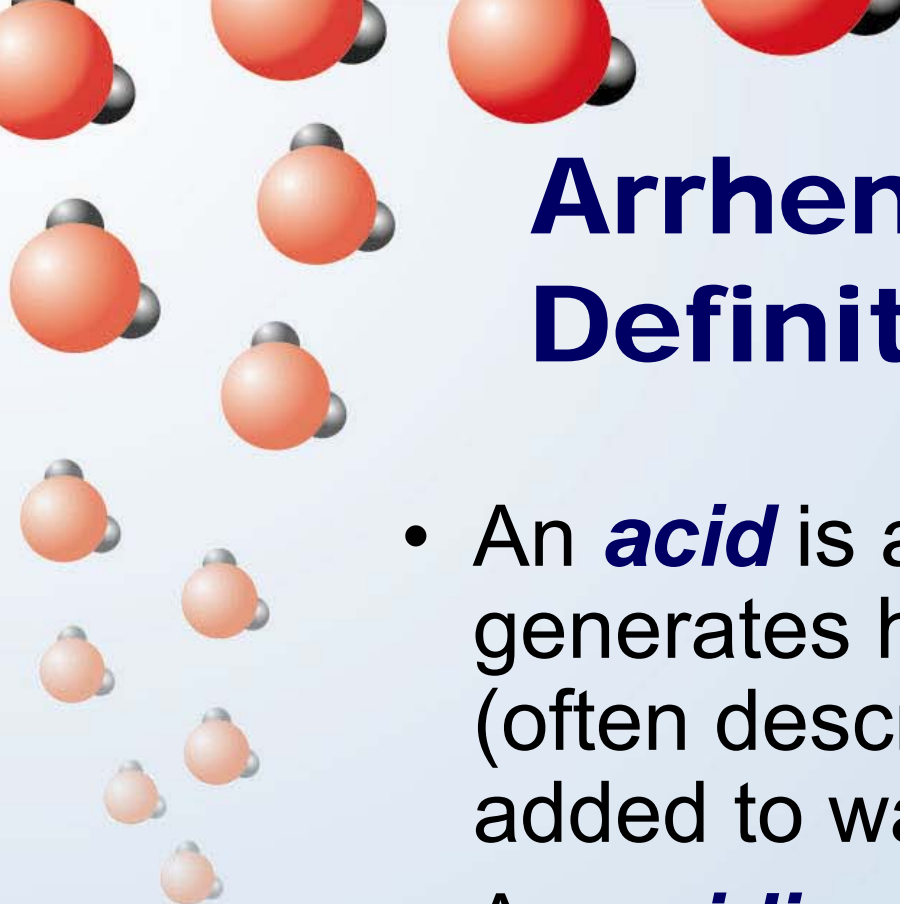
# Chapter 6

## Acids, Bases, and Acid-Base Reactions



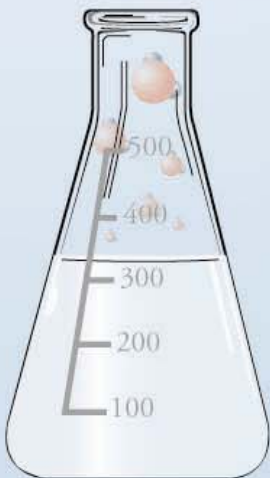
# Chapter Map





# Arrhenius Acid Definition

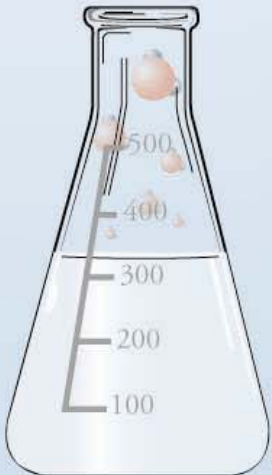
- An **acid** is a substance that generates hydronium ions,  $\text{H}_3\text{O}^+$  (often described as  $\text{H}^+$ ), when added to water.
- An **acidic solution** is a solution with a significant concentration of  $\text{H}_3\text{O}^+$  ions.



A vertical column of water molecules (H<sub>2</sub>O) is shown on the left side of the slide. Each molecule consists of one large red sphere (oxygen) and two smaller black spheres (hydrogen) bonded to it. The molecules are arranged in a descending staircase pattern from top to bottom.

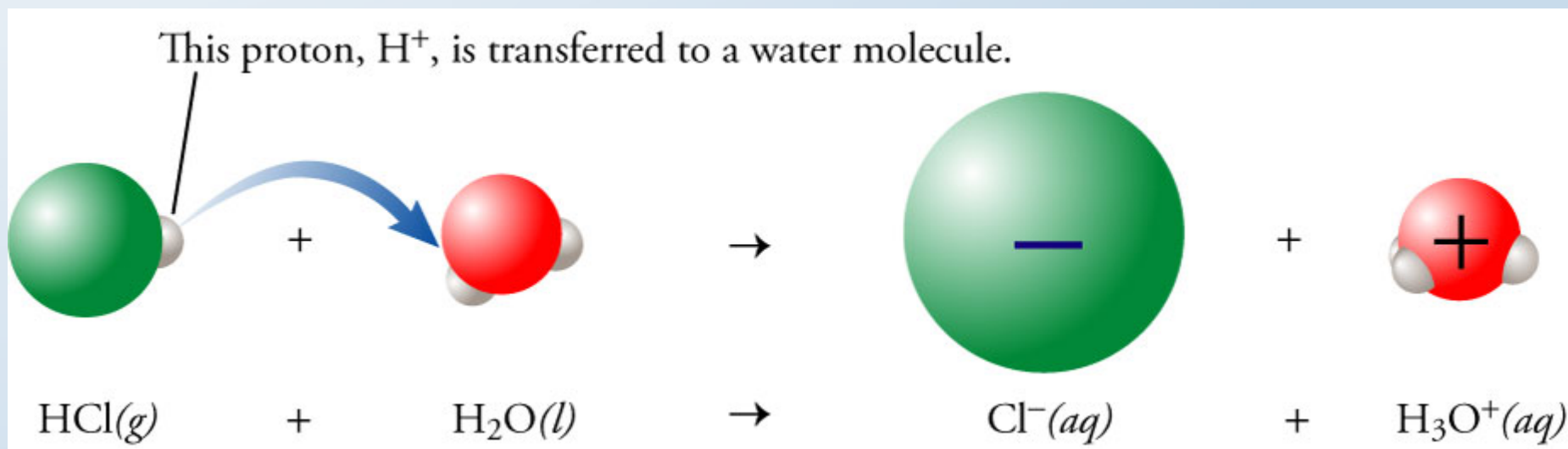
# Characteristics of Acids

- Acids have a sour taste.
- Acids turn litmus from blue to red.
- Acids react with bases.



# Strong Acid and Water

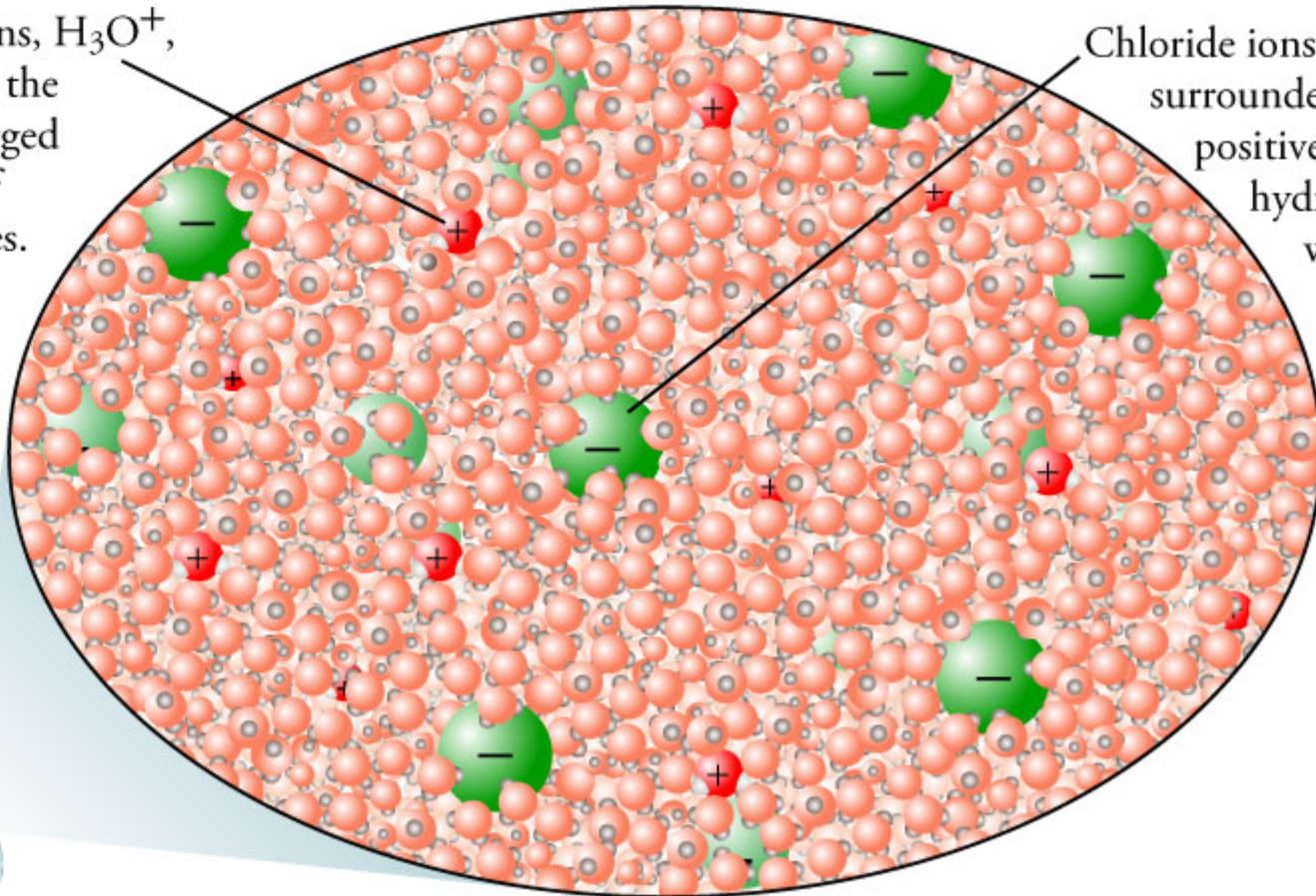
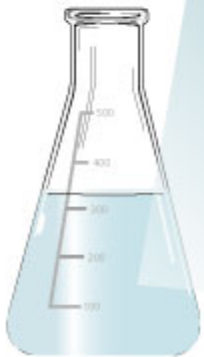
When HCl dissolves in water, hydronium ions,  $\text{H}_3\text{O}^+$ , and chloride ions,  $\text{Cl}^-$ , ions form.



# Solution of a Strong Acid

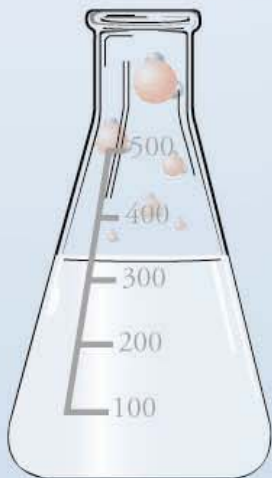
Hydronium ions,  $\text{H}_3\text{O}^+$ ,  
surrounded by the  
negatively charged  
oxygen ends of  
water molecules.

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

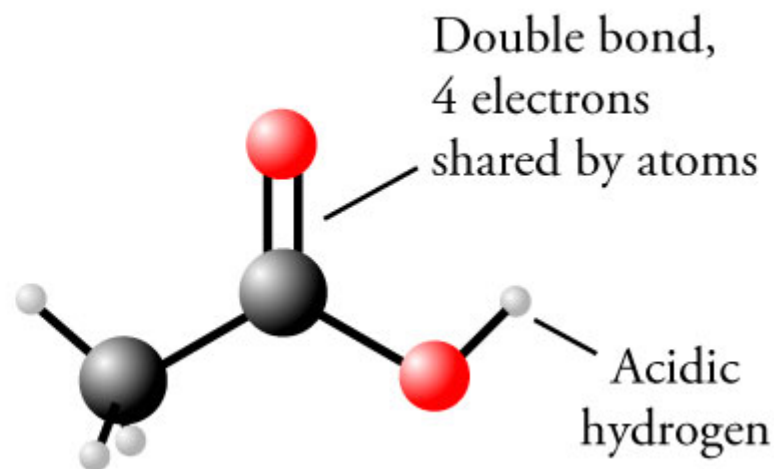
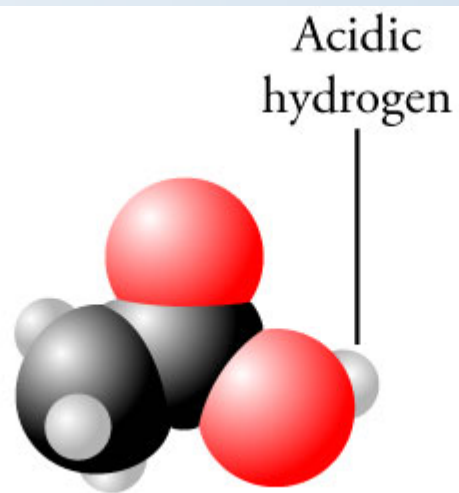
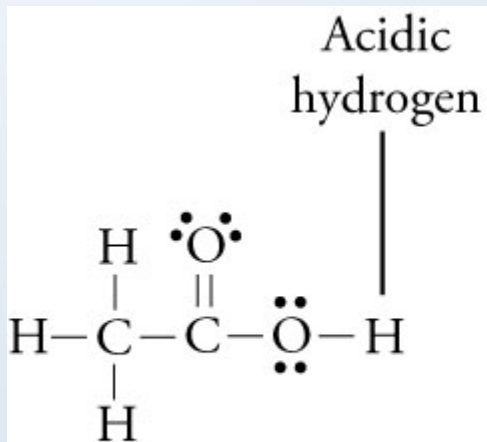


# Types of Acids

- Binary acids have the general formula of  $HX(aq)$ 
  - $HF(aq)$ ,  $HCl(aq)$ ,  $HBr(aq)$ , and  $HI(aq)$
- Oxyacids have the general formula  $H_aX_bO_c$ 
  - $HNO_3$  and  $H_2SO_4$
- Organic (carbon-based) acids
  - $HC_2H_3O_2$



# Acetic Acid



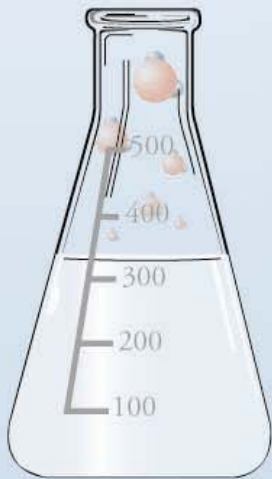
The image shows a series of ball-and-stick models of water molecules (H<sub>2</sub>O) falling from the top left towards a flask at the bottom left. Each molecule consists of one large orange sphere (oxygen) and two smaller grey spheres (hydrogen). The flask is a conical flask with a scale on its side, marked with 100, 200, 300, 400, and 500. The flask is partially filled with a liquid, and several water molecules are shown entering it from the top.

# 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,  $\text{H}_2\text{SO}_4$ , has two acidic hydrogen atoms.
- Some acids, such as phosphoric acid,  $\text{H}_3\text{PO}_4$ , are **triprotic acids**.

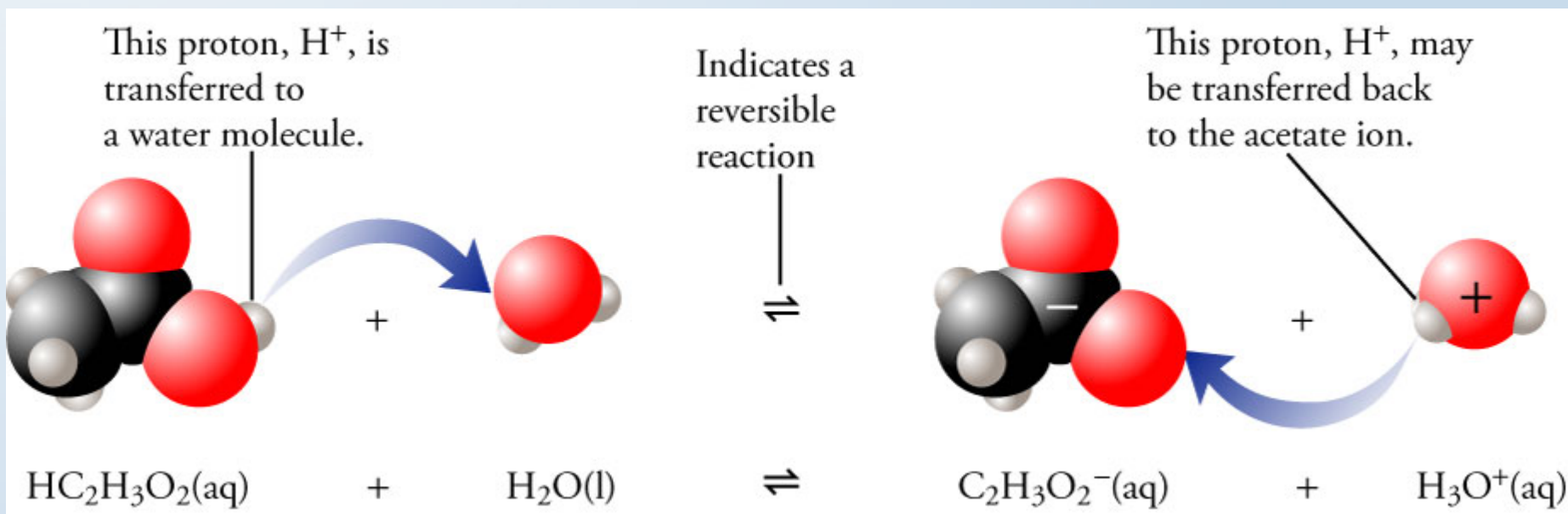
# Strong and Weak Acids

- **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.
- **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.



# Weak Acid and Water

Acetic acid reacts with water in a reversible reaction, which forms hydronium and acetate ions.

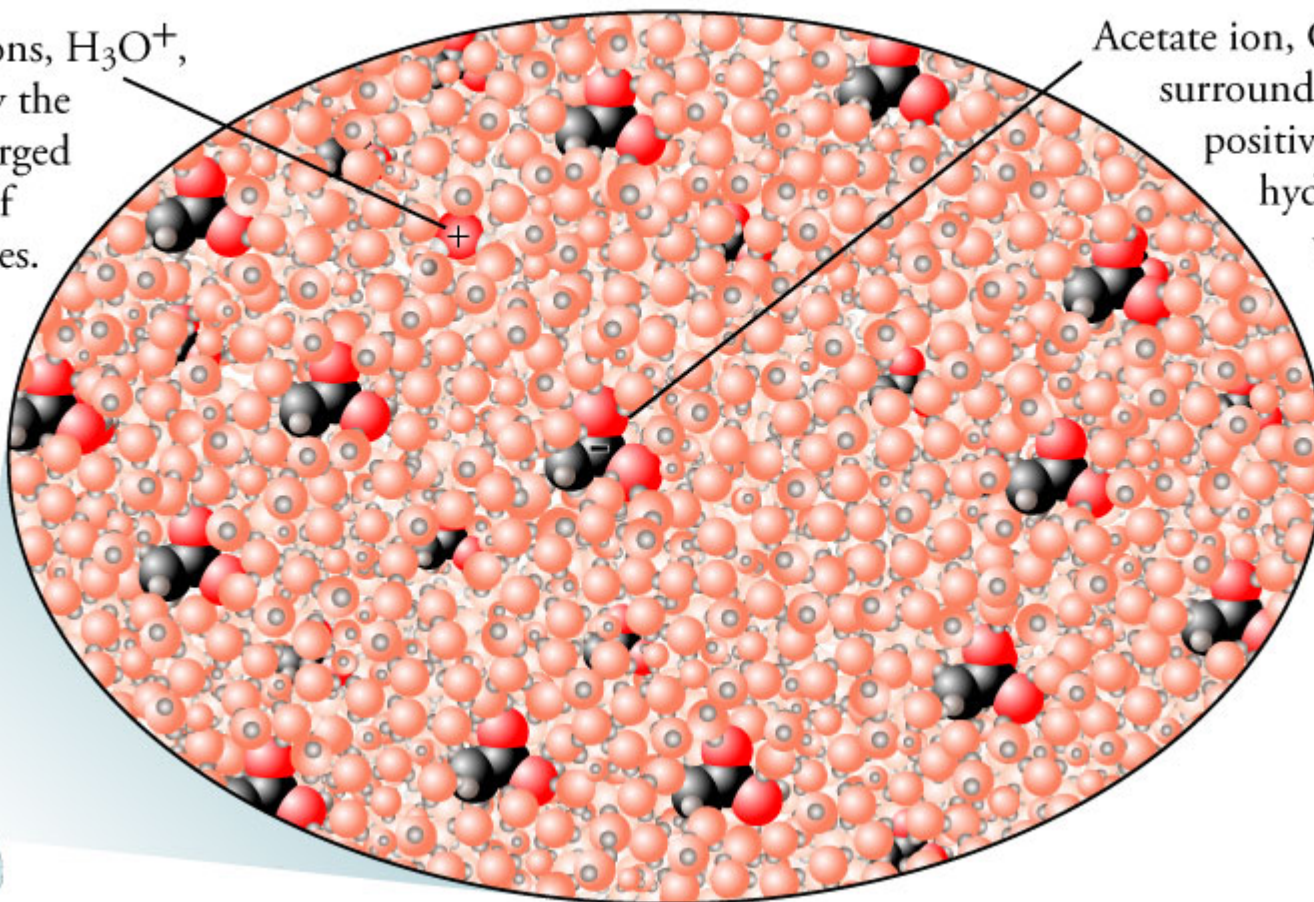
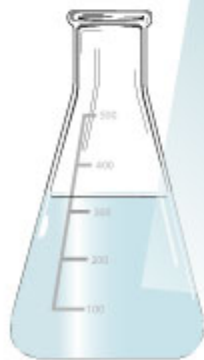


# Solution of Weak Acid

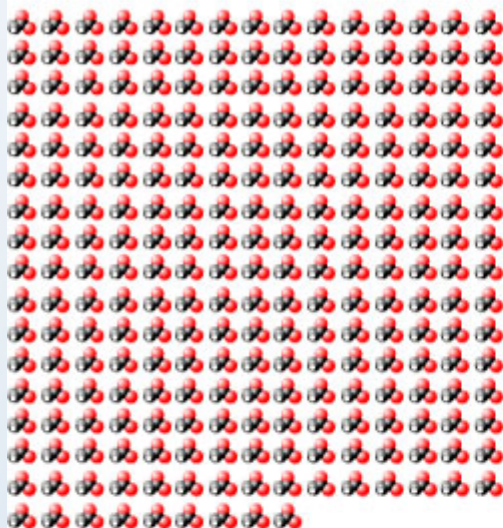
In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules,  $\text{HC}_2\text{H}_3\text{O}_2$ , as acetate ions,  $\text{C}_2\text{H}_3\text{O}_2^-$ .

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

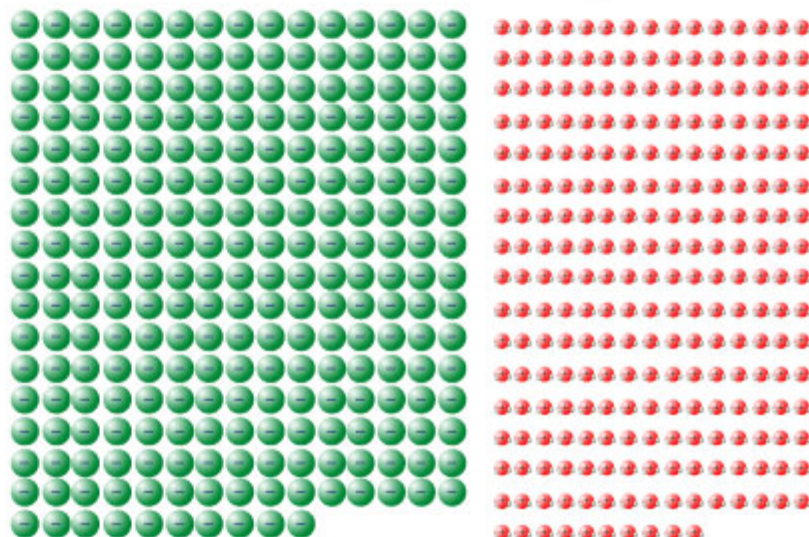
Acetate ion,  $\text{C}_2\text{H}_3\text{O}_2^-$ ,  
surrounded by the  
positively charged  
hydrogen ends of  
water molecules.



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



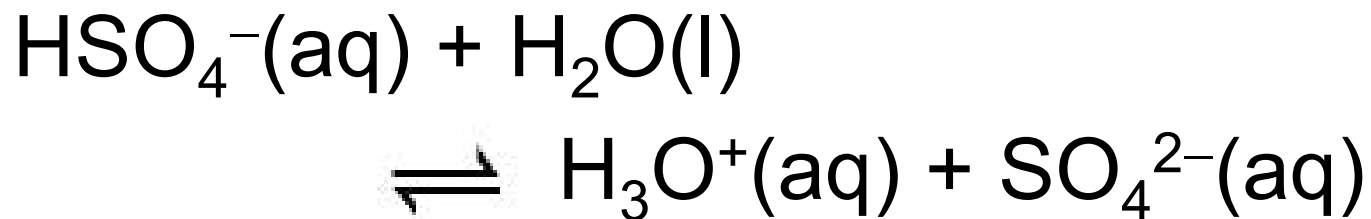
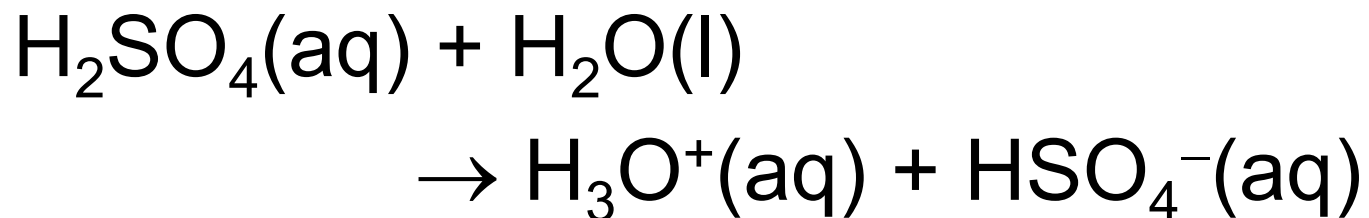
For every 250 molecules of the strong acid hydrochloric acid,  $\text{HCl}$ , added to water, there are about



# Strong and Weak Acids



# Sulfuric Acid



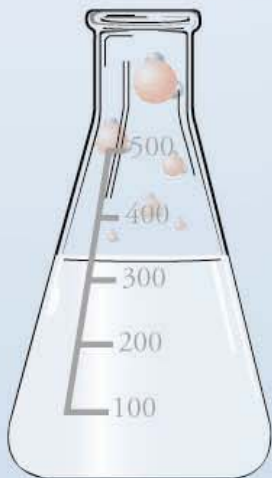
# Acid Summary

	<b>Strong</b>	<b>Weak</b>
<b>Binary acid</b>	hydrochloric acid, HCl(aq)	hydrofluoric acid
<b>Oxyacid</b>	nitric acid, HNO <sub>3</sub> sulfuric acid, H <sub>2</sub> SO <sub>4</sub>	other acids with H <sub>a</sub> X <sub>b</sub> O <sub>c</sub>
<b>Organic acid</b>	none	acetic acid, HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>



# Names and Formulas of Binary Acids

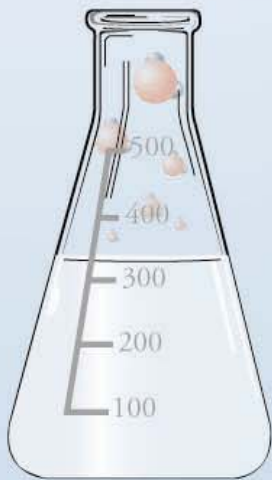
- Names have the general form of *hydro(root)ic acid*, such as hydrochloric acid.
- The formulas are usually followed by *(aq)*, such as  $\text{HCl}(aq)$ .



A decorative border on the left side of the slide consists of several water molecules. Each molecule is represented by a large red sphere (oxygen) and two smaller black spheres (hydrogen) bonded together. The molecules are arranged in a vertical, slightly curved line, appearing to fall from the top left towards the bottom left.

# Names and Formulas for Oxyacids

- If enough  $\text{H}^+$  ions are added to a (root)ate polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.
  - Nitrate,  $\text{NO}_3^-$ , goes to nitric acid,  $\text{HNO}_3$ .
  - Sulfate,  $\text{SO}_4^{2-}$ , goes to sulfuric acid,  $\text{H}_2\text{SO}_4$ . (Note the -ur- in the name.)
  - Phosphate,  $\text{PO}_4^{3-}$ , goes to phosphoric acid,  $\text{H}_3\text{PO}_4$ . (Note the -or- in the name.)



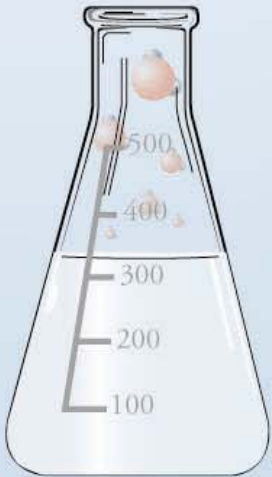
A decorative graphic on the left side of the slide shows several water molecules (represented by one red sphere and two white spheres) falling from the top left towards a flask at the bottom left. The flask is a conical flask with a scale on its side, ranging from 100 to 500. The water level is indicated by a horizontal line at approximately 350. The molecules are shown in various stages of falling, with some already inside the flask.

# 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.

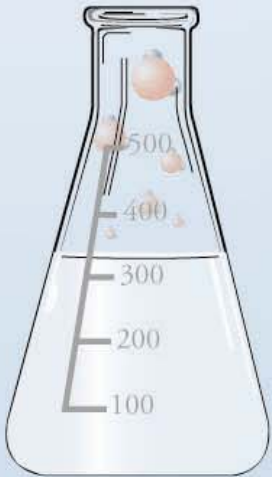
# Arrhenius Base Definitions

- 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.



# Characteristics of Bases

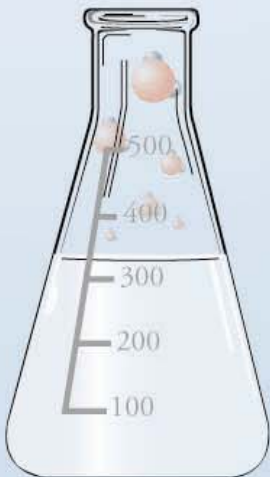
- Bases have a bitter taste.
- Bases feel slippery on your fingers.
- Bases turn litmus from red to blue.
- Bases react with acids.



A series of water molecules, each consisting of one red oxygen atom and two black hydrogen atoms, are shown falling from the top left towards a flask at the bottom left. The molecules are arranged in a vertical line, with some appearing to be in motion as they fall.

# Strong Bases

- **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.



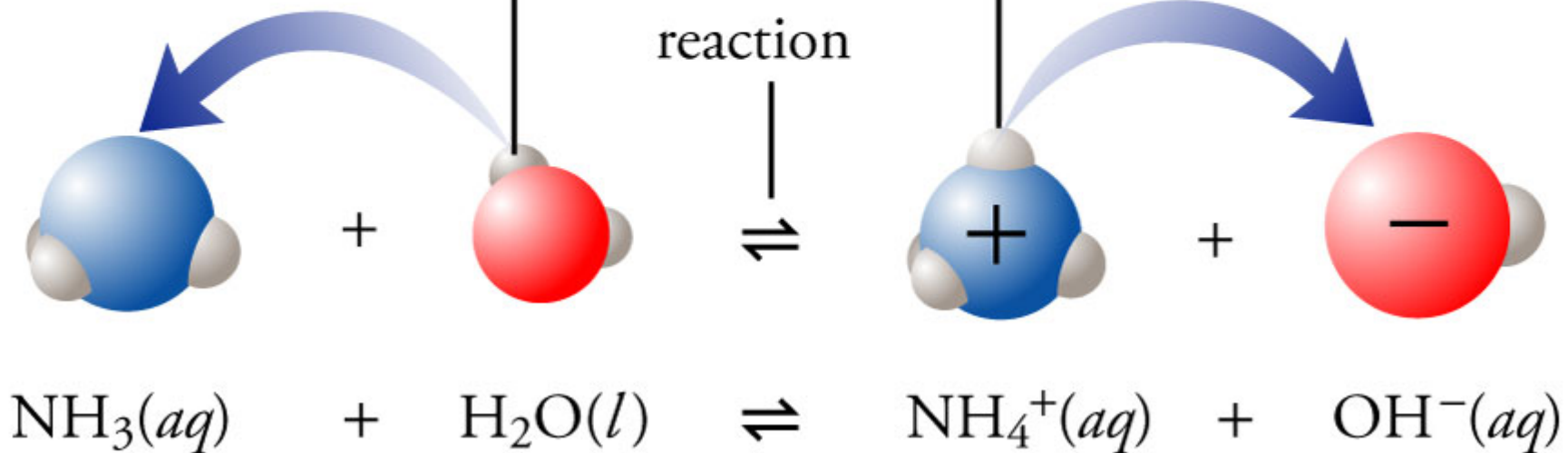
# Ammonia and Water

Ammonia reacts with water in a reversible reaction, which forms ammonium and hydroxide ions.

This proton,  $\text{H}^+$ , is transferred to an ammonia molecule.

Indicates a reversible reaction

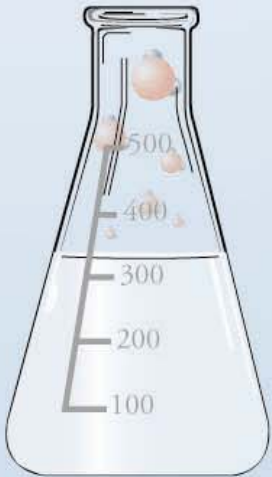
This proton,  $\text{H}^+$ , may be transferred back to the hydroxide ion.





# Weak Base

- **Weak Base** = due to a reversible reaction with water, generates significantly less than one  $\text{OH}^-$  for each formula unit of base added to water.
  - Ammonia and ionic compounds that contain  $\text{CO}_3^{2-}$  or  $\text{HCO}_3^-$  are weak bases.

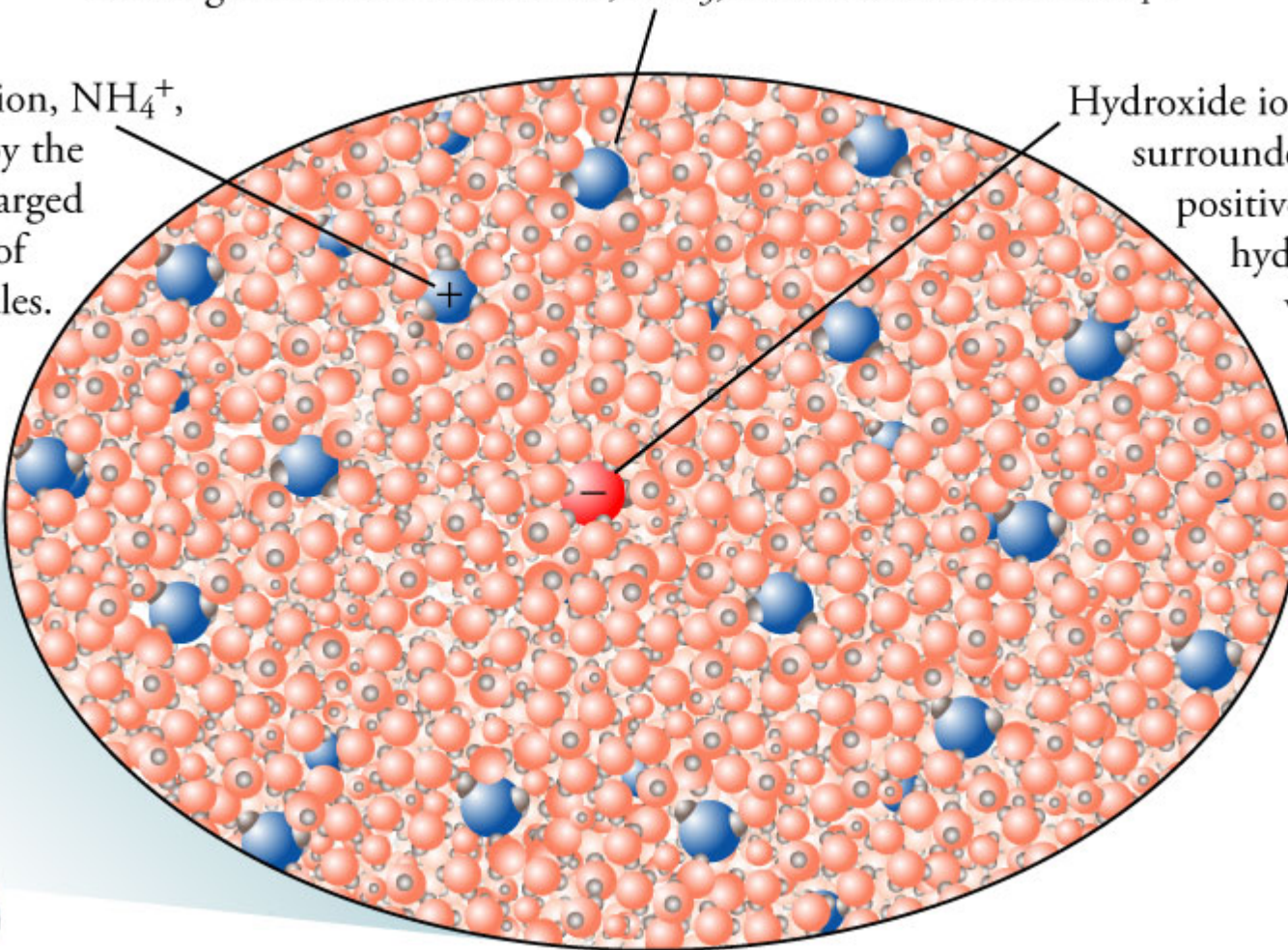
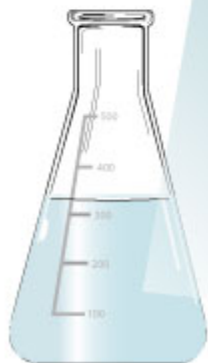


# Ammonia Solution

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



# Carbonate Bases



# Arrhenius Bases

**Strong**

**Weak**

**Ionic  
Compounds**

Metal  
hydroxides

Ionic compounds  
with  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$

**Certain  
Uncharged  
molecules**

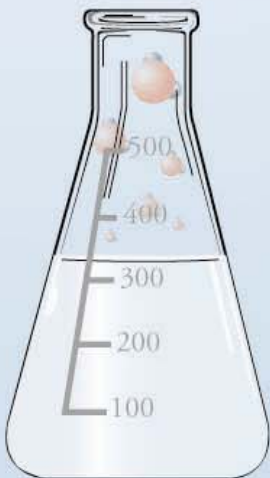
None

$\text{NH}_3$

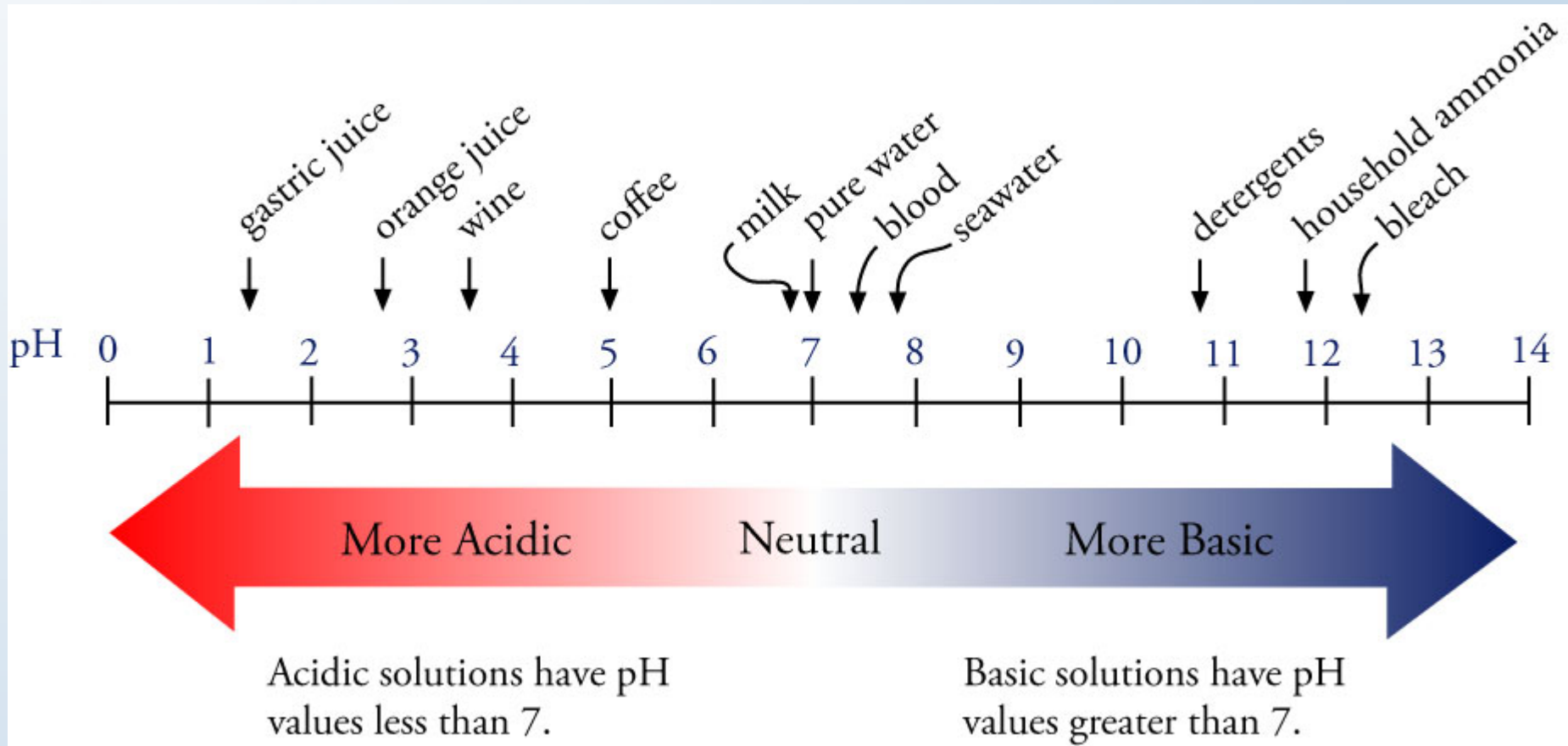


# pH

- 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.



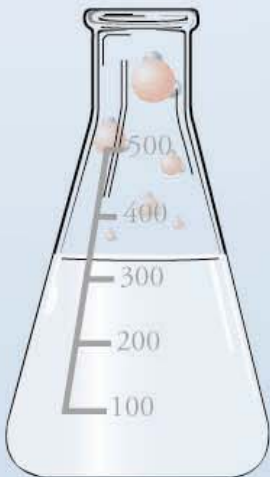
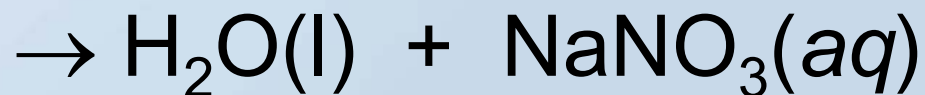
# pH Range



A decorative border on the left side of the slide consists of several water molecules (H<sub>2</sub>O) represented by a red sphere (oxygen) and two black spheres (hydrogen).

# Neutralization Reactions

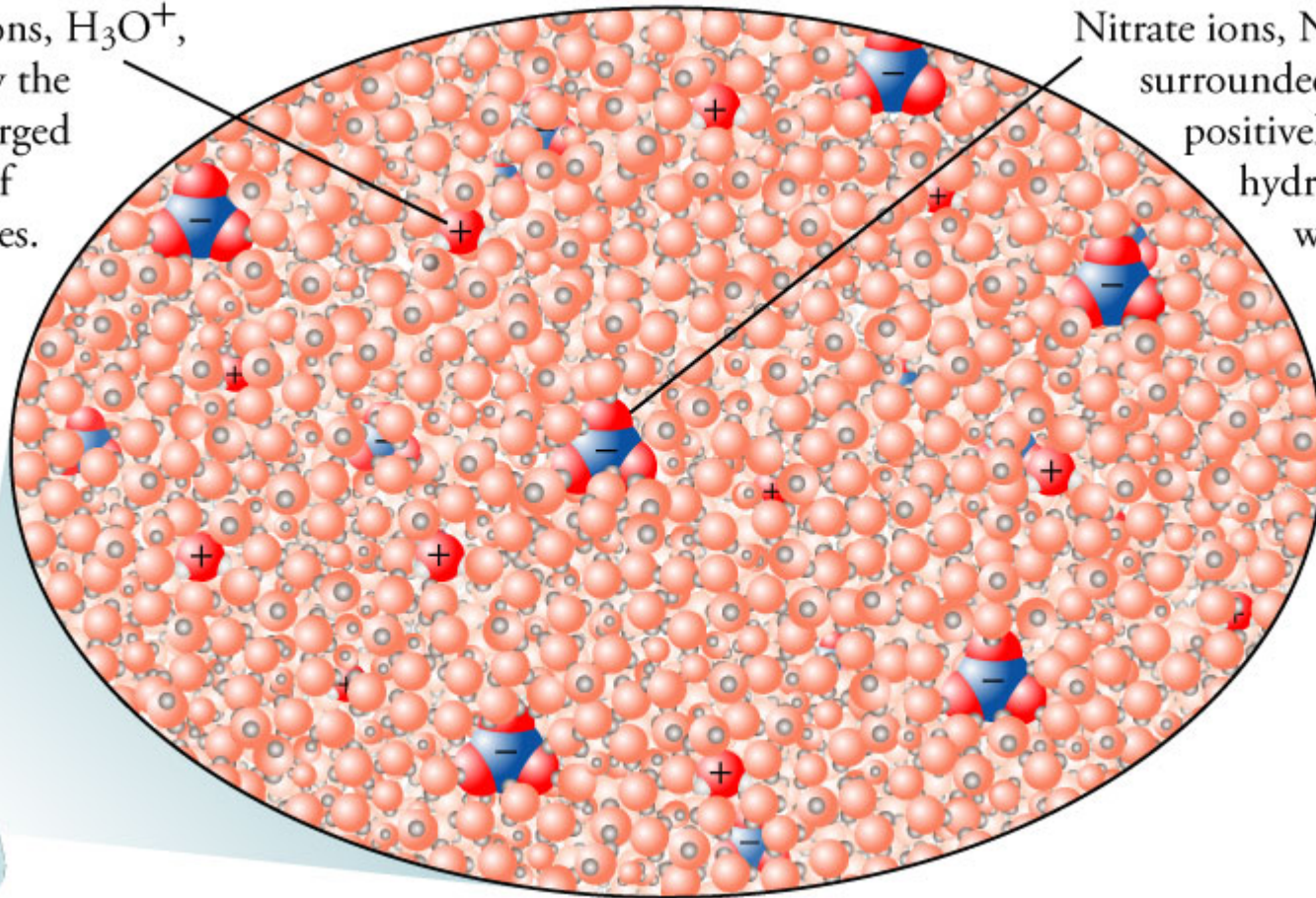
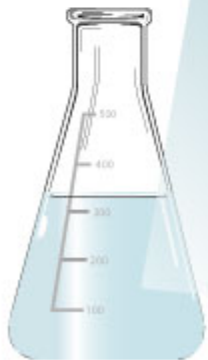
- Reactions between Arrhenius acids and Arrhenius bases are called ***neutralization reactions***.



# Aqueous Nitric Acid

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

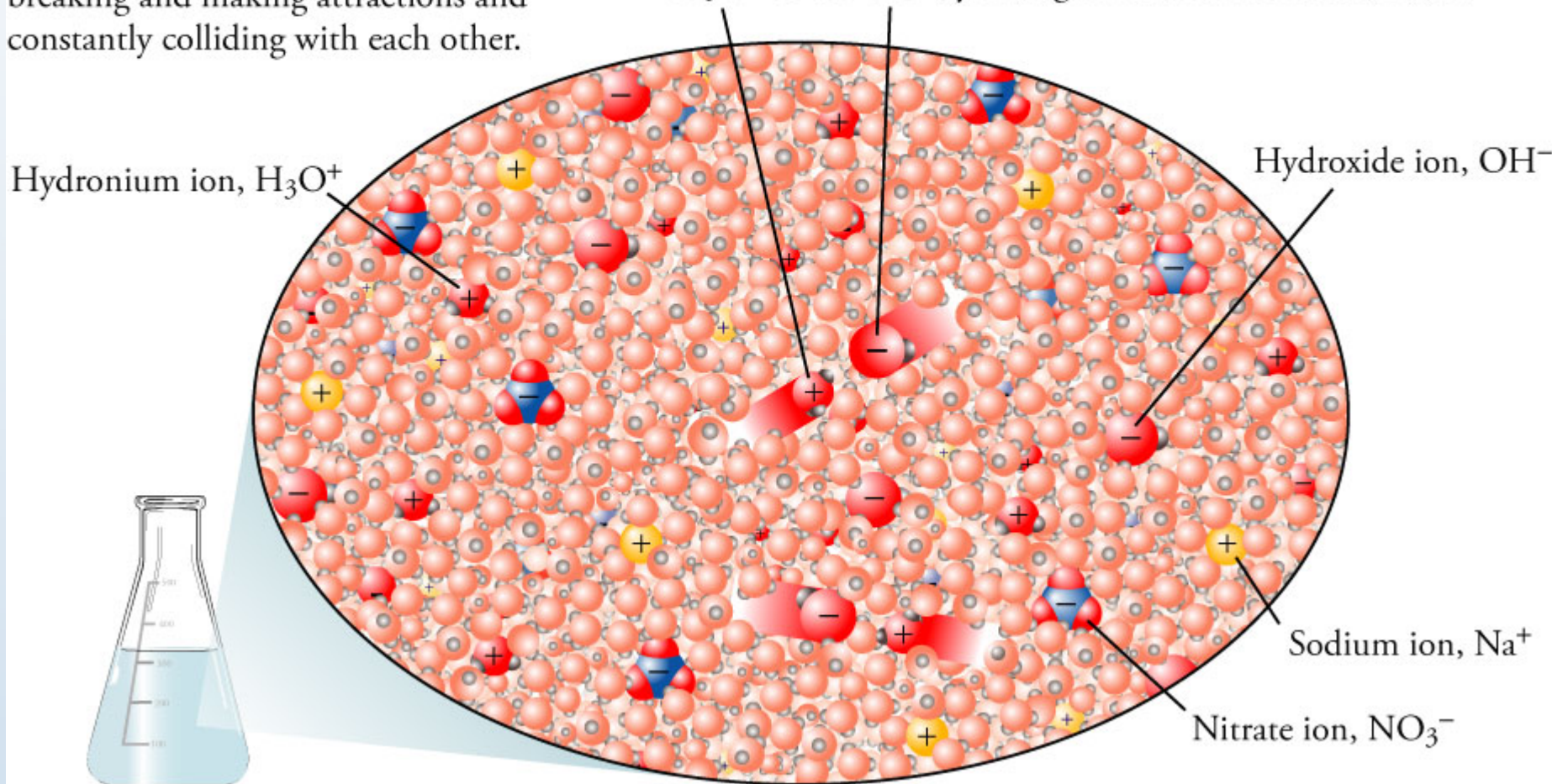
Nitrate ions,  $\text{NO}_3^-$ ,  
surrounded by the  
positively charged  
hydrogen ends of  
water molecules.



# Mixture of $\text{HNO}_3$ and $\text{NaOH}$ 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.

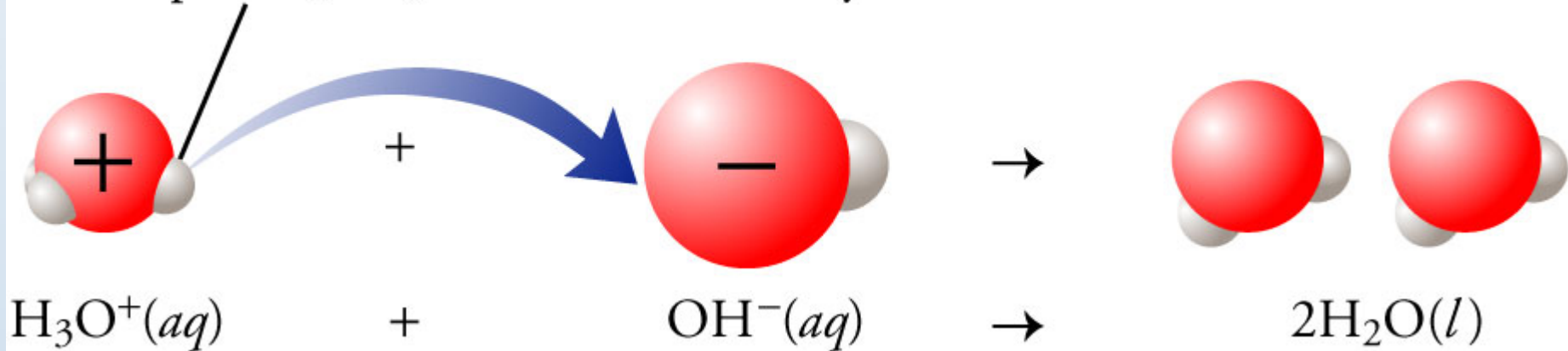
When a hydroxide ion,  $\text{OH}^-$ , collides with a hydronium ion,  $\text{H}_3\text{O}^+$ , an  $\text{H}^+$  ion is transferred from the  $\text{H}_3\text{O}^+$  to the  $\text{OH}^-$ , yielding two water molecules,  $\text{H}_2\text{O}$ .



# Strong Acid and Strong Base Reaction

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,  $\text{H}_2\text{O}$ .

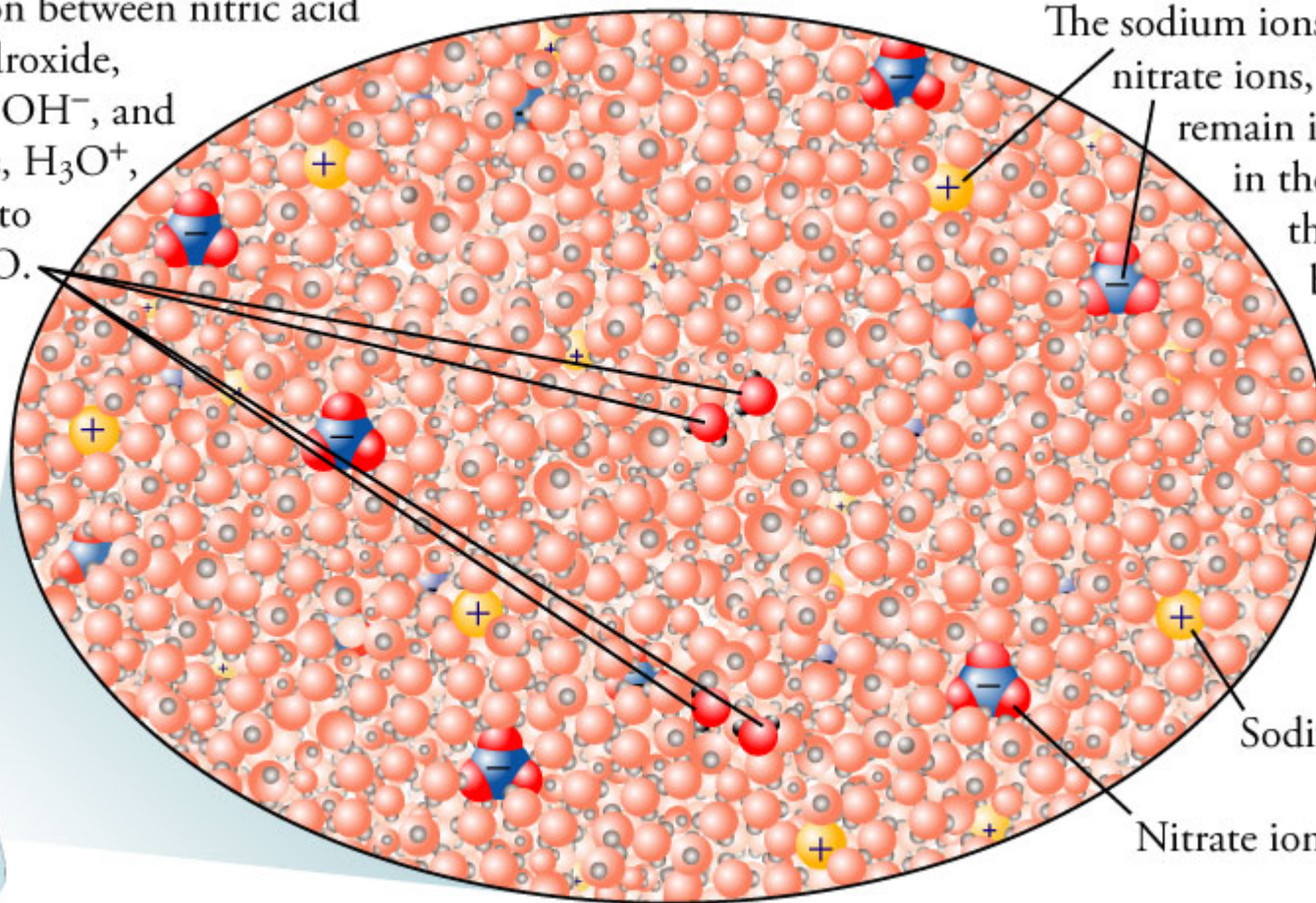
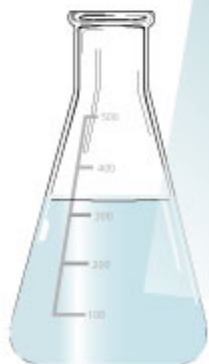
This proton,  $\text{H}^+$ , is transferred to a hydroxide ion.



# Mixture of $\text{HNO}_3$ and $\text{NaOH}$ After the Reaction

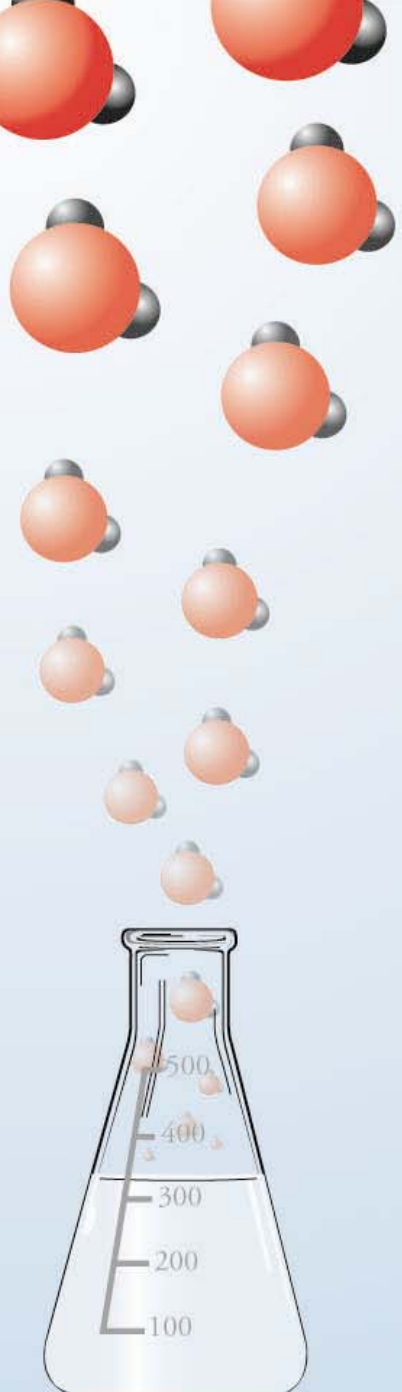
After the reaction between nitric acid and sodium hydroxide, hydroxide ions,  $\text{OH}^-$ , and hydronium ions,  $\text{H}_3\text{O}^+$ , have combined to form water,  $\text{H}_2\text{O}$ .

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



Sodium ion,  $\text{Na}^+$

Nitrate ion,  $\text{NO}_3^-$

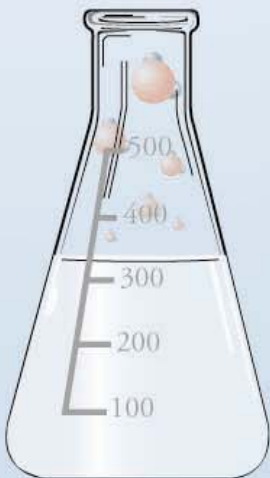


## Reaction between an Acid and a Hydroxide Base.

- The reaction has the double displacement form.



- 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.



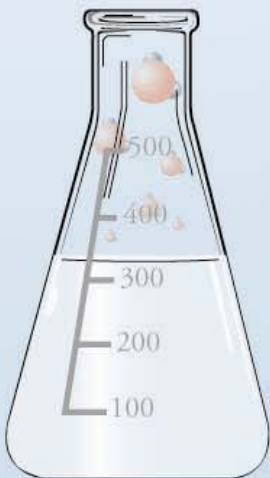
## Reaction between an Acid and a Carbonate Base

- The reaction has the double displacement form.

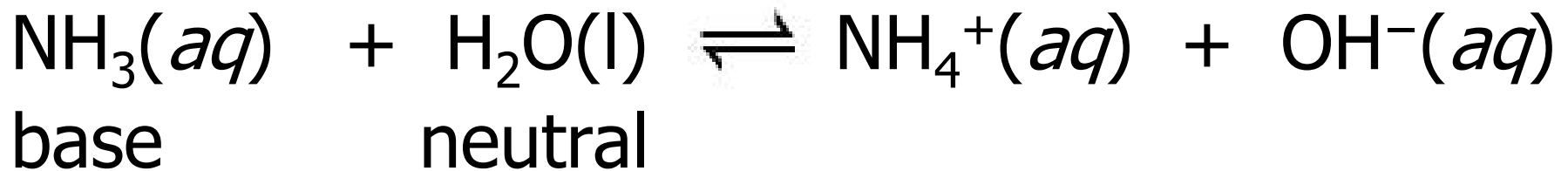


– The positive part of the acid is  $H^+$ .

- The products are water, carbon dioxide, and a water-soluble ionic compound. The  $H_2O$  and the  $CO_2$  come from the decomposition of the initial product  $H_2CO_3$ .



# Arrhenius Acid-Base Reactions?



A decorative vertical column of water molecules (H<sub>2</sub>O) on the left side of the slide. Each molecule is represented by a large red sphere (oxygen) and two smaller black spheres (hydrogen) bonded together. The molecules are arranged in a descending staircase pattern from top to bottom.

# Acid and Base Definitions

- **Acid**

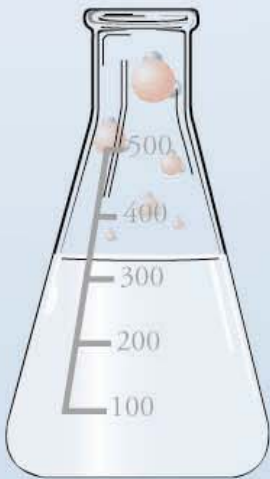
- Arrhenius: a substance that generates  $\text{H}_3\text{O}^+$  in water
- Brønsted-Lowry: a proton,  $\text{H}^+$ , donor

- **Base**

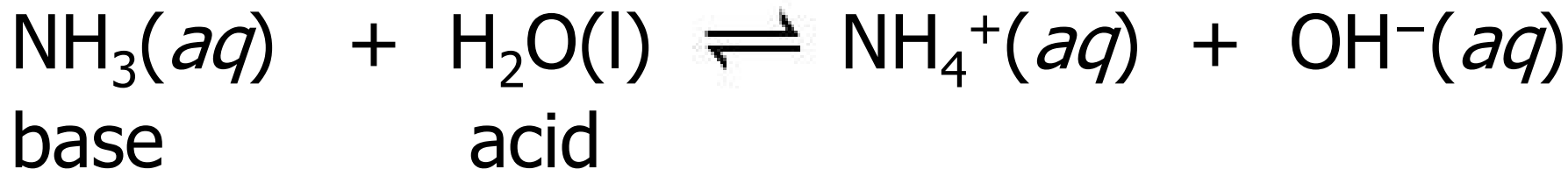
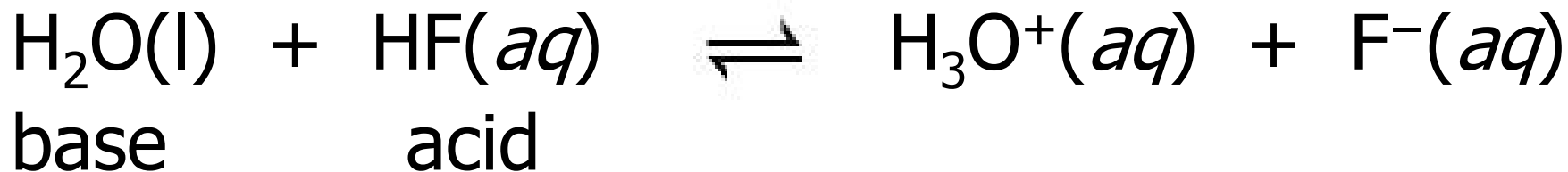
- Arrhenius: a substance that generates  $\text{OH}^-$  in water
- Brønsted-Lowry: a proton,  $\text{H}^+$ , acceptor

- **Acid-Base Reaction**

- Arrhenius: between an Arrhenius acid and base
- Brønsted-Lowry: a proton ( $\text{H}^+$ ) transfer

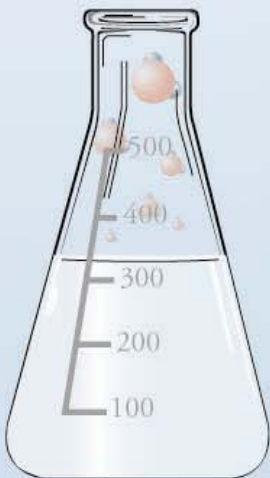


# Brønsted-Lowry Acids and Bases



# Why Two Definitions for Acids and Bases? (1)

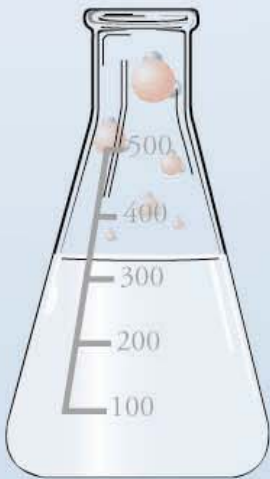
- Positive Aspects of Arrhenius Definitions
  - All isolated substances can be classified as acids (generate  $\text{H}_3\text{O}^+$  in water), bases (generate  $\text{OH}^-$  in water), or neither.
  - Allows predictions, including (1) whether substances will react with a base or acid, (2) whether 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.



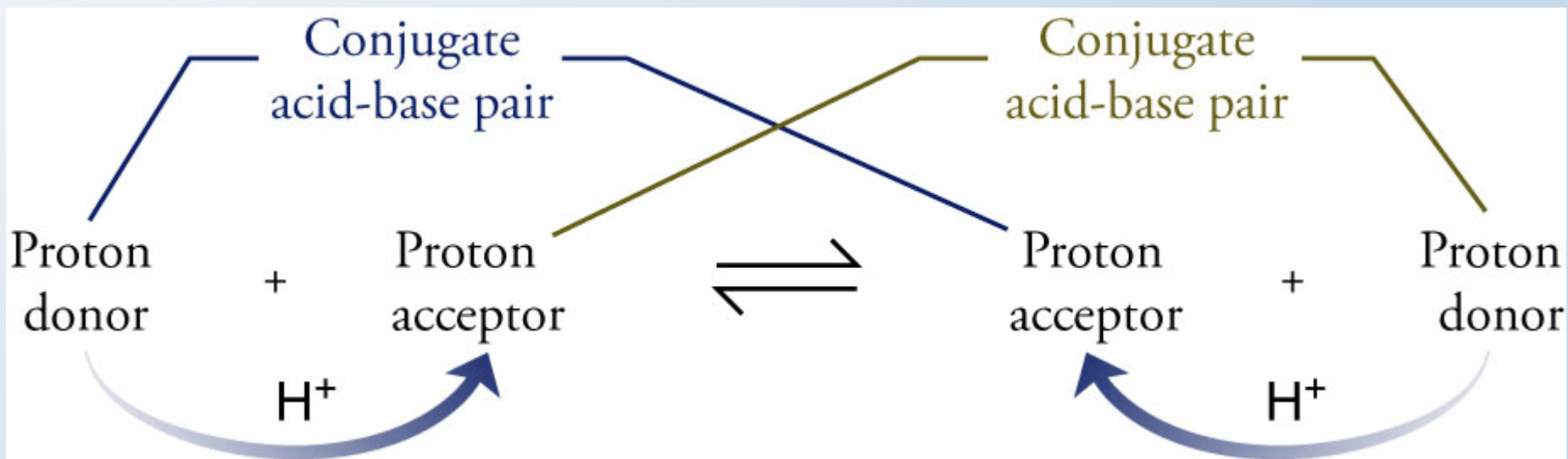
A decorative border of water molecules (H<sub>2</sub>O) is located on the left side of the slide. Each molecule is represented by a large red sphere (oxygen) and two smaller black spheres (hydrogen) bonded together.

## Why Two Definitions for Acids and Bases? (2)

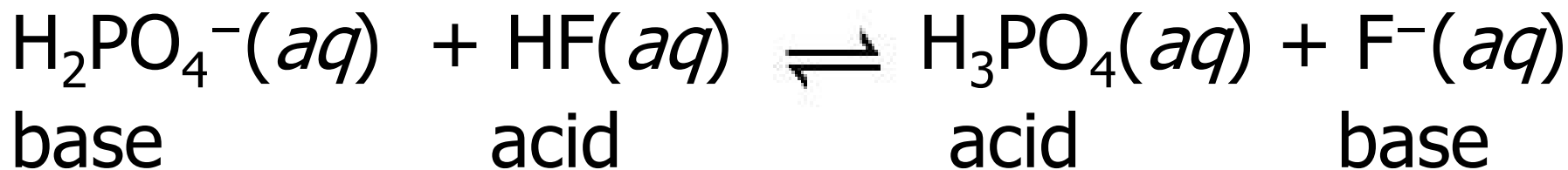
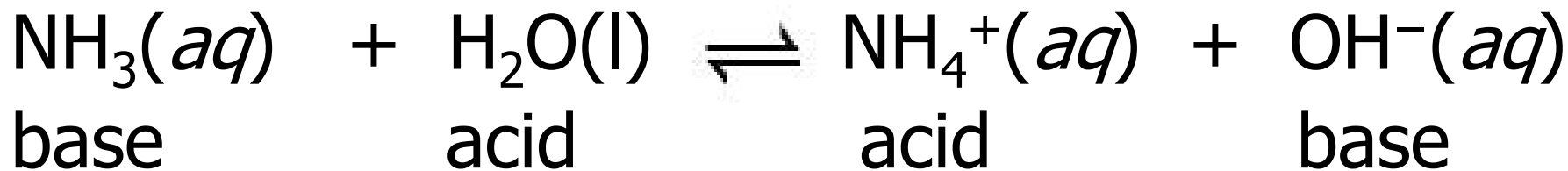
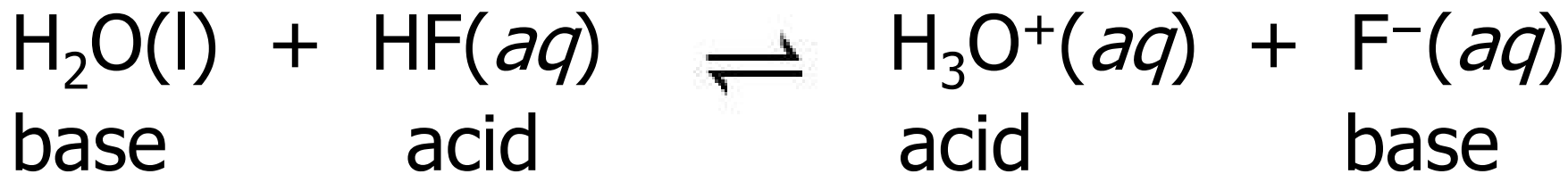
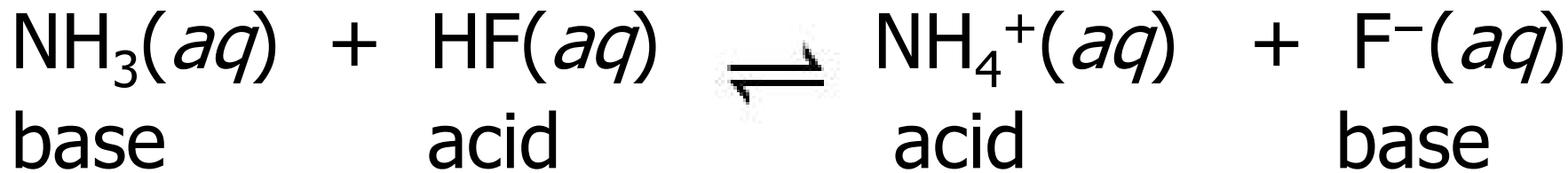
- Positive Aspects of Brønsted-Lowry Definitions
  - Includes similar reactions (H<sup>+</sup> transfer reactions) as acid-base reactions.
- Negative Aspects of Brønsted-Lowry Definitions
  - Cannot classify isolated substances as acids (generate H<sub>3</sub>O<sup>+</sup> in water), bases (generate OH<sup>-</sup> 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



# Brønsted-Lowry Acids and Bases



# Amphoteric Substances

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



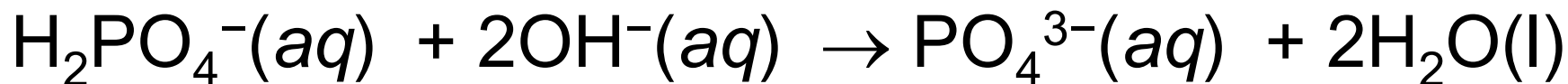
base                      acid



acid                      base



base                      acid



acid                      base