

ACID-BASE CONCEPTS

General Properties:

	ACIDS	BASES
Taste	sour	Bitter
Change color of indicators	↓	↓
Blue Litmus	turns red	no change
Red Litmus	no change	turns blue
Phenolphthalein	Colorless	turns pink
Neutralization	React with bases to form salt and water	React with acids to form salt and water

Arrhenius Concept of Acids and Bases:

- Arrhenius definition of acids and bases is based on their behavior in water (aqueous solutions)

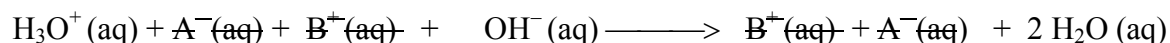
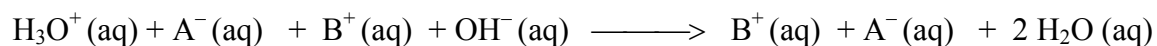
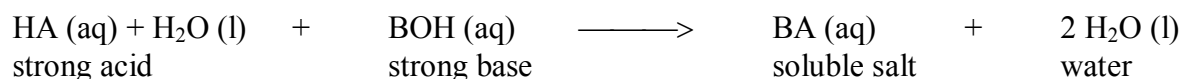
ACIDS	BASES
<ul style="list-style-type: none"> • Substances that dissolved in water to increase the concentration of H_3O^+ (hydronium ions) • Accepted simplification: H^+ • H^+ is always attached to a water molecule. $\left[\begin{array}{c} \text{H}-\ddot{\text{O}}-\text{H} \\ \text{H} \end{array} \right]^+$	<ul style="list-style-type: none"> • Substances that dissolved in water to increase the concentration of OH^- (hydroxide ions) $\left[\begin{array}{c} \ddot{\text{O}}-\text{H} \\ \ddot{\text{O}} \end{array} \right]^-$

STRONG ACIDS AND BASES

- **Strong acids and bases completely ionize** in aqueous solutions and are therefore **strong electrolytes**.

STRONG ACIDS	STRONG BASES
<ul style="list-style-type: none"> • Completely ionize in aqueous solution to form H_3O^+ and an anion $\text{HA (aq)} + \text{H}_2\text{O (l)} \longrightarrow \text{H}_3\text{O}^+ + \text{A}^- \text{ (aq)}$ <p>Examples:</p> $\text{HCl (aq)} + \text{H}_2\text{O (l)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{Cl}^- \text{ (aq)}$ $\text{HNO}_3 \text{ (aq)} + \text{H}_2\text{O (l)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{NO}_3^- \text{ (aq)}$ $\text{H}_2\text{SO}_4 \text{ (aq)} + \text{H}_2\text{O (l)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{HSO}_4^- \text{ (aq)}$ $\text{HClO}_4 \text{ (aq)} + \text{H}_2\text{O (l)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{ClO}_4^- \text{ (aq)}$	<ul style="list-style-type: none"> • Completely ionize in aqueous solution to form OH^- and a cation $\text{BOH (s)} \xrightarrow{\text{H}_2\text{O}} \text{B}^+ \text{ (aq)} + \text{OH}^- \text{ (aq)}$ <p>Examples:</p> $\text{NaOH (s)} \xrightarrow{\text{H}_2\text{O}} \text{Na}^+ \text{ (aq)} + \text{OH}^- \text{ (aq)}$ $\text{KOH (s)} \xrightarrow{\text{H}_2\text{O}} \text{K}^+ \text{ (aq)} + \text{OH}^- \text{ (aq)}$ $\text{Ca(OH)}_2 \text{ (s)} \xrightarrow{\text{H}_2\text{O}} \text{Ca}^{2+} \text{ (aq)} + 2 \text{OH}^- \text{ (aq)}$ $\text{Ba(OH)}_2 \text{ (s)} \xrightarrow{\text{H}_2\text{O}} \text{Ba}^{2+} \text{ (aq)} + 2 \text{OH}^- \text{ (aq)}$

NEUTRALIZATION REACTIONS BETWEEN STRONG ACIDS AND STRONG BASES

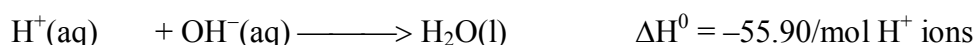


NOTE: It has been observed that all neutralization reactions between strong acids and bases:

- are exothermic
- have the same enthalpy of reaction per mol of H^+ = -55.90 kJ

CONCLUSION:

- The neutralization reaction between any strong acid and any strong base is:



WEAK ACIDS AND BASES

- **Weak** acids and bases **partially ionize** in aqueous solutions and are therefore **weak electrolytes**.
- Weak acids and bases exist in reversible reactions (equilibrium) with the corresponding ions.

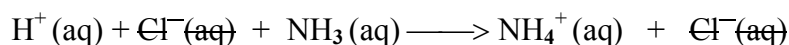
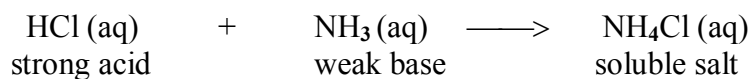
WEAK ACIDS:**WEAK BASES:****Limitations of the Arrhenius Concept:**

1. Considers acid-base reactions **only** in aqueous solutions
2. Singles out the OH^- ion as the source of base character (other species can play a similar role)

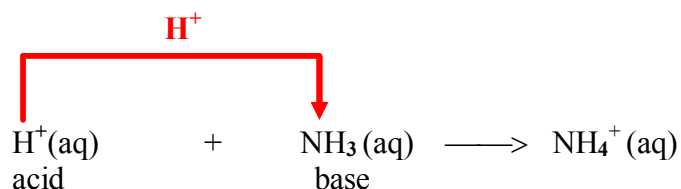
BRONSTED-LOWRY CONCEPT OF ACIDS AND BASES

- Bronsted and Lowry defined acids and bases in terms of H^+ (proton) transfer.

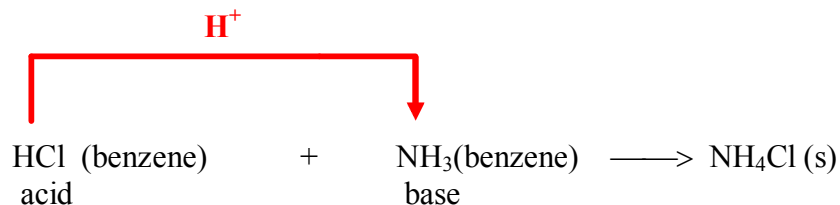
ACIDS	BASES
H^+ (proton) donors	H^+ (proton) acceptors
NEUTRALIZATION: A reaction in which a H^+ (proton) is transferred	



N.I.E.

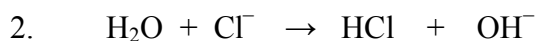
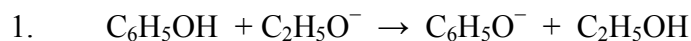


- Bronsted-Lowry neutralization can also occur in a non-aqueous system:



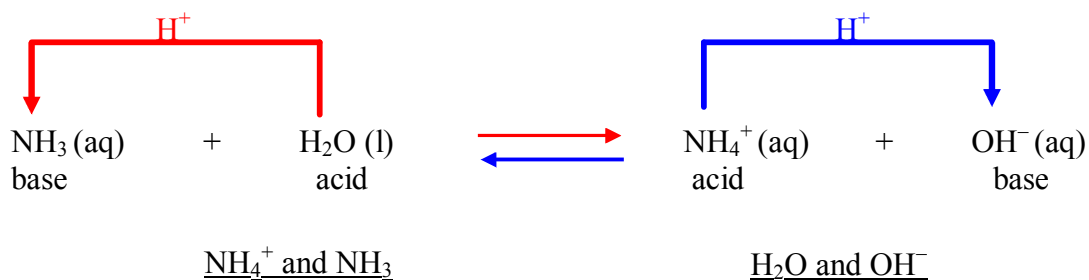
Examples:

Identify the Bronsted-Lowry acid and base in each of the following equations:

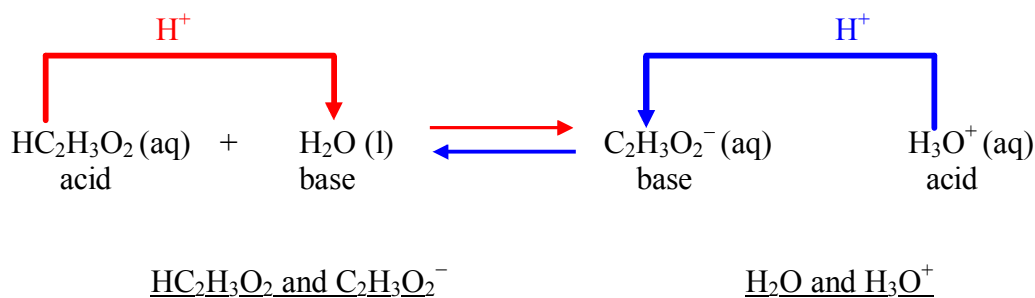


BRONSTED-LOWRY CONCEPT OF ACIDS AND BASES

- In a reversible acid-base reaction, both forward and reverse reactions involve H^+ transfer



- | | |
|--|--|
| <ul style="list-style-type: none"> differ by a H^+ are a conjugate acid-base pair NH_4^+ is the conjugate acid of NH_3 NH_3 is the conjugate base of NH_4^+ | <ul style="list-style-type: none"> differ by a H^+ are a conjugate acid-base pair H_2O is the conjugate acid of OH^- OH^- is the conjugate base of H_2O |
|--|--|

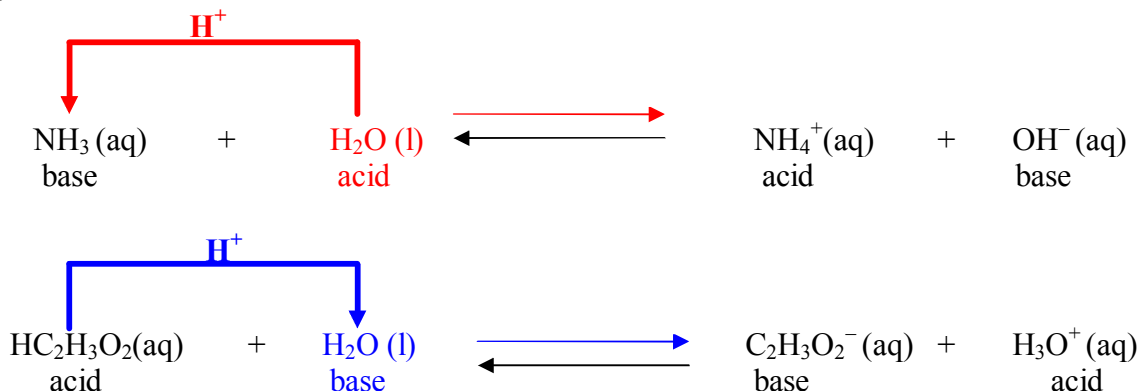


- | | |
|--|--|
| <ul style="list-style-type: none"> differ by a H^+ are a conjugate acid-base pair $HC_2H_3O_2$ is the conjugate acid of $C_2H_3O_2^-$ $C_2H_3O_2^-$ is the conjugate base of $HC_2H_3O_2$ | <ul style="list-style-type: none"> differ by a H^+ are a conjugate acid-base pair H_2O is the conjugate base of H_3O^+ H_3O^+ is the conjugate acid of H_2O |
|--|--|

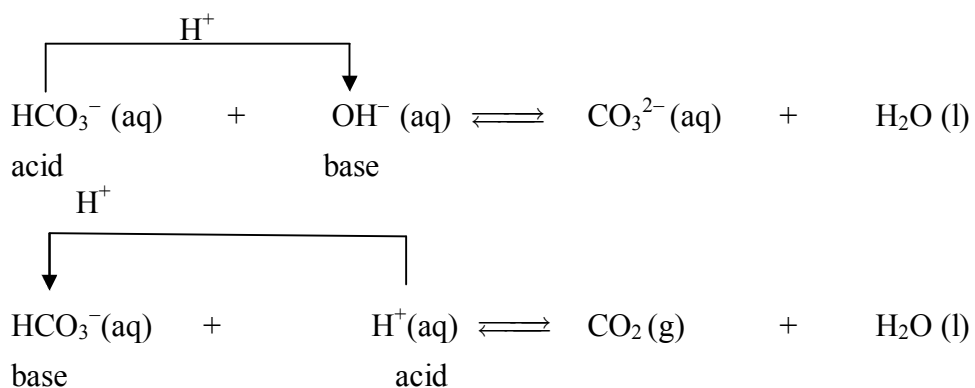
In General: A conjugate acid-base pair consists of two species in an acid-base reaction that differ by the loss or gain of a H^+ (proton)

- Species that can act both as **an acid and a base** are called **amphiprotic**.

Consider:



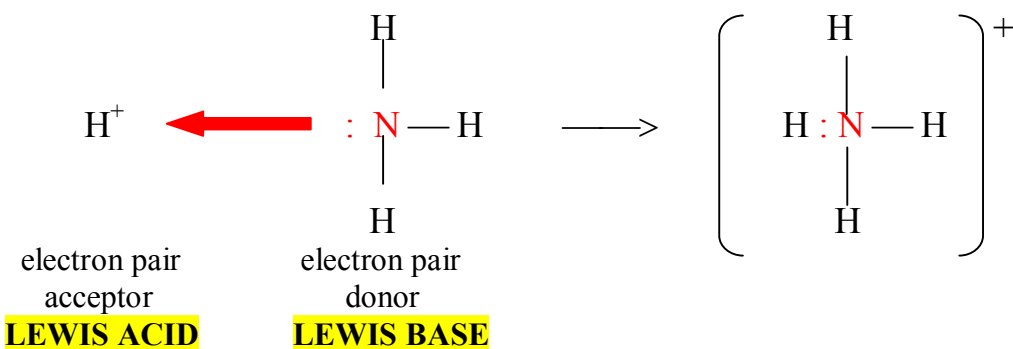
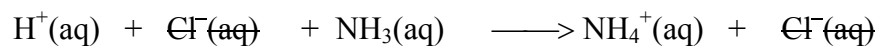
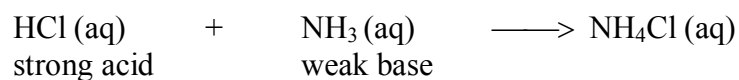
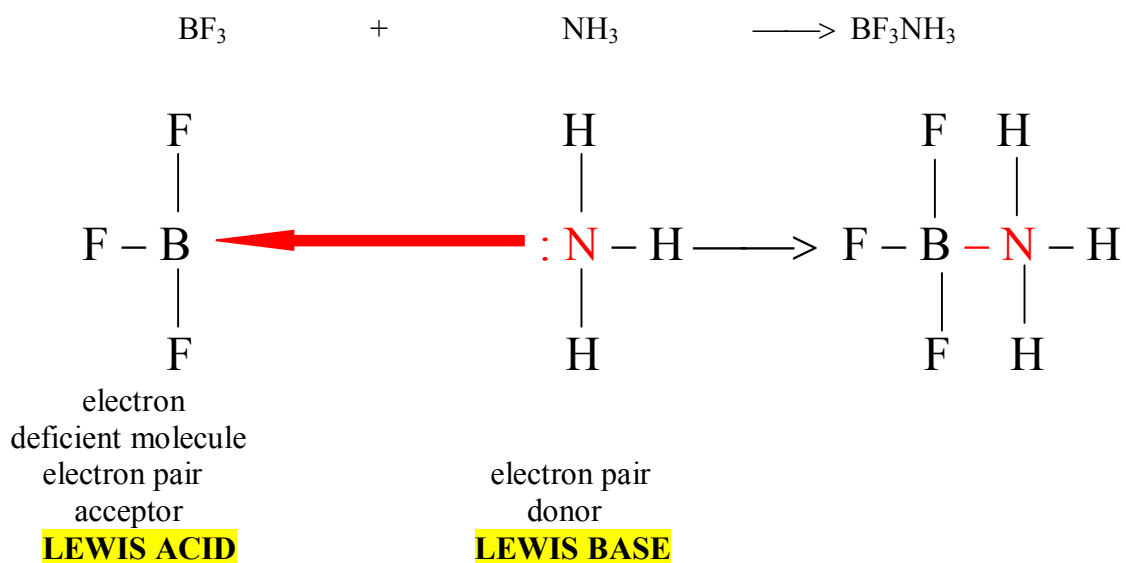
- H₂O can
 - lose a H⁺ and act as an acid (with the weak base NH₃)
 OR
 - gain a H⁺ and act as a base (with the weak acid HC₂H₃O₂)
- H₂O is an amphiprotic species
- Bicarbonate ion(HCO₃⁻) is another example of amphiprotic species, as illustrated by the following reactions:

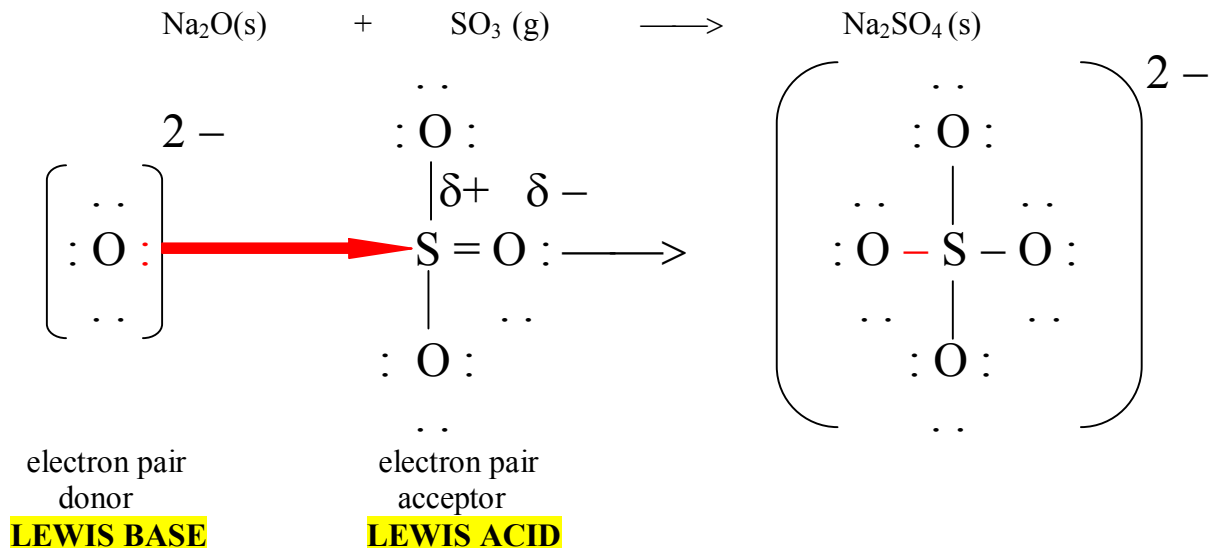


- The Bronsted-Lowry Concept of Acids & Bases is more general than the Arrhenius concept.
- Bronstead-Lowry Concept introduces additional points of view:
 - A base is a species that accepts H⁺ ions (OH⁻ is only one example of a base)
 - Acids and Bases can be ions as well as molecular substances
 - Acid-Base reactions are not restricted to aqueous solutions
 - Amphiprotic species can act as either acids or bases depending on what the other reactant is.

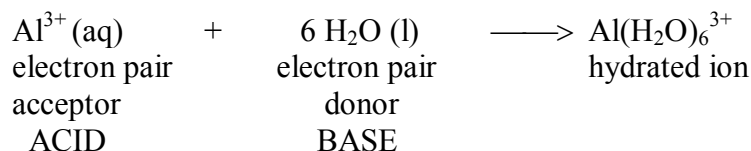
LEWIS CONCEPT OF ACIDS AND BASES

- Gilbert Lewis defined acids and bases in terms of electron-pair transfer.


Example 1:


Example 2:**Example 3:**

Formation of complex ions



In General:

LEWIS ACIDS	LEWIS BASES
electron pair acceptors Usually positive ions or electron deficient molecules	electron pair donors Usually negative ions or molecules with lone pairs
NEUTRALIZATION: A reaction in which an electron pair is transferred	

SUMMARY OF ACID – BASE CONCEPTS

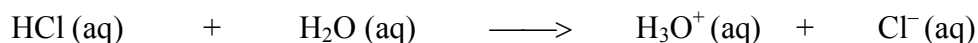
	ACID	BASE	NEUTRALIZATION
Arrhenius Concept (least general)	Substance that dissolved in water increases concentration of H_3O^+	Substance that dissolved in water increases concentration of OH^-	$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
Bronsted-Lowry Concept	A H^+ donor	A H^+ acceptor	A H^+ transfer
Lewis Concept	An electron pair acceptor	An electron pair donor	An electron pair transfer

ACID AND BASE STRENGTHS
Relative Strengths of Acids

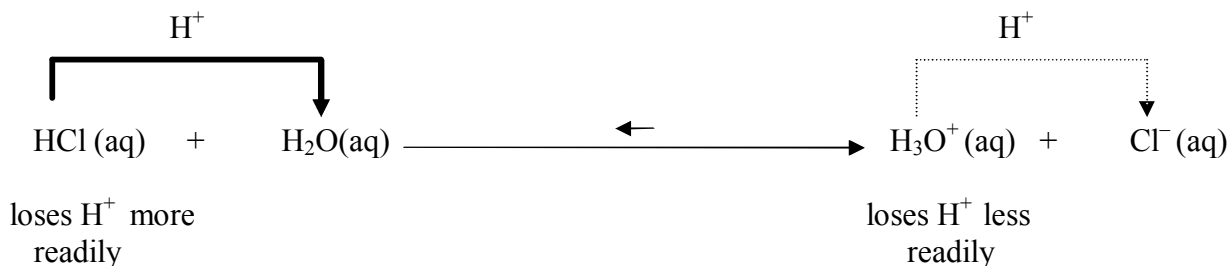
- An acid is stronger than another acid if it loses H^+ more readily
- To estimate relative acidic strength, several comparisons between pairs of acids will be made.

HCl(aq) and H_3O^+ (aq)

- Recall that HCl(aq) is a strong acid and as such it ionizes completely in water:



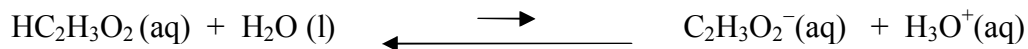
- The reaction goes completely to products.
- “ASSUME” that a reverse reaction were possible to a very small extent:



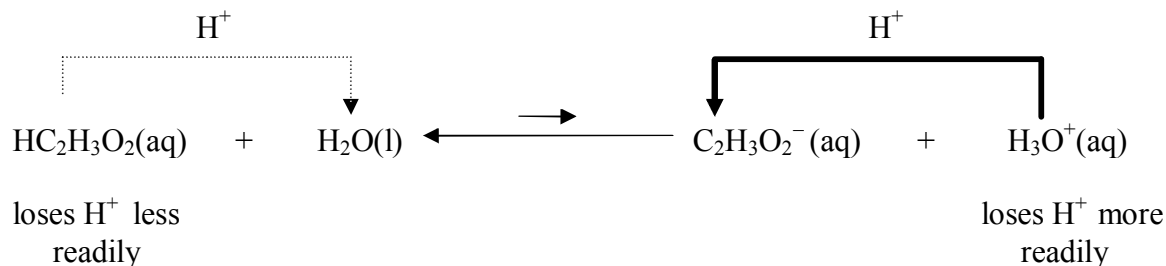
- **HCl(aq) is a stronger acid than H_3O^+ (aq)** **$HCl(aq) > H_3O^+(aq)$**

HC₂H₃O₂(aq) and H_3O^+ (aq)

- Recall that HC₂H₃O₂(aq) is a weak acid and as such ionizes only partially in water:



- The reaction goes mostly to reactants. Only about 1 % of the acetic acid molecules are ionized.



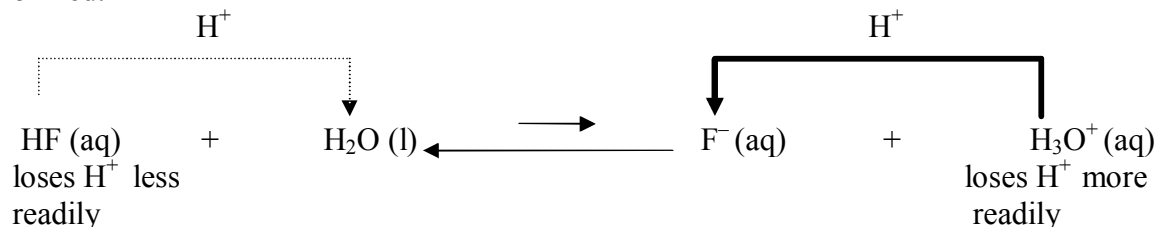
- **H_3O^+ (aq) is a stronger acid than HC₂H₃O₂(aq)** **$H_3O^+(aq) > HC_2H_3O_2(aq)$**

ACID AND BASE STRENGTHS
HF(aq) and H₃O⁺(aq)

- Recall that HF(aq) is a weak acid and as such, ionizes only partially in water:



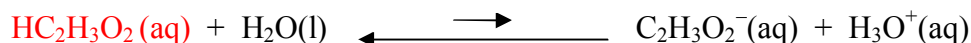
- The reaction goes mostly to reactants. Only about 3 % of the hydrofluoric acid molecules are ionized.



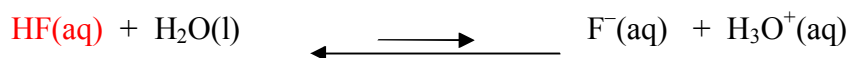
- H₃O⁺(aq) is a stronger acid than HF(aq)** **H₃O⁺(aq) > HF(aq)**

HC₂H₃O₂(aq) and HF(aq)

- Both are weak acids and both are partially ionized in water, but not to the same extent:



- Only about 1% of the acetic acid molecules are ionized.

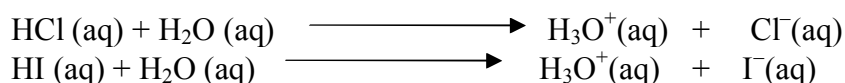


- Only about 3% of the hydrofluoric acid molecules are ionized.

- HF(aq) is a stronger acid than HC₂H₃O₂ (aq)** **HF(aq) > HC₂H₃O₂ (aq)**

HCl(aq) and HI(aq)

- Both are strong acids, and as such, are completely ionized in water



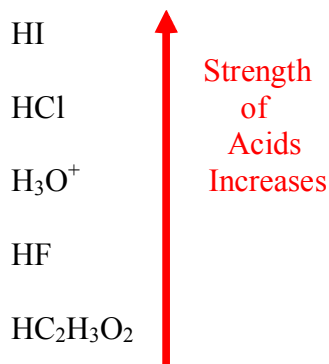
- These reactions prove that both HCl(aq) and HI(aq) are stronger than H₃O⁺(aq), but it does not tell which one is the stronger of the two.
- To determine the relative strength of HCl and HI, a solvent other than water must be used (H₂O has a leveling effect on the strengths of the strong acids, since it is able to capture all H⁺ from both acids)
- HI is more ionized in acetic acid (non-aqueous solvent) than HCl. Therefore

- HI is a stronger acid than HCl** **HI > HCl**

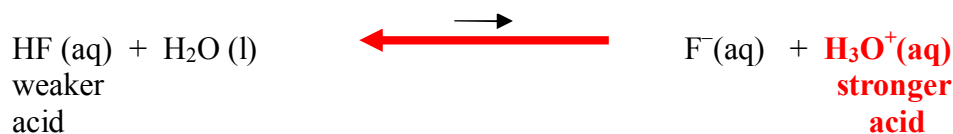
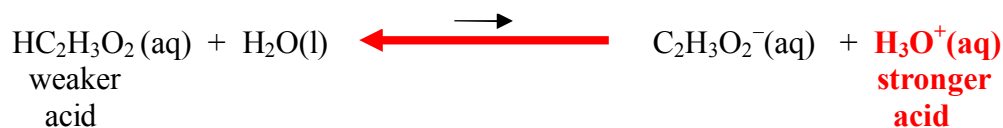
ACID AND BASE STRENGTHS
SUMMING UP:

1. HCl(aq) is a stronger acid than $\text{H}_3\text{O}^+(\text{aq})$ **$\text{HCl(aq)} > \text{H}_3\text{O}^+(\text{aq})$**
2. $\text{H}_3\text{O}^+(\text{aq})$ is a stronger acid than $\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$ **$\text{H}_3\text{O}^+(\text{aq}) > \text{HC}_2\text{H}_3\text{O}_2(\text{aq})$**
3. $\text{H}_3\text{O}^+(\text{aq})$ is a stronger acid than HF(aq) **$\text{H}_3\text{O}^+(\text{aq}) > \text{HF(aq)}$**
4. HF(aq) is a stronger acid than $\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$ **$\text{HF(aq)} > \text{HC}_2\text{H}_3\text{O}_2(\text{aq})$**
5. HI is a stronger acid than HCl **$\text{HI} > \text{HCl}$**

- A Table of Relative Strengths of acids can now be constructed:

Strongest Acid

Weakest Acid

- An acid-base reaction always goes in the direction of the weaker acid:



ACID AND BASE STRENGTHS
Relative Strengths of Bases

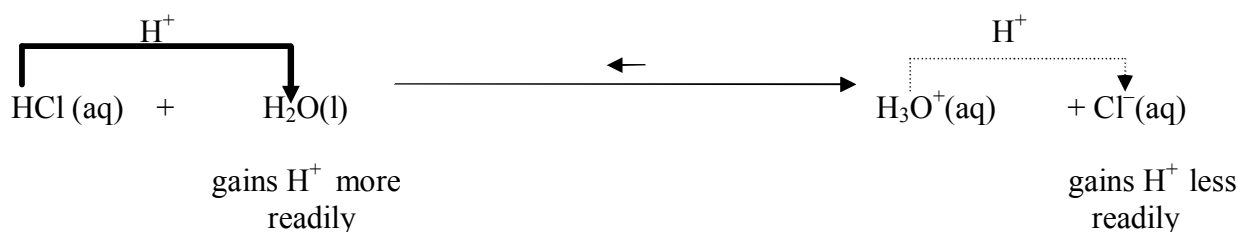
- A base is stronger than another base if it gains H^+ more readily
- To estimate relative basic strength, several comparisons between pairs of bases will be made

 $H_2O(l)$ and $Cl^-(aq)$

- Recall that $HCl(aq)$ is a strong acid and as such it ionizes completely in water:



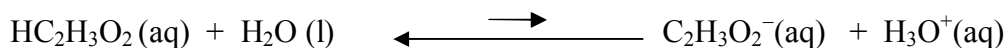
- The reaction goes completely to products.
- “ASSUME” that a reverse reaction were possible to a very small extent:



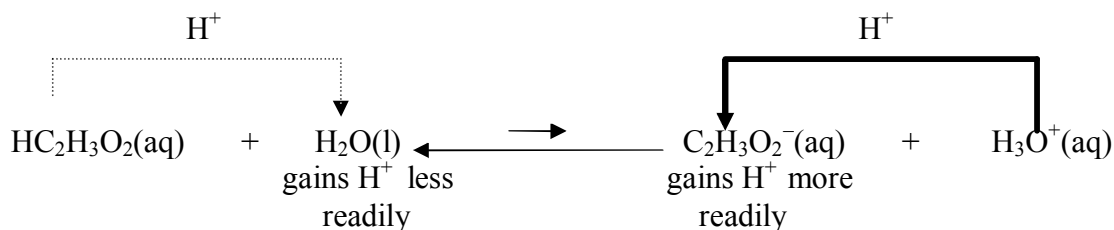
- **$H_2O(l)$ is a stronger base than $Cl^-(aq)$** **$H_2O(l) > Cl^-(aq)$**

 $C_2H_3O_2^-(aq)$ and $H_2O(l)$

- Recall that $HC_2H_3O_2(aq)$ is a weak acid and as such ionizes only partially in water:



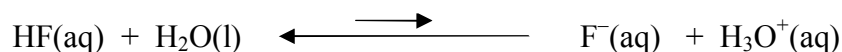
- The reaction goes mostly to reactants. Only about 1 % of the acetic acid molecules are ionized.



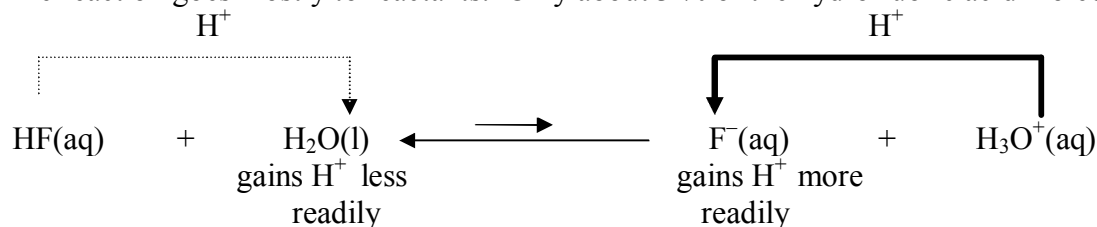
- **$C_2H_3O_2^-(aq)$ is a stronger base than $H_2O(l)$** **$C_2H_3O_2^-(aq) > H_2O(l)$**

F⁻(aq) and H₂O(aq)

- Recall that HF(aq) is a weak acid and as such, ionizes only partially in water:



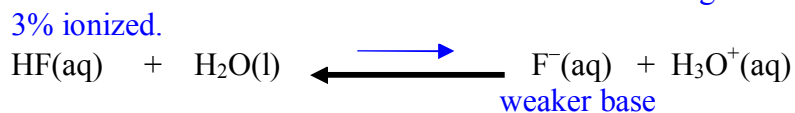
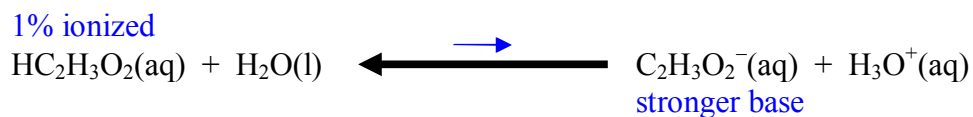
- The reaction goes mostly to reactants. Only about 3 % of the hydrofluoric acid molecules are ionized.



- F⁻(aq) is a stronger base than H₂O(aq)** **F⁻(aq) > H₂O(aq)**

C₂H₃O₂⁻(aq) and F⁻(aq)

- Recall that HC₂H₃O₂(aq) and HF(aq) are weak acids and both are partially ionized in water, but not to the same extent:



- C₂H₃O₂⁻(aq) gains H⁺ more readily than F⁻**
- C₂H₃O₂⁻(aq) is a stronger base than F⁻(aq)** **C₂H₃O₂⁻(aq) > F⁻(aq)**

Cl⁻ and I⁻

- Recall that HI is a stronger acid than HCl
- loses H⁺ more readily
loses H⁺ less readily

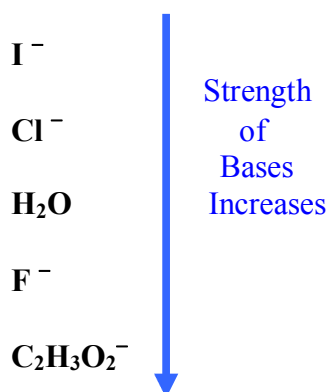
It follows:

- Cl⁻ gains H⁺ more readily than I⁻**
- Cl⁻ is a stronger base than I⁻** **Cl⁻ > I⁻**

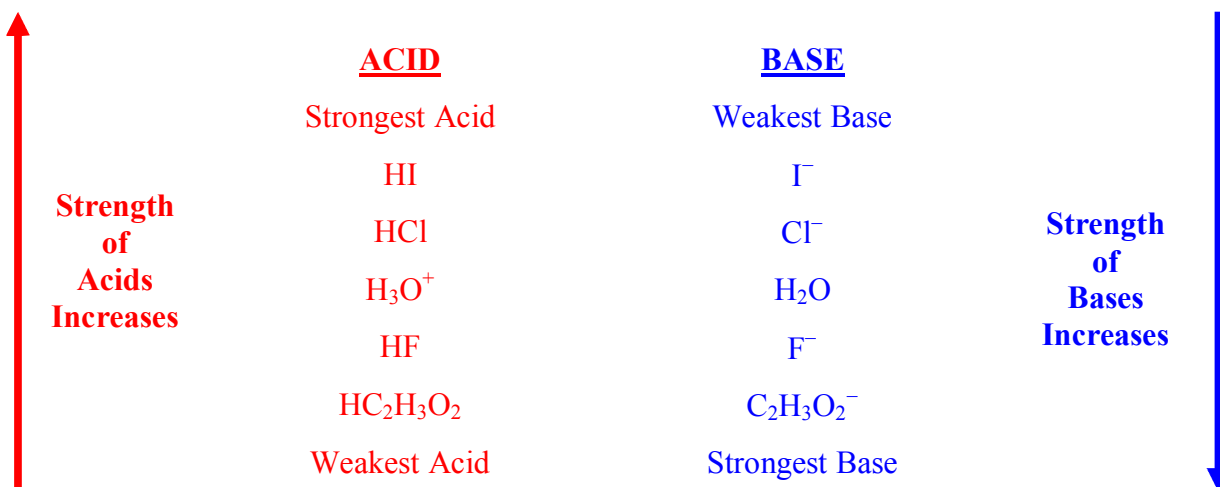
SUMMING UP:

1. $\text{H}_2\text{O}(\text{l})$ is a stronger base than $\text{Cl}^-(\text{aq})$ $\text{H}_2\text{O}(\text{l}) > \text{Cl}^-(\text{aq})$
2. $\text{C}_2\text{H}_3\text{O}_2^-(\text{aq})$ is a stronger base than $\text{H}_2\text{O}(\text{l})$ $\text{C}_2\text{H}_3\text{O}_2^-(\text{aq}) > \text{H}_2\text{O}(\text{l})$
3. $\text{F}^-(\text{aq})$ is a stronger base than $\text{H}_2\text{O}(\text{aq})$ $\text{F}^-(\text{aq}) > \text{H}_2\text{O}(\text{aq})$
4. $\text{C}_2\text{H}_3\text{O}_2^-(\text{aq})$ is a stronger base than $\text{F}^-(\text{aq})$ $\text{C}_2\text{H}_3\text{O}_2^-(\text{aq}) > \text{F}^-(\text{aq})$
5. Cl^- is a stronger base than I^- $\text{Cl}^- > \text{I}^-$

- A Table of Relative Strengths of bases can now be constructed:

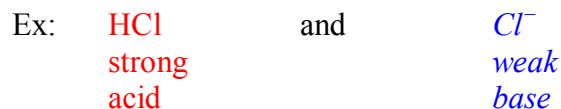
Weakest Base**Strongest Base**

- The Tables of Relative Strengths of **Acids** and Relative Strengths of **Bases** can now be combined:



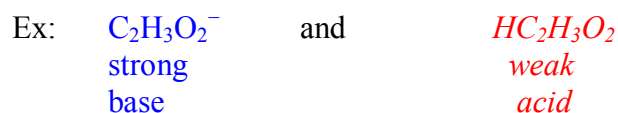
CONCLUSIONS:

1. When an acid loses its H^+ readily, its conjugate base does not hold the H^+ very tightly.



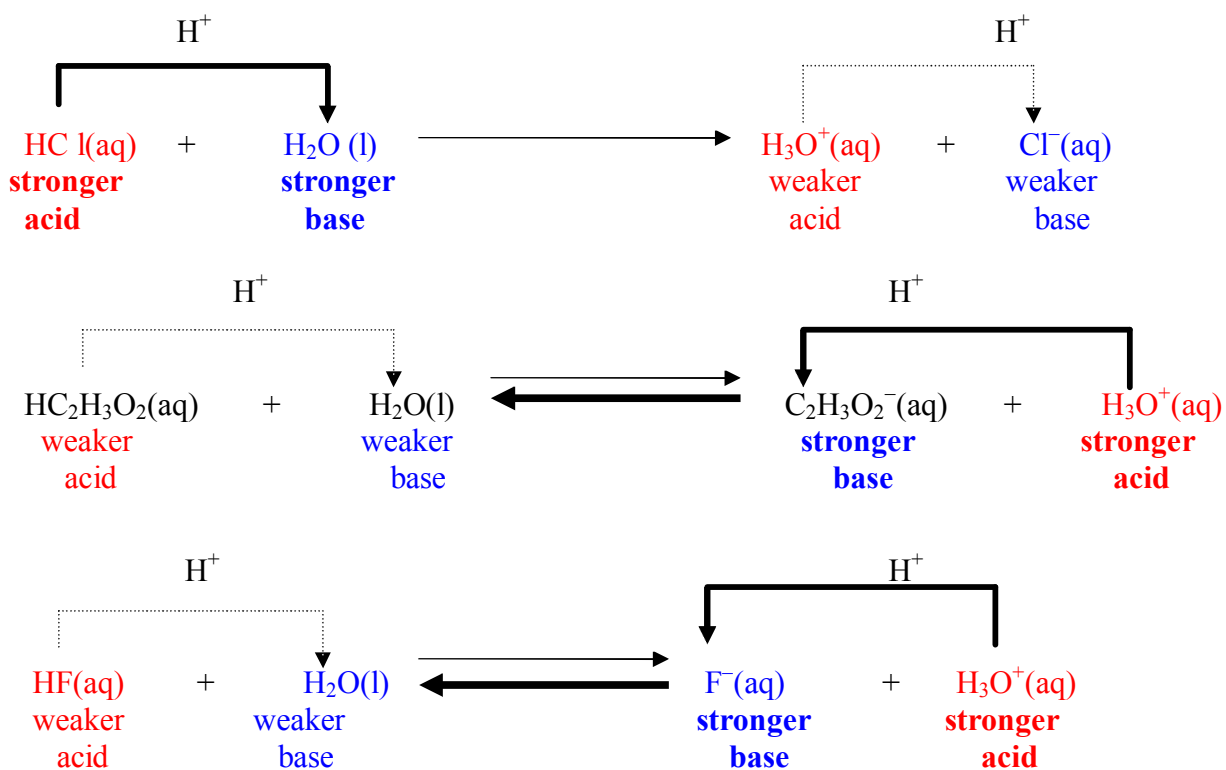
- The **strongest acids** have the **weakest conjugate bases**

2. When a base holds the H^+ very tightly, its conjugate acid does not lose the H^+ readily



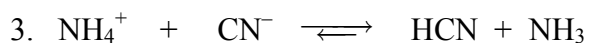
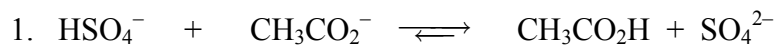
- The **strongest bases** have the **weakest conjugate acids**

3. The direction of an acid-base reaction always favors the formation of the weaker acid and the weaker base:



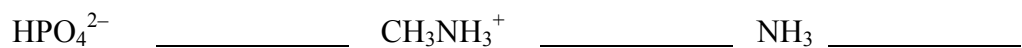
Examples:

For each reaction below, determine the conjugate acid-base pairs and their relative strengths:



4. The hydrogen oxalate ion (HC_2O_4^-) is amphoteric. Write a balanced equation showing how it reacts as an acid towards water and another equation showing how it reacts as a base towards water.

5. For each acid shown below, write the formula of its conjugate base:



6. For each base shown, write the formula of its conjugate acid:

