IV.4 - The Bronsted-Lowry Theory of Acids and Bases

- The Bronsted-Lowry theory…
  - More general than the Arrhenius theory
  - Incorporates all of the Arrhenius theory into a more general scheme
  - Allows for the effect of equilibrium reactions and permits us to extend our ideas of acids and bases to a wider range of species.

- According to the Bronsted-Lowry theory:

  An **ACID** is a substance which **DONATES A PROTON**.

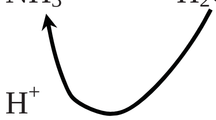
  A **BASE** is a substance which **ACCEPTS A PROTON.**

An ACID is a PROTON DONER *(gives away an H^+) and* ***A BASE is a PROTON ACCEPTOR*** *(gets an H^+)*

- Here are 2 typical Bronsted-Lowry acid-base reactions equations:

Examples:

1. $NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$



In the above Reaction:

NH_3 reacts to become NH_4^+

NH_3 has gained an extra “H” and a “+” charge

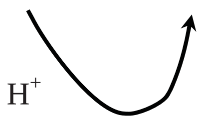
NH_3 is acting as a **BASE**: it has “accepted a proton” (H^+).

If the NH_3 accepted a proton (H^+) then it had to get the H^+ from something - the H_2O

H_2O must have donated a proton and hence must be an **ACID**

H_2O has lost (that is, donated) an H^+, and produced an OH^-

2. $CH_3COOH + H_2O \longrightarrow CH_3COO^- + H_3O^+$



In the above Reaction:

CH_3COOH donated (loses) and H^+ to become CH_3COO^-

CH_3COOH must be acting as an **ACID** (The fact that acetic acid acts as an acid should make sense!)

H_2O accepted a proton to become H_3O^+

H_2O must be acting as a **BASE**

Types of Acids

Monoprotic Acid: A MONOPROTIC ACID is an acid which can supply only one proton. Example: HCl

Diprotic Acid: A DIPROTIC ACID is an acid which can supply up to two protons. Example: H_2SO_4

Triprotic Acid: TRIPROTIC ACID is and acid which can supply up to three protons. Example: H_3PO_4

Polyprotic Acid: POLYPROTIC ACID is a general term for an acid which can supply more than one proton. Examples: H_2SO_4, H_3PO_4

Look at these reactions…notice anything?

$$\underset{\text{base}}{NH_3} + \underset{\text{acid}}{H_2O} \Rightarrow NH_4^+ + OH^-$$

$$\underset{\text{acid}}{CH_3COOH} + \underset{\text{base}}{H_2O} \longrightarrow CH_3COO^- + H_3O^+$$

Conclusion: In some circumstances a substance may act as a Bronsted-Lowry acid, whereas in other circumstances the same substance may act as a Bronsted-Lowry base. Water acts as a Bronsted-Lowry base when it is forced to react with an acid, but will act as an acid when forced to react with a base.

Such a substance is said to be **amphoteric** or **amphiprotic**.

An **amphoteric (amphiprotic)** substance is a substance which can act as either an acid or a base. Some amphiprotic substances are H_2O, $H_2PO_4^-$, HS^-, HCO_3^-.

Examples:

$$H_3PO_4 \xleftarrow{+H^+} H_2PO_4^- \xrightarrow{-H^+} HPO_4^{2-}$$

$$H_2S \xleftarrow{+H^+} HS^- \xrightarrow{-H^+} S^{2-}$$

If a substance:

a) possesses a **NEGATIVE CHARGE**, and

b) still has an easily removable **HYDROGEN**, then the substance will be **AMPHIPROTIC**.

- Comparing Bronsted-Lowry and Arrhenius Reactions

In the old **Arrhenius theory**:

$$\text{ACID} + \text{BASE} \longrightarrow \text{SALT} + \text{WATER.}$$

Now, in the **Bronsted-Lowry theory**:

$$\text{ACID} + \text{BASE} \rightleftharpoons \text{BASE} + \text{ACID.}$$

In every case of a Bronsted-Lowry reaction we will have an acid and a base on both sides of the equation.

- Identifying ACIDS and BASES in Bronsted-Lowry Reactions.

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

Determine the identity of one species on the reactant side, by seeing whether it gains or loses a proton. For example, CH_3COOH here is acting as an acid since it is losing a proton.

You can automatically determine the identity of the "similar species" on the product side. It will be the opposite (for example, BASE) of the species you first identify (for example, ACID).

To this point we now have

$$\underset{\text{acid}}{CH_3COOH} + \underset{\text{base}}{H_2O} \rightleftharpoons CH_3COO^- + H_3O^+$$

- Use the fact that each side must have both an ACID and a BASE to complete our assignment. For example:

$$\underset{\text{acid}}{CH_3COOH} + \underset{\text{base}}{H_2O} \rightleftharpoons \underset{\text{base}}{CH_3COO^-} + \underset{\text{acid}}{H_3O^+}$$

Examples:

1. January 2004

What is a general characteristic of all Brønsted-Lowry bases?

A. They all accept H^+ .
B. They all accept OH^- .
C. They will turn litmus a pink colour.
D. They will react with acids to produce H_2 gas.

2. August 2002

A *Brønsted-Lowry acid* is defined as a substance that

A. releases $H^+_{(aq)}$
B. releases $OH^-_{(aq)}$
C. accepts a proton
D. donates a proton

3. June 2004

Consider the following equilibrium:

$$HCO_3^- + H_2PO_4^- \rightleftarrows HPO_4^{2-} + H_2CO_3$$

What are the Brønsted-Lowry acids in this equilibrium?

A. HCO_3^- and H_2CO_3
B. HCO_3^- and HPO_4^{2-}
C. $H_2PO_4^-$ and H_2CO_3
D. $H_2PO_4^-$ and HPO_4^{2-}

*****Do Hebden Questions #11 - 14, pgs 117 - 119*****

IV.5 - Conjugate Acids and Bases

- ***Conjugate Acid-Base Pair***: A conjugate acid-base pair (or conjugate pair) is a pair of chemical species, which differ by only one proton.
- ***Conjugate Acid***: A conjugate acid is the member of the conjugate pair which has the extra proton.
- ***Conjugate Base***: A conjugate base is the member of the conjugate pair which lacks the extra proton.

Example: In the equilibrium reaction

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$

there are ***two*** conjugate pairs:

conjugate pair	***conjugate acid***	***conjugate base***

- If we are asked to find the **CONJUGATE ACID** of NH_3, then we want to know the formula of the acid which has **ONE MORE** proton than NH_3 (which is assumed to be a base). Hence, we add H^+ to NH_3 to get NH_4^+.
- If we are asked to find the **CONJUGATE BASE** of NH_3, then we want to know the formula of the base which has **ONE LESS** proton than NH_3 (which is assumed to be an acid). Hence, we take away an H^+ from NH_3 to get NH_2^-.
- Note: simple **organic acids** end with a **COOH** group, and the H at the end of the group is acidic.

$$CH_3CH_2COOH \rightleftharpoons CH_3CH_2COO^- + H^+.$$

organic bases contain an $\mathbf{NH_2}$ group or an **NH** group. The nitrogen atom will accept an extra proton.

$$CH_3CH_2NH_2 + H^+ \rightleftharpoons CH_3CH_2NH_3^+$$

$$(CH_3)_2NH + H^+ \rightleftharpoons (CH_3)_2NH_2^+$$

Conclusion: A Bronsted-Lowry acid-base reaction just involves a proton transfer.

Example: Write the acid-base equilibrium that occurs when H_2S and CO_3^{2-} are mixed in solution.

Examples:

1. April 2003

In which of the following is HSO_3^- acting as a Brønsted-Lowry acid?

A. $HSO_3^- + H_2O \rightarrow H_2SO_3 + OH^-$
B. $NH_3 + HSO_3^- \rightarrow NH_4^+ + SO_3^{2-}$
C. $HSO_3^- + HPO_4^{2-} \rightarrow H_2SO_3 + PO_4^{3-}$
D. $H_2C_2O_4 + HSO_3^- \rightarrow HC_2O_4^- + H_2SO_3$

2. August 2005

What is the conjugate acid of the base $HAsO_4^{2-}$?

A. AsO_4^{3-}
B. $H_2AsO_4^{2-}$
C. $H_2AsO_4^-$
D. H_3AsO_4

3. August 2003

Consider the following reaction:

$$HCN + CH_3NH_2 \rightleftarrows CN^- + CH_3NH_3^+$$

Which of the following describes a conjugate acid-base pair in the equilibrium above?

	Acid	Base
A.	CN^-	HCN
B.	$CH_3NH_3^+$	CN^-
C.	HCN	$CH_3NH_3^+$
D.	$CH_3NH_3^+$	CH_3NH_2

4. August 2004

Identify the two conjugate pairs in the equilibrium provided.

$$H_2PO_4^- + HCO_3^- \rightleftarrows HPO_4^{2-} + H_2CO_3$$

	Pair 1	Pair 2
A.	$H_2PO_4^- / H_2CO_3$	HCO_3^- / HPO_4^{2-}
B.	$H_2PO_4^- / HPO_4^{2-}$	HCO_3^- / H_2CO_3
C.	HCO_3^- / HPO_4^{2-}	$H_2PO_4^- / H_2CO_3$
D.	$H_2PO_4^- / HCO_3^-$	HPO_4^{2-} / H_2CO_3

*****Do Hebden Questions #15 - 19, pgs 119 - 121*****