Chemistry 132 NT

A man is rich in proportion to the number of things he can let alone.

Henry David Thoreau

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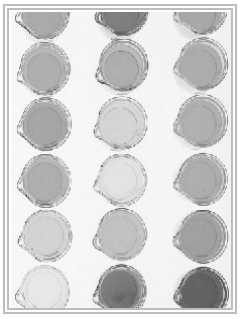
Chem 132 NT

Acids and Bases

Module 1

Acid-Base Concepts

- **Arrhenius Concept of Acids and Bases**
- **Bronsted-Lowry Concept of Acids and Bases**
- **Lewis Concept of Acids and Bases**



Acid-base indicator dye.

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Acid Base Concepts

- Acids and bases were first recognized by simple properties, such as taste.
  - Acids taste sour.
  - Bases taste bitter
  - Acids and bases change the color of certain dyes called “indicators”.
  - According to Arrhenius, acids increase the concentration of $\mathbf{H^+}$ in a solution while bases increase the concentration of $\mathbf{OH^-}$.

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Acid Base Concepts

- In the first part of this chapter we will look at several concepts of acid-base theory including:
  - The **Arrhenius** concept
  - The **Bronsted Lowry** concept
  - The **Lewis** concept

  This chapter expands on what you learned in 1st semester chemistry about acids and bases.

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Acid Base Concepts

- Antoine Lavoisier was one of the first chemists to try to explain what makes a substance acidic.
  - In 1777 he proposed that oxygen was an essential element in acids.
  - The actual cause of acidity and basicity was ultimately explained in terms of the **effect these compounds have on water** by Svante Arrhenius in 1884.

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Arrhenius Concept of Acids and Bases

- According to the Arrhenius concept of acids and bases, an **acid** is **a substance that, when dissolved in water, increases the concentration of hydronium ion (H_3O^+).**
  - Chemists often use the notation $H^+(aq)$ for the $H_3O^+(aq)$ ion, and call it the hydrogen ion.
  - Remember, however, that the aqueous hydrogen ion is actually chemically bonded to water, that is, H_3O^+.

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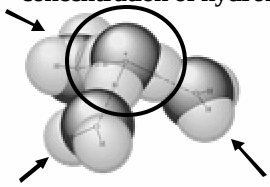
Arrhenius Concept of Acids and Bases

- According to the Arrhenius concept of acids and bases, an **acid** is **a substance that, when dissolved in water, increases the concentration of hydronium ion (H_3O^+).**



The H_3O^+ is shown here hydrogen bonded to three water molecules.

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Arrhenius Concept of Acids and Bases

- A **base**, in the Arrhenius concept, is **a substance that when dissolved in water increases the concentration of hydroxide ion, $OH^-(aq)$.**
  - The special role of the hydronium ion (or hydrogen ion) and the hydroxide ion in aqueous solutions arises from the following equilibrium.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

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Arrhenius Concept of Acids and Bases

- In the Arrhenius concept, a **strong acid** is a substance that **ionizes completely** in aqueous solution to give $H_3O^+(aq)$ and an anion.
  - An example is perchloric acid, $HClO_4$.

$$HClO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + ClO_4^-(aq)$$

  - Other strong acids include **HCl, HBr, HI, HNO_3 and H_2SO_4.**

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Arrhenius Concept of Acids and Bases

- In the Arrhenius concept, a **strong base** is a substance that **ionizes completely** in aqueous solution to give $OH^-(aq)$ and a cation.
  - An example is sodium hydroxide, NaOH.

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

  - Other strong bases include **LiOH, KOH, $Ca(OH)_2$, $Sr(OH)_2$, and $Ba(OH)_2$.**

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Common Strong Acids and Bases

Strong Acids	Strong Bases
HCl	LiOH
HBr	NaOH
HI	KOH
H_2SO4	$Ca(OH)_2$ RbOH
HNO_3	$Sr(OH)_2$ CsOH
$HClO_4$	$Ba(OH)_2$

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Arrhenius Concept of Acids and Bases

- Most other acids and bases that you encounter are **weak**. They are **not completely ionized** and exist in reversible reaction with the corresponding ions.
  - An example is acetic acid, $HC_2H_3O_2$.

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_2H_3O_2^-(aq)$$

  - Ammonium hydroxide, NH_4OH, is a weak base.

$$NH_4OH(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

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Arrhenius Concept of Acids and Bases

- The Arrhenius concept is limited in that it looks at acids and bases in aqueous solutions only.
  - In addition, it singles out the OH^- ion as the source of base character, when other species can play a similar role.
  - Broader definitions of acids and bases are discussed in the next sections.

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Brønsted-Lowry Concept of Acids and Bases

- According to the Brønsted-Lowry concept, an **acid** is the species **donating the proton** in a proton-transfer reaction.
- A **base** is the species **accepting the proton** in a proton-transfer reaction.
  - In any reversible acid-base reaction, both forward and reverse reactions involve proton transfer.

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Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

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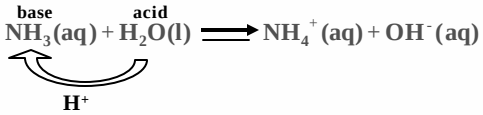
Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.



- In the **forward reaction**, NH_3 accepts a proton from H_2O. Thus, **NH_3 is a base** and **H_2O is an acid**.

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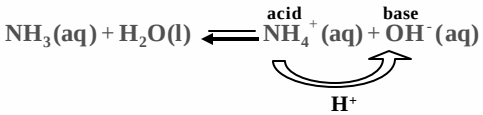
Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.



- In the **reverse reaction**, NH_4^+ donates a proton to OH^-. The **NH_4^+ ion is the acid** and **OH^- is the base**.

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Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.

$$\underset{\text{base}}{NH_3(aq)} + H_2O(l) \rightleftharpoons \underset{\text{acid}}{NH_4^+(aq)} + OH^-(aq)$$

  - The species NH_4^+ and NH_3 are a conjugate acid-base pair.
  - A **conjugate acid-base pair** consists of two species in an acid-base reaction, one acid and one base, that **differ by the loss or gain of a proton**.

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Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.

$$\underset{\text{base}}{NH_3(aq)} + H_2O(l) \rightleftharpoons \underset{\text{acid}}{NH_4^+(aq)} + OH^-(aq)$$

  - Here **NH_4^+ is the conjugate acid** of NH_3 and **NH_3 is the conjugate base** of NH_4^+.
  - The Brønsted-Lowry concept defines a species as an acid or a base according to its function in the proton transfer reaction.

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Brønsted-Lowry Concept of Acids and Bases

- Consider the reaction of NH_3 and H_2O.

$$\underset{\text{acid}}{NH_3(aq)} + H_2O(l) \rightleftharpoons \underset{\text{base}}{NH_4^+(aq)} + OH^-(aq)$$

  - We can also view **H_2O as the conjugate acid** of OH^- and **OH^- as the conjugate base** of H_2O.
  - They **differ by one proton** with H_2O as the **proton donor (acid)** in the forward reaction and OH^- as the **proton acceptor (base)** in the reverse reaction.

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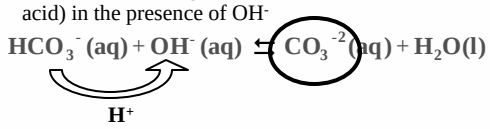
Brønsted-Lowry Concept of Acids and Bases

- Some species can act as an acid or a base.
  - An **amphoteric species** is a species that can act either as an acid or a base (it can gain or lose a proton).
  - For example, HCO_3^- acts as a proton donor (an acid) in the presence of OH^-



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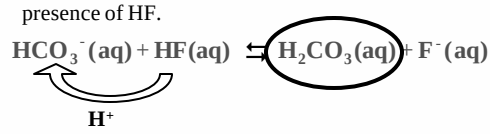
Brønsted-Lowry Concept of Acids and Bases

- Some species can act as an acid or a base.
  - An **amphoteric species** is a species that can act either as an acid or a base (it can gain or lose a proton).

    Or it can act as a proton acceptor (a base) in the presence of HF.



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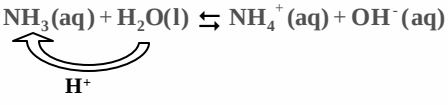
Brønsted-Lowry Concept of Acids and Bases

- The amphoteric characteristic of water is important in the acid-base properties of aqueous solutions.
  - Water reacts as an acid with the base NH_3.



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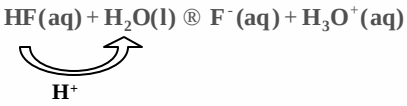
Brønsted-Lowry Concept of Acids and Bases

- The amphoteric characteristic of water is important in the acid-base properties of aqueous solutions.
  - Water can also react as a base with the acid HF.



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Brønsted-Lowry Concept of Acids and Bases

- In the Brønsted-Lowry concept:

1. A base is a species that accepts protons; OH^- is only one example of a base.
2. Acids and bases can be ions as well as molecular substances.
3. Acid-base reactions are not restricted to aqueous solution.
4. Some species can act as either acids or bases depending on what the other reactant is.

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A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.

$$HCO_3^-(aq) + OH^-(aq) \leftrightarrows CO_3^{2-}(aq) + H_2O(l)$$

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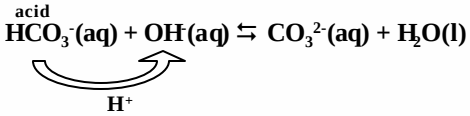
A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.



On the left, HCO_3^- is the proton donor, making it an acid.

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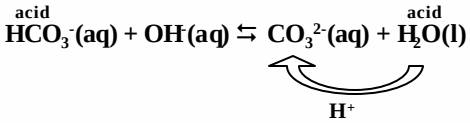
A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.



On the right, H_2O is the proton donor, making it an acid.

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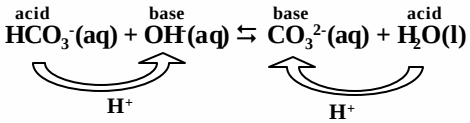
A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.

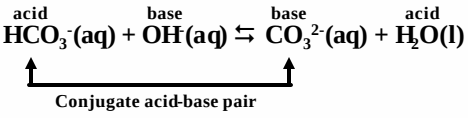


The proton acceptors are OH^- and CO_3^{2-} making them bases.

30

A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.



Here, HCO_3^- and CO_3^{2-} are a conjugate acid-base pair.

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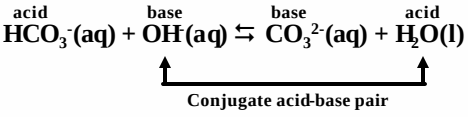
A Problem To Consider

- In the following equation, label each species as an **acid** or a **base**. Show the **conjugate acid-base pairs**.



H_2O and OH^- are also a conjugate acid-base pair.

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Lewis Concept of Acids and Bases

- The Lewis concept defines an **acid as an electron pair acceptor** and a **base as an electron pair donor.**
  - This concept broadened the scope of acid-base theory to include reactions that did not involve H^+.
  - The Lewis concept embraces many reactions that we might not think of as acid-base reactions.

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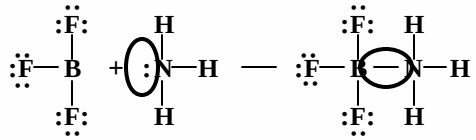
Lewis Concept of Acids and Bases

- The reaction of boron trifluoride with ammonia is an example.



  - Boron trifluoride accepts the electron pair, so is a **Lewis acid**. Ammonia donates the electron pair and so is the **Lewis base**.

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A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

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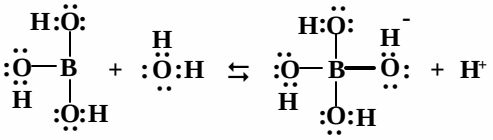
A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

- We must write the equation using Lewis structures.



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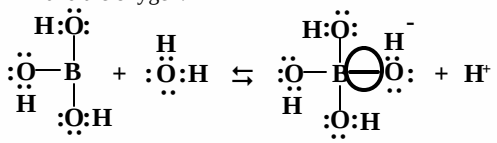
A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

- Notice the new bond formed between the boron and the oxygen.



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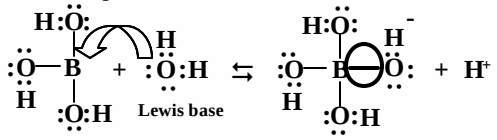
A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

- The electron pair was donated by the oxygen making water the Lewis base.



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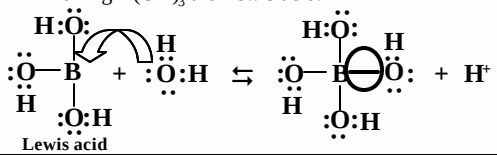
A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

- The electron pair was accepted by the boron making $B(OH)_3$ the Lewis acid.



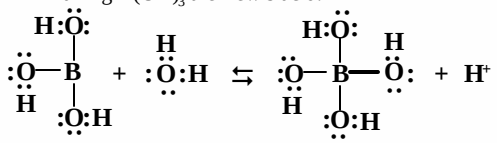
39

A Problem To Consider

- In the following reaction, identify the Lewis acid and the Lewis base.

$$B(OH)_3 + H_2O \leftrightarrows B(OH)_4^- + H^+$$

- The electron pair was accepted by the boron making $B(OH)_3$ the Lewis acid.



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Summary

- According to the Arrhenius concept of acids and bases, an **acid** is **a H^+ (proton) donor.**
- According to the Arrhenius concept of acids and bases, an **base** is **a OH^- (hydroxide) donor.**

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Summary

- According to the Bronsted-Lowry concept of acids and bases, an **acid** is **a H^+ (proton) donor.**
- According to the Bronsted-Lowry concept of acids and bases, a **base** is **a H^+ (proton) acceptor.**

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Summary

- The Lewis concept defines an **acid as an electron pair acceptor** and a **base as an electron pair donor.**

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Operational Skills

- Identifying acid and base species
- Identifying Lewis acid and base species

Time for a few review questions.

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