E5 Lewis Acids and Bases: lab 2
March 26, 27, and 31

Session one lab
Parts 1 and 2A

Session two lab
Parts 2B, 3, and 4

Lewis Acid-Base Reactions

- Metal ions are Lewis acids and bond to electron pairs on Lewis bases (e.g., water molecules!)

\[ \text{Na}^+ + 6 \text{H}_2\text{O} \rightarrow [\text{Na(H}_2\text{O)}]_6^{2+} \]

- Metal ions may react with - bond to - a different Lewis base than water

\[ \text{Ni}^{2+} + 6 \text{H}_2\text{O} \rightarrow [\text{Ni(H}_2\text{O)}]_6^{2+} \]

- Colored aquo transition metal complex ions alter color upon bonding to a new Lewis base.

Charge of the Complex Product

- The charge on the complex product = the algebraic sum of the oxidation number of the metal and the charge/s of the bonded base/s.

\[ [\text{Co(H}_2\text{O)}]_6^{2+} + 6 \text{NH}_3 \rightarrow [\text{Co(NH}_3)_6]^{2+} + 6 \text{H}_2\text{O} \]
**Charge of the Complex Product**
- The complex will be insoluble if the complex product charge = zero

![Image of nickel nitrate and nickel hydroxide](image)

**Lewis Acid-Base Reaction Extent**
- A Lewis acid must be able to bond with a Lewis base if reaction is to occur
- A Lewis acid must form a strong bond with a Lewis base for an extensive reaction to occur

**Reaction Extent of Lewis Acids and Bases**
- Lewis acids and bases react to different extents; some never reach the “finish line”

**Part 2B. Complexation, Structure and Periodicity**
- Compare the reactions of different metal aquo complex ions (pre-transition, transition, and post-transition) with the Lewis bases NH$_3$ and OH$^-$

- Pre-transition, transition, and post-transition metal ions differ in ability to bond well with different bases (e.g. OH$^-$ and NH$_3$) because of differences in metal ion electron configurations.

- Reaction extent is linked to Lewis acid strength
- Pre-transition, transition, and post-transition metal ions differ in Lewis acid strength

**Part 2B. Complexation, Structure and Periodicity**

![Image of periodic table](image)
**Lewis Acid-Base Reaction Extent**

- The Lewis acid strength of $\text{Al}^{3+}$ is greater than $\text{Na}^+$
- $\text{Al}^{3+}$ bonds well to hydroxide ions and reacts more extensively with hydroxide ions than $\text{Na}^+$

\[
[\text{Na(H}_2\text{O)}_6]^{\text{3}^+} + \text{OH}^- \rightarrow \text{no reaction}
\]

\[
[\text{Al(H}_2\text{O)}_6]^{\text{3}^+} + 6 \text{OH}^- \rightarrow \text{reaction}
\]

**Example 1**

$\text{Al}^{3+}$ (aq) reacts extensively with $\text{OH}^-$:

\[
[\text{Al(H}_2\text{O)}_6]^{\text{3}^+} + 6 \text{OH}^- \rightarrow [\text{Al(OH)}_6]^{\text{3}^+} + 6 \text{H}_2\text{O}
\]

**Stoichiometry of Reaction Products:** $\text{Al}^{3+}$ to $\text{OH}^-$

**Lewis Acid-Base Reaction Extent**

**Acid strength:** $\text{Al}^{3+} > \text{Na}^+$

**Example 3**

$\text{Na}^+$ (aq) does not react with $\text{OH}^-$:

\[
[\text{Na(H}_2\text{O)}_6]^{\text{3}^+} + \text{OH}^- \rightarrow \text{no reaction}
\]

**Lewis Acid-Base Reaction Extent**

- Post-transition metal ions bond well to and react extensively with $\text{OH}^-$ ions
- Transition metal ions bond well to and react extensively with $\text{NH}_3$

**Reaction Extent of Metal Ions**

\[
[\text{Ni(H}_2\text{O)}_6]^{\text{2}^+} + 6 \text{NH}_3 \rightarrow [\text{Ni(NH}_3)_6]^{\text{2}^+} + 6 \text{H}_2\text{O}
\]

**Reminder:** Lewis Acid-Base reactions are reversible equilibrium systems
Lewis Acid-Base Reaction Extent

\[ \text{[Hg(H}_2\text{O)}_4]^{2+} + 4 \text{I}^- \leftrightarrow \text{[Hg(I)}_4]^{2+} + 4 \text{H}_2\text{O} \]

**Lewis Acid-Base Reaction Extent**

- Reaction extent is concentration dependent.

\[ \text{[Hg(H}_2\text{O)}_4]^{2+} + x \text{I}^-(\text{aq}) \leftrightarrow \text{[Hg(I)}_x]^{(aq)} + x \text{H}_2\text{O(}_{\text{aq})} \]

**DEMO:**
1. Add 0.10 M Hg²⁺ to 0.10 M I⁻.
2. Add 0.10 M Hg²⁺ to 1.0 M I⁻.

Part 3. Solubility and Complexation

- Collect data on the behavior of different metal ion precipitates when NH₃ or OH⁻ is added. Does the precipitate dissolve when NH₃ and OH⁻ is added?

**Precipitation Reactions**

- Precipitation reactions are Lewis acid-base reactions
- Precipitation reactions are equilibrium systems

**DEMO 1:**
\[ \text{[Ag(H}_2\text{O)}_2]^{+} + \text{Cl}^- \leftrightarrow \text{silver chloride precipitate} \]
Q. When 0.1 M NaCl is added to 0.1 M AgNO₃, a precipitate of silver chloride forms. Choose the correct equation for the net Lewis precipitation reaction.

Information: Ag⁺ exists as [Ag(H₂O)₂]⁺

1. [Ag(H₂O)₂]⁺ + Cl⁻ ⇌ [Ag(H₂O)(Cl)]⁻ + H₂O
2. [Ag(H₂O)₂]⁺ + 2 Cl⁻ ⇌ [AgCl₂]⁻ + 2 H₂O
3. [Ag(H₂O)₂]⁺ + 2 Cl⁻ ⇌ [Ag(OH)(Cl)]⁻ + HCl

Note: The traditional net ppt. equation is:

\[ Ag^+ (aq) + Cl^- (aq) \rightarrow Ag(Cl)(s) \]

Lewis Acid-Base Precipitation Reactions

- Addition of a BETTER base to a precipitate (e.g., silver chloride) will cause a new acid-base reaction to occur between the metal ion and the BETTER base and result in an equilibrium shift in the precipitation reaction:

Example: Add NH₃ to a ppt of silver chloride.

\[ [Ag(H₂O)₂]⁺ + Cl⁻ \rightarrow [Ag(H₂O)(Cl)]⁻ + H₂O \]

Precipitation Reactions

1. Formation of silver chloride ppt.
2. Addition of NH₃

Q. What will you observe if you add acid (5 M H+) to the product mixture formed upon adding ammonia to precipitated silver chloride?

Silver chloride + NH₃

Add the “better” base NH₃. Reaction takes place. The Ag⁺ forms a soluble ammine complex ion with the NH₃, the silver chloride ppt. dissolves and a clear, colorless solution remains.

\[ [Ag(NH₃)₂]⁺ \]

Answer?

___________

___________
Reminder: Hydrogen ion is the BEST Lewis acid!
*If a better Lewis acid is available a Lewis base will react (exchange partners)!

Acid1-Base1 + H⁺ → reaction

Precipitation Reactions

1. Addition of 0.1 M NaCl to 0.1 M AgNO₃.
2. Addition of 5 M NH₃ to step 1 products.
3. Addition of acid (HNO₃) to step 2 products.

* If a better acid is available a Lewis base will react (exchange partners)!

Acid1-Base1 + Acid2 → Acid2-Base1

[Ag - (NH₃)₂]⁺ + 2 H⁺ = 2 [H - (NH₃)]⁺

Q. Predict what you will OBSERVE if you reverse the addition of reagents:

1. Add 5 M NH₃ to 10 mL of 0.1 M AgNO₃.

2. Add 10 mL of 0.1 M NaCl to the step 1 products.

 Observations

1. Add 5 M NH₃ to 10 mL of 0.1 M AgNO₃.

   = clear and colorless solution

   Ag⁺ bonds to NH₃ = [Ag(NH₃)₂]⁺

2. Add 10 mL of 0.1 M NaCl to the step 1 products.

   + NaCl (aq) = clear and colorless solution

   Ag⁺ remains bonded to NH₃.

   • Ag⁺ forms a stronger bond with NH₃ than Cl⁻.
Questions?
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