Properties of Acids

- Solutions of acids have a sour taste
  - Don’t taste them in the lab !!! ☠️

- They change the colors of many indicators
  - Acids turn blue litmus to red
  - Acids turn bromothymol blue from blue to yellow

- They react with metals to generate hydrogen gas, $H_2$
Metal Activity Series

- More active
  - Li, K, Ca, Na, Mg, Al, Mn, Zn, Fe, Co, Ni, Pb, H, Cu, Hg, Ag, Pt, Au

- Less active
  - Active enough to displace hydrogen from an acid
  - Cannot displace hydrogen from an acid
Properties of Acids

- They react with metal oxides forming the salt of the metal and water
  \[ \text{CaO} + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} \]

- They react with metal hydroxides forming the salt of the metal and water
  \[ \text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O} \]
Oxides

- Compounds of oxygen and another element

- There are two ways to name oxides
  - Based on the oxidation number of the element
    - Li₂O - lithium oxide
    - BaO - barium oxide
    - FeO - iron(II) oxide
    - Fe₂O₃ - iron(III) oxide
  - Based on the number of atoms of each element
    - Li₂O - dilithium oxide
    - BaO - barium oxide
    - FeO - iron oxide
    - Fe₂O₃ - diiron trioxide
Example 1

- Name the following compounds:
  - BeO, Al₂O₃, Cu₂O, OsO₄, Cr₂O₃, CrO₃
Example 2

Write formulas for the following compounds:

- Potassium oxide
- Boron oxide
- Diindium trioxide
- Cobalt(II) oxide
- Dinitrogen pentoxide
- Rhenium(VI) oxide
- Xenon tetroxide
- Carbon monoxide
- Carbon dioxide
- Manganese(VII) oxide
Example 3

- Write total and net ionic equations for the reaction between cobalt (III) oxide and diluted hydroiodic acid
Example 4

Write total and net ionic equations for the reaction between dialuminum trioxide and diluted hydrobromic acid.
Hydroxides

- Consist of metal cations and hydroxide (OH⁻) anions
- Usually named based on the oxidation number
  - LiOH – lithium hydroxide
  - Ba(OH)₂ – barium hydroxide
  - Fe(OH)₂ – iron(II) hydroxide
  - Fe(OH)₃ – iron(III) hydroxide
Example 5

- Name the following compounds:
  - Be(OH)$_2$, Al(OH)$_3$, CuOH, Cr(OH)$_3$
Example 6

- Write formulas for the following compounds:
  - Potassium hydroxide
  - Manganese(II) hydroxide
  - Cobalt(III) hydroxide
  - Strontium hydroxide
Example 7

Write total and net ionic equations for the reaction between cobalt (III) hydroxide and hydrofluoric acid
Example 8

- Write total and net ionic equations for the reaction between aluminum hydroxide and diluted sulfuric acid
Properties of Acids - Summary

- Solutions of acids have a sour taste
- They change the colors of many indicators
- They react with metals to generate hydrogen gas, \( H_2 \)
- They react with metal oxides forming the salt of the metal and water
- They react with metal hydroxides forming the salt of the metal and water
- Aqueous solutions of acids conduct an electric current
Acids as Electrolytes

- Strong acids – strong electrolytes
- Weak acids – weak electrolytes

### Strong Acids

<table>
<thead>
<tr>
<th>Binary</th>
<th>Ternary</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>HClO$_4$</td>
</tr>
<tr>
<td>HBr</td>
<td>HClO$_3$</td>
</tr>
<tr>
<td>HI</td>
<td>HNO$_3$</td>
</tr>
<tr>
<td></td>
<td>H$_2$SO$_4$</td>
</tr>
</tbody>
</table>
Classification of Acids

According to the number of different elements they contain

- Binary acids contain only 2 elements
  HF, HCl, HBr, HI, H₂S, H₂Se, H₂Te
- Ternary acids contain 3 elements
  HClO₃, HIO₄, H₂SO₄, H₃PO₄, HNO₃

According to the number of protons

- Monoprotic
  HF, HCl, HBr, HI, HNO₃, HClO₄
- Polyprotic
  H₂SiO₃, H₂SO₄, H₃PO₄
Ionization of Acids

Monoprotic acids ionize in one step:
- \( \text{HI}(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{I}^-(aq) \)
- \( \text{HNO}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{NO}_3^-(aq) \)

Polyprotic acids ionize in two or three steps:
- \( \text{H}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{HSO}_4^-(aq) \)
  \( \text{HSO}_4^-(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{SO}_4^{2-}(aq) \)

The first step in the ionization of a polyprotic acids always occur to a greater extent than the second or the third step
Example 9

- Write sequence of reactions that takes place upon ionization of phosphoric acid
Structure of Acids

- Structures of binary acids usually are obvious

- In most ternary acids the central atom is surrounded by oxygen atoms and then hydrogen atoms are connected to oxygen atoms
Strengths of Binary Acids

The strength of an acid reflects the ease of removing a proton from that acid

- The H–X bond strength in hydrohalic acids:
  \[ \text{HF} \gg \text{HCl} > \text{HBr} > \text{HI} \]
  Acid strength has the reverse trend:
  \[ \text{HF} \ll \text{HCl} < \text{HBr} < \text{HI} \]

- The same trend applies to the binary acids formed by the VIA elements
  Bond strength order:
  \[ \text{H}_2\text{O} \gg \text{H}_2\text{S} > \text{H}_2\text{Se} > \text{H}_2\text{Te} \]
  Acid strength has the reverse trend:
  \[ \text{H}_2\text{O} \ll \text{H}_2\text{S} < \text{H}_2\text{Se} < \text{H}_2\text{Te} \]
Strengths of Ternary Acids

- In most ternary acids the proton to be removed is bound to an oxygen atom.
- Therefore, the strength of the acid depends on the strength of the O-H bond.

- $\text{HClO}$
- $\text{HClO}_2$
- $\text{HClO}_3$
- $\text{HClO}_4$

- Red - more negative (higher electron density)
- Blue - more positive (lower electron density)
Strengths of Ternary Acids

- Ternary acid strength usually increases with:
  - an increasing oxidation state of the central atom for the acids of the same element
  - an increasing electronegativity of the central atom for the acids containing elements from the same group in the same oxidation state

Examples
- Which acid in each pair is stronger:
  - $\text{HNO}_2$ or $\text{HNO}_3$?
  - $\text{H}_2\text{SO}_4$ or $\text{H}_2\text{SO}_3$?
  - $\text{H}_2\text{SeO}_3$ or $\text{H}_2\text{SO}_3$?
Strengths of Ternary Acids

- It is important to remember that the comparison of acid strengths can be carried out only for the acids with similar structures.
- For example, ternary acids of phosphorus represent an important exception.

- $\text{H}_3\text{PO}_2$  $\text{H}_3\text{PO}_3$  $\text{H}_3\text{PO}_4$
The Preparation of Acids

- The binary acids are prepared by reacting the nonmetallic element with $H_2$:
  \[ H_2(g) + Cl_2(g) \rightarrow 2HCl(g) \]

- Volatile acids, ones with low boiling points, are prepared by reacting salts with a nonvolatile acid like sulfuric or phosphoric:
  \[ NaF(s) + H_2SO_4(conc.) \rightarrow NaHSO_4(s) + HF(g) \]
  \[ NaCl(s) + H_2SO_4(conc.) \rightarrow NaHSO_4(s) + HCl(g) \]
  
  We must use phosphoric acid to prepare $HBr$ or $HI$:
  \[ NaBr(s) + H_3PO_4(conc.) \rightarrow NaH_2PO_4(s) + HBr(g) \]
  \[ NaI(s) + H_3PO_4(conc.) \rightarrow NaH_2PO_4(s) + HI(g) \]
The Preparation of Acids

- Ternary acids are made by reacting nonmetal oxides (acid anhydrides) with water:
  \[
  \begin{align*}
  \text{SO}_2(g) + \text{H}_2\text{O}(l) & \rightarrow \text{H}_2\text{SO}_3(aq) \\
  \text{N}_2\text{O}_5(g) + \text{H}_2\text{O}(l) & \rightarrow 2\text{HNO}_3(aq)
  \end{align*}
  \]

- Oxides of some metals in high oxidation state are acidic - they form acids when reacting with water:
  \[
  \begin{align*}
  \text{Mn}_2\text{O}_7(s) + \text{H}_2\text{O}(l) & \rightarrow 2\text{HMnO}_4(aq) \\
  \text{CrO}_3(s) + \text{H}_2\text{O}(l) & \rightarrow \text{H}_2\text{CrO}_4(aq)
  \end{align*}
  \]

- Some nonmetal halides and oxyhalides react with water to give both a binary and a ternary acid:
  \[
  \begin{align*}
  \text{PCl}_5(s) + 4\text{H}_2\text{O}(l) & \rightarrow \text{H}_3\text{PO}_4(aq) + 5\text{HCl}(aq) \\
  \text{POCl}_3(l) + 3\text{H}_2\text{O}(l) & \rightarrow \text{H}_3\text{PO}_4(aq) + 3\text{HCl}(aq)
  \end{align*}
  \]
Properties of Bases

- Solutions of bases have a bitter taste
  - Don’t taste them in the lab !!! ☠️
- Solutions of bases have slippery feeling
- They change the colors of many indicators
  - Bases turn red litmus to blue
  - Bases turn bromothymol blue from yellow to blue
Properties of Bases

- They react with nonmetal oxides to form salt and water
  
  \[2\text{NaOH} + \text{SO}_2 \rightarrow \text{Na}_2\text{SO}_3 + \text{H}_2\text{O}\]

- They react with acids to form salt and water
  
  \[\text{Ca(OH)}_2 + 2\text{HCl} \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}\]
Bases as Electrolytes

- Aqueous basic solutions conduct electricity
- Strong bases - strong electrolytes
- Weak bases - weak electrolytes

<table>
<thead>
<tr>
<th>Strong Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH</td>
</tr>
<tr>
<td>NaOH</td>
</tr>
<tr>
<td>KOH</td>
</tr>
<tr>
<td>Ca(OH)_2</td>
</tr>
<tr>
<td>RbOH</td>
</tr>
<tr>
<td>Sr(OH)_2</td>
</tr>
<tr>
<td>CsOH</td>
</tr>
<tr>
<td>Ba(OH)_2</td>
</tr>
</tbody>
</table>
The Preparation of Bases

- Strong bases are prepared by reacting the metal or its oxide with water:
  
  \[ 2\text{Na}(s) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{NaOH(aq)} + \text{H}_2(g) \]
  
  \[ \text{Ca}(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{Ca(OH)}_2(s) + \text{H}_2(g) \]
  
  \[ \text{K}_2\text{O(s)} + \text{H}_2\text{O}(l) \rightarrow 2\text{KOH(aq)} \]

- The other hydroxides can be obtained by metathesis reactions:
  
  \[ \text{Cd(NO}_3)_2(aq) + \text{Ba(OH)}_2(aq) \rightarrow \text{Cd(OH)}_2(s) + \text{Ba(NO}_3)_2(aq) \]
  
  \[ \text{FeCl}_3(aq) + 3\text{NaOH(aq)} \rightarrow \text{Fe(OH)}_3(s) + 3\text{NaCl(aq)} \]
Amphotericism

- Some compounds can behave as both acids and bases
- They are called **amphoteric**
- Examples of amphoteric species are hydroxides of elements with intermediate electronegativity
- Zn(OH)$_2$ and Al(OH)$_3$ behave as hydroxides in the presence of strong acids and as acids in the presence of strong bases
Example 10

Write total and net ionic equations for the reactions of zinc hydroxide with:
- sulfuric acid
- sodium hydroxide
Acid-Base Reactions

- There are four acid-base reaction combinations that are possible:
  - Strong acids - strong bases
  - Strong acids - weak bases
  - Weak acids - strong bases
  - Weak acids - weak bases

- General name - neutralization reactions

- Most of these reactions result in the formation of salt and water
Strong Acid + Strong Base

- Type 1 - formation of a soluble salt:
  - $\text{HNO}_3(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\ell)$
  - $2\text{HBr}(\text{aq}) + \text{Ca(OH)}_2(\text{s}) \rightarrow \text{CaBr}_2(\text{aq}) + 2\text{H}_2\text{O}(\ell)$

- Type 2 - formation of an insoluble salt:
  - $\text{H}_2\text{SO}_4(\text{aq}) + \text{Ba(OH)}_2(\text{aq}) \rightarrow \text{BaSO}_4(\text{aq}) + 2\text{H}_2\text{O}(\ell)$
Strong Acid + Weak Base

- Always form a soluble salt:
  - $\text{HNO}_3(\text{aq}) + \text{NH}_3(\text{g}) \rightarrow \text{NH}_4\text{NO}_3(\text{aq})$
  - $\text{H}_2\text{SO}_4(\text{aq}) + \text{NH}_3(\text{g}) \rightarrow (\text{NH}_4)_2\text{SO}_4(\text{aq})$

- Reactions of acids with ammonia lead only to the formation of soluble salts

- Water is not formed in these reactions
Weak Acid + Strong Base

- Always form a soluble salt:
  - \( \text{HNO}_2(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaNO}_2(\text{aq}) + \text{H}_2\text{O} (\ell) \)
  - \( \text{H}_2\text{SO}_3(\text{aq}) + 2\text{RbOH}(\text{aq}) \rightarrow \text{Rb}_2\text{SO}_3(\text{aq}) + 2\text{H}_2\text{O} (\ell) \)
Weak Acid + Weak Base

- Always form a soluble salt:
  - $CH_3COOH(l) + NH_3(g) \rightarrow NH_4(CH_3COO)(aq)$
  - $HF(g) + NH_3(g) \rightarrow NH_4F(aq)$

- But...

  these reactions proceed in the opposite direction because the products are unstable in water

- The salts formed by weak acid and weak base are not stable in aqueous solution!!!
Assignments & Reminders

- Go through the lecture notes
- Read Chapter 10 completely
- Read Sections 4-5 & 4-6 of Chapter 4
- Read Section 6-8 of Chapter 6