STOICHIOMETRY OF ACID-BASE NEUTRALIZATION REACTIONS

Ms. Grobsky
ACID-BASE NEUTRALIZATION REACTIONS

- Remember, an **acid-base neutralization reaction** is a special type of double replacement reaction in which an Arrhenius acid and an Arrhenius base in an aqueous solution react
  - In a DR reaction, cations trade places!
- Neutralization is said to occur when the moles of the acid equal the moles of the base
- Neutralization does NOT mean the ending solution’s pH is 7!
  - This is dependent on the type of acid and base being titrated
    - Remember, there are strong acids/bases (dissociate completely in water) and weak acids/bases (do not dissociate completely in water)
SO, WHY DO NEUTRALIZATION REACTIONS OCCUR?

• Recall, Arrhenius acids form \( H^+ \) ions and Arrhenius bases form \( OH^- \) ions when dissolved in water
  • These ions combine to form liquid water
• The other product is a salt - an ionic compound
• Example:
  • Molecular equation:
    \[
    \text{HCl (aq)} + \text{NaOH (aq)} \rightarrow \text{H}_2\text{O (l)} + \text{NaCl (aq)}
    \]
  • Complete ionic equation:
    \[
    \text{H}^+(aq) + \text{Cl}^-(aq) + \text{Na}^+(aq) + \text{OH}^-(aq) \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) + \text{H}_2\text{O(l)}
    \]
  • By eliminating the spectator ions, we discover the driving force behind the neutralization of strong acid by a strong base
  • Net ionic equation:
    \[
    \text{H}^+(aq) + \text{OH}^-(aq) \rightarrow \text{H}_2\text{O(l)}
    \]
THE NET IONIC EQUATION FOR THE REACTION BETWEEN ACIDS AND BASES

• So, the driving force for ALL neutralization reactions is the formation of liquid water!

\[ \text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O}(l) \]

• The net ionic equation above applies for ALL acid-base neutralization reactions!
ACID-BASE STOICHIOMETRY AND TITRATIONS

- The stoichiometry of a acid-base neutralization reaction provides the basis for a procedure called a titration
- A titration is used to analyze the acid or base content of a solution
HOW IS A TITRATION PERFORMED?
ACID-BASE REACTIONS - TITRATIONS

• A titration involves the delivery of a measured volume of a solution of known concentration (TITRANT OR STANDARD SOLUTION) from a buret into the solution being analyzed (ANALYTE)

• Titrant is added slowly to the analyte until exactly enough has been added to just react with all of the analyte
  • At this point, the acid and base have same numbers of moles present in the combined solution
    – Called the EQUIVALENCE POINT and it represents the point at which neutralization occurs
      \[ [H^+] = [OH^-] \]

• Acid/base indicator or pH meter is used to determine equivalence point

• The point at which the indicator used in a titration changes color is called the end point of the titration

• Equivalence point ≠ End point!
WHAT IS AN ACID-BASE INDICATOR AGAIN?

• Chemical dyes whose colors are affected by acidic and basic solutions are called **acid-base indicators**

• Each has its own particular pH or pH ranges over which it changes color
  – It is important to choose an indicator for a titration that will change color at the equivalence point of the titration
  – Remember that the role of the indicator is to indicate to you, by means of a color change, that just enough of the titrating solution has been added to neutralize the unknown solution

• Chemists have several choices in selecting indicators
  – Bromthymol blue is a good choice for the titration of a strong acid with a strong base
  – Phenolphthalein changes color at the equivalence point of a titration of a weak acid with a strong base
TYPES OF TITRATIONS
STRONG ACID-STRONG BASE TITRATION

- Notice how the pH of the solution changes during the titration of 50.0 mL of 0.100 M HCl, a strong acid with 0.100 M NaOH, a strong base
  - The initial pH of the 0.100 M HCl is 1.00
- As NaOH is added, the acid is neutralized and the solution’s pH increases gradually
- When nearly all of the H\(^+\) ions from the acid have been used up, the pH increases dramatically with the addition of an exceedingly small volume of NaOH
  - This abrupt change in pH occurs at the equivalence point of the titration
  - Occurs at a pH of 7!
- Beyond the equivalence point, the addition of more NaOH again results in the gradual increase in pH
WEAK ACID-STRONG BASE TITRATION

• You might think that all titrations must have an equivalence point at pH 7.
• Notice - the equivalence point for the titration between a weak acid and strong base is not at a pH of 7!
  – This is because some salts are more acidic or basic than others.
  – In this case, the salt is more basic and hence, the pH at the equivalence point is greater than 7!
SOLVING TITRATION PROBLEMS
HOW TO SOLVE A TITRATION-TYPE PROBLEM

Based on stoichiometry!

1. Write a balanced chemical equation
2. Calculate the number of moles of the standard solution present in the solution
   - Standard solution is the solution in the buret and has a known concentration
     - Will always be given a volume and concentration of the standard solution
3. Use the molar relationship from the equation (STOICHIOMETRY) to convert from moles of standard solution into moles of unknown solution
4. Calculate the unknown quantity (molarity or volume) of the unknown solution by using the relationship $M = \frac{n}{V}$ using the number of moles found in step 3
5. Sometimes, you will need to convert from moles to other quantities such as grams
   - Remember your stoichiometry road map!
Boric acid (H$_3$BO$_3$) is a solid acid that is good for controlling ants. How many grams of boric acid would be needed to neutralize 35.00 grams of calcium hydroxide?
35.62 mL of NaOH is neutralized with 25.2 mL of 0.0998 M HCl by titration to an equivalence point.

What is the concentration of the NaOH?
CALCULATING PH OF ACID-BASE SOLUTIONS
REMEMBER...

- According to Arrhenius:
  - An acid is a substance that produces $H^+$ ions when dissolved in water
  - Come to find out, the $H^+$ ion is so reactive, it does not exist in water!
    - Rather, it reacts with $H_2O$ to give the hydronium ion, $H_3O^+$
  - You may use $H^+$ or $H_3O^+$ interchangeably!
- A base is a substance that produces $OH^-$ ions when dissolved in water
- Keep in mind, these definitions are limited to substances in an aqueous solution!
- Remember, the strength of an acid or a base is dependent on the amount that it dissociates in water
  - 100% dissociation = strong acid/base
  - Incomplete dissociation = weak acid/base
- So, how does the amount of $H^+$ or $OH^-$ ions in solution affect the pH of a solution?
SIMULATION TIME!

• Watch the simulation and answer the questions below:
  – What is the pH, [H₃O⁺], and [OH⁻] of:
    • Water
      – pH
      – [H₃O⁺]
      – [OH⁻]
    • Drain cleaner
      – pH
      – [H₃O⁺]
      – [OH⁻]
    • Soda
      – pH
      – [H₃O⁺]
      – [OH⁻]
    • Blood
      – pH
      – [H₃O⁺]
      – [OH⁻]
    • Vomit
      – pH
      – [H₃O⁺]
      – [OH⁻]

  – Is the relationship between the hydronium ion concentration and the pH direct or inverse? Explain.

  – Is the relationship between the hydroxide ion concentration and the pH direct or inverse? Explain.
# How to Read the pH Scale

<table>
<thead>
<tr>
<th>OH⁻ concentration moles per liter</th>
<th>Mid-points of pH ranges for process control</th>
<th>pH values of some common substances</th>
<th>H⁺ concentration moles per liter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottle washing</td>
<td>Household lye</td>
<td>0.0000000000000001</td>
</tr>
<tr>
<td>0.1</td>
<td>Copper plating</td>
<td>Bleach</td>
<td>0.0000000000000001</td>
</tr>
<tr>
<td>0.01</td>
<td>Brass plating</td>
<td>Ammonia</td>
<td>0.0000000000000001</td>
</tr>
<tr>
<td>0.001</td>
<td>Lime-soda softening</td>
<td>Milk of magnesia</td>
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<tr>
<td>0.0001</td>
<td></td>
<td>Borax</td>
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<tr>
<td>0.00001</td>
<td></td>
<td>Baking soda</td>
<td>0.0000000000000001</td>
</tr>
<tr>
<td>0.000001</td>
<td></td>
<td>Sea water</td>
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</tr>
<tr>
<td>0.0000001</td>
<td></td>
<td>Blood</td>
<td></td>
</tr>
<tr>
<td>0.00000001</td>
<td></td>
<td>Distilled water</td>
<td></td>
</tr>
<tr>
<td>0.000000001</td>
<td></td>
<td>Milk</td>
<td></td>
</tr>
<tr>
<td>0.0000000001</td>
<td></td>
<td>Corn</td>
<td></td>
</tr>
<tr>
<td>0.00000000001</td>
<td></td>
<td>Boric acid</td>
<td>0.00001</td>
</tr>
<tr>
<td>0.000000000001</td>
<td></td>
<td>Orange juice</td>
<td>0.001</td>
</tr>
<tr>
<td>0.0000000000001</td>
<td></td>
<td>Vinegar</td>
<td>0.1</td>
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<tr>
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<td></td>
<td>Lemon juice</td>
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<tr>
<td>0.000000000000001</td>
<td></td>
<td>Battery acid</td>
<td></td>
</tr>
<tr>
<td>0.0000000000000001</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**EXTREMELY ALKALINE**

**EXTREMELY ACID**
As we saw in the simulation, pH is a way to measure the concentration of $H^+$ (or $H_3O^+$) in an aqueous solution. Because the concentration of $H^+$ (or $H_3O^+$) in an aqueous solution is typically quite small, a logarithmic pH scale is used. By definition:

$$pH = -\log [H^+]$$

$$[H^+] = 10^{-pH}$$
MORE ON PH

• The pH scale, similar to the Richter scale, describes a wide range of values
  – Because the pH scale is a log scale based on 10, the pH changes by 1 for every power-of-10 change in the concentration of H⁺
• For example, an earthquake of “6” is 10 times as violent as a “5”
• Thus, the pH scale condenses possible values of [H⁺] to a 14 point scale
• Also, it is easier to say pH = 7 vs. [H⁺] = 1 x 10⁻⁷ M
SOURCES OF H+ IONS IN AQUEOUS SOLUTIONS

• The hydrogen ions (or hydronium ions) in an aqueous solution of a strong acid have two sources:
  – The dissociation of the acid
  – The dissociation of water itself
• Say WHAT?!?!?!
Some small amount of water will always dissociate, whether pure water or part of a solution.
THE AUTOIONIZATION OF WATER AND THE PH SCALE

• How much water will dissociate is predictable using the following math relationship:

$$[H^+][OH^-] = 1 \times 10^{-14} = K_w$$

• $K_w$ is called the **ION-PRODUCT constant** for water

• In any aqueous solution, no matter what it contains, the product of $[H+]$ and $[OH-]$ must equal $1.0 \times 10^{-14}$
pH = - \log [H^+]; [H^+] = 10^{-pH}
(Remember that the [ ] mean Molarity)

• What is the pH if \([H^+] = 6.3 \times 10^{-5}\)?
  Ans: 4.2

• What is the \([H^+]\) if pH = 7.4?
  3.98 \times 10^{-8} \text{ M}
MORE PRACTICE

Calculate the pH of each of the following:

• A 0.15 M solution of hydrochloric acid

• A $3.00 \times 10^{-7}$ M solution of sulfuric acid
Since acids and bases are opposites, pH and pOH are opposites!

pOH does not really exist, but it is useful for changing bases to pH

pOH looks at the perspective of a base:

\[ \text{pOH} = - \log [\text{OH}^-] \]

Since pH and pOH are on opposite ends:

\[ \text{pH} + \text{pOH} = 14 \]
PRACTICE!

• The pH of rainwater collected in a certain region of the northeastern United States on a particular day was 4.82. What is the H\(^+\) ion concentration of the rainwater?

• The OH\(^-\) ion concentration of a blood sample is 2.5 \times 10^{-7} \text{ M}. What is the pH of the blood?
pH TESTING

- There are several ways to test pH
  - Blue litmus paper
    - red = acid
  - Red litmus paper
    - blue = basic
  - pH paper
    - multi-colored
  - pH meter
    - 7 is neutral, <7 acid, >7 base
  - Universal indicator
    - multi-colored
  - Chemical Indicators
    - Phenolphthalein
    - Natural indicators like red cabbage, radishes