**E4 Acids, Bases, and Salts**

Session two
- Parts 3, 4, and 5
- Complete the team report and discussion presentation.

**Part 3. Neutralization and Indicators.**
- Study the use of indicators as monitors for an acid-base neutralization reaction.

**Neutralization:**

\[ \text{HCl(aq)} + \text{NH}_4\text{OH(aq)} \rightarrow \text{NH}_4\text{Cl(aq)} + \text{HOH(l)} \]

**DEMO - proton transfer reaction:**

\[ \text{HCl(g)} + \text{NH}_3(g) \rightarrow \text{NH}_4\text{Cl(s)} \]

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**Carboxylic Acids (Parts 3 - 5)**
- Monitor the neutralization of carboxylic acids with NaOH

**Carboxylic acids contain the** \(-\text{C}_2\text{H}_4\text{O}_2\text{H}\) group

**Electronegativity of the elements:**

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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**Carboxylic Acids and Ionizable Protons**
- The electronegativity of H and O differ and therefore H in the COOH group of carboxylic acids is ionizable.
- The electronegativity of H and C are similar and therefore C-H bonds are stable and the proton in the C-H bond is NOT ionizable.
Carboxylic acids (Parts 3 and 4)

Part 3: Acetic acid
\[ \text{CH}_3\text{COOH} \]

Part 4: Oxalic acid
\[ \text{H}_2\text{C}_2\text{O}_4 \]

Acid-Base Neutralization Equilibria

- Adding base to the weak (partially ionized) carboxylic acid drives the reaction (donation of proton/s) to completion.
- At neutralization, only the products (salt and water) are present.

\[ \text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{HOH} \]

Acid-Base Reaction Stoichiometry

- Reaction stoichiometry is dependant on the number of ionizable protons.

Acetic acid (Part 3):

\[ \text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{HOH} \]

1 mol 1 mol

Oxalic acid (Part 4):

\[ \text{HOOC-COOH} + 2 \text{NaOH} \rightarrow 2\text{COONa} + 2\text{HOH} \]

1 mol 2 mol

Titration (Parts 3 - 5)

- A procedure for determining the concentration of a measured volume of acid (or base) by measuring the volume of base (or acid) of known concentration required for neutralization.

- A procedure for determining the identity of a measured mass of acid (or base) by measuring the volume of base (or acid) of known concentration required for neutralization.
Q. Identify the acid (acetic or oxalic) if 10.0 mL of 0.10 M NaOH neutralizes 10.0 mL of 0.10 M acid.

**Acetic acid**
\[ \text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{HOH} \]

**Oxalic acid**
\[ \text{HOOC-COOH} + 2 \text{NaOH} \rightarrow 2\text{COONa} + 2\text{HOH} \]

**Answer.** Acetic acid.

\[
\text{mmol acid} = \text{mmol base} \\
10.0 \text{ mL} \times 0.10 \text{ M} = 10.0 \text{ mL} \\
\frac{5.0 \text{ mL} \times 0.10 \text{ M}}{2} = 10.0 \text{ mL} \times 0.10 \text{ M}
\]

*note: 5.0 mL of 0.10 M oxalic acid neutralizes 10.0 mL of 0.10 M NaOH:*

\[
2 \times (\text{mmol acid}) = \text{mmol base} \\
2 \times (5.0 \text{ mL} \times 0.10 \text{ M}) = 10.0 \text{ mL} \times 0.10 \text{ M}
\]

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**Part 3 Indicators**

- Compare the use of three indicators for monitoring the neutralization of acetic acid with sodium hydroxide
  - Bromothymol blue and bromophenol blue
    - **Acids turn yellow** \[ \text{Bases turn blue} \]
  - Phenolphthalein
    - **Acids are colorless** \[ \text{Bases turn pink} \]

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**Indicator End Point pH**

- The pH interval at which the indicator changes color
  - **Acids are colorless** \[ \text{Bases are pink} \]
    - Phenolphthalein: pH 8.2 - pH 10.1
      - pH 9.1
    - The indicator color change is observable at the mid-point of the end point pH range.
**Indicator pH End Points**

* Indicators have different end-point pH color changes

* For information on lab indicators, see the lab manual, p. 183

**Equivalence Point pH**

* The pH of the salt and water products of the acid-base neutralization reaction = the equivalence point pH.

\[ \text{CH}_2\text{COOH} + \text{NaOH} \rightarrow \text{CH}_2\text{COONa} + \text{HOH} \]

Equivalence point pH

≈ pH 8

“Ideally, the indicator end point pH equals the equivalence point pH = pH 8.”

**Titration and Indicator pH End Points**

**Titration of Oxalic Acid (Part 4)**

Q. You titrate 0.4502 g of oxalic acid with 1.0 M NaOH. How many mL of 1.0 M NaOH are required for neutralization?

Oxalic acid: \( \text{MW} = 90.04 \)

\[ \text{HOOC-COOH} + 2 \text{NaOH} \rightarrow 2\text{COONa} + 2\text{HOH} \]

0.5 mol \( \rightarrow \) 1 mol

45.02 g \( \rightarrow \) 1 mol (or 1000 mmol)

Answer:

Fact: 0.4502 g acid will neutralize 10 mmol of NaOH.

\[ \text{X mL} \times 1.0 \text{ M NaOH} = 10 \text{ mmol NaOH} \]

\[ \text{X} = 10 \text{ mL of 1.0 M NaOH} \]
Part 5. Identification of an Unknown Acid

- Identify a carboxylic acid from melting point and titration data
- The melting point range will be determined using a melting point apparatus
- The equivalent weight will be determined by titrating a known mass of the unknown acid with NaOH

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>MW</th>
<th>EW</th>
<th>MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-hydroxybenzoic acid acetate</td>
<td><img src="image1" alt="Structure" /></td>
<td>180</td>
<td>180</td>
<td>135</td>
</tr>
<tr>
<td>trans-cinnamic acid</td>
<td><img src="image2" alt="Structure" /></td>
<td>148</td>
<td>148</td>
<td>135-136</td>
</tr>
<tr>
<td>2-chlorobenzoic acid</td>
<td><img src="image3" alt="Structure" /></td>
<td>157</td>
<td>157</td>
<td>140</td>
</tr>
<tr>
<td>cis-butenedioic (maleic) acid</td>
<td><img src="image4" alt="Structure" /></td>
<td>116</td>
<td>58</td>
<td>139-140</td>
</tr>
</tbody>
</table>

Equivalent Weight (EW)

Theoretical
- EW = Molecular Wt/# ionizable protons

Examples:
- $\text{H}_2\text{SO}_4$ = molecular weight of 98
- $\text{H}_2\text{SO}_4$ = equivalent weight of 49
- $\text{HCl}$ = molecular weight of 36.5
- $\text{HCl}$ = equivalent weight of 36.5

Unknowns and Carboxylic Acid Structure

- Benzoic acid
  - One ionizable proton.
  - $\text{C}_6\text{H}_5\text{COOH}$
  - $\text{MW} = \text{EW}$
- No ionizable protons.
- Not an acid.
O H H H O
H - O - C - C - C - C - C - O - H
H H H H

Adipic acid
HOOC(CH₂)₄COOH

Molecular Weight = 146
Equivalent weight = _____________?

Q. An acid has an equivalent weight (EW) of 88.92. The EW = molecular wt/#ionizable protons. List the number of any compound from the table that may be the acid.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ethanoic acid</td>
<td>CH₃COOH</td>
<td>60</td>
</tr>
<tr>
<td>2. Butanoic acid</td>
<td>CH₃CH₂CH₂COOH</td>
<td>88</td>
</tr>
<tr>
<td>3. Oxalic acid</td>
<td>HOOC-COOH</td>
<td>90</td>
</tr>
<tr>
<td>4. 1-methyl, 1,2-benzenedicarboxylic acid</td>
<td>CH₃C₆H₃(COOH)₂</td>
<td>180</td>
</tr>
</tbody>
</table>

Answer. Compounds # 2 and # 4.

A teammate titrates a carboxylic acid and calculates the EW of the acid to be 72.50. The result is correct within 2%. The MW of the acid is determined to be 1.5 x 10²

A. How many ionizable protons/mol are in the acid?
   Let X = # ionizable protons.
   EW = 72.50 = MW/X = 150/X
   X = ~ 2

B. Circle each structure that is consistent with the data.

Adipic Acid, MW = 146:
HO₂CCH₂CH₂CH₂CO₂H

Trans-cinnamic acid, MW=148:
<CH>CH=CH-COOH

Citric Acid, MW = 192:
HO₂C-CH₃-C(OH)-CH₂-CO₂H

Oxalic acid, MW = 90:
HO₂C-CO₂H

EW from Experiment Data (Part 5)

• Determine the equivalent weight of an unidentified carboxylic acid by determining the volume of base of known concentration required to neutralize a measured mass of the unknown acid.

• EW = Mass (g) of acid neutralizing 1 mol OH⁻.

EW = \frac{\text{mass acid (g)}}{\text{moles of OH⁻ neutralized}}
Q. 10.0 mL of 1.0 M NaOH neutralizes 0.4502 grams of oxalic acid, what is the equivalent weight of the acid?

Oxalic acid:  \[ \text{MW} = 90.04 \]

\[ \text{HOOC-COOH} + 2 \text{NaOH} \rightarrow 2\text{COONa} + 2\text{HOH} \]

0.5 mol \[ \rightarrow \] 1 mol

45.02 g \[ \rightarrow \] 1 mol (or 1000 mmol)

**Answer.** 0.4502 g neutralized 10.0 mmol of NaOH. The mass of acid needed to neutralize 1 mol = 45.02 g = EW

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**Equivalent weight determination.**

1) **Determine mol of NaOH the acid has neutralized.**

Known: The acid mass neutralized 30.00 mL of 0.10 M NaOH

\[
\text{mol OH}^- = \frac{V(L) \times M \text{NaOH}}{V}
\]

\[
= \frac{0.0300 \times 0.10 \text{ mol}}{1}
\]

\[
= 3.0 \times 10^{-3} \text{ mol}
\]

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Q. You titrate 0.175 g of an acid. 30.00 mL of 0.10 M NaOH neutralizes the sample.

1) What is the acid’s EW based on the data?

2) Identify the acid from the list below.

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<td>trans-cinnamic acid</td>
<td>OCH_CH_COOH</td>
<td>148</td>
<td>135-136</td>
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<td>OCl_COOH</td>
<td>157</td>
<td>140</td>
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<tr>
<td>cis-butenedioic (maleic) acid</td>
<td>H_COOC_COOH</td>
<td>116</td>
<td>139-140</td>
</tr>
</tbody>
</table>

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**Equivalent Weight determination.**

2) **Determine the mass of acid that would neutralize one mol of hydroxide ions.**

Known:  \[
\frac{0.175 \text{ g}}{X \text{ g acid}} = \frac{0.0030 \text{ mol OH}^-}{1 \text{ mol OH}^-}
\]

\[
X = \frac{0.175 \times 1}{0.0030} \text{ g}
\]

\[
X = 58 \text{ g}
\]
<table>
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<th>Name</th>
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<td>2-hydroxybenzoic acid acetate</td>
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Questions?
Contact nkerner@umich.edu