Chapter 10 Lecture Notes:

Carboxylic Acids, Amines, and Amides

Educational Goals

1. Given the structure of a carboxylic acid, carboxylate ion, ester, amide, or amine molecule, be able to give the systemic names and vice versa.
2. Know and understand the intermolecular forces that attract carboxylic acid, amine, or amide molecules to one another, and how these forces affect boiling points and melting points.
3. Identify amines as primary (1°), secondary (2°), or tertiary (3°). Compare and contrast amines and quaternary ammonium ions.
4. Predict the products for the reactions of carboxylic acids with water, alcohols, amines, ammonia, or with strong bases.
5. Predict the products for the reactions of amines with water or with strong acids.
6. Predict the products for the base-catalyzed hydrolysis of an ester.
7. Predict the products for the acid-catalyzed hydrolysis of an amide.
8. Identify chiral carbon atoms in structural formulas. Given the number of chiral carbons in a molecule, determine the number of stereoisomers.

Carboxylic Acids

From now on, we will write “R” instead of “Hydrocarbon” in structures.

Naming Carboxylic Acids

- When naming a carboxylic acid according to the IUPAC rules, the parent is the longest continuous carbon chain that ___________________ the ____________________________.

- Numbering ___________________________ at the carbonyl carbon, and alkyl groups are identified by name, position, and number of appearances.

Carboxylic acid (RCOOH or RCO₂H)
• Example:

\[
\begin{array}{c}
\text{CH}_3\text{CH}_2\text{C} \equiv \text{OH} \\
\text{carbon #1}
\end{array}
\]

• IUPAC names for carboxylic acid parent chains are formed by dropping the final “e” on the name of the corresponding hydrocarbon and adding “__________________”.

\[
\begin{array}{ll}
\text{propanoic acid} & \text{3-methylbutanoic acid}
\end{array}
\]

You try it:

\[
\begin{array}{c}
\text{CH}_3\text{CH}_2 \quad \text{O} \\
\text{CH}_3\text{CH}_2\text{CHCH}_2\text{C} \equiv \text{OH} \\
\text{CH}_3
\end{array}
\]

Name: ________________________________

Draw structures of each the carboxylic acids:

a. 2-methylpentanoic acid

b. 4-ethylhexanoic acid

Some carboxylic acids use common names:

methanoic acid = formic acid
ethanoic acid = acetic acid (vinegar is a 5% acetic acid solution)

Group work: Draw each molecule.
NOTE: When named as a substituent, -OH is hydroxy, -Cl is chloro, and -Br is bromo.

a. butanoic acid

b. 2-hydroxypropanoic acid

c. 4-chlorohexanoic acid

d. 2-chloro-3-hydroxydecanoic acid
Properties of Carboxylic Acids

- Compared to other organic compounds with a similar molecular weight, carboxylic acids have relatively high boiling points due to their ability to form hydrogen bonds with one another.

- The ability to form hydrogen bonds, in addition to the presence of polar C=O, C–O, and O–H bonds, gives small carboxylic acids a significant water solubility.

- An increasing number of carbon atoms leads to a decrease in water solubility.

<table>
<thead>
<tr>
<th>Molecule Name</th>
<th>Condensed Structure</th>
<th>Water Solubility (g/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanoic acid</td>
<td>HCOOH</td>
<td>miscible*</td>
</tr>
<tr>
<td>ethanoic acid</td>
<td>CH₃COOH</td>
<td>miscible</td>
</tr>
<tr>
<td>propanoic acid</td>
<td>CH₃CH₂COOH</td>
<td>miscible</td>
</tr>
<tr>
<td>butanoic acid</td>
<td>CH₃CH₂CH₂COOH</td>
<td>miscible</td>
</tr>
<tr>
<td>pentanoic acid</td>
<td>CH₃CH₂CH₂CH₃COOH</td>
<td>3.7</td>
</tr>
<tr>
<td>hexanoic acid</td>
<td>CH₃CH₂CH₂CH₂CH₃COOH</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Common Carboxylic Acids

Formic acid, HCOOH: Chemical that is present in the sting of ants.
Acetic acid, CH₃COOH: dilute (5%) aqueous acetic acid is known as vinegar
Butyric acid, CH₃CH₂CH₂COOH: Chemical responsible for odor of rancid butter.
Caproic acid, CH₃CH₂CH₂CH₂CH₂COOH: First isolated from the skin of goats—which has distinct smell.
Citric acid: Present in citrus fruits and blood.
Reactions of Carboxylic Acids

1) Reaction with Water

Carboxylic acids are__________________________ _______________________.

- Acid strengths of common carboxylic acids are about the same as that for acetic acid.

Remember this from chapter 9?

- For the acid (HA) and its conjugate base (A⁻),
  \[ HA + H_2O \rightleftharpoons A^- + H_3O^+ \]
- There is more HA when the pH is lower than the pKₐ.
- There is more A⁻ when the pH is higher than the pKₐ.
- There are equal amounts of HA and A⁻ when the pH = pKₐ.

2) Neutralization: Reaction with OH⁻

Carboxylic acids undergo__________________________ ________________________ with bases and produce water and a carboxylic acid salt.

- The resulting carboxylate ions are__________________________ ________________________ in water than the carboxylic acids themselves.
  - The ions have a full charge = more water soluble.

Solubility of Carboxylate Ions

In general, carboxylate anions with 12 or more carbon atoms, like palmitate ion, are__________________________, while those with fewer than 12 carbon atoms are water soluble.
Summary: Solubility of Carboxylic Acids and their Conjugate Bases

<table>
<thead>
<tr>
<th>Acid Form</th>
<th>Base Form</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Chemical Structure" /></td>
<td><img src="image2.png" alt="Chemical Structure" /></td>
</tr>
</tbody>
</table>

When $R$ gets to be 5 carbons, the solubility decreases rapidly.

If $R$ has less than 12 carbons:
- Soluble (aq)

If $R$ has 12 or more carbons:
- Amphipathic
- Forms monolayers or micelles

Naming Carboxylate Ions

- To name a carboxylate ion, the ending on the name (IUPAC or common) of the related carboxylic acid is changed from "ic acid" to "ate".

- Example:
  - acetic acid becomes acetate ion
    
    ![Acetate ion](image3.png)

- Palmitic acid becomes palmitate ion
  
  ![Palmitate ion](image4.png)
**You try it:**
Draw and name the conjugate base (carboxylate ion) for the following carboxylic acids:

- Propanoic acid
- 2-Methylbutanoic acid

---

**Other Reactions of Carboxylic Acids**

3) **Esterification**
   - Esterification is carried out by warming a mixture of a carboxylic acid and an alcohol in the presence of a strong acid catalyst.

**Ester formation**

\[
\text{R-C-OH} + \text{H-OR'} \xrightarrow{\text{H}^+ \text{ catalyst}} \text{R-C-OR'} + \text{H}_2\text{O}
\]

This -OH group is replaced by this -OR’ group.

Note that the reaction is reversible!
Esters undergo hydrolysis to give back the carboxylic acid.
- *we saw this in chapter 6!*

**Ester hydrolysis** reactions can be catalyzed by either an *acid* or a *base*. Here is the net result:

\[
\text{R-C-OR'} + \text{H-OH} \rightarrow \text{R-C-OH} + \text{H-OR'}
\]

This -OR’ group is replaced by this -OH group.
Naming Esters

• When naming an ester, place the name of the alkyl group (R') in front of the name of the carboxylate part (RCOO) as follows:

Example:

\[
\begin{align*}
\text{O} & \quad \text{||} \\
R - C - O - R' & \\
\end{align*}
\]

You try it:

Name this ester:

\[
\begin{align*}
\text{O} & \quad \text{||} \\
\text{CH}_3C - O - \text{CH}_3 & \\
\end{align*}
\]
4) Decarboxylation of Carboxylic Acids

\[
R - C - O - H \rightleftharpoons R - H + CO_2
\]

- Break the COOH off, and replace the H!

- Common in biological systems for keto-acids
  - Keto acids are carboxylic acids with *ketone* functionality (carbonyl groups)

You Try It! Draw the products of each decarboxylation reaction.

- **Acetoacetic acid**
  - **Acetone**

- **Pyruvic acid**
  - **Acetaldehyde**
Summary of Reactions of Carboxylic Acids:

1) Reaction with water:

\[ \text{R – C – OH} + \text{H}_2\text{O} \rightleftharpoons \text{R – C – O}^- + \text{H}_3\text{O}^+ \]

2) Neutralization (reaction with OH\(^-\)):

\[ \text{R – C – OH} + \text{NaOH (aq)} \rightleftharpoons \text{R – C – O}^- \text{ Na}^+ (\text{aq}) + \text{H}_2\text{O} \]

3) Esterification (reaction with alcohol):

A carboxylic acid
\[ \text{R – C – OH} \]

An alcohol
\[ \text{H – OR’} \]

An ester
\[ \text{R – C – OR’} \]

\[ \text{H}^+ \text{catalyst} \]

This –OH group is replaced by this –OR’ group.

4) Decarboxylation:

\[ \text{R – C – O}^- \text{ H} \rightleftharpoons \text{R – H} + \text{CO}_2 \]
Amines

Amines are compounds that contain one or more organic groups bonded to nitrogen.

- They are classified as primary, secondary, and tertiary according to how many organic groups are bonded to the nitrogen atom.
  - **Primary (1°)** - only one organic group (R) is attached to the amine nitrogen atom
  - **Secondary (2°)** - two organic groups attached to the amine nitrogen
  - **Tertiary (3°)** - three organic groups attached to the amine nitrogen

In a primary, secondary, or tertiary amine, the amine nitrogen has a _______________ _______________ of electrons.

When a **fourth group** bonds to the nitrogen, the product is a quaternary ammonium ion, which has a _______________ _______________ charge and forms ionic compounds.

- The nitrogen carries a +1 charge.
Naming Amines

- To name a 1°, 2°, or 3° amine using IUPAC rules, the parent, the longest chain of carbon atoms attached to the amine nitrogen atom, is numbered from the end nearer the point of attachment of the nitrogen.
- The parent chains of amines are named by dropping “e” from the name of the corresponding hydrocarbon and adding “amine.”
- Write the carbon number of the point of attachment to the nitrogen in front of the parent name.
  - \( \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2 = 1\text{-propanamine} \)
  - \( \text{CH}_3\text{CHCH}_3 = 2\text{-propanamine} \)
  - \( \text{CH}_3\text{CH}_2\text{CH}_2\text{NHCH}_3 = N\text{-methyl-1-propanamine} \)
  - \( \frac{\text{CH}_3\text{CH}_2\text{CH}_2\text{NHCH}_3}{\text{CH}_3\text{NCH}_3} = N,N\text{-Dimethyl-2-butamime} \)

- If an amine is 2° or 3°, the carbon-containing groups attached to the nitrogen atom that are not part of the parent chain are substituents and \( N \) is used to indicate their location (\( N\)-methyl, \( N,N\)-diethyl, etc.).

Simple amines, those with a relatively few number of carbon atoms, are often identified by common names by placing “amine” after the names of the groups attached to the nitrogen.
- methylamine = \( \text{CH}_3\text{NH}_2 \)

You Try It!
Match each IUPAC and common name to the correct structural formula:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( \text{CH}_3\text{CH}_2\text{CH}_2\text{NHCH}_2\text{CH}_3 )</td>
<td>b. ( \text{CH}_3\text{CH}_2\text{NCH}_2\text{CH}_3 )</td>
<td>c. ( \text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{CH}_3 )</td>
</tr>
<tr>
<td>1-butanamine</td>
<td>( N,N)-diethyl-1-propanamine</td>
<td>( N)-ethyl-1-propanamine</td>
</tr>
</tbody>
</table>

Practice: Draw the line structure for the following compound, and then name it!
• When NH$_2$- group is present as a substituent in a molecule it is called an ________________ group.

• All proteins are made up of ________________ ________________.

**Properties of Amines**

• __________________ on amines can hydrogen bond to water. (water solubility better than alkanes)

• Primary and secondary amines can hydrogen bond to themselves and each other amines.
  
  – As a result of hydrogen bonding, primary and secondary amines have ________________ ________________ ________________ than alkanes of similar size.

![Diagram of alkanes and amines with hydrogen bonds]

<table>
<thead>
<tr>
<th>Formula</th>
<th>IUPAC Name</th>
<th>Common Name</th>
<th>Boiling Point (°C)</th>
<th>Water Solubility (g/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$NH$_2$</td>
<td>Methanamine</td>
<td>Methylamine</td>
<td>−7.5</td>
<td>Very large</td>
</tr>
<tr>
<td>CH$_3$CH$_2$NH$_2$</td>
<td>Ethanamine</td>
<td>Ethylamine</td>
<td>17</td>
<td>Very large</td>
</tr>
<tr>
<td>CH$_3$CH$_2$CH$_2$NH$_2$</td>
<td>1-Propanamine</td>
<td>Propylamine</td>
<td>49</td>
<td>Very large</td>
</tr>
<tr>
<td>CH$_3$CH$_2$NHCH$_3$</td>
<td>N-Methylethanamine</td>
<td>Ethylmethylamine</td>
<td>36–37</td>
<td>Very large</td>
</tr>
<tr>
<td>N(CH$_3$)$_3$</td>
<td>N,N-Dimethylmethanamine</td>
<td>Trimethylamine</td>
<td>3</td>
<td>91</td>
</tr>
<tr>
<td>N(CH$_2$CH$_3$)$_3$</td>
<td>N,N-Diethylethanamine</td>
<td>Triethylamine</td>
<td>89</td>
<td>14</td>
</tr>
</tbody>
</table>

• Volatile amines have strong ____________________________.
  
  - Amines smell like rotten fish.
Many amines are physiologically active.
- Smaller amines are irritating to the skin, eyes, and mucous membrane and are toxic by ingestion.

**Heterocyclic Nitrogen Compounds**
Rings that contain atoms other than carbon are known as Heterocyclic rings are very common in natural compounds found in plants and animals.

Example (left): DNA
Reactions of Amines

1) Reactions of Amines with Water

Amines are __________________________.

- This basic property is due to the electron lone pair on the amine nitrogen that can be used to form a covalent bond with a H\(^+\) ion from water or an acid.

\[
\begin{align*}
\text{H–N–H}^{(aq)} + \text{H}_2\text{O} (l) & \rightleftharpoons \text{H–N}^+\text{H}^{(aq)} + \text{OH}^- \\
\end{align*}
\]

The lone pair on the nitrogen makes it a Lewis base.

Amines react with water to form __________________________ and OH\(^-\).

\[
\begin{align*}
\text{CH}_3\tilde{\text{N–H}} + \text{H–O–H} & \rightleftharpoons \text{CH}_3\text{N}^+\text{H} + \text{O–H} \\
\text{Methylamine} & \quad \text{Methylammonium ion} \\
\text{predominates when pH > pK}_a & \quad \text{predominates when pH < pK}_a
\end{align*}
\]

2) Reactions of Amines with Acid

A __________________________ convert an amine into its conjugate acid. (pH<pK\(_a\))

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{NH}_2 + \text{HCl} & \rightarrow \text{CH}_3\text{C}_2\text{NH}_3\text{Cl}^- \\
\text{Ethylamine} & \quad \text{Ethylammonium chloride}
\end{align*}
\]

\[
\begin{align*}
\text{C}_6\text{H}_3\text{CHNHCH}_3 + \text{HCl} & \rightarrow \text{C}_6\text{H}_3\text{C}_\text{H}^+\text{NH}_2\text{CH}_3 \text{Cl}^- \\
\text{Ephedrine} & \quad \text{Ephedrine hydrochloride}
\end{align*}
\]
Amines in Plants: Alkaloids

- _______________ are naturally occurring nitrogen compounds isolated from plants.
- Most alkaloids are usually bitter-tasting, physiologically active, and _____________ in high doses.
- Some alkaloids are very familiar, such as the stimulants caffeine and nicotine.
- Other alkaloids are used as pain killers, sleep inducers, and for the creation of euphoria.

![Morphine](image1.png)

![Heroin](image2.png)

![Codeine](image3.png)
Amides
Amides result when the –OH from a carboxylic acid is replaced with an –NH₂ or an ________________.

R—C—OH

Carboxylic acid

Amides

RCONH₂, RCONHR’, RCONR’₂

Amides contain an –NH₂ group with none, one, or both of the N-hydrogens replaced with alkyl groups (R).
- Examples:

R—C—NH₂

R—C—NH

R—C—N—R’

Naming Amides
- Name is based on the longest continuous carbon chain that contains the carbonyl (C=O).
  - Just like naming the carboxylic acids!
- Drop the “e” on the parent chain and add “amide”
- List the substituents as usual, making carbonyl-carbon #1

Name: ______________________________

You try one:

Name the compound shown below:

O

CH₃CH₂CH₂CH₂C—NH₂

Name: ______________________________
**Formation of Amides**

Amides can be made from ________________ and ________________.

![Chemical reaction diagram](image)

Examples:

- \( \text{CH}_3\text{CH}_2\text{C} - \text{OH} + \text{NH}_3 \xleftrightarrow{} \text{CH}_3\text{CH}_2\text{C} - \text{NH}_2 + \text{H}_2\text{O} \)

- \( \text{CH}_3\text{CH}_2\text{C} - \text{OH} + \text{H}_2\text{NCH}_3 \xleftrightarrow{} \text{CH}_3\text{CH}_2\text{C} - \text{NHCH}_3 + \text{H}_2\text{O} \)

Note that the reaction is _______________________.

![Chemical reaction diagram](image)
Stereoisomers

Definition:
- Stereoisomers are molecules that have the same formula and atomic connections, but different three dimensional shapes.
- We have seen some examples of stereoisomers in the past:
  - Geometric isomers (cis and trans)

We will learn about a new class of stereoisomers called _______________________.

Enantiomers are nonsuperimposable mirror image molecules.

- The term chiral is used to describe objects that cannot be superimposed on their mirror image.
  - Example: Your hands are chiral because your left hand is not superimposable on your right hand, its mirror image. (Try it!)
Chapter 10 Lecture Notes

A carbon is **chiral** if it has __________ different groups bonded to it!

**You Try It!** Use an asterisk (*) to label the **chiral** carbon(s) in each molecule.

- Pairs of enantiomers are identical in almost every way.
- Biological systems such as smell and taste receptors, enzymes, and antibodies are selective with respect to enantiomers.
Molecules with More than One Chiral Carbon Atom

As the number of chiral carbon atoms in a molecule increases, so does the number of stereoisomers that can exist.

**Number of stereoisomers =** \(2^n\)

where \(n\) is the number of ________________ carbon atoms.

**You Try It!**

a. How many chiral carbon atoms does 2-bromo-3-chlorobutane have?
b. How many stereoisomers are possible for this molecule?

**Diastereomers**

- Stereoisomers that are not enantiomers (mirror images) are called ________________.

**Example:**

The stereoisomers of 2-bromo-3-chlorobutane.

**Diastereomers**

A pair of enantiomers