Chapter 21:
Carboxylic Acid Derivatives
• **Class I** carbonyl compounds are those that will react by acyl substitutions. They are all derivatives of carboxylic acids:

- cannot be replaced by a nucleophile

- aldehyde
- ketone

**Class II**

- compounds with groups that can be replaced by a nucleophile

- carboxylic acid
- ester
- anhydride
- acyl halides
- amides
• **Physical Properties (21-3)**

• **Boiling points increases with the strength of the dipolar interactions.**

<table>
<thead>
<tr>
<th>Examples</th>
<th>bp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td></td>
</tr>
<tr>
<td>CH₃—C—NH₂</td>
<td>222</td>
</tr>
<tr>
<td>CH₃—C—OH</td>
<td>118</td>
</tr>
<tr>
<td>CH₃CH₂CH₂OH</td>
<td>97</td>
</tr>
<tr>
<td>CH₃CH₂—C≡N</td>
<td>97</td>
</tr>
<tr>
<td>H—C—OCH₃</td>
<td>32</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₃</td>
<td>0</td>
</tr>
</tbody>
</table>

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The large boiling points of nitriles, acids and amides is due to the strong dipolar forces that are found in these compounds.
Interconversion of Acid Derivatives (21-5)

Acid derivatives normally react by nucleophilic acyl substitution. The general mechanism of this process is given below. Following this mechanism, it is possible to transform one acid derivative into another one.

\[
\begin{align*}
\text{Nuc}^- + \text{R} - \text{C} - \text{Y} & \xrightleftharpoons{\text{nucleophilic attack}} \text{R} - \text{C} - \text{Y} - \text{Nuc}^- \\
\text{tetrahedral intermediate} & \quad \text{tetrahedral intermediate} \\
& \quad \text{products} + \text{leaving group}
\end{align*}
\]
The reactivity of acid derivatives can be correlated to the leaving group ability of the base that is expelled. The better the leaving group, the more reactive will be the acid derivative. Not surprising that acid chloride are the most reactive derivatives.

<table>
<thead>
<tr>
<th>Reactivity</th>
<th>Derivative</th>
<th>Leaving group</th>
<th>Basicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>more reactive</td>
<td>acid chloride, R—C—Cl</td>
<td>Cl⁻</td>
<td>less basic</td>
</tr>
<tr>
<td></td>
<td>anhydride, R—C—O—C—R</td>
<td>O—C—R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ester, R—C—O—R'</td>
<td>O—R'</td>
<td></td>
</tr>
<tr>
<td></td>
<td>amide, R—C—NH₂</td>
<td>NH₂</td>
<td></td>
</tr>
<tr>
<td>less reactive</td>
<td>carboxylate, R—C—O⁻</td>
<td>🍒</td>
<td>more basic</td>
</tr>
</tbody>
</table>
• This is the reason ketones and aldehydes will not react by acyl substitutions. The leaving group is either $R^-$ or $H^-$, which are very basic, therefore poor leaving groups.
In theory, it is possible to go from one acid derivatives to another one. In practice, only the following reactions are normally used. Rule: a more reactive intermediate can be converted into a less reactive one.
Conversion of Acid Chloride to Anhydride

**Step 1:** Addition of the nucleophile.

\[
R\text{—C—Cl} + HO\text{—C—R}’ \rightleftharpoons R\text{—C—Cl} \rightleftharpoons R\text{—C—O—C—R}’ + H\text{—Cl}
\]

- Acid chloride
- Acid
- Tetrahedral intermediate

**Step 2:** Elimination of the leaving group.

**Step 3:** Loss of a proton.

Example

\[
CH_3(CH_2)_5\text{—C—Cl} + CH_3(CH_2)_5\text{—C—OH} \rightarrow CH_3(CH_2)_5\text{—C—O—C—(CH_2)_5CH_3}
\]

- Heptanoyl chloride
- Heptanoic acid
- Heptanoic anhydride

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Conversion of Acid Chloride to Esters

**Step 1:** Addition of the nucleophile.

\[ \text{acid chloride} + \text{alcohol} \rightarrow \text{tetrahedral intermediate} \]

**Step 2:** Elimination of the leaving group.

\[ \text{tetrahedral intermediate} \rightarrow \text{ester} + \text{HCl} \]

**Step 3:** Loss of a proton.

\[ \text{ester} + \text{HCl} \]

**Example**

\[ \text{cyclopentanecarbonyl chloride} + \text{2-propanol} \rightarrow \text{2-propyl cyclopentanecarboxylate} + \text{HCl} \]
Conversion of Acid Chloride to Amides

**Step 1:** Addition of the nucleophile.

\[
\text{acid chloride} + 2 \text{amine} \rightleftharpoons \text{tetrahedral intermediate}
\]

**Step 2:** Elimination of the leaving group.

**Step 3:** Loss of a proton.

Example

\[
\text{hexanoyl chloride} + \text{cyclohexylamine} \rightarrow \text{N-cyclohexylhexanamide} + \text{HCl}
\]

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Conversion of Anhydrides to Esters

**Step 1:** Addition of the nucleophile.

\[
\text{R-C(=O)-O-C-R + R'-OH} \rightleftharpoons \text{R-C(=O)-O-C-R} \quad \text{anhdyride} \quad \text{alcohol}
\]

**Step 2:** Elimination of the leaving group.

\[
\text{R-C(=O)-O-C-R} \quad \text{tetrahedral intermediate}
\]

**Step 3:** Loss of a proton.

\[
\text{R-C(=O)-O-C-R} \quad \text{ester} \quad \text{acid}
\]

**Example**

\[
\text{cyclopentanol} + \text{CH}_3\text{C(=O)-O-C-CH}_3 \rightarrow \text{cyclopentyl acetate} + \text{AcOH}
\]
Conversion of Anhydrides to Amides

**Step 1:** Addition of the nucleophile.

$$\text{anhydride} + \text{amine} \rightleftharpoons \text{tetrahedral intermediate}$$

**Step 2:** Elimination of the leaving group.

**Step 3:** Loss of a proton.

$$\text{amide} + \text{acetic acid}$$

**Example**

- **aniline** + **acetic anhydride** → **acetanilide** + **acetic acid**
Practice Questions

- If you were starting with acetyl chloride, what nucleophile would you use to prepare the following compounds.
- Write a detailed stepwise mechanism of the reaction taking place between acetyl chloride and water.
Conversion of Esters to Amides (Ammonolysis)

**Step 1:** Addition of the nucleophile.

\[ R\text{-C-O-}\text{R'} + \text{R''-NH}_2 \]

primary amine (or \( \text{NH}_3 \))

**Step 2:** Elimination of the leaving group.

\[ R\text{-C-O-}\text{R'} \rightarrow R\text{-C-}^\text{+}\text{NH}_2 \]

tetrahedral intermediate

**Step 3:** Loss of a proton.

\[ R\text{-C-NHR''} + \text{R'-OH} \]

amide + alcohol

*Example*

\[
\begin{align*}
\text{H-C-O-CH}_2\text{CH}_3 & \quad + \quad \text{cyclohexylamine} \\
\text{ethyl formate} & \quad \rightarrow \\
\text{N-cyclohexylformamide} & \quad + \quad \text{ethanol}
\end{align*}
\]

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In all of these reactions, the key feature was the basicity of the nucleophile and leaving group. If the nucleophile is more basic than the leaving group, the reaction will proceed. However, if the nucleophile is less basic than the leaving group, no reaction will occur. Hence, knowing $pK_a$ is important.

\[ \text{this reaction will not proceed since } \text{Cl}^- \text{ is a weaker base than } \text{NH}_2^- \]

\[ \text{however this reaction is easy since the leaving group } \text{Cl}^- \text{ is a weaker base than } \text{NH}_2^- \]
• **Transesterification** (21-6)

This reaction is very similar to the hydrolysis reaction (see 21-7). The only difference is that an alcohol is used in large excess instead of water. This results in the formation of a new ester, one that has the structure of the alcohol that was used in excess. The reaction can be performed under basic or acidic conditions, the latter being more common.

*Transesterification*

\[
\text{R-C-O-R'} + \overset{\text{H}^+ \text{ or } \text{OR}^*}{\overset{\leftrightarrow}{\text{R''-OH}}} \rightarrow \text{R-C-O-R''} + \text{R'-OH}
\]

(large excess)

*Example*

\[
\text{ethyl benzoate} + \text{CH}_3\text{OH} \overset{\text{H}^+ \text{ or } \text{OCH}_3}{\rightarrow} \text{methyl benzoate} + \text{CH}_3\text{CH}_2\text{OH}
\]

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Mechanism of Transesterification

First half: Acid-catalyzed addition of the nucleophile.

**Step 1:** Protonation

**Step 2:** Nucleophile attack.

**Step 3:** Deprotonation.

Second half: Acid-catalyzed elimination of the leaving group.

**Step 1:** Protonation of the leaving group.

**Step 2:** Elimination of the leaving group.

**Step 3:** Deprotonation.

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• **Hydrolysis of Acid Derivatives** (21-7)

This reaction is the reason all of these compounds are considered acid derivatives...because they produce carboxylic acids upon hydrolysis. This reaction can be performed under acidic or basic conditions.

**Acid Chlorides/Anhydrides**

These two compounds are so reactive that the hydrolysis can be performed under neutral conditions.

\[
\begin{align*}
R\text{C}=\text{Cl} + \text{H}_2\text{O} & \rightarrow R\text{C}=\text{Cl} \\
 & \rightarrow R\text{C}\text{OCl} \\
 & \rightarrow R\text{C}O\text{H} + \text{HCl}
\end{align*}
\]
Esters

Esters can be hydrolyzed under acidic or basic conditions. Under basic conditions, the reaction is known as “saponification”

Step 1: Addition of the nucleophile.

\[
\text{ester} + \text{acid} \rightarrow \text{tetrahedral intermediate}
\]

Step 2: Elimination of the leaving group.

\[
\text{tetrahedral intermediate} \rightarrow \text{alkoxide} \rightarrow \text{carboxylate} \rightarrow \text{alcohol}
\]

Step 3: Proton transfer.

\[
\text{acid} \rightarrow \text{ester}
\]

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Under acidic conditions, the mechanism of hydrolysis is the reversed of the Fisher Esterification.
Amides

Amides also hydrolyze to acids under basic or acidic conditions.

**Basic hydrolysis**

\[ R\text{-}C\text{-}NHR' + \text{Na}^+\text{-}OH \rightarrow \text{R}\text{-}C\text{-}O}^- + \text{Na} + \text{R}'\text{NH}_2 \]

**Acid hydrolysis**

\[ R\text{-}C\text{-}NHR' + \text{H}_3\text{O}^+ \rightarrow \text{R}\text{-}C\text{-}OH + \text{R}'\text{NH}_3 \]
Base Catalyzed Hydrolysis of Amides

Step 1: Addition of the nucleophile.

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

Step 2: Elimination of the leaving group.

\[ \text{R–C–O}^- + \text{H}^+ \rightarrow \text{R–C} = \text{O} \]

Step 3: Proton transfer.

\[ \text{R–C} = \text{O} + \text{H}^+ \rightarrow \text{R–C} = \text{O}^+ \]

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Acid Catalyzed Hydrolysis of Amides

First half: Acid-catalyzed addition of the nucleophile (water).

**Step 1:** Protonation of the carbonyl.

\[
\text{R-C-\text{NH}_2} + \text{H}^+ \quad \Leftrightarrow \quad \text{R-C-\text{NH}_2}^+ + \text{H}_2\text{O}^-
\]

**Step 2:** Addition of the nucleophile.

\[
\text{R-C-\text{NH}_2}^+ + \text{H}_2\text{O}^- \quad \Leftrightarrow \quad \text{R-C-\text{NH}_2} + \text{H}_3\text{O}^+
\]

**Step 3:** Loss of a proton.

\[
\text{R-C-\text{NH}_2} + \text{H}_3\text{O}^+ \quad \Leftrightarrow \quad \text{R-C-\text{NH}_2}^+ + \text{H}_2\text{O}^-
\]

Second half: Acid-catalyzed elimination of the leaving group.

**Step 1:** Protonation of the leaving group.

\[
\text{R-C-\text{NH}_2} + \text{H}^+ \quad \Leftrightarrow \quad \text{R-C-\text{NH}_2}^+ + \text{H}_2\text{O}^-
\]

**Step 2:** Elimination of the leaving group.

\[
\text{R-C-\text{NH}_2}^+ + \text{H}_2\text{O}^- \quad \Leftrightarrow \quad \text{R-C-\text{NH}_3}^+ + \text{H}_2\text{O}^-
\]

**Step 3:** Deprotonation.

\[
\text{R-C-\text{NH}_3}^+ + \text{NH}_3 \quad \rightarrow \quad \text{R-C-\text{O}^-} + \text{NH}_4^+
\]

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Nitriles

Nitriles are considered acid derivatives because they generate the corresponding acids under hydrolysis conditions. Reactions can be performed under acidic or basic conditions.

**Basic hydrolysis of nitriles**

\[
\begin{align*}
\text{nitrile} & \quad \text{H}_2\text{O} & \quad \text{H}_2\text{O}^{-} & \quad \text{amide} & \quad \text{H}_2\text{O}^{-} & \quad \text{carboxylate ion} \\
R{-C\equiv N} & + & H_2O & \rightarrow & R{-C-NH}_2 & \rightarrow & R{-C-O^{-}} & + & :NH_3
\end{align*}
\]

**Acidic hydrolysis of nitriles**

\[
\begin{align*}
\text{nitrile} & \quad \text{H}_2\text{O} & \quad \text{H}^{+} & \quad \text{amide} & \quad \text{H}^{+} & \quad \text{carboxylic acid} & \quad \text{NH}_4^{+} \\
R{-C\equiv N} & \rightarrow & R{-C-NH}_2 & \rightarrow & R{-C-OH} & + & \text{NH}_4^{+}
\end{align*}
\]
Base Catalyzed Hydrolysis of Nitriles

\[
\begin{align*}
R - C = N : & \quad \Leftrightarrow \quad R - C = N : - O^+ \cdot H^- \\
\text{nitrile} & \\
& \\
\text{enol tautomer} & \\
R - C = N - H & \quad \Leftrightarrow \quad R - C = N - H + O^- \cdot H^+ \\
\text{enolate of an amide} & \\
& \\
\text{amide} & \\
\end{align*}
\]
Practice Question

- What product would be formed from the acid-catalyzed hydrolysis of the following esters?
• **Reduction** (21-8)

Like other compounds bearing C=O functions, acid derivatives can be reduced easily using reagents such as (LiAlH₄). The majority of the reductions of acid derivatives give the corresponding primary alcohols. Aldehydes and amines can also be generated.

**Esters** (formation of 1o alcohol)

\[
\text{R—C—O—R'} \xrightarrow{\text{LiAlH}_4} \text{R—CH}_2\text{O}^-\text{Li}^+ + \text{R'}—\text{O}^-\text{Li}^+ \xrightarrow{\text{H}_3\text{O}^+} \text{R—CH}_2\text{OH} + \text{R'}—\text{OH}
\]

**Example**

\[
\begin{align*}
\text{CH}_2—\text{C—OCH}_2\text{CH}_3 \xrightarrow{(1) \text{LiAlH}_4, (2) \text{H}_3\text{O}^+} & \text{CH}_2—\text{CH}_2\text{OH} + \text{CH}_3\text{CH}_2\text{OH} \\
\text{ethyl phenylacetate} & \text{2-phenylethanol}
\end{align*}
\]
Mechanism of Ester Reduction

**Step 1:** Addition of the nucleophile (hydride).

\[
\text{ester} \quad \overset{\text{O}}{\text{C}}\text{O} - \overset{\text{H}}{\text{O}} \quad + \quad \overset{\text{H}}{\text{Al}}\text{H} - \overset{+\text{Li}}{\text{H}} \quad \rightarrow \quad \overset{\text{O}}{\text{C}}\text{O} - \overset{\text{H}}{\text{O}} \quad \rightarrow \quad \overset{\text{O}}{\text{C}}\text{H} - \overset{+\text{Li}}{\text{H}}
\]

**Step 2:** Elimination of alkoxide.

\[
\overset{\text{O}}{\text{C}}\text{O} - \overset{\text{H}}{\text{O}} \quad \rightarrow \quad \overset{\text{O}}{\text{C}}\text{H} - \overset{\text{H}}{\text{O}} + \overset{+\text{Li}}{\text{H}} \quad \overset{\text{tetrahedral intermediate}}{\text{aldehyde}} \quad \overset{\text{alkoxide}}{\text{alkoxide}}
\]

**Step 3:** Addition of a second hydride ion.

\[
\overset{\text{C}}{\text{C}}\overset{\text{O}}{\text{H}} + \overset{\text{H}}{\text{Al}}\text{H} - \overset{+\text{Li}}{\text{H}} \quad \rightarrow \quad \overset{\text{C}}{\text{C}}\overset{\text{H}}{\text{H}} \quad \overset{\text{aldehyde}}{\text{salt}} \quad \overset{\text{primary alcohol}}{\text{H}_2\text{O}^+}
\]

**Step 4:** Add acid in the workup to protonate the alkoxide.

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Acid Chlorides

They can be reduced to the corresponding primary alcohols with LiAlH₄. However, the use of a bulkier reagent prevents the reduction to continue past the aldehyde product.

Example

\[
\begin{align*}
\text{CH}_3\text{(CH}_2\text{)}_6\text{C} & \overset{\text{Li(t-BuO)}_3\text{AlH}}{\underset{\text{ether}}{\longrightarrow}} \text{CH}_3\text{(CH}_2\text{)}_6\text{C} \\
\text{octanoyl chloride} & \text{octanal}
\end{align*}
\]
Amides (formation of amines)

Amides are reduced to 1°, 2° or 3° amines with LiAlH₄.

**Example**

\[
\begin{align*}
R-C-NH_2 & \quad \text{primary amide} \\
\text{(1) LiAlH}_4 \quad \text{(2) H}_2\text{O} & \quad R-CH_2-NH_2 \quad \text{primary amine} \\
R-C-NHR' & \quad \text{secondary amide} \\
\text{(1) LiAlH}_4 \quad \text{(2) H}_2\text{O} & \quad R-CH_2-NHR' \quad \text{secondary amine} \\
R-C-NR_2' & \quad \text{tertiary amide} \\
\text{(1) LiAlH}_4 \quad \text{(2) H}_2\text{O} & \quad R-CH_2-NR_2' \quad \text{tertiary amine}
\end{align*}
\]
Mechanism of Amide Reduction

**Step 1:** Addition of hydride.  
**Step 2:** Oxygen leaves.  
**Step 3:** Second hydride adds.

amide  
tetrahedral intermediate  
iminium salt  
amine

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Nitriles

In a similar reactions, nitriles can also be reduced to the corresponding primary alcohols.

\[
\text{R—C≡N:} \xrightarrow{\text{H}_2/\text{Pt} \; or \; (1) \text{LiAlH}_4; (2) \text{H}_2\text{O}} \xrightarrow{\quad} \text{R—C—N:}
\]
Reactions of Acids Derivatives with Grignards
(21-9)

We have seen that esters and acid chlorides add two equivalents of Grignard reagent to give tertiary alcohols.

\[
\begin{align*}
\text{H} & \quad \text{O} \\
\text{H} & \quad \smallint \text{C} \quad \text{OEt} \quad + \quad 2 \quad \text{C}_4\text{H}_9\text{Li} \quad \rightarrow \quad \text{H} & \quad \smallint \text{C} \quad \text{C}_4\text{H}_9 \\
\text{a formate ester} & \quad \text{C}_4\text{H}_9 & \quad \text{a 2° alcohol}
\end{align*}
\]

\[
\begin{align*}
\text{CH}_3\text{CH}_2 & \quad \text{C} \quad \text{Cl} \quad + \quad 2 \quad \text{PhMgBr} \quad \rightarrow \quad \text{CH}_3\text{CH}_2 & \quad \text{C} \quad \text{Ph} \\
\text{an acid chloride} & \quad \text{Ph} & \quad \text{a 3° alcohol}
\end{align*}
\]

\[
\begin{align*}
\text{R} & \quad \text{C} \quad \text{OR}’ \quad + \quad \text{R}'' & \quad \text{MgX} \quad \rightarrow \quad \text{R} & \quad \text{C} \quad \text{OR}’ \\
\text{ester} & \quad \text{Grignard} & \quad \text{tetrahedral intermediate} & \quad \text{ketone}
\end{align*}
\]
Nitriles

Nitriles also react with Grignard reagent to give the corresponding imine. Under acidic conditions, imines are easily converted to the corresponding ketones (see Chapter 18-16)

Attack on the electrophilic cyano group

\[
\begin{align*}
\text{R'—Mg—X} & \quad \text{protonation} \\
\text{R—C≡N} & \quad \text{H}_3\text{O}^+ \\
\text{salt of imine} & \quad \text{imine} \\
\text{imine} & \quad \text{H}_3\text{O}^+ \\
\text{ketone} & \quad \\
\end{align*}
\]

Example

\[
\begin{align*}
\text{Ph—C≡N} & + \text{CH}_3\text{MgI} \\
\text{benzonitrile} & \quad \text{methylmagnesium iodide} \\
\text{magnesium salt} & \quad \text{acetophenone} \\
\end{align*}
\]

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Summary: Acid Chlorides (21-10)

Acid Chlorides (21-10)

\[ \text{R} - \text{C} - \text{OH} \xrightarrow{\text{SOCl}_2 \text{ or (COCl)}_2} \text{R} - \text{C} - \text{Cl} + \text{SO}_2 \uparrow + \text{HCl} \uparrow \]

- Acid (Section 21-7A)
- Ester (Sections 20-15 and 21-5)
- Amide (Sections 20-15 and 21-5)
- Anhydride (Section 21-5)

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acid chloride (acyl chloride)

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

(1) 2 R'MgX
(2) H₂O

(Sections 10-9 and 21-9)

3° alcohol

R'CuLi

(Section 18-11)
ketone

(1) LiAlH₄
(2) H₂O

(Sections 10-11 and 21-8A)
1° alcohol

Li(t-BuO)₃AlH

(Sections 18-11 and 21-8B)
aldehyde

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Summary: Anhydrides (21-11)

\[
\begin{align*}
\text{acid chloride} & : R-C-Cl + \text{carboxylate (or acid)} & \rightarrow & R-C-O-C-R' + \text{acid anhydride} \\
\text{anhydride} & : R-C-O-C-R & \xrightarrow{H_2O} & R-C-COOH + R-COOH (Section 21-7A) \\
& & \xrightarrow{R'OH} & \text{ester} + R-COOH (Section 21-5) \\
& & \xrightarrow{R'NH_2} & \text{amide} + R-COOH (Section 21-5)
\end{align*}
\]
Summary: Esters (21-12)

\[ R - C - OR' \]

ester

\[ \xrightarrow{H_2O} \]

\[ \xrightarrow{H^+ \text{ or } -OH} \]

\[ R - C - OH \]

acid

\[ + R'OH \]

(Section 21-7B)

\[ R - C - OR'' \]

ester

\[ \xrightarrow{R''OH} \]

\[ \xrightarrow{H^+ \text{ or } -OR''} \]

\[ R - C - NHR'' \]

amide

\[ + R'OH \]

(Section 21-5)

\[ \xrightarrow{(1) LiAlH_4} \]

\[ \xrightarrow{(2) H_2O} \]

\[ R - CH_2OH \]

1° alcohol

\[ + R'OH \]

(Sections 10-11 and 21-8A)

\[ \xrightarrow{(1) 2 R''MgX} \]

\[ \xrightarrow{(2) H_2O} \]

\[ R - C - R'' \]

3° alcohol

\[ + R'OH \]

(Sections 10-9D and 21-9)

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Summary: Amides (21-13)

Amides (21-13)

[Diagram showing reactions of amides and their products]

- **1° amide (R—C—NH₂)**
  - Reaction with H₂O and H⁺ or −OH
  - Reaction with LiAlH₄
  - Reaction with Br₂ and −OH (Hofmann rearrangement)
  - Reaction with POCl₃ (or P₂O₅)

- **Amide (R—C—NHR')**
  - Reaction with H₂O
  - Reaction with LiAlH₄
  - Reaction with Br₂ and −OH (Hofmann rearrangement)

- **Products**
  - R—C—OH (acid)
  - R—CH₂NHR' (amine)
  - R—NH₂ (1° amine)
  - R—C≡N (nitrile)

(Sections 21-7C, 19-19B, 21-8C, 19-21D, 21-13)

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**Summary: Nitriles (21-14)**

![Chemical reactions involving nitriles](image)

- **R—C≡N (nitrile)**
  - H$_2$O, H$^+$ or OH$^-$
  - (1)LiAlH$_4$
  - (2)H$_2$O
  - MgX

- **R—C—NH$_2$ (amide)**
  - H$_2$O, H$^+$ or OH$^-$

- **R—CH$_2$NH$_2$ (amine)**

- **R—C—C—R’ (imine salt)**
  - H$_3$O$^+$

- **R—C—OH (acid)**

- **R—C—O—R’ (ketone)**

(Sections 21-7D, 19-21B, 21-8C, 18-10, 21-9)

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