

Handout: Organic Chemistry Reactions

Reactions Organized by Compound Families

Alkanes

1. Combustion
2. Halogenation

Alkenes and Alkynes

1. Additions: hydrogenation, halogenation, hydrohalogenation, hydration
2. Polymerization

Aromatic Compounds

Substitutions: nitration, halogenation, sulfonation

Alcohols

1. Elimination: dehydration
2. Oxidations

Thiols

Oxidation

Amines

Acid-Base reactions

Aldehydes and Ketones

1. Addition: Acetal/hemiacetal formation by alcohol addition
(Reverse rxn: Acetal hydrolysis with acid)
2. Oxidation and Reduction for aldehydes
(*Ketones go through reduction only)

Carboxylic Acids

1. Substitutions: esterification, amidation
(Reverse rxns: ester hydrolysis with acid or base, amide hydrolysis with acid or base)
2. Acid-base reactions

Phosphoric acid and Phosphates

Phosphoric acid: Esterification with alcohol

Phosphates: Phosphorylation

Reactions Organized by Reaction Type

Family	Reaction	Example
1. ADDITION		
Alkenes and alkynes	Hydrogenation	$\begin{array}{c} \text{H} & & \text{H} \\ & \backslash & / \\ & \text{C}=\text{C} \\ & / & \backslash \\ \text{H} & & \text{H} \end{array} + \text{H}_2 \xrightarrow{\text{Pd catalyst}} \begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{H} \\ & \\ \text{H} & & \text{H} \end{array}$ $\text{H}-\text{C}\equiv\text{C}-\text{H} + 2\text{H}_2 \xrightarrow{\text{Pd catalyst}} \begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{H} \\ & \\ \text{H} & & \text{H} \end{array}$
	Halogenation	$\begin{array}{c} \text{H} & & \text{H} \\ & \backslash & / \\ & \text{C}=\text{C} \\ & / & \backslash \\ \text{H} & & \text{H} \end{array} + \text{Cl}_2 \text{ (or Br}_2) \longrightarrow \begin{array}{c} \text{Cl} & \text{Cl} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{H} \\ & \\ \text{H} & & \text{H} \end{array}$
	Hydro-halogenation	$\begin{array}{c} \text{H} & & \text{H} \\ & \backslash & / \\ & \text{C}=\text{C} \\ & / & \backslash \\ \text{H} & & \text{CH}_3 \end{array} + \text{HCl (or HBr)} \longrightarrow \begin{array}{c} \text{H} & \text{Cl} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{H} \\ & \\ \text{H} & & \text{CH}_3 \end{array}$ <p style="text-align: right;">Markonikov's Rule applies: H adds to C with more Hs already.</p>
	Hydration	$\begin{array}{c} \text{H} & & \text{H} \\ & \backslash & / \\ & \text{C}=\text{C} \\ & / & \backslash \\ \text{H} & & \text{CH}_3 \end{array} + \text{H}_2\text{O} \xrightarrow{\text{H}^+ \text{ catalyst}} \begin{array}{c} \text{H} & \text{OH} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{H} \\ & \\ \text{H} & & \text{CH}_3 \end{array}$ <p style="text-align: right;">Markonikov's Rule applies.</p>
Aldehydes and ketones	Addition of alcohol to get hemiacetals or acetals	$\text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{H(R)} + \text{CH}_3\text{CH}_2\text{OH} \xrightarrow{\text{H}^+ \text{ catalyst}} \begin{array}{c} \text{OH} \\ \\ \text{H}_3\text{C}-\text{C}-\text{H(R)} \\ \\ \text{O}-\text{CH}_2\text{CH}_3 \end{array} + \text{CH}_3\text{CH}_2\text{OH}$ <p style="text-align: center;">hemiacetal</p> $\xrightarrow{\text{H}^+ \text{ catalyst}} \begin{array}{c} \text{O}-\text{CH}_2\text{CH}_3 \\ \\ \text{H}_3\text{C}-\text{C}-\text{H(R)} \\ \\ \text{O}-\text{CH}_2\text{CH}_3 \end{array} + \text{H}_2\text{O}$ <p style="text-align: center;">acetal</p>

2. SUBSTITUTION

Aromatic compounds	Nitration	$\text{C}_6\text{H}_6 + \text{HNO}_3 \xrightarrow{\text{H}_2\text{SO}_4 \text{ catalyst}} \text{C}_6\text{H}_5\text{NO}_2$
	Halogenation	$\text{C}_6\text{H}_6 + \text{Cl}_2 \text{ (or Br}_2) \xrightarrow{\text{FeCl}_3 \text{ (or FeBr}_3) \text{ catalyst}} \text{C}_6\text{H}_5\text{Cl}$
	Sulfonation	$\text{C}_6\text{H}_6 + \text{SO}_3 \xrightarrow{\text{H}_2\text{SO}_4 \text{ catalyst}} \text{C}_6\text{H}_5\text{SO}_3\text{H}$
Carboxylic acids	Esterification with alcohol	$\text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3\text{CH}_2\text{OH} \xrightarrow{\text{H}^+ \text{ catalyst}} \text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OCH}_2\text{CH}_3 + \text{H}_2\text{O}$
	Amidation with amine	$\text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3\text{NH}_2 \xrightarrow{\text{heat}} \text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NHCH}_3 + \text{H}_2\text{O}$
Phosphoric acid and Phosphates	Phosphoric acid: Esterification with alcohol	$\text{HO}-\overset{\text{O}}{\parallel}{\text{P}}(\text{OH})_2 + \text{CH}_3\text{OH} \longrightarrow \text{HO}-\overset{\text{O}}{\parallel}{\text{P}}(\text{OH})(\text{OCH}_3) + \text{H}_2\text{O}$
	Phosphates: Phosphorylation	$\text{Adenosine}-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}^- + \text{ROH} \longrightarrow \text{Adenosine}-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}^- + \text{RO}-\overset{\text{O}}{\parallel}{\text{P}}(\text{O}^-)-\text{O}^- + \text{Energy}$

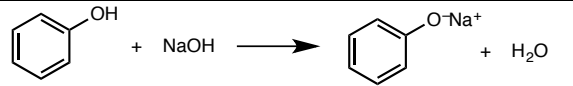
3. ELIMINATION

Alcohols	Dehydration	$\begin{array}{c} \text{H} \quad \text{OH} \\ \quad \\ \text{H}_3\text{C}-\text{C}-\text{C}-\text{CH}_3 \\ \quad \\ \text{H} \quad \text{H} \end{array} \xrightarrow{\text{H}_2\text{SO}_4 \text{ catalyst}} \begin{array}{c} \text{H} \quad \quad \text{CH}_3 \\ \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \quad \diagdown \\ \text{H}_3\text{C} \quad \quad \text{H} \end{array} + \begin{array}{c} \text{H} \\ \\ \text{H}_3\text{C}-\text{C}-\text{C}=\text{CH}_2 \\ \quad \\ \text{H} \quad \text{H} \end{array} + \text{H}_2\text{O}$ <p style="text-align: center;">major minor</p> <p>Zaitsev's Rule applies: More highly substituted alkene is major product.</p>
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4. OXIDATION/REDUCTION

Alcohols	Oxidation	$1^\circ \begin{array}{c} \text{OH} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{H} \end{array} \xrightarrow{[\text{O}]} \begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{H} \end{array} \xrightarrow{[\text{O}]} \begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{OH} \end{array}$ <p style="text-align: center;">aldehyde carboxylic acid</p> $2^\circ \begin{array}{c} \text{OH} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{R} \end{array} \xrightarrow{[\text{O}]} \begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{R} \end{array}$ <p style="text-align: center;">Ketone</p> $3^\circ \begin{array}{c} \text{OH} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{R} \end{array} \xrightarrow{[\text{O}]} \text{No Rxn}$
Thiols	Oxidation	$2 \text{RSH} \xrightarrow{[\text{O}]} \text{R-S-S-R} \quad \left(\text{Reverse rxn: } \text{R-S-S-R} \xrightarrow{[\text{H}]} 2 \text{RSH} \right)$
Aldehydes	Oxidation	$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{H} \end{array} \xrightarrow{[\text{O}]} \begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{OH} \end{array}$ <p style="text-align: center;">aldehyde carboxylic acid</p>
	Reduction (also addition)	$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{H} \end{array} \xrightarrow{[\text{H}]} \begin{array}{c} \text{OH} \\ \\ \text{R}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$
Ketones	Reduction (also addition)	$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{CH}_3 \end{array} \xrightarrow{[\text{H}]} \begin{array}{c} \text{OH} \\ \\ \text{R}-\text{C}-\text{CH}_3 \\ \\ \text{H} \end{array}$

5. ACID-BASE

Amines (Basic)	Rxn with water	$\text{CH}_3\text{CH}_2\text{NH}_2 + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{CH}_2\text{NH}_3^+ + \text{OH}^-$
	Neutralization with strong acid to get ammonium ion or salt	$\begin{array}{l} \text{CH}_3\text{CH}_2\text{NH}_2 + \text{H}_3\text{O}^+ \longrightarrow \text{CH}_3\text{CH}_2\text{NH}_3^+ + \text{H}_2\text{O} \\ \text{CH}_3\text{CH}_2\text{NH}_2 + \text{HCl} \longrightarrow \text{CH}_3\text{CH}_2\text{NH}_3^+ \text{Cl}^- \\ \left(\text{Reverse rxn: ammonium ion or salt} + \text{base} \right) \\ \text{CH}_3\text{CH}_2\text{NH}_3^+ \text{Cl}^- + \text{NaOH} \longrightarrow \text{CH}_3\text{CH}_2\text{NH}_2 + \text{NaCl} + \text{H}_2\text{O} \end{array}$
Carboxylic acids (Acidic)	Rxn with water	$\begin{array}{c} \text{O} \\ \\ \text{H}_3\text{C}-\text{C}-\text{OH} \end{array} + \text{H}_2\text{O} \longrightarrow \begin{array}{c} \text{O} \\ \\ \text{H}_3\text{C}-\text{C}-\text{O}^- \end{array} + \text{H}_3\text{O}^+$
	Neutralization with strong base to get carboxylic acid salt	$\begin{array}{c} \text{O} \\ \\ \text{H}_3\text{C}-\text{C}-\text{OH} \end{array} (\text{aq}) + \text{NaOH} (\text{aq}) \longrightarrow \begin{array}{c} \text{O} \\ \\ \text{H}_3\text{C}-\text{C}-\text{O}^- \end{array} \text{Na}^+(\text{aq}) + \text{H}_2\text{O}$
Phenols (very weakly acidic)	Neutralization with strong base to get salt	

Other Reaction Types

<u>Family</u>	<u>Reaction</u>	<u>Example</u>
RADICAL REACTIONS		
Alkanes	Combustion (Also oxidation/reduction reaction)	$\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \xrightarrow{\text{heat}} \text{CO}_2 + 2\text{H}_2\text{O} + \text{Heat}$
	Halogenation	$\text{CH}_3\text{CH}_2\text{CH}_3 + \text{Cl}_2 \xrightarrow{\text{light or heat}} \text{HCl} + \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{CH}_3\text{CH}(\text{Cl})\text{CH}_3$ $+ \begin{array}{c} \text{Cl} \\ \\ \text{CH}_2\text{CH}_2\text{CH}_2 \\ \\ \text{Cl} \end{array} + \begin{array}{c} \text{Cl} \quad \text{Cl} \\ \quad \\ \text{CH}_2\text{CHCH}_3 \\ \\ \text{Cl} \end{array} + \begin{array}{c} \text{Cl} \\ \\ \text{CH}_3\text{CCH}_3 \\ \\ \text{Cl} \end{array} + \begin{array}{c} \text{Cl} \\ \\ \text{CHCH}_2\text{CH}_3 \\ \\ \text{Cl} \end{array}$ <p style="text-align: center;">Mixed products</p>
Alkenes	Polymerization	$\text{CH}_3\text{CH}=\text{CH}_2 \xrightarrow{\text{initiator}} \left(\begin{array}{c} \text{CH}_3 \\ \\ \text{---C---} \\ \\ \text{H} \end{array} \text{---} \begin{array}{c} \text{H}_2 \\ \\ \text{---C---} \\ \\ \text{H} \end{array} \right)_n$
HYDROLYSIS		
Esters (Reverse rxns of carboxylic acid esterification)	Acid hydrolysis to get carboxylic acid and alcohol	$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_3 + \text{H}_2\text{O} \xrightarrow{\text{H}^+ \text{ catalyst}} \text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3\text{OH}$
	Saponification: Base hydrolysis to get carboxylic acid salt and alcohol	$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_3 + \text{NaOH (aq)} \xrightarrow{\text{H}_2\text{O}} \text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}^-\text{Na}^+ + \text{CH}_3\text{OH}$
Amides (Reverse rxns of carboxylic acid amidation)	Acid hydrolysis to get amine	$\text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{N}(\text{H})-\text{CH}_3 + \text{H}_2\text{O} \xrightarrow{\text{H}^+ \text{ catalyst}} \text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3\text{NH}_2$
	Base hydrolysis to get amine	$\text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{N}(\text{H})-\text{CH}_3 + \text{NaOH (aq)} \xrightarrow{\text{H}_2\text{O}} \text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3\text{NH}_2$
Acetals (Reverse reaction of acetal formation from aldehydes/ketones)	Acid hydrolysis to get aldehydes or ketones (reverse of acetal formation)	$\text{H}_3\text{C}-\overset{\text{H}}{\underset{\text{O}-\text{CH}_2\text{CH}_3}{\text{C}}}-\text{O}-\text{CH}_2\text{CH}_3 + \text{H}_2\text{O} \xrightarrow{\text{H}^+ \text{ catalyst}} \text{H}_3\text{C}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + 2 \text{CH}_3\text{CH}_2\text{OH}$

*Note that organic chemistry reactions can be classified in several different ways.