Summary of Alcohol Syntheses, Ch. 17 (and Review of Old Ones).

1. \( R-\text{OH} \xrightarrow{\text{Na}} R-\text{ONa} \)
   - Potassium (K) analogous.
   - Key way to convert alcohol to alkoxide, reactive as S_N2 nucleophile and E2 base.
   - 17.3
   - Alkoxide formation-S_N2 route to ether
   - The electrophile \( R'-X \) must be S_N2 reactive, preferably 1º with a good leaving group
   - 17.3

2. \( R-\text{OH} \xrightarrow{1. \text{Na}} R-O-\text{R}' \xrightarrow{2. \text{R'}-X} \)
   - Li is analogous for making RLi, which also act analogously.
   - MgBr is spectator: \( R \ominus \) is key.
   - 10.8

3. \( R-\text{Br} \xrightarrow{\text{Mg}} \text{RMgBr} \)
   - Formaldehyde
   - Aldehyde
   - Ketone
   - Ester (or carbonyl chloride)
   - Ethylene oxide
   - Mech?
   - All three R groups can be different.
   - At least 2 R groups must be the same

Mech: 1 carbon chain extension
Review Routes to Alcohols

9. $\text{R}^\text{O}H$ aldehyde, $\text{NaBH}_4$ or $\text{LiAlH}_4$ produces $\text{R}^\text{H}OH$ 1° alcohol

10. $\text{R}^\text{O}\text{R}''$ ketone, $\text{NaBH}_4$ or $\text{LiAlH}_4$ produces $\text{R}^\text{H}\text{R}''$ 2° alcohol

11. $\text{R}^\text{O}\text{R}$ ester, $\text{LiAlH}_4$ produces $\text{R}^\text{H}OH$ 1° alcohol

12. $\text{R}^\text{O}\text{R}$ ester, $\text{BH}_3$-THF produces $\text{R}^\text{H}OH$ anti-Markovnikov

13. $\text{R}-\text{X}$, $\text{NaOH}$ produces $\text{R}^\text{OH}$ $\text{S}_{\text{N}}2$ mech, needs 1° or 2° system and an excellent leaving group

$\text{NaBH}_4$ will not react with esters
Summary of Mechanisms, Ch. 17

For Test:

1. $R^\Theta$  
   $\text{R} \quad \text{R'}$  
   $\text{O}$  
   $\text{OH}$  
   $\text{Z}$  
   $\text{R} \quad \text{R'}$  
   aldehyde or ketone or formaldehyde  
   $\text{Z}^\Theta$ may be $R^\Theta$ (RMgBr) or $H^\Theta$ (NaBH₄ or LiAlH₄)

   mech:

   $\text{R} \quad \text{O}$  
   $\text{R'}$  
   $\text{O}$  
   $\text{OH}$  
   $\text{Z}$  
   $\text{R} \quad \text{R'}$  
   $\text{O}$  
   $\text{Z}$  
   $\text{OH}$  

2. $\text{R} \quad \text{O}$  
   $\text{O}$  
   $\text{R'}$  
   esters or acid chlorides  
   $\text{Z}^\Theta$ may be $R^\Theta$ (RMgBr) or $H^\Theta$ (LiAlH₄)

   mech:

   $\text{Cl}$  
   $\text{OH}$  
   $\text{Z}$  
   $\text{OH}$  
   $\text{Z}$  

3. $\text{Z}$  
   $\text{R}$  
   $\text{OH}$  
   $\text{R}$  
   $\text{OH}$  
   $\text{H}_3\text{O}^\Theta$  
   $\text{OH}$  
   $\text{Z}$  
   $\text{OH}$  

   mech:
17.1 Intro, Classification

**“Alcohol”**: OH attached to a saturated, sp³, “alkyl” carbon

1º, 2º, 3º **Alcohols**: based on whether the carbon with the OH is 1º, 2º, or 3º

```
1º    2º    3º
CH3-OH  CH2-OH  CH-OH
```

**“Phenol”**: OH attached to an aromatic
-Note: phenol, not phenyl

```
\[\text{phenol}\]
```

**“Enol” or “vinyl alcohol”**: OH attached to an alkene

```
\[\text{enol or vinyl alcohol}\]
```

Problem: Classify each of the following either as a phenol, as a carboxylic acid, or as a 1º, 2º, 3º, or vinyl alcohol:

```
\[\text{OH}
\]
```

**Nomenclature**

A. IUPAC, when alcohol is priority functional group and is part of the core name: x-alkanol
- Choose longest carbon chain **that has the OH attached**
- Remember to number!
- The oxygen itself does **not** count as a number

```
\[\text{OH}
\]
```

B. Cycloalkanols: The OH-carbon is automatically Number 1

```
\[\text{OH}
\]
C. **x-Alken-z-ol.** When an alkene is in the main carbon chain, you need two number descriptors, one for the alkene, the second for the alcohol.
   - The OH still dictates the numbering
   - The OH number gets moved right before the “ol”
   - The alkene number goes in front, in front of the “alken” portion
   - Note: you only put the OH number right in front of the “ol” when you have an alkenol (or alkynol)

![OH](image)

D. **Diols:** x,y-alkane**diol**

![OH](image)

E. Functional Group Priority: \( \text{CO}_2\text{H} > \text{C}=\text{O} > \text{OH} > \text{amine} > \text{alkene} > \text{halide} \)
   - When you have more than one functional group, the higher priority dictates the numbering
   - **The higher priority is used in the “core name”**
   - **The lower priority group may be forced to be named as a substituent**

F. **OH as a Substituent:** “**Hydroxy**”

![OH](image)

G. **Common Names:** Alkyl alcohol

CH\(_3\)OH

![OH](image)

H. **Substituted Phenols**
   - **IUPAC:** use numbers, with OH carbon #1
   - **Common:**
     - **Ortho:** 2-position, adjacent
     - **Meta:** 3-position, two carbons away
     - **Para:** 4 position
   - **Skill:** be able to use or recognize either system

![OH](image)

IUPAC:

**Common:**
17.2 Physical Properties: Dominated by H-Bonding

BP: Match the boiling point for the following structures: 35º, 137º, 187º

Water solubility: water solubility decreases as hydrophobic R gets longer
- In general,
  - R ≤ 4 carbons, ROH substantially water soluble
  - R ≥ 5 carbons, ROH minimal water solubility

Commercially Important Alcohols
- Toxic: All alcohols are “toxic” if swallowed in sufficient quantities

<table>
<thead>
<tr>
<th>CH₃OH</th>
<th>( \text{OH} )</th>
<th>( \text{OH} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap</td>
<td>200 mL (7 oz) ( \rightarrow ) death</td>
<td>Rubbing alcohol</td>
</tr>
<tr>
<td>Solvent</td>
<td>Least toxic alcohol</td>
<td>100 mL ( \rightarrow ) death</td>
</tr>
<tr>
<td>Fuel</td>
<td>Alcoholic beverages</td>
<td>Kills germs on skin, but not absorbed</td>
</tr>
<tr>
<td>100 mL ( \rightarrow ) death</td>
<td>Fermentation</td>
<td></td>
</tr>
<tr>
<td>15 mL ( \rightarrow ) blindness</td>
<td>Solvent</td>
<td></td>
</tr>
</tbody>
</table>

11.3 Acidity of Alcohols and Phenols
A. Alcohols are weak acids \( \rightarrow \) can be ionized by stronger bases

\[
\text{ROH} + \text{B}^- \rightarrow \text{RO}^- + \text{BH}
\]
- goes to the right (alkoxide) only if RO\(^-\) is more stable than B\(^-\)
- ex. \( \text{NH}_2, \text{CH}_3 \)
- ex. If a less stable oxygen anion can convert to a more stable oxygen anion
B. Acidity Table

<table>
<thead>
<tr>
<th>Class</th>
<th>Structure</th>
<th>Ka</th>
<th>Acid Strength</th>
<th>Anion</th>
<th>Base Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Acids</td>
<td>H-Cl</td>
<td>$10^2$</td>
<td></td>
<td>Cl⁻</td>
<td></td>
</tr>
<tr>
<td>Carboxylic Acid</td>
<td>R-(\text{CO}_2\text{H})</td>
<td>$10^{-5}$</td>
<td></td>
<td>R-(\text{CO}_2\text{H}^\text{-})</td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td>(\text{C}_6\text{H}_5\text{OH})</td>
<td>$10^{-10}$</td>
<td></td>
<td>(\text{C}_6\text{H}_5\text{O}^-)</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>$10^{-16}$</td>
<td></td>
<td>HO⁻</td>
<td></td>
</tr>
<tr>
<td>Alcohol</td>
<td>ROH</td>
<td>$10^{-18}$</td>
<td></td>
<td>RO⁻</td>
<td></td>
</tr>
<tr>
<td>Amine (N-H)</td>
<td>RNH₂</td>
<td>$10^{-33}$</td>
<td></td>
<td>RNH⁻</td>
<td></td>
</tr>
<tr>
<td>Alkane (C-H)</td>
<td>RCH₃</td>
<td>$10^{-50}$</td>
<td></td>
<td>RCH₂⁻</td>
<td></td>
</tr>
</tbody>
</table>

Notes/skills:
1. Be able to rank acidity.
2. Memorize/understand neutral OH acidity ranking: \(\text{RCO}_2\text{H} > \text{H}_2\text{O} > \text{ROH}\)
   • Reason: resonance stabilization of the anion
3. Predict deprotonation (acid/base) reactions
   • Any weak acid will be deprotonated by a stronger base (lower on table)
   • Any weak acid will not be deprotonated by a weaker base (higher on table)
4. Predict ether/water extraction problems
   • If an organic chemical is neutral and stays neutral, it will stay in ether layer
   • If an organic chemical is ionized (by an acid-base reaction), it will extract into the aqueous layer

Problems
1. Draw arrow to show whether equilibrium favors products or reactants. (Why?)

\[ \text{OH}^- + \text{H}-\text{C} \rightarrow \text{H}_2\text{O} + \text{H}-\text{C}^- \]

2. Which of the following will deprotonate methanol?

H₂O \quad \text{CH}_3\text{CO}_2\text{Na} \quad \text{PhONa} \quad \text{NaOH} \quad \text{NaNH}_2 \quad \text{CH}_3\text{MgBr}

An acid (left side) will only be deprotonated by an anion/base that is lower on the right side.
3. When the following are dissolved in ether and then treated with NaOH/water, which would extract out of the ether layer into the water layer?

![Chemical structures]

**Formation of Sodium, Potassium Alkoxides: 2-Step Conversion of Alcohols into Ethers via the Alkoxides**

<table>
<thead>
<tr>
<th>Step</th>
<th>Reaction</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>R-OH Na → R-ONa</td>
<td>Potassium (K) analogous. Key way to convert alcohol to alkoxide, reactive as S_N2 nucleophile and E2 base.</td>
</tr>
<tr>
<td>2.</td>
<td>R-OH → 1. Na → R-O-R' 2. R'-X</td>
<td>Alkoxide formation-S_N2 route to ether. The electrophile R'-X must be S_N2 reactive, preferably 1º with a good leaving group.</td>
</tr>
</tbody>
</table>

Reaction 1: Key source of nucleophilic/basic alkoxides

![Chemical structures]

17.3 Synthesis of Alcohols: Review: See p. 2, from Alkyl Halides (S_N2) and Alkenes
10.7 Organometallics: \( \text{RM} (M = \text{Metal}) = R \ominus M^+ \)

3. \[ \begin{align*} R-\text{Br} \rightarrow & \quad \text{Mg} \quad \text{RMgBr} \\
\text{“Grignard Reagent”} \end{align*} \]

- MgBr is spectator: \( R \ominus \) is key.

- Li is analogous for making RLi, which also act analogously.

1. We will focus on the magnesium reagents RMgBr
2. RMgBr = “Grignard Reagents” (Victor Grignard)
3. Key: This is the way to make \( R \ominus \), strong nucleophiles/bases
4. RMgBr are formed via redox reaction.
   - Mg gives up two electrons, is oxidized
   - Bromine is reduced to bromide anion
   - Carbon is reduced to carbanion

\[
\begin{align*}
R^-\text{Br} + \text{Mg} & \rightarrow R^- + \text{Br}^- + \text{Mg}^+ \\
\text{Not for Test}
\end{align*}
\]

5. The formation of Grignard Reagents is completely general for all R-Halides:
   - 3º, 2º, and 1º alkyl halides all work well
   - Aryl and Vinyl halides as well as alkyl halides work well
   - RCl, RBr, and RI all work well
   - For class, we will normally use bromides, due to synthetic accessibility

6. **View as carbanions: RMgBr = R \ominus Super Strong Bases and Nucleophiles**
   - The counterion metal is a spectator
   - Stability-reactivity principle: very unstable \( \rightarrow \) very reactive
   - This great reactivity is very useful (as nucleophile)
   - This great reactivity (as base) has implication for proper technical use (see following)

7. Solvent and handling: Grignard reactants RMgBr must be made, stored, and handled in special solvents under special conditions:
   - No water allowed
     - \( R^- \ominus + \text{H}_2\text{O} \rightarrow \text{R-H} + \text{HO}^- \) Destroys carbanion
   - No alcohol or amines or acids allowed either, or carbanion will just deprotonate them too
   - If any chemicals with carbonyls are present, they too will react with the carbanion by nucleophile/electrophile reaction

\[
\begin{align*}
R^- \ominus + \text{O} \rightarrow \text{O}^- \ominus R
\end{align*}
\]
   - Grignards and other organometallics are made in either alkane or ether solvents.
   - These don’t have any acidic hydrogens that protonate carbanions.
   - These don’t have any carbonyls that react with carbanions

8. Two perspectives for dealing with organometallics in general and RMgBr in particular
   - Mechanistic Thinking: \( R^- \)
   - Predict-the-product thinking: R-MgBr: easier to see source and substitution product.
17.5 Addition of RMgBr to Carbonyl Compounds: Alcohols are Produced

Exothermic Addition of Carbon or Hydrogen Anions:
- $\sigma$ bond (made) stronger than $\pi$ bond (broken)
- oxygen anion more stable than carbanion

Carbonyl is strongly electrophile
- much stronger even than a 1º alkyl iodide!
  1. Breakable $\pi$ bond
  2. Carbonyl polarity

Additions of Grignard Reagents to Carbonyl Compounds

From Carbonyl’s Perspective

<table>
<thead>
<tr>
<th>Reaction</th>
<th>From Carbonyl’s Perspective</th>
<th>From Grignard’s Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Formaldehyde</td>
<td>R'MgBr + H₂O⁺ → R'OH</td>
</tr>
<tr>
<td>5</td>
<td>Aldehyde</td>
<td>R'MgBr + H₂O⁺ → R'OH</td>
</tr>
<tr>
<td>6</td>
<td>Ketone</td>
<td>R'MgBr + H₂O⁺ → R'OH</td>
</tr>
<tr>
<td>7</td>
<td>Ester (or carbonyl chloride)</td>
<td>R'MgBr + H₂O⁺ → R'OH</td>
</tr>
</tbody>
</table>

Mech

Pattern:
1. After reaction, the original carbonyl carbon will have one and only one C-O single bond
2. For formaldehyde, aldehydes, and ketones, one R group adds (reactions 4-6)
3. For esters or carbonyl chlorides (“acid chlorides”), two R groups add
   - Replace not only the carbonyl p-bond, but also the “extra” C-O or C-Cl single bond
4. Product output:
   - Formaldehyde (2 H’s) $\rightarrow$ 1º alcohol
   - Aldehyde (1 H) $\rightarrow$ 2º alcohol
   - Ketone (0 H) $\rightarrow$ 3º alcohol. No need for all 3 attachments to be the same.
   - Ester (0 H) $\rightarrow$ 3º alcohol. At least two common attachments at end.
Predicting Grignard Reaction Products

1. From carbonyl perspective:
   - The carbanion R’ adds to the carbonyl carbon
   - The carbonyl =O gets replaced by –OH
   - For formaldehyde, aldehydes, and ketones: the two attachments on the original carbonyl carbon remain attached as spectators
   - For esters or acid chlorides: the one non-heteroatom attachment on the original carbonyl carbon remain attached as spectators.
     o The “extra” heteroatom gets replaced by a second carbanion R’

2. From Grignard perspective:
   - Where R-MgBr begins, R-C-OH ends.
     o In other words, the MgBr gets replaced by the carbonyl carbon

Note: Be sure that in the product, no carbon has more than one C-O bond

Draw products from the following reactions.

1. $\text{PhMgBr} \rightarrow \text{H}_3\text{O}^+$

2. $\text{MgBr} \rightarrow \text{H}_3\text{O}^+$

3. $\text{MgBr} \rightarrow \text{H}_3\text{O}^+$

4. $\text{excess CH}_3\text{MgBr} \rightarrow \text{H}_3\text{O}^+$

5. $\text{Mg} \rightarrow \text{PhCH}_3 \rightarrow \text{H}_3\text{O}^+$

6. $\text{Mg} \rightarrow \text{H}_2\text{C}=\text{O} \rightarrow \text{H}_3\text{O}^+$
18.6 Grignard Reaction with Ethylene Oxide (Simplest Epoxide)

Notes

1. Results in a 1º Alcohol
2. Predicting product: Two carbons end up in between the carbanion R’ and the OH
3. Ethylene oxide and formaldehyde are complementary Grignard acceptors leading to 1º alcohols
   - Ethylene oxide extends the carbon chain by two (relative to the original RMgBr)
   - Formaldehyde extends the carbon chain by one (relative to the original RMgBr)
4. 2-Carbon ethylene oxide and 2-carbon ethanal give different products
   - Ethylene oxide $\rightarrow$ the OH is 1º and the OH is two carbons removed from the carbanion R
   - Ethanal $\rightarrow$ the OH is 2º and the OH and carbanion R are both connected to the same carbon

Draw products from the following reactions.
Reaction Mechanisms for Grignard Reactions

Formaldehyde, Aldehyde, or Ketone as Carbonyl Compound (Reactions 4, 5, and 6)

1. Two simple steps:
   a. **Addition**
   b. **Protonation**

2. Timing:
   a. The carbanion is added first, at one step in time, under strongly anionic conditions
   b. Later acid is added, in a second laboratory step. This provides a cationic environment

3. $RMgBr = R^{-}MgBr = R^{-}$ carbanion
   a. The $MgBr$ stuff is spectator, doesn’t need to be drawn in
   b. Ignore in mechanisms
   c. In reality, it actually does play a nontrivial role, but we’ll save that for grad school!

Draw mechanisms for the following reactions:

1. $\text{O}$
   1. $\text{PhMgBr}$
   2. $H_3O^+$

2. $\text{O}$
   1. $\text{MgBr}$
   2. $H_3O^+$
Esters or Acid Chlorides: More Complex, Needs to Explain Two Additions and More Bond Breakings

1. Four Step Mechanism:
   a. **Addition**
   b. **Elimination**
   c. **Addition**
   d. **Protonation**

2. Timing:
   a. The carbanion is added first, at one point in time, under strongly anionic conditions
      o The first three steps all occur under these anionic conditions
   b. Acid is only added much later, in a second laboratory step. This gives a cationic environment.
   c. Why don’t you just protonate after the first step?
      o There is no proton source available, and the elimination proceeds instead!

3. What if I add only one RMgBr?

Why? Kinetics and Reactivity. **MEMORIZE.**

- Large differences in reactivity, with ketone > ester
- Elimination step 2 is also very fast
- Thus, under the anionic conditions, the addition is the slow step
  o After it does happen, elimination and another addition happens bang-bang.
Draw Mechanism:

\[
\begin{align*}
\text{O} & \quad 1. \text{PhMgBr (excess)} \quad \text{OH} \\
\text{OCH}_3 & \quad 2. \text{H}_3\text{O}^+ \\
\text{Ph} & \\
\end{align*}
\]

**Cyclic Ester**: The O-Carbonyl single bond breaks, but the other C-O single bond does **not** break -the result is formation of a dialcohol

Draw product and mechanism for the following:

\[
\begin{align*}
\text{O} & \quad 1. \text{PhMgBr (excess)} \\
\text{Cyclic Ester} & \quad 2. \text{H}_3\text{O}^+ \\
\end{align*}
\]

**Ethylene Oxide Mechanism**

\[
\begin{align*}
\text{O} & \quad 1. \text{R}^- \\
\text{1. R}^- & \quad 2. \text{H}_3\text{O}^+ \\
\text{R} & \quad \text{OH} \\
\end{align*}
\]

Draw product and mechanism for the following:

\[
\begin{align*}
\text{MgBr} & \quad 1. \text{O} \quad \text{R}^- \\
\text{2. H}_3\text{O}^+ & \\
\end{align*}
\]
More Grignard Practice. Including polyfunctional Molecules: (Know relative reactivity)

1. \[ \begin{align*} &\text{H}_3\text{CO} \quad \text{PhMgBr (excess)} \\
&\text{1. } \text{H}_3\text{O}^+ \end{align*} \]

2. \[ \begin{align*} &\text{H}_3\text{CO} \quad \text{PhMgBr (1.0 equivalent)} \\
&\text{1. } \text{H}_3\text{O}^+ \end{align*} \]

3. \[ \begin{align*} &\text{H}_3\text{CO} \quad \text{PhMgBr (1.0 equivalent)} \\
&\text{1. } \text{H}_3\text{O}^+ \end{align*} \]

4. \[ \begin{align*} &\text{PhH} \\
&\text{1. MgBr} \\
&\text{2. } \text{H}_3\text{O}^+ \end{align*} \]

5. \[ \begin{align*} &\text{BrMg} \\
&\text{1. } \text{H}_3\text{O}^+ \end{align*} \]

6. \[ \begin{align*} &\text{Br} \\
&\text{1. Mg} \\
&\text{2. } \text{H}_2\text{C}=\text{O} \\
&\text{3. } \text{H}_3\text{O} \end{align*} \]

7. \[ \begin{align*} &\text{O} \\
&\text{1. CH}_3\text{MgBr (excess)} \\
&\text{2. } \text{H}_3\text{O}^+ \end{align*} \]

8. \[ \begin{align*} &\text{BrMg} \\
&\text{1. } \text{H}_3\text{O}^+ \end{align*} \]
Grignards in Synthesis: Provide Precursors.

- **Think backwards from Targets to Reactants.**
- Identify possible Grignards and Grignard acceptors
- **Pattern:**
  - 3º alcohol, all three attachments different ← Ketone Precursor
  - 3º alcohol, two (or more) of the attachments identical ← Ester
  - 2º alcohol ← Aldehyde
  - 1º alcohol ← Formaldehyde or ethylene oxide

```
                OH
       Ph

   a.

                OH
       Ph

   b.

                OH
       H

   c.

                OH
       Ph

   d.
```
Provide Reagents for the Following Transformations. You may use whatever reagents, including ketones or aldehydes or Grignards or esters, that you need.

- Key: Try to identify key C-C connection in the product that wasn’t present to start with
- Try to identify the where the reactant carbons are in the final product
- Numbering your carbon chains is very helpful.
- Usually best to work backwards from the product

a. \( \text{Ph} \text{Br} \rightarrow \text{Ph} \text{OH} \) 2 steps plus H\(_2\)O\(^+\) workup

b. \( \text{H}_3\text{O}^+ \text{workup} \)

c. \( \text{H}_3\text{O}^+ \text{workup} \)

d. \( \text{OH} \)

e. \( \text{OH} \)
Combining Grignard Reactions with Other Reactions

1. PhMgBr
2. H₃O⁺
3. H₂SO₄, heat

b. 1. Mg
2. PhBr
3. H₃O⁺
4. H₂SO₄
5. BH₃-THF
6. NaOH-H₂O₂

Restrictions on Grignard Reactions

- RMgBr = R⁻ carbanion, highly unstable, highly reactive.
- Unstable in the presence of:
  1. OH’s (get proton transfer reaction)
  2. Carbonyls (get Grignard-type nucleophilic addition)

1. Solvent limitations. RMgBr cannot be formed and used in the presence of
   - H₂O
   - ROH
   - Any solvent with a C=O

   Which Solvents (if any) Would be OK for Handling RMgBr?,

2. Substrate limitations. Any organohalide that also contains an OH or C=O bond can’t be converted into a useful RMgBr, because it will self-destruct.

   Which substrates could be converted into RMgBr, and subsequently reacted with CH₃CHO?

3. Atmosphere/Glassware/Storage limitations. Make, store, and use in:
   - water-free dried glassware
   - moisture-free atmosphere. (Dried air, or else under nitrogen or argon atmosphere)
   - When stored for extended periods, must have very good seals so that no air can leak in.
17.4 Alcohols by Reduction of Carbonyls: $\text{H}^\ominus$ Addition

**Mechanism**

**Aldehydes and Ketones**

Aldehyde or ketone or formaldehyde

$$\text{RCHO} + \text{NaBH}_4 \rightarrow \text{RCHOH}$$

Addition

$$\text{RCHO} + \text{LiAlH}_4 \rightarrow \text{RCHOH}$$

Elimination

$$\text{RCHO} + \text{H}_2\text{O} \rightarrow \text{RCHOH}$$

1° alcohol

**Esters**

$$\text{RCOOR''} + \text{NaBH}_4 \rightarrow \text{RCOOR''H}$$

Addition

$$\text{RCOOR''} + \text{LiAlH}_4 \rightarrow \text{RCOOR''H}$$

Elimination

$$\text{RCOOR''} + \text{H}_2\text{O} \rightarrow \text{RCOOR''H}$$

2° alcohol

**Cyclic Esters**

$$\text{Cyclic Esters}$$

Addition

$$\text{Cyclic Esters}$$

Elimination

$$\text{Cyclic Esters}$$

Double Protonation
Notes:
• Mechanisms are exactly like with Grignard reactions
• LiAlH₄ and NaBH₄ function as hydride anions H⁻
• For mechanisms, just draw H⁻ rather than trying to involve the Li and Al and Na and B...

\[
\begin{align*}
\text{NaBH}_4 &= \text{Na}^+ \text{H}^- \text{B}^- \text{H}^- \\
\text{LiAlH}_4 &= \text{Li}^+ \text{H}^- \text{Al}^- \text{H}^-
\end{align*}
\]

• Boron is one row higher than aluminum, and in keeping with normal periodic patterns is more electronegative
  o Because boron is more electronegative, the BH₄⁻ anion is more stable, and less reactive.
    ▪ The boron holds the H⁻ more tightly.
  o Aluminum being less electronegative doesn’t attract and hold the H⁻ as well, and thus is considerably more reactive.

Reactivity

<table>
<thead>
<tr>
<th></th>
<th>Aldehydes</th>
<th>Ketones</th>
<th>Esters</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiAlH₄</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>NaBH₄</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**LiAlH₄ is much stronger, NaBH₄ much weaker**
1. LiAlH₄ is strong enough to react with esters, NaBH₄ isn’t
2. **Selective reduction**: if both an ester and an aldehyde/ketone are present:
   • LiAlH₄ reduces both
   • NaBH₄ selectively reduces the aldehyde/ketone but leaves the ester untouched
3. **LiAlH₄ is strong enough to react with and be destroyed by water or alcohol; NaBH₄ isn’t**
   
   \[\text{LiAlH}_4 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{(gas)} + \text{LiOH} + \text{AlH}_3 + \text{heat}\]
   a. As a result, LiAlH₄ is harder to use and store
   b. Acid has to be added in a subsequent step with the LiAlH₄; (thus, 2-step recipe)
   c. NaBH₄ can be run in alcohol solvent which serves as a proton source for protonating alkoxide
   d. Solvent restrictions, glassware must be dry, wet air must be excluded, etc.
   e. Because NaBH₄ is stable to water, it’s easier to handle in air, easier to store, much easier to work with
   f. **Default**: for a simple aldehyde or ketone reduction, normally use NaBH₄ because it’s so much easier
4. LiAlH₄ is strong enough to react with esters, NaBH₄ isn’t
Draw the products for the following reactions.

1. \[
\begin{align*}
\text{O} & \quad \text{O} \\
\text{CH}_3 & \quad \text{OCH}_3
\end{align*}
\]

1. LiAlH\(_4\)
2. H\(_3\)O\(^+\)

2. \[
\text{O} \quad \text{O}
\]

\[
\text{H}_3\text{O}^+ \quad \text{H}_2\text{O}
\]

3. \[
\text{O}
\]

1. LiAlH\(_4\)
2. H\(_3\)O\(^+\)

4. \[
\begin{align*}
\text{C}_6\text{H}_5\text{O}_2
\end{align*}
\]

1. LiAlH\(_4\)
2. H\(_3\)O\(^+\)

or \[
\begin{align*}
\text{NaBH}_4 \\
\text{H}_2\text{O}
\end{align*}
\]

5. \[
\begin{align*}
\text{Ph} & \\
\text{OH}
\end{align*}
\]

Draw the mechanism for the following reaction.

6. \[
\begin{align*}
\text{Ph} & \\
\text{O} & \quad \text{H}
\end{align*}
\]

\[
\text{NaBH}_4 \quad \text{CH}_3\text{OH}
\]

\[
\begin{align*}
\text{Ph} & \\
\text{OH}
\end{align*}
\]

7. \[
\text{O} \\
\text{O}
\]

1. LiAlH\(_4\)
2. H\(_3\)O
Summary of Alcohol Reactions, Ch. 17.

1. Deprotonation by a base.
2. Controlled by relative stability of RO⁻ versus Z⁻.
3. Consider relative electronegativity and whether either anion is resonance stabilized.

- Potassium (K) analogous.
- Key way to convert alcohol to alkoxide, reactive as S_N2 nucleophile and E2 base.

- Alkoxide formation-S_N2 route to ether
- The electrophile R'-X must be S_N2 reactive, preferably 1º with a good leaving group

- Key access to aldehydes, which are useful for more Grignard chemistry.
- Note difference between PCC and H_2CrO_4
- PCC does not react with 2º alcohols very rapidly

- Key access to ketones.
- PCC does not react very fast with 2º alcohols

- Note difference between
- PCC and H_2CrO_4 when reacting with 1º alcohols.

- HI, HCl analogous
- Converts alcohol into a bromide that can be used in Grignards, E2 reactions
- Cation mechanism
- Usually not method of choice for 1º, 2º alcohols
9. \[ \text{R-OH} \xrightarrow{\text{PBr}_3} \text{R-Br} \]
   1° or 2° alcohols

10. \[ \text{R-OH} \]
    1. \[ \xrightarrow{\text{PBr}_3 \text{ or HBr}} \text{R-MgBr} \]
    2. \[ \xrightarrow{\text{Mg}} \text{R-MgBr} \]

12. \[ \text{R-OH} \xrightarrow{\text{SOCI}_2} \text{R-Cl} \]
   1° or 2° alcohols

13. \[ \text{R-OH} \xrightarrow{\text{TsCl, NEt}_3} \text{R-OTs} \]

14. \[ \text{R} \xrightarrow{\text{HBr}} \text{Br} \]

15. \[ \text{R} \xrightarrow{\text{HBr, peroxides}} \text{R-BR} \]

16. \[ \text{R-H} \xrightarrow{\text{Br}_2, hv} \text{R-Br} \]

17. \[ \text{OH} \xrightarrow{\text{H}_2\text{SO}_4, \text{heat}} \text{R} \text{R} \]

- Converts alcohol into a bromide that can be used in Grignards, E2, S_N2 reactions
- Inversion of stereochem
- Not good for 3° alcohols

- Quick 2-step conversion of alcohol into a nucleophilic Grignard

- Retention of stereo!

- Tosylates are super leaving groups, better even than iodides.
- Tosylates are well suited to S_N2 and E2 reactions.

- Markovnikov addition

- anti-Markovnikov addition

- Radical mechanism, 3° > 2° > 1°

- Zaytsev elimination
Mechanisms for ROH $\rightarrow$ RBr Reactions

R-OH $\xrightarrow{\text{HBr}}$ R-Br

3° mostly, sometimes 1°

HBr Mech for 3° ROH:

\[
\begin{align*}
\text{R-Br} & \quad \xrightarrows{\text{H-Br}} \quad \text{R-OH} \quad \xrightarrows{\text{H-Br}} \quad \text{R-Br} \\
& \quad + \text{Br}^{-} \quad + \text{H}_2\text{O}
\end{align*}
\]

HBr Mech for 1° ROH:

\[
\begin{align*}
\text{R-Br} & \quad \xrightarrows{\text{H-Br}} \quad \text{R-OH} \quad \xrightarrows{\text{H-Br}} \quad \text{R-Br} \quad + \text{H}_2\text{O}
\end{align*}
\]

R-OH $\xrightarrow{\text{PBr}_3}$ R-Br

1°, 2°

Mech:

\[
\begin{align*}
\text{R-Br} & \quad \xrightarrows{\text{Br-PBr}_2} \quad \text{R-OH-PBr}_2 \quad \xrightarrows{\text{Br}} \quad \text{Br-R} \quad + \text{HO-PBr}_2
\end{align*}
\]
Ch. 17.6-8 Reactions of Alcohols

A. Conversion to Alkoxides (Sections 17.2)

“alkoxide” = RO⁻ anion

1. By acid-base deprotonation
   - A rather reactive anion base is required that is *less* stable than an alkoxide anion
   - Carbanions (RMgBr) or nitrogen anions can do this
   - NaOH can’t
2. By redox reaction with sodium or potassium (or some other metals)

|   | 2. Controlled by relative stability of | 2. Controlled by relative stability of  
|   | R–ONa + Hz RO⁻ versus Z⁻. | RO⁻ versus Z⁻.  
|   | Acid-Base 3. Consider relative electronegativity and | 3. Consider relative electronegativity and  
|   | whether either anion is resonance stabilized. | whether either anion is resonance stabilized.  

|   | R–OH + Na 1. Na 2. R′-X | Potassium (K) analogous.  
|   | R–ONa  3. Alkoxide formation-S_N2 route to ether | Key way to convert alcohol to  
|   | 1. Na 4. R−O−R′ | alkoxide, reactive as S_N2 nucleophile  
|   | 2. R′-X | and E2 base.  

B. Conversion to Ethers via Alkoxide

|   | R–OH 1. Na R−O−R′ 2. R′-X | Alkoxide formation-S_N2 route to ether  
|   | R–ONa | The electrophile R′-X must be S_N2  
|   | 1. Na 2. Br | reactive, preferably 1° with a good  
|   | PhOH 2. | leaving group  

C. Oxidation of Alcohols to Carbonyl Compounds (17.7)

Summary: 2 Oxidants

1. **PCC = mild** 1° alcohols → aldehydes
   - **“Pyridinium chlorochromate”:** soluble in water-free dichloromethane
   - Mild, selective for 1° over 2° alcohols, and when 1° alcohols are used stops at aldehyde
2. **H₂CrO₄ = strong**
   a. 2° alcohols → ketones
   b. 1° alcohols → carboxylic acids
   c. 3° alcohols → no reaction
   d. aldehydes → carboxylic acids
   - H₂CrO₄ = CrO₃ + H₂O or Na₂Cr₂O₇ + H₂SO₄ (make in the reaction flask)
   - Always made and used in the presence of some water
   - Very strong, when 1° alcohols are used goes 1° RCH₂OH → RCHO → RCO₂H without stopping at aldehyde
Key access to aldehydes, which are useful for more Grignard chemistry.
- Note difference between PCC and $\text{H}_2\text{CrO}_4$
- PCC does not react with $2^\circ$ alcohols very rapidly

Key access to ketones.
- PCC does not react very fast with $2^\circ$ alcohols

Note difference between PCC and $\text{H}_2\text{CrO}_4$ when reacting with $1^\circ$ alcohols.

Draw the products for the following oxidation reactions.

1. \( \text{Ph} - \text{OH} \xrightarrow{\text{PCC}} \)

2. \( \text{Ph} - \text{OH} \xrightarrow{\text{H}_2\text{CrO}_4} \)

3. \( \text{OH} \xrightarrow{\text{H}_2\text{CrO}_4} \)

4. \( \text{OH} \xrightarrow{\text{PCC}} \)

5. \( \text{OH} \xrightarrow{\text{H}_2\text{CrO}_4} \)

\( \text{H}_2\text{CrO}_4 = \text{Na}_2\text{Cr}_2\text{O}_7, \text{H}_2\text{SO}_4 \) or \( \text{CrO}_3/\text{H}_2\text{O} \)
Oxidation Combined with Grignard Reactions (in either order): Indirectly Enables Substitution of Carbon for Hydrogen

1. **1° alcohol** + PCC $\rightarrow$ aldehyde + RMgBr $\rightarrow$ **2° alcohol**
2. **2° alcohol** + H$_2$CrO$_4$ $\rightarrow$ ketone + RMgBr $\rightarrow$ **3° alcohol**
   - Oxidation followed by Grignard reaction essentially substitutes a carbon group for a hydrogen
3. Aldehyde + RMgBr $\rightarrow$ 2° alcohol + H$_2$CrO$_4$ $\rightarrow$ ketone
   - Grignard reaction followed by oxidation essentially substitutes a carbon group for a hydrogen
Jones Test $\text{H}_2\text{CrO}_4$ for Alcohols (test responsible)

- $\text{H}_2\text{CrO}_4$ (Jones Reagent) is clear orange
- Treatment of an unknown with Jones reagent:
  - Solution stays clear orange $\Rightarrow$ no $1^\circ$ or $2^\circ$ alcohol present (negative reaction)
  - Solution gives a green/brown precipitate $\Rightarrow$ $1^\circ$ or $2^\circ$ alcohol present (positive reaction)
  - $3^\circ$, vinyl, and aryl alcohols do not react. Nor do ketones, ethers, or esters.

Structure and Mechanism (not test responsible)

<table>
<thead>
<tr>
<th>$\text{H}_2\text{CrO}_4$ = chromic acid = $\text{Na}_2\text{Cr}_2\text{O}_7 = \text{CrO}_3/\text{H}_2\text{O} = \text{Cr}^{+6}$ oxidation state</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water soluble</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pyridinium carbons renders PCC soluble in organic solvents, thus it is functional in organic solvent and in the absence of water</th>
</tr>
</thead>
</table>

General Mechanism

- PCC operates analogously

$1^\circ$ Alcohols, Aldehydes, and the Presence or Absence of Water:

Q: Why does Anhydrous PCC stop at Aldehyde but Aqueous $\text{H}_2\text{CrO}_4$ continues to Carboxylic Acid?

1. Both PCC and $\text{H}_2\text{CrO}_4$ convert $1^\circ$ alcohols to aldehydes
2. In the presence of acidic water, aldehydes undergo an equilibrium addition of water to provide a small equilibrium population of acetal
3. The acetal form gets oxidized (very rapidly) to carboxylic acid
   - The aldehyde form cannot itself get oxidized to carboxylic acid
   - Since PCC is used in absence of water, the aldehyde is not able to equilibrate with acetal and simply stays aldehyde.
   - Since it can’t convert to acetal, therefore no oxidation to carboxylic acid can occur
4. Chromic acid, by contrast, is in water
   - Therefore the aldehyde is able to equilibrate with acetal
   - The acetal is able to be oxidized.
   - Thus, the aldehyde via the acetal is able to be indirectly oxidized to carboxylic acid, and in fact does so very rapidly.
General Recognition of Oxidation/Reduction in Organic Chemistry

oxidation
\[
\begin{array}{c}
\text{1° alcohol} \\
\text{or}
\end{array}
\text{oxidation}
\begin{array}{c}
\text{or}
\end{array}
\text{reduction}
\begin{array}{c}
\text{2° alcohol}
\end{array}
\]
 reduction
\[
\begin{array}{c}
\text{Aldehyde} \\
\text{or}
\end{array}
\text{Carboxylic Acid}
\]

Oxidation: The number of oxygen bonds to a carbon increases, and the number of hydrogens bonded to a carbon decreases

Reduction: The number of oxygen bonds to a carbon is reduced, and the number of hydrogens bonded to a carbon increases.

More General: # of bonds to heteroatoms versus to hydrogens

Classify the following transformations as “oxidations” or “reductions”

1. \[
\begin{array}{c}
\text{NH} \\
\text{or}
\end{array}
\text{NH}_2
\]

2. \[
\begin{array}{c}
\text{NH}_2 \\
\text{or}
\end{array}
\text{C}_2\text{N}
\]

3. \[
\begin{array}{c}
\text{O} \\
\text{or}
\end{array}
\text{O}
\]

4. \[
\begin{array}{c}
\text{Br} \\
\text{or}
\end{array}
\text{O}
\]

Other methods for Oxidizing Alcohols. (No test)
There are lots of other recipes used for oxidizing alcohols (and for other oxidation reactions)

1. KMnO₄
2. CuO
3. “Jones”: H₂CrO₄ with acetone added to temper reactivity
4. Collins: H₂CrO₄ with pyridine added to temper reactivity
5. “Swern”: (COCl)₂ and (CH₃)₂S=O then NEt₃
6. HNO₃
7. Biological Oxidant 1: “NAD” “nicotamide adenine dinucleotide”

8. Biological Oxidant 2: “Quinones and hydroquinones”
In General: Recognizing Oxidizing versus Reducing Agents

**Oxidizing Agents:** Often have:
- **Highly Oxidized Metals or Nonmetals**
- **Extra Oxygen**

**Reducing Agents:** Often involve:
- **Hydrides in Formulas**
- **Highly Reduced Metals**
- **Metals + H₂**
- **Metals + acid**

OsO₄ (+8)  
KMnO₄ (+7)  
CrO₄ (+6)  
H₂CrO₄ (+6)  
HNO₃ (+5)  
H₂O₂ → H₂O  
RCO₂H → RCO₂H  
O₃ → O₂

- The ability to qualitatively recognize when a transformation involves an oxidation or reduction can be very helpful.
- The ability to recognize a reactant as an oxidizing agent or a reducing agent can be very helpful.
- Often on standardized tests!

Some Biological Alcohol Oxidations (Not for Test)

1. Oxidation of “carbohydrates” or “sugars” is the primary source of bioenergy
   - multiple enzymes are involved for the many steps
   - A “carbohydrate” basically has a formula with one OH per carbon

\[
\text{C}_6\text{H}_6(\text{OH})_6 \equiv \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{energy}
\]

2. Most alcohols are biooxidized to give toxic carbonyl derivatives (“intoxication”)
   - the presence of substantial aldehydes and especially ketones in the blood is symptomatic of various problems
     - intoxication
     - alcoholism
     - uncontrolled diabetes
     - etc (other metabolic disorders)
17.6 Conversion of Alcohols to Alkyl Halides

8  
\[ R-\text{OH} + \text{HBr} \rightarrow R-\text{Br} \]  
3° alcohols

Mech: Be able to draw!

9  
\[ R-\text{OH} + \text{PBr}_3 \rightarrow R-\text{Br} \]  
1° or 2° alcohols

10  
\[ R-\text{OH} + \text{PBr}_3 \text{ or HBr} \rightarrow R\text{MgBr} \]  
1° or 2° alcohols

12  
\[ R-\text{OH} + \text{SOCl}_2 \rightarrow R-\text{Cl} \]  
1° or 2° alcohols

Summary:

<table>
<thead>
<tr>
<th>Class</th>
<th>1° ROH</th>
<th>2° ROH</th>
<th>3° ROH</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-Br</td>
<td>PBr₃,</td>
<td>PBr₃,</td>
<td>HBr</td>
</tr>
<tr>
<td>R-Cl</td>
<td>SOCl₂</td>
<td>SOCl₂</td>
<td>HCl</td>
</tr>
</tbody>
</table>

Vinyl or Aryl

Nothing works

Nothing works

**Straight Reaction with H-X (Section 17.7)**

- Ideal only for 3° ROH,
- Sometimes works with 1° alcohols, with a complex mechanism
- Only occasionally for 2° alcohols
- Method of choice for 3°, but not for 1° or 2°

1  
\[ R-OH \rightarrow HBr \]

2  
\[ \text{HO} \rightarrow \text{HI} \]

3  
\[ \text{OH} \rightarrow \text{Br} \]

Mechanism for H-X reactions with 3° Alcohols: Cationic

\[ \text{HBr Mech for 3° ROH:} \]

\[ R-\text{OH} + \text{HBr} \rightarrow R-\text{OH}_2^+ \]

\[ + \text{Br}^- \rightarrow R-\text{Br} \]

Notes:
1. Memorize the 3º alcohol mechanism (test responsible)
   a. Protonate
   b. Leave to give Cation. This is the slow step for 3º alcohols
   c. Capture
2. Analogous with HI or HCl
   • HCl slower, normally enhanced with ZnCl2, which enhances rate of cation formation
     (Lucas test, see later)
   • Outside of 3º systems, side reactions are common and yields aren’t often very good
3. Outside of 3º alcohols, side reactions are common and yields aren’t often very good
   • Elimination reactions and cation rearrangements…
4. S_N1 type: carbocation-forming step is the rate-determining step, so R+ stability key
   • 3º alcohols fastest
   • 2º alcohols are way slower
   • 1º alcohols can’t react at all via this mechanism, because 1º R+ are too unstable.
   • Ditto for vinyl or aryl alcohols
5. HBr can also react with 1º ROH to give 1º RBr, although it is not often the method of choice
   • The mechanism is different, but rather interesting (not test responsible)

   ![HBr Mech for 1º ROH](image)

   • carbocation formation never occurs
   • bromide ion simply does S_N2 on the protonated alcohol, with water as an excellent
     leaving group
   • yields tend to be pretty inconsistent

**Reaction of 1º and 2º Alcohols with PBr_3**
• Default recipe for 1º and 2º alcohols

   ![Mech](image)

   • PBr_3 is an exceptional electrophile, and reacts even with neutral alcohols
   • The first step activates the oxygen as a leaving group.
   • The second step involves an S_N2 substitution
     o **stereochemical inversion occurs chirality present (common for 2º alcohols)**
   • Because the second step is an S_N2 substitution, the reaction fails for 3º ROH

1. ![Image 1](image)
2. ![Image 2](image)
3. ![Image 3](image)
Conversions of Alcohols into Other Reactive Species in Multi-Step Syntheses

1. Oxidation can convert an alcohol into a carbonyl = **Grignard acceptor** (electrophile)
2. PBr$_3$/Mg or HBr/Mg can convert an alcohol into RMgBr = **Grignard donor** (nucleophile)
3. PBr$_3$ or HBr can convert an alcohol into RBr, capable of normal substitution and elimination reactions.

**Retrosynthesis Problems (In which you decide what to start from):** Design syntheses for the following.

**Allowed starting materials include:**
- Bromobenzene
- Cyclopentanol
- Any acyclic alcohol or alkene with $\leq$4 carbons
- Any esters
- Ethylene oxide
- Formaldehyde (CH$_2$O)
- Any "inorganic" agents (things that won't contribute carbons to your skeleton)

**Tips:**
1. Focus on the functionalized carbon(s)
2. Try to figure out which groups of the skeleton began together, and where new C-C bonds will have been formed
3. When “breaking” it up into sub-chunks, try to make the pieces as large as possible (4 carbon max, in this case, for acyclic pieces)
4. Remember which direction is the “true” laboratory direction.
5. Be careful that you aren’t adding or substracting carbons by mistake

1. ![Diagram of retrosynthesis problem](image1)

2. ![Diagram of retrosynthesis problem](image2)
Normal Synthesis Design: In which you are given at least one of the starting Chemicals. Provide Reagents. You may use whatever reagents, including ketones or aldehydes or Grignards or esters, that you need. Tips:

- Identify where the reactant carbons are in the product
- Is the original carbon still oxygenated? → it will probably function as a Grignard acceptor
- Is the original carbon not still oxygenated? → it should probably function as Grignard donor
- Working backwards helps.

a. \chem{PhOH} \rightarrow \chem{PhCH_2CH_2OH}

b. \chem{PhOH} \rightarrow \chem{PhCH_2CH(OH)CH_2OH}

c. \chem{PhOH} \rightarrow \chem{PhCH_2CH_2CH_2OH}

d. \chem{PhOH} \rightarrow \chem{PhCH_2CH_2CH_2CH_2OH}

e. \chem{CH_2OH} \rightarrow \chem{CH_2=CH_2}

f. \chem{CH_2OH} \rightarrow \chem{CH_2CH_2CH_2CH_2COOH}
Retrosynthesis Problems: Design syntheses for the following.

Allowed starting materials include:
- Bromobenzene
- Cyclopentanol
- Any acyclic alcohol or alkene with \( \leq 4 \) carbons
- Any esters
- Ethylene oxide
- Formaldehyde (CH\(_2\)O)
- Any "inorganic" agents (things that won't contribute carbons to your skeleton)

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4. Remember which direction is the "true" laboratory direction.
5. Be careful that you aren't adding or subtracting carbons by mistake
Unknowns and Chemical Tests
1. H₂/Pt test for alkenes
2. Br₂ test for alkenes
3. Jones reagent (H₂CrO₄) Test for 1º or 2º alcohols
   - 3º alcohols do not react
   - 2º alcohols keep the same number of oxygens but lose two hydrogens in the formula
   - 1º alcohols lose two H’s but also add one oxygen
4. Lucas Test: HCl/ZnCl₂ for 3º or 2º alcohols

<table>
<thead>
<tr>
<th>Jones (H₂CrO₄)</th>
<th>Lucas (HCl/ZnCl₂)</th>
<th>H₂/Pt</th>
<th>Required Facts</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₅H₁₀O</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>C₆H₁₂O</td>
<td>Yes, 1-5 min</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₆H₁₂O</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>C₇H₁₂O</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, Produces C₇H₁₄O</td>
<td></td>
</tr>
<tr>
<td>C₃H₆O</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>C₃H₆O</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>C₃H₆O</td>
<td>Yes, produces C₃H₄O₂</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>C₃H₆O</td>
<td>Yes, produces C₃H₄O₂</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>C₃H₆O</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
Conversion of Alcohols to “Tosylates”, and their use as Exceptional Leaving Groups in $S_N2$, $S_N1$, E2, and E1 Reactions

**Notes:**
1. Tosylates are easy to form
2. “Toluene sulfonate”
3. Tosylate anion is really stable, comparable to the anion from sulfuric acid
   - Both the electronegative sulfur and the resonance/charge sharing with the other oxygens helps
4. Whereas a normal OH has a poor leaving group (hydroxide anion), conversion to the tosylate provides a super good leaving group.
5. Leaving Group Reactivity: Better than the best of the halides
   - OTs >> I > Br > Cl
6. Tosylates are highly reactive toward $S_N2$, $S_N1$, E2, and E1 Reactions
7. Triethylamine is used as an HCl scavenger in the tosylate formation
   - Often a weaker amine base called pyridine is used, to avoid unintentionally providing E2 on the tosylate

**Draw Products**

1. \( \text{OH} \)  
   - 1. TsCl, NEt₃  
   - 2. NaOCH₃

2. \( \text{OH} \)  
   - 1. Na  
   - 2. Br-CH₃

3. \( \text{OH} \)  
   - 1. TsCl, NEt₃  
   - 2. NEt₃

4. \( \text{OH} \)  
   - 1. TsCl, NEt₃  
   - 2. NaOCH₃

5. \( \text{H₃C} \)  
   - 1. TsCl, NEt₃  
   - 2. NaOCH₃

6. \( \text{OH} \)  
   - 1. TsCl, NEt₃  
   - 2. NaOH
**Reaction of 1° and 2° Alcohols with SOCl₂**

- Default recipe for 1° and 2° alcohols

- Mechanism: Not for test responsibility
- Mechanism differs for 1° and 2° alcohols
- 1° involve an SN₂ substitution
- 2° involve an SN1 type substitution
- The chloride that captures the cation is normally on the same side of the molecule on which the oxygen began, and often captures the cation very rapidly from that same side
- This results in a very unusual **retention of stereochemistry**.
- When they work, these reactions are convenient because the side products, SO₂ and HCl, are both gases. So workup is really easy. Simply rotovap the mixture down, and everything except for product is gone.

Draw Products or Provide Appropriate Reactants for the following Transformations

4. \[
\text{Ph} \xrightarrow{\text{P/I₂}}
\]

5. \[
\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{SOCl}_2}
\]

6. \[
\text{CH}_2\text{OH} \xrightarrow{\text{SOCl}_2}
\]

Draw the Mechanism:

\[
\text{Cyclohexanol} \xrightarrow{\text{HBr}} \text{Cyclohexyl bromide}
\]
Draw the mechanisms for the following reactions.

1. \( \text{PhCH}_2\text{O} \xrightarrow{1. \text{MeMgBr}} \text{PhCH}_2\text{OH} \xrightarrow{2. \text{H}_2\text{O}} \text{PhCHOH} \)

2. \( \text{HOCH}_3\text{CCH}_2\text{O} \xrightarrow{1. \text{excess MeMgBr}} \text{HOCH}_3\text{CCH}_2\text{OH} \xrightarrow{2. \text{H}_2\text{O}} \text{HOCH}_3\text{CCH}_2\text{OH} \)

3. \( \text{PhMgBr} \xrightarrow{1. \text{ethylene oxide}} \text{PhCH}_2\text{OH} \xrightarrow{2. \text{H}_3\text{O}^+} \text{PhCH}_2\text{OH} \)

4. \( \text{HOCH}_3\text{CCH}_2\text{O} \xrightarrow{1. \text{excess LiAlH}_4} \text{HOCH}_3\text{CCH}_2\text{OH} \xrightarrow{2. \text{H}_3\text{O}^+} \text{HOCH}_3\text{CCH}_2\text{OH} \)

5. \( \text{C}_{6}\text{H}_{12} \xrightarrow{\text{NaBH}_4} \text{C}_{6}\text{H}_{12} \xrightarrow{\text{NaBH}_4} \text{C}_{6}\text{H}_{12} \)

6. \( \text{BrCH}_2\text{CCH}_2\text{Br} \xrightarrow{1.0 \text{PhMgBr}} \text{PhCH}_2\text{CCH}_2\text{OH} \)

7. \( \text{HOCH}_3\text{CCH}_2\text{O} \xrightarrow{1. \text{PhMgBr (excess)}} \text{HOCH}_3\text{CCH}_2\text{OH} \xrightarrow{2. \text{H}_3\text{O}^+} \text{HOCH}_3\text{CCH}_2\text{OH} \)

8. \( \text{HOCH}_3\text{CCH}_2\text{OH} \xrightarrow{\text{HBr}} \text{BrCH}_2\text{CCH}_2\text{Br} \)
REVIEW. To make organometallic reagents, you must have RBr compounds (or RCl or RI).

\[
\begin{align*}
\text{Alkene} & \quad \text{HBr, peroxides (anti-Mark) or HBr (Mark)} \\
\text{Alkene} & \quad \text{PBr}_3 \\
\text{RBr} & \quad \text{HBr} \\
\text{Mg} & \quad \text{R-MgBr} \\
\text{Sn}^2 \quad Z & \quad \text{E2 (normal or bulky base)} \\
\text{R-Z} & \quad \text{Grignard Acceptors} \\
\end{align*}
\]

etc.

a. 

\[ \text{PhOH} \rightarrow \text{PhCH}_2 \text{CH}_2 \text{OH} \]

b. 

\[ \text{ethyl} \rightarrow \text{CH}_3 \text{CH(OH)} \text{CH}_3 \]

c. 

\[ \text{propyl} \rightarrow \text{CH}_3 \text{CH}(\text{PhOH}) \text{CH}_2 \text{CH}_2 \text{CH}_3 \]

d. 

\[ \text{cyclopentane} \rightarrow \text{cyclopentanoic acid} \]
**Alkene Concept Map**

- **R–Br**
  - Base
  - E2
  - H2
  - H2SO4
- **R–OH**
  - Oxidative Cleavage
- **Alcohol**
  - H2SO4
- **1. TsCl, NEt3**
- **2. E2 Base**

**Alkene**

- **H–Br addns**
- **H–OH addns**
- **H2 Addn**
- **Br2**
- **Dihalide**
- **Epoxide**
- **Diol**
- **Aldehydes, Ketones, Acids**

**Ether Concept Map**

- **R–Br**
  - NaOR'
  - S_n2
- **R–OH**
  - 1. ROH, Hg(OAc)_2
  - 2. NaBH_4
- **R–O–R’**
  - 1. alkene, Hg(OAc)_2
  - 2. NaBH_4
- **R–OH**
  - 1. TsCl, NEt3
  - 2. NaOR'

**Alkene**

- **R–OH**
- **alkane**

**Ethers**

- **1. Na**
- **2. R’-Br**

**Diols**

- **1. NaOH**
- **2. NaOHa**