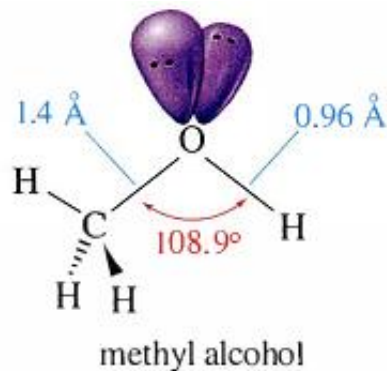
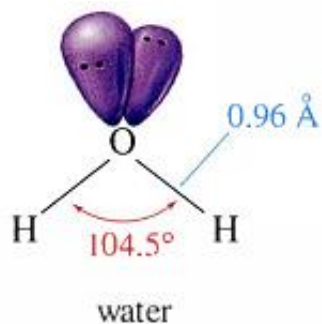
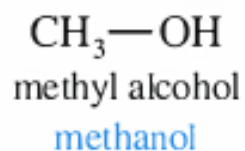
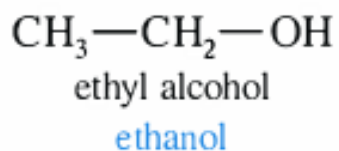
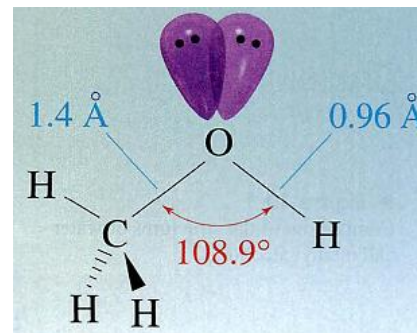
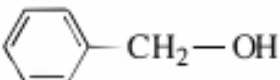
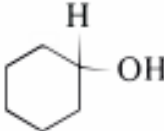
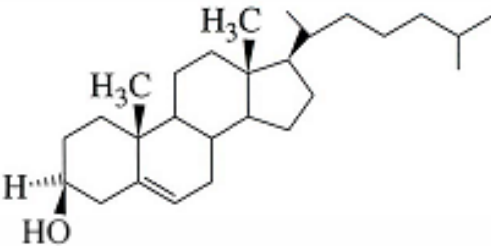
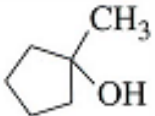

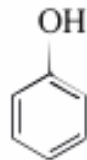
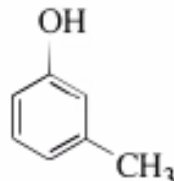
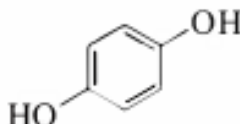


# Structure and Synthesis of Alcohols

**Alcohols** are organic compounds containing hydroxyl ( $\text{—OH}$ ) groups.



Type	Structure	Examples
Primary alcohol	$\begin{array}{c} \text{H} \\   \\ \text{R}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$	$\text{CH}_3\text{CH}_2-\text{OH}$ $\text{CH}_3\overset{\text{CH}_3}{\text{CH}}\text{CH}_2-\text{OH}$  ethanol    2-methyl-1-propanol    benzyl alcohol
Secondary alcohol	$\begin{array}{c} \text{R}' \\   \\ \text{R}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$	$\begin{array}{c} \text{CH}_3 \\   \\ \text{CH}-\text{OH} \\   \\ \text{CH}_2 \\   \\ \text{CH}_3 \end{array}$   2-butanol    cyclohexanol    cholesterol
Tertiary alcohol	$\begin{array}{c} \text{R}' \\   \\ \text{R}-\text{C}-\text{OH} \\   \\ \text{R}'' \end{array}$	$\begin{array}{c} \text{CH}_3 \\   \\ \text{CH}_3-\text{C}-\text{OH} \\   \\ \text{CH}_3 \end{array}$ $\begin{array}{c} \text{Ph} \\   \\ \text{Ph}-\text{C}-\text{OH} \\   \\ \text{Ph} \end{array}$  2-methyl-2-propanol    triphenylmethanol    1-methylcyclopentanol
Phenols		   phenol    3-methylphenol    hydroquinone

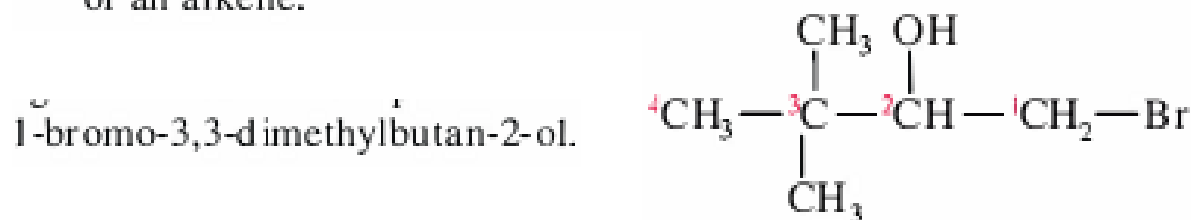
▲ **Figure 10-2**

Classification of alcohols. Alcohols are classified according to the type of carbon atom (primary, secondary, or tertiary) bonded to the hydroxyl group. Phenols have a hydroxyl group bonded to a carbon atom in a benzene ring.

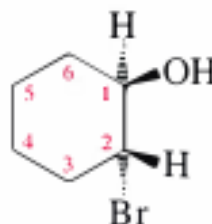
## IUPAC Names ("Alcohol" Names)

The formal rules are summarized in the following three steps:

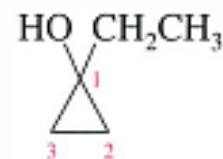
1. Name the longest carbon chain that contains the carbon atom bearing the  $\text{—OH}$  group. Drop the final *-e* from the alkane name and add the suffix *-ol* to give the root name.
2. Number the longest carbon chain starting at the end nearest the hydroxyl group, and use the appropriate number to indicate the position of the  $\text{—OH}$  group. (The hydroxyl group takes precedence over double and triple bonds.)
3. Name all the substituents and give their numbers, as you would for an alkane or an alkene.



Cyclic alcohols are named using the prefix *cyclo-*; the hydroxyl group is assumed to be on C1.

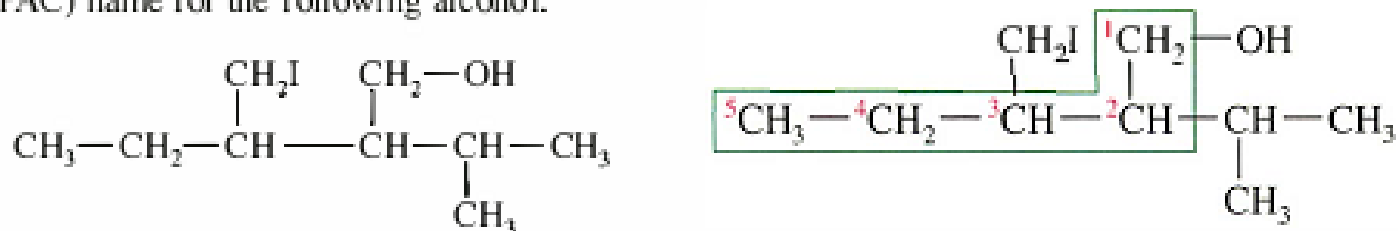


IUPAC name: *trans*-2-bromocyclohexanol  
new IUPAC name: *trans*-2-bromocyclohexan-1-ol

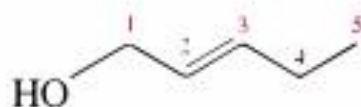


1-ethylcyclopropanol  
1-ethylcyclopropan-1-ol

Give the systematic (IUPAC) name for the following alcohol.

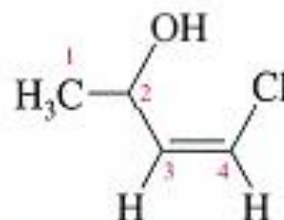


The correct name for this compound is 3-(iodomethyl)-2-isopropylpentan-1-ol.

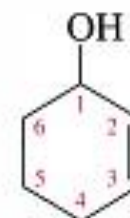


IUPAC name:  
new IUPAC name:

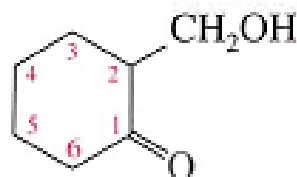
*trans*-2-penten-1-ol  
*trans*-pent-2-en-1-ol



(*Z*)-4-chloro-3-buten-2-ol  
(*Z*)-4-chlorobut-3-en-2-ol



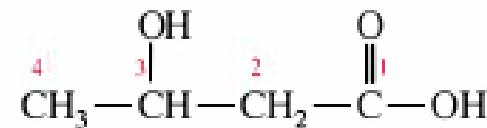
2-cyclohexen-1-ol  
cyclohex-2-en-1-ol



2-hydroxymethylcyclohexanone



*trans*-3-(2-hydroxyethyl)cyclopentanol

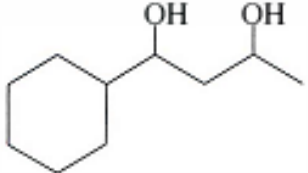
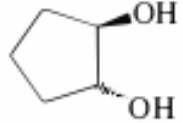


3-hydroxybutanoic acid

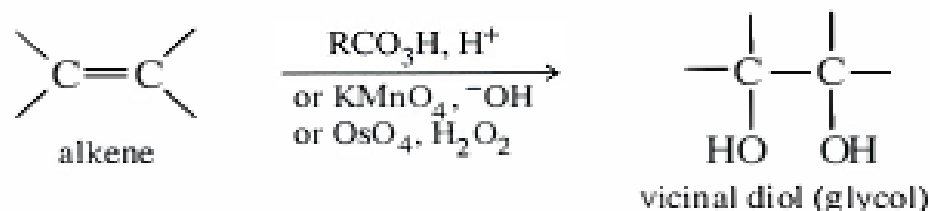
## Common Names of Alcohols

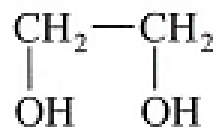
common name:	$\text{CH}_3\text{—OH}$ methyl alcohol	$\text{CH}_3\text{CH}_2\text{CH}_2\text{—OH}$ <i>n</i> -propyl alcohol	$\text{CH}_3\text{—}\overset{\text{CH}_3}{\text{C}}\text{—CH}_3$ isopropyl alcohol	$\text{H}_2\text{C}=\text{CH—CH}_2\text{—OH}$ allyl alcohol
IUPAC name:	methanol	1-propanol	2-propanol	2-propen-1-ol
common name:	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{—OH}$	$\text{CH}_3\text{—}\overset{\text{OH}}{\text{C}}\text{—CH}_2\text{CH}_3$	$\text{CH}_3\text{—}\overset{\text{CH}_3}{\underset{\text{CH}_3}{\text{C}}}\text{—OH}$	$\text{CH}_3\text{—}\overset{\text{CH}_3}{\text{C}}\text{—CH}_2\text{—OH}$
IUPAC name:	<i>n</i> -butyl alcohol 1-butanol	<i>sec</i> -butyl alcohol 2-butanol	<i>t</i> -butyl alcohol 2-methyl-2-propanol	isobutyl alcohol 2-methyl-1-propanol

## Names of Diols

	$\text{CH}_3\text{—}\overset{\text{OH}}{\text{C}}\text{—CH}_2\text{OH}$		
IUPAC name:	propane-1,2-diol	1-cyclohexylbutane-1,3-diol	<i>trans</i> -cyclopentane-1,2-diol

The term *glycol* generally means a 1,2-diol, or **vicinal diol**, with its two hydroxy groups on adjacent carbon atoms. Glycols are usually synthesized by the hydroxylation of alkenes, using peroxyacids, osmium tetroxide, or potassium permanganate (Section 8-14).



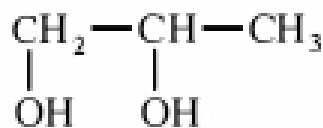


IUPAC name:

common name:

ethane-1,2-diol

ethylene glycol

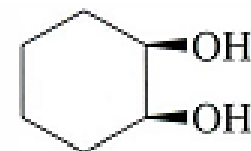


IUPAC name:

common name:

propane-1,2-diol

propylene glycol



IUPAC name:

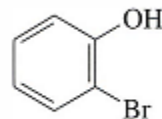
common name:

*cis*-cyclohexane-1,2-diol

*cis*-cyclohexene glycol

## Names of Phenols

Because the phenol structure involves a benzene ring, the terms *ortho* (1,2-disubstituted), *meta* (1,3-disubstituted), and *para* (1,4-disubstituted) are often used in the common names. The following examples illustrate the systematic names and the common names of some simple phenols.

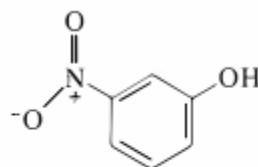


IUPAC name:

common name:

2-bromophenol

*ortho*-bromophenol

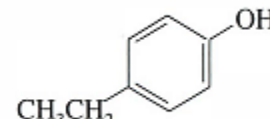


IUPAC name:

common name:

3-nitrophenol

*meta*-nitrophenol

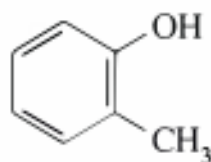


IUPAC name:

common name:

4-ethylphenol

*para*-ethylphenol

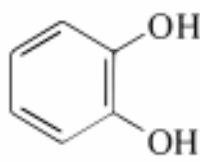


IUPAC name:

common name:

2-methylphenol

*ortho*-cresol

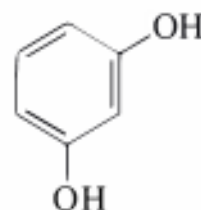


IUPAC name:

common name:

benzene-1,2-diol

catechol

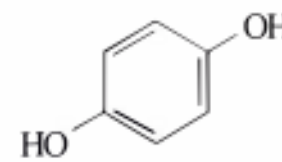


IUPAC name:

common name:

benzene-1,3-diol

resorcinol



IUPAC name:

common name:

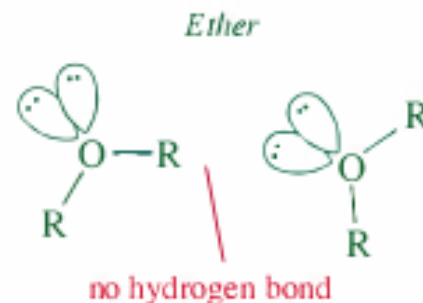
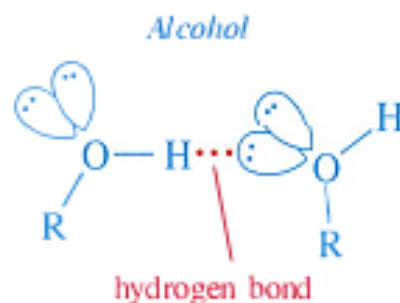
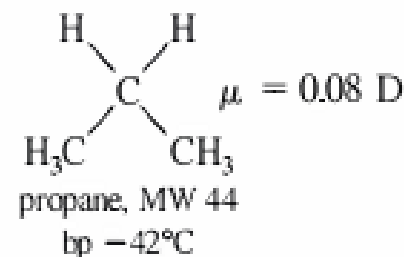
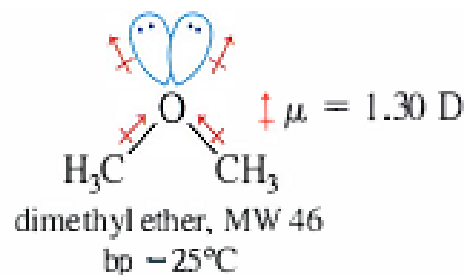
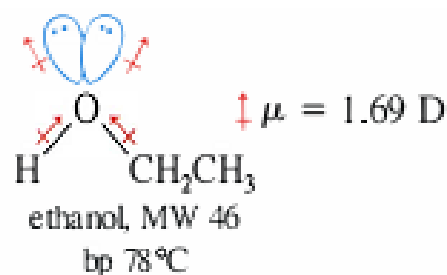
benzene-1,4-diol

hydroquinone

## Physical Properties of Alcohols

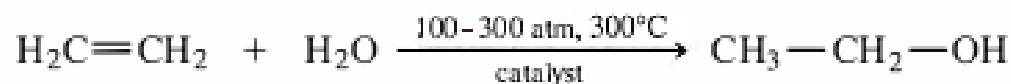
Most of the common alcohols, up to about 11 or 12 carbon atoms, are liquids at room temperature. Methanol and ethanol are free-flowing volatile liquids with characteristic fruity odors. The higher alcohols (the butanols through the decanols) are somewhat viscous, and some of the highly branched isomers are solids at room temperature. These higher alcohols have heavier but still fruity odors. 1-Propanol and 2-propanol fall in the middle, with a barely noticeable viscosity and a characteristic odor often associated with a physician's office. Table 10-2 lists the physical properties of some common alcohols.

### Boiling Points of Alcohols

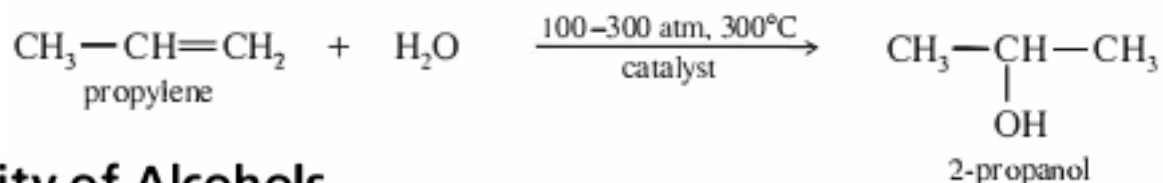




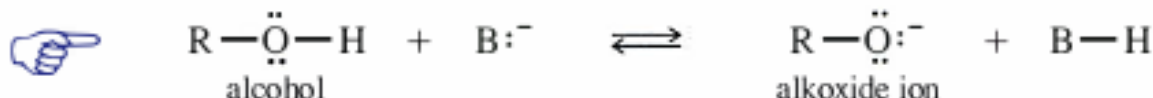




## 2-Propanol



## Acidity of Alcohols and Phenols



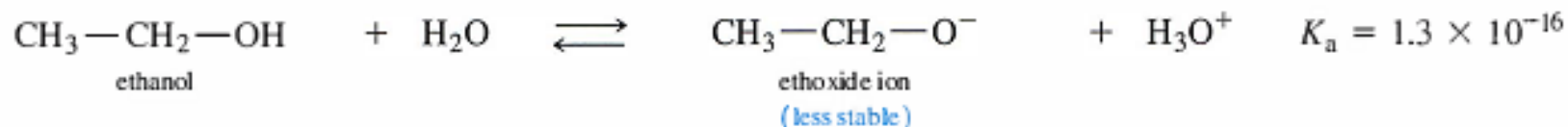
### Example



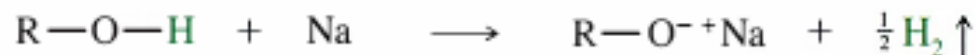
$$K_a = \frac{[\text{H}_3\text{O}^+][\text{RO}^-]}{[\text{ROH}]} \quad \text{p}K_a = -\log(K_a)$$

## Effects on Acidity

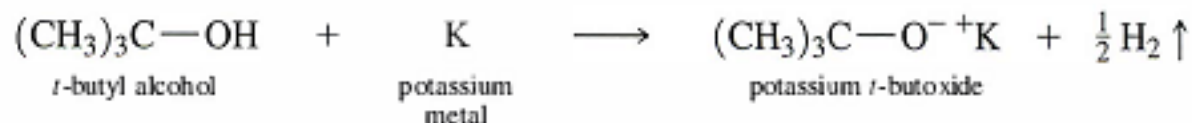
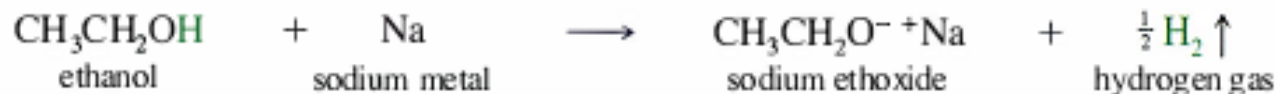
Alcohol	Structure	$K_a$	$pK_a$
methanol	$\text{CH}_3\text{—OH}$	$3.2 \times 10^{-16}$	15.5
ethanol	$\text{CH}_3\text{CH}_2\text{—OH}$	$1.3 \times 10^{-16}$	15.9
2-chloroethanol	$\text{Cl—CH}_2\text{CH}_2\text{—OH}$	$5.0 \times 10^{-15}$	14.3
2,2,2-trichloroethanol	$\text{Cl}_3\text{C—CH}_2\text{—OH}$	$6.3 \times 10^{-13}$	12.2
isopropyl alcohol	$(\text{CH}_3)_2\text{CH—OH}$	$3.2 \times 10^{-17}$	16.5
<i>t</i> -butyl alcohol	$(\text{CH}_3)_3\text{C—OH}$	$1.0 \times 10^{-18}$	18.0
cyclohexanol	$\text{C}_6\text{H}_{11}\text{—OH}$	$1.0 \times 10^{-18}$	18.0
phenol	$\text{C}_6\text{H}_5\text{—OH}$	$1.0 \times 10^{-10}$	10.0
<i>Comparison with Other Acids</i>			
water	$\text{H}_2\text{O}$	$1.8 \times 10^{-16}$	15.7
acetic acid	$\text{CH}_3\text{COOH}$	$1.6 \times 10^{-5}$	4.8
hydrochloric acid	$\text{HCl}$	$1.6 \times 10^{+2}$	-2.2



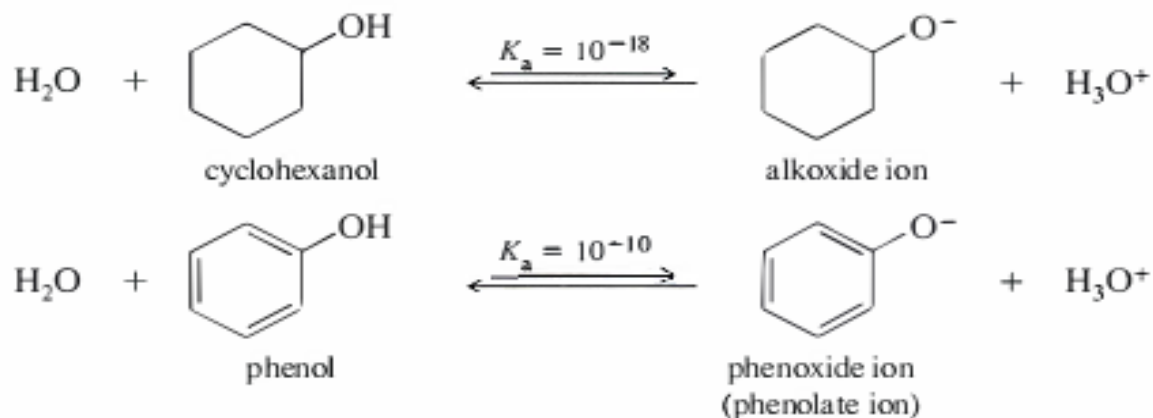
## Formation of Sodium and Potassium Alkoxides

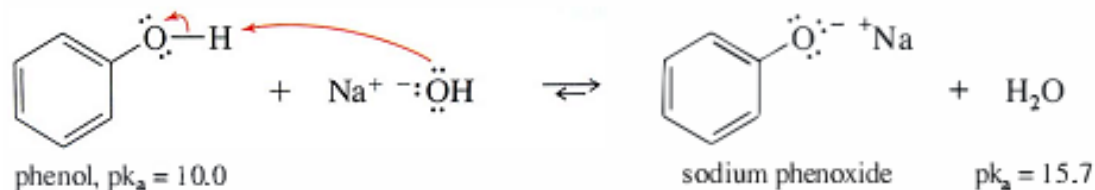
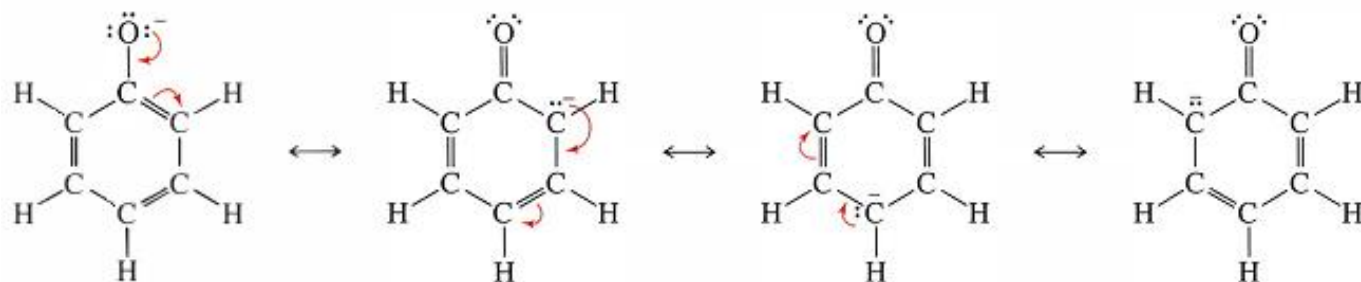


### Example



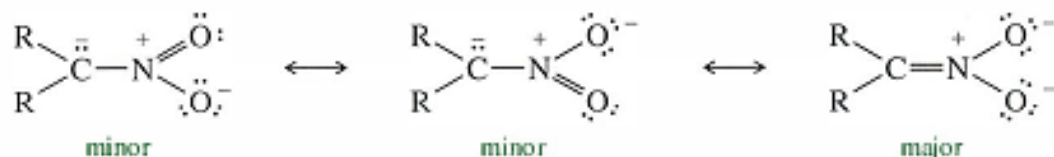
## Acidity of Phenols



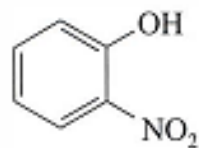


### PROBLEM 10-9

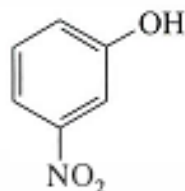
A nitro group ( $-\text{NO}_2$ ) effectively stabilizes a negative charge on an adjacent carbon atom through resonance:



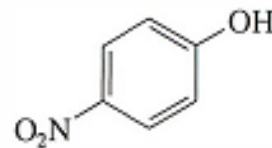
Two of the following nitrophenols are much more acidic than phenol itself. The third compound is only slightly more acidic than phenol. Use resonance structures of the appropriate phenoxide ions to show why two of these anions should be unusually stable.



2-nitrophenol



3-nitrophenol

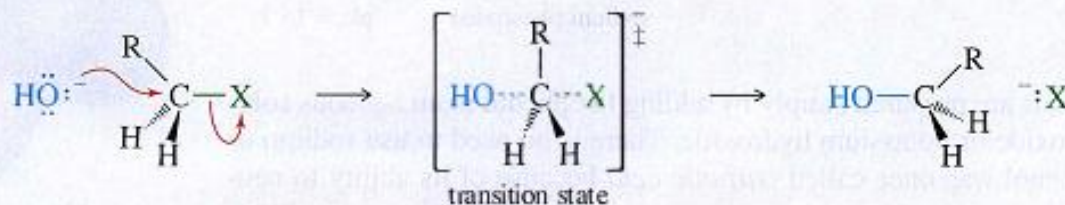


4-nitrophenol

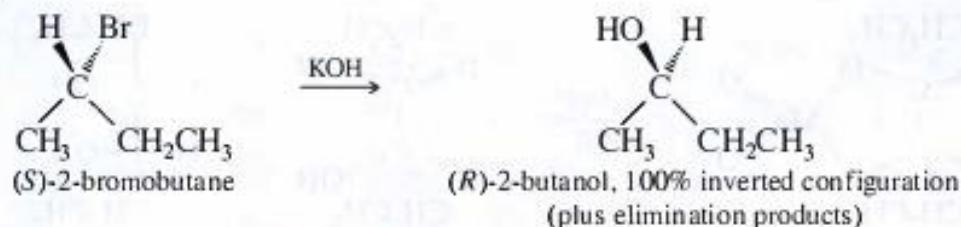
# Synthesis of Alcohols: Introduction and Review

## Nucleophilic Substitution on an Alkyl Halide

Usually via the  $S_N2$  mechanism; competes with elimination.

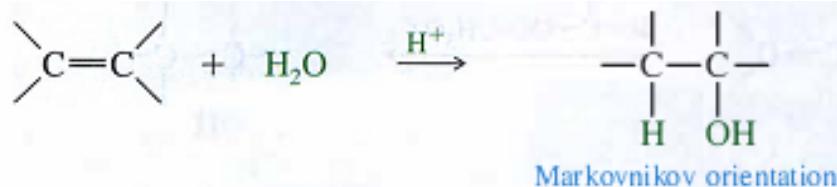


Example

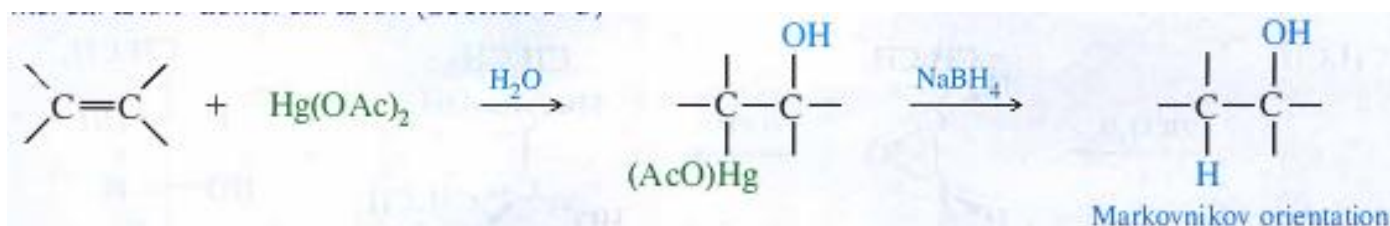


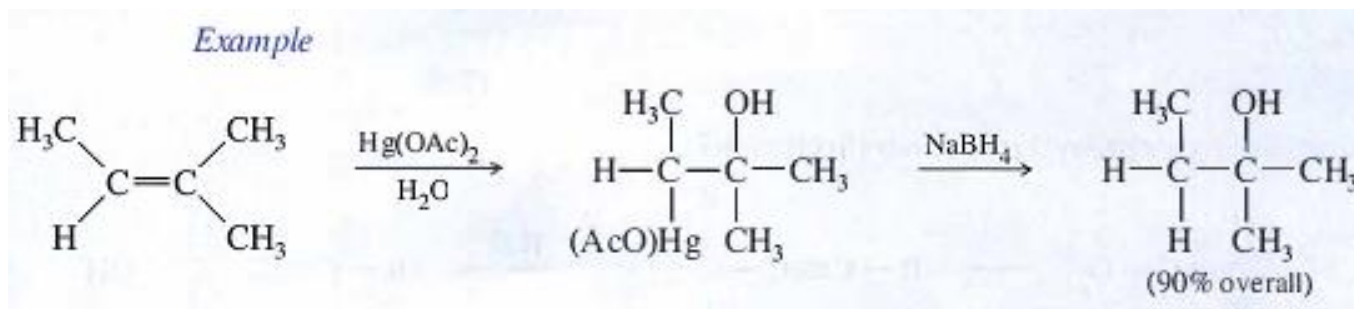
## Synthesis of Alcohols from Alkenes

1. Acid-catalyzed hydration

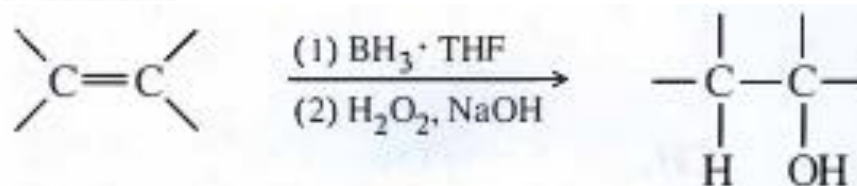


2. Oxymercuration–demercuration

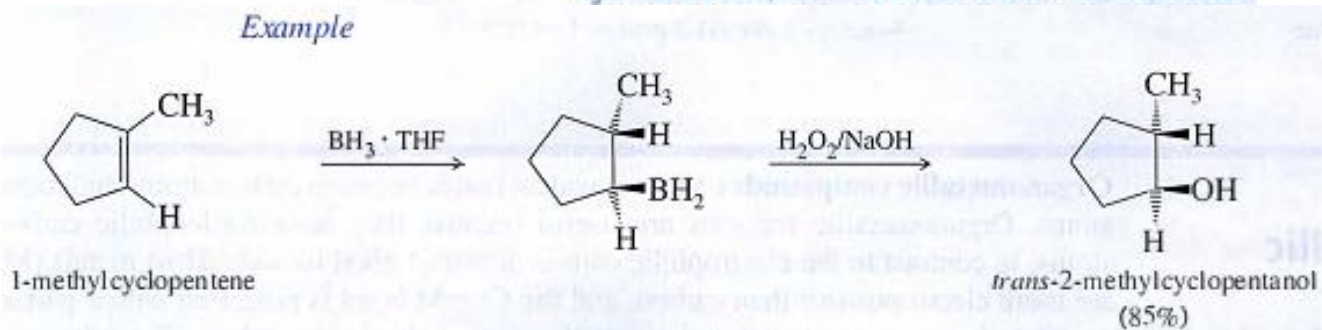




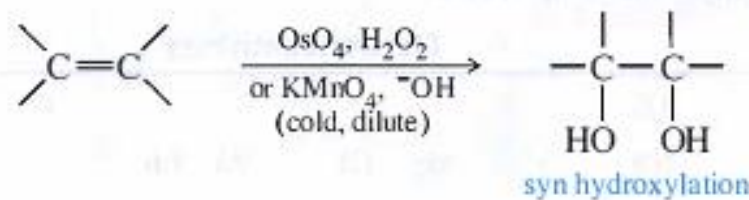
### 3. Hydroboration-oxidation

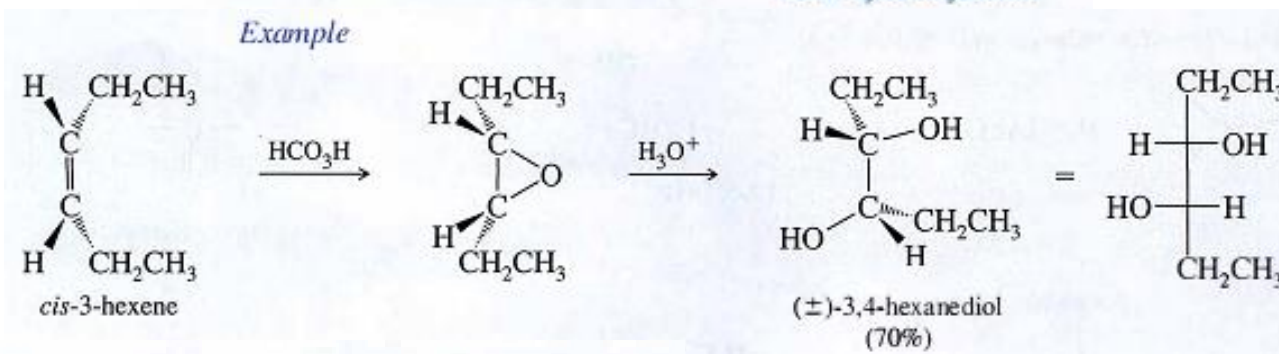
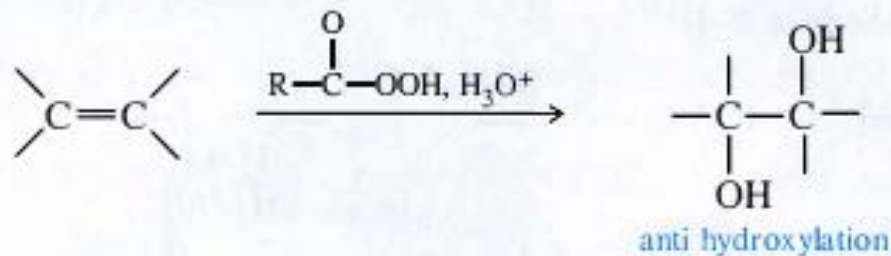
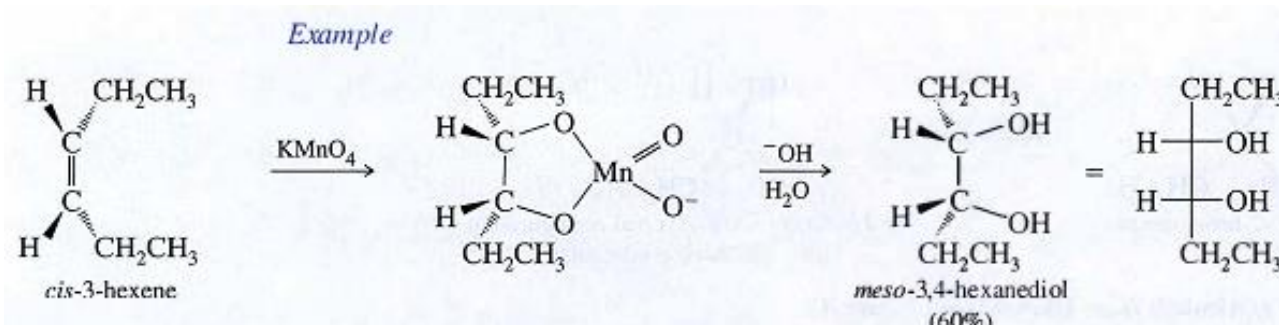


syn addition, anti-Markovnikov orientation

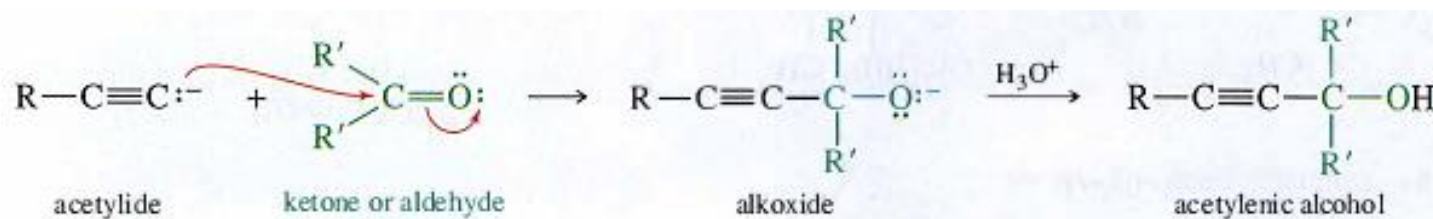


### 4. Hydroxylation: synthesis of 1,2-diols from alkenes





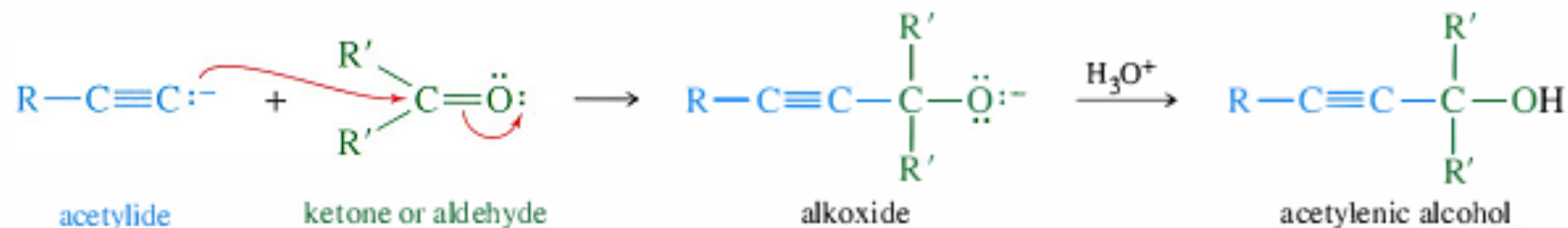
## 5. Addition of acetylides to carbonyl compounds



## Organometallic Reagents for Alcohol Synthesis

**Organometallic compounds** contain covalent bonds between carbon atoms and metal atoms. Organometallic reagents are useful because they have nucleophilic carbon atoms, in contrast to the electrophilic carbon atoms of alkyl halides. Most metals (M) are more electropositive than carbon, and the C—M bond is polarized with a partial positive charge on the metal and a partial negative charge on carbon. The following partial periodic table shows the electronegativities of some metals used in making organometallic compounds.

Electronegativities						C — M bond	
Li	1.0					C $\overset{\delta^-}{\leftarrow} \overset{\delta^+}{\text{Li}}$	
Na	0.9	•	Mg	1.3	Al	1.6	C $\overset{\delta^-}{\leftarrow} \overset{\delta^+}{\text{Mg}}$
K	0.8						





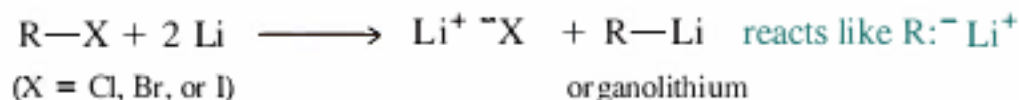


## Organolithium Reagents

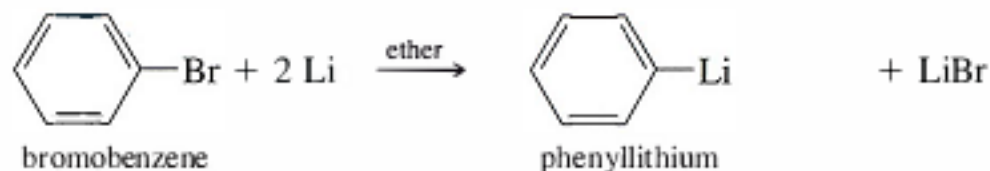
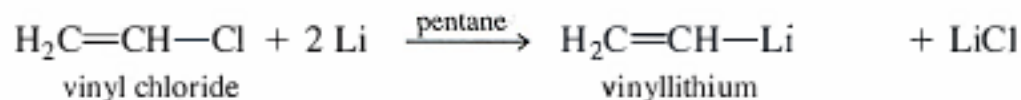
Like magnesium, lithium reacts with alkyl halides, vinyl halides, and aryl halides to form organometallic compounds. Ether is not necessary for this reaction. **Organolithium reagents** are made and used in a wide variety of solvents, including alkanes.



EPM of CH<sub>3</sub>Li



### Examples

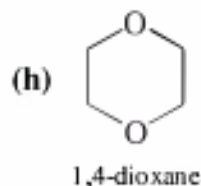
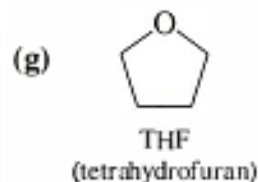


The electrostatic potential map (EPM) of methyl lithium is shown at left. The blue (electron-poor) color of the metal results from its partial positive charge, and the red (electron-rich) color of the methyl group shows its partial negative charge.

### PROBLEM 10-11

Which of the following compounds are suitable solvents for Grignard reactions?

- (a) *n*-hexane                      (b) CH<sub>3</sub>—O—CH<sub>3</sub>                      (c) CHCl<sub>3</sub>  
(d) cyclohexane                      (e) benzene                      (f) CH<sub>3</sub>OCH<sub>2</sub>CH<sub>2</sub>OCH<sub>3</sub>

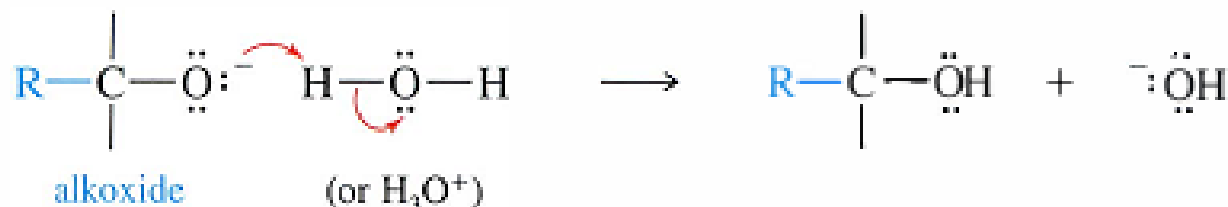
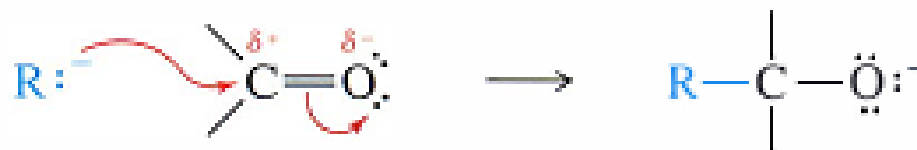


### PROBLEM 10-12

Predict the products of the following reactions.

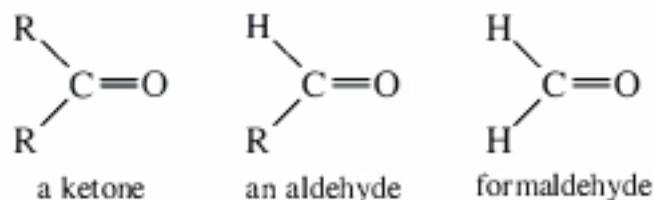
- (a) CH<sub>3</sub>CH<sub>2</sub>Br + Mg  $\xrightarrow{\text{ether}}$   
(b) isobutyl iodide + Li  $\xrightarrow{\text{hexane}}$   
(c) 1-bromo-4-fluorocyclohexane + Mg  $\xrightarrow{\text{THF}}$   
(d) CH<sub>2</sub>=CCl—CH<sub>2</sub>CH<sub>3</sub> + Li  $\xrightarrow{\text{ether}}$

## Addition of Organometallic Reagents to Carbonyl Compounds

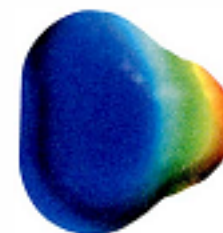


Either a Grignard reagent or an organolithium reagent can serve as the nucleophile in this addition to a carbonyl group. The following discussions refer to Grignard reagents, but they also apply to organolithium reagents. The Grignard reagent adds to the carbonyl group to form an alkoxide ion. Addition of dilute acid (in a separate step) protonates the alkoxide to give the alcohol.

We are interested primarily in the reactions of Grignard reagents with ketones and aldehydes. **Ketones** are compounds with two alkyl groups bonded to a carbonyl group. **Aldehydes** have one alkyl group and one hydrogen atom bonded to the carbonyl group. **Formaldehyde** has two hydrogen atoms bonded to the carbonyl group.



The electrostatic potential map (EPM) of formaldehyde shows the polarization of the carbonyl group, with an electron-rich (red) region around oxygen and an electron-poor (blue) region near carbon.

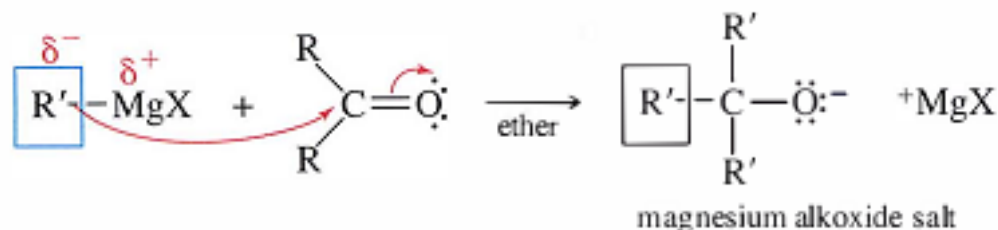


EPM of formaldehyde

**Formation of the Grignard reagent:** Magnesium reacts with an alkyl halide in an ether solution.



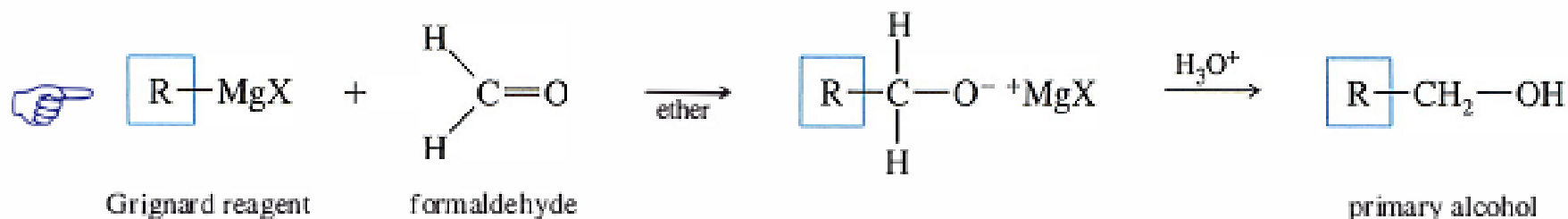
**Reaction 1:** The Grignard reagent attacks a carbonyl compound to form an alkoxide salt.



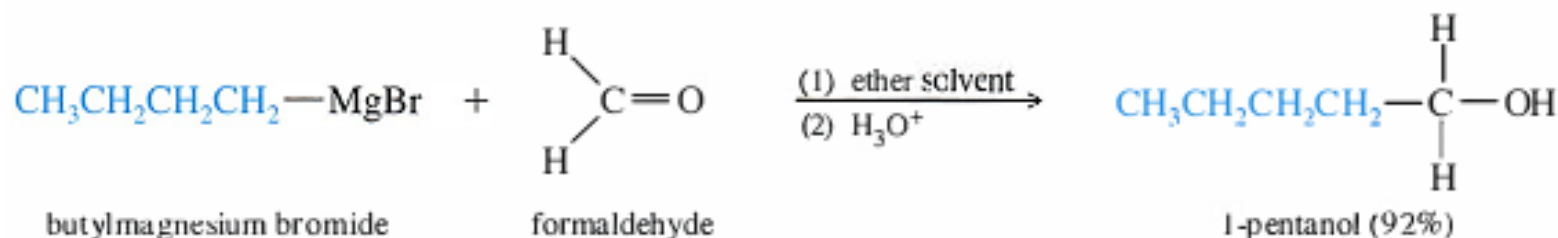
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## Addition to Formaldehyde: Formation of Primary Alcohols

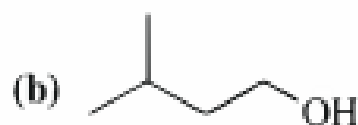
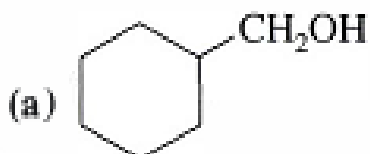


For example,

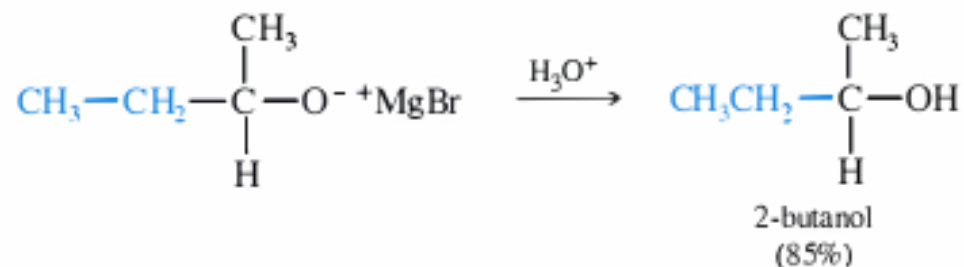
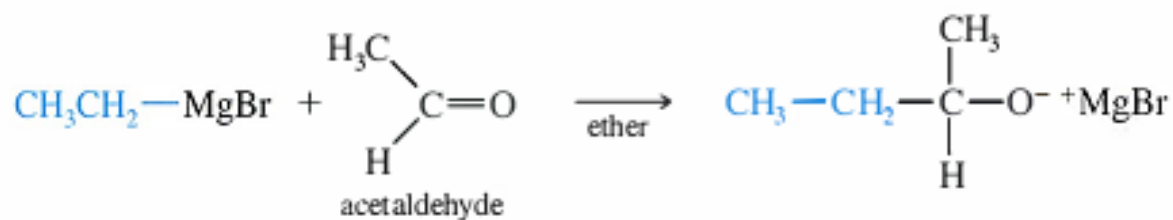
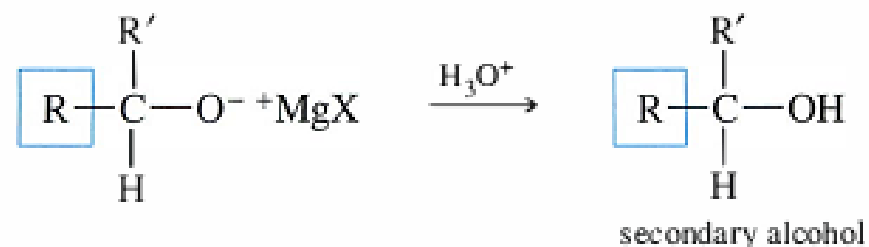
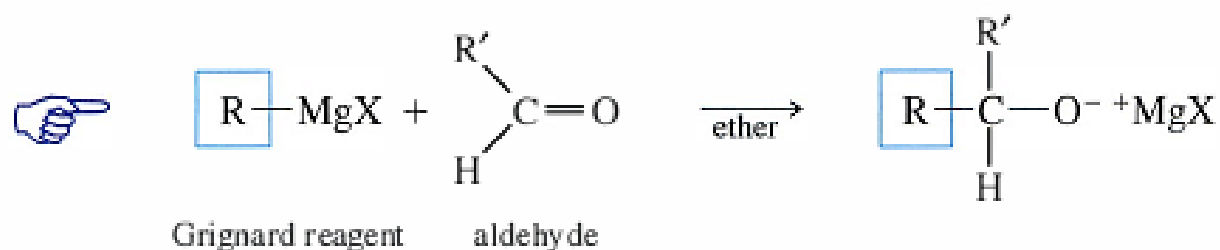


### PROBLEM 10-13

Show how you would synthesize the following alcohols by adding an appropriate Grignard reagent to formaldehyde.



## Addition to Aldehydes: Formation of Secondary Alcohols

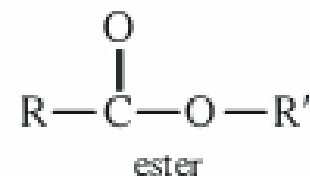
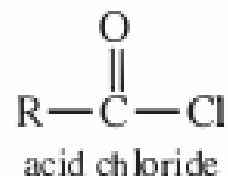
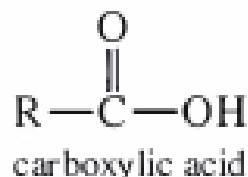




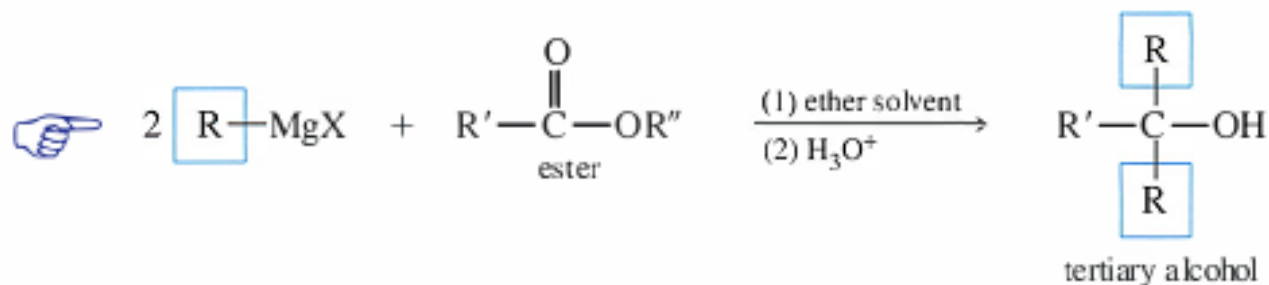
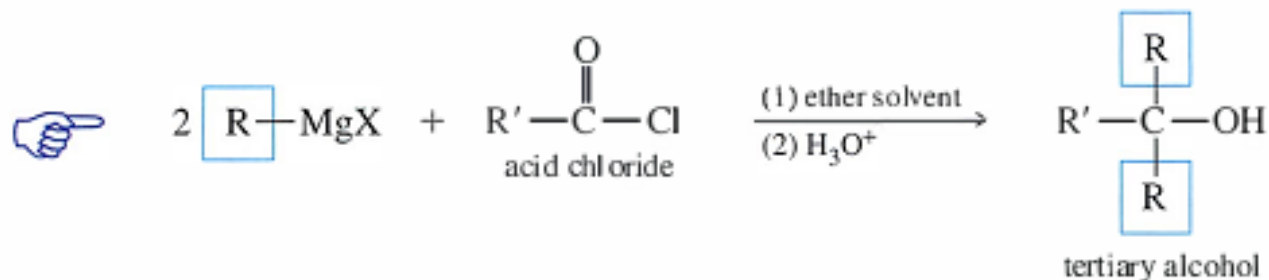


## Addition to Acid Chlorides and Esters

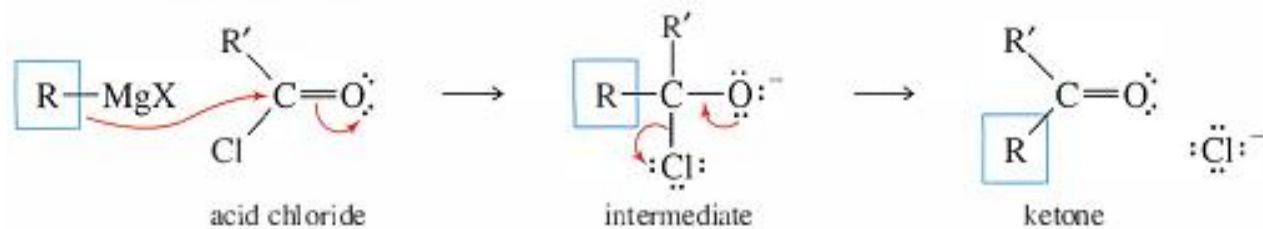
**Acid chlorides** and **esters** are derivatives of carboxylic acids. In such **acid derivatives**, the  $\text{—OH}$  group of a carboxylic acid is replaced by other electron-withdrawing groups. In acid chlorides, the hydroxyl group of the acid is replaced by a chlorine atom. In esters, the hydroxyl group is replaced by an alkoxy ( $\text{—O—R}$ ) group.



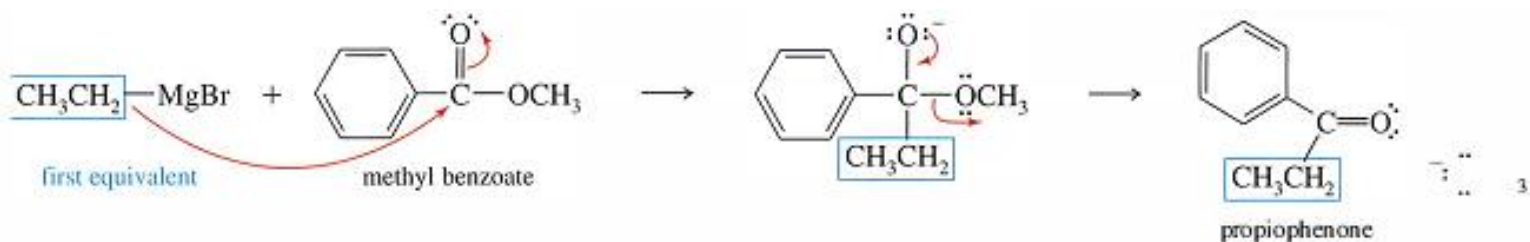
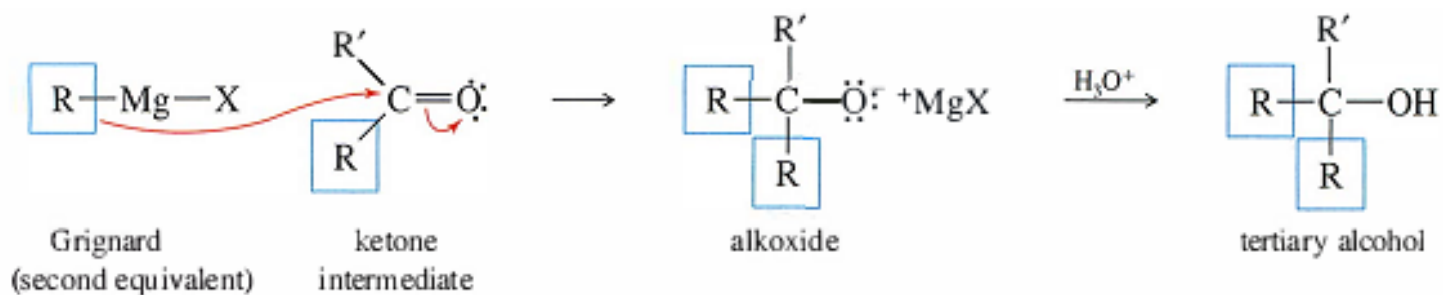
Acid chlorides and esters react with two equivalents of Grignard reagents to give (after protonation) tertiary alcohols.

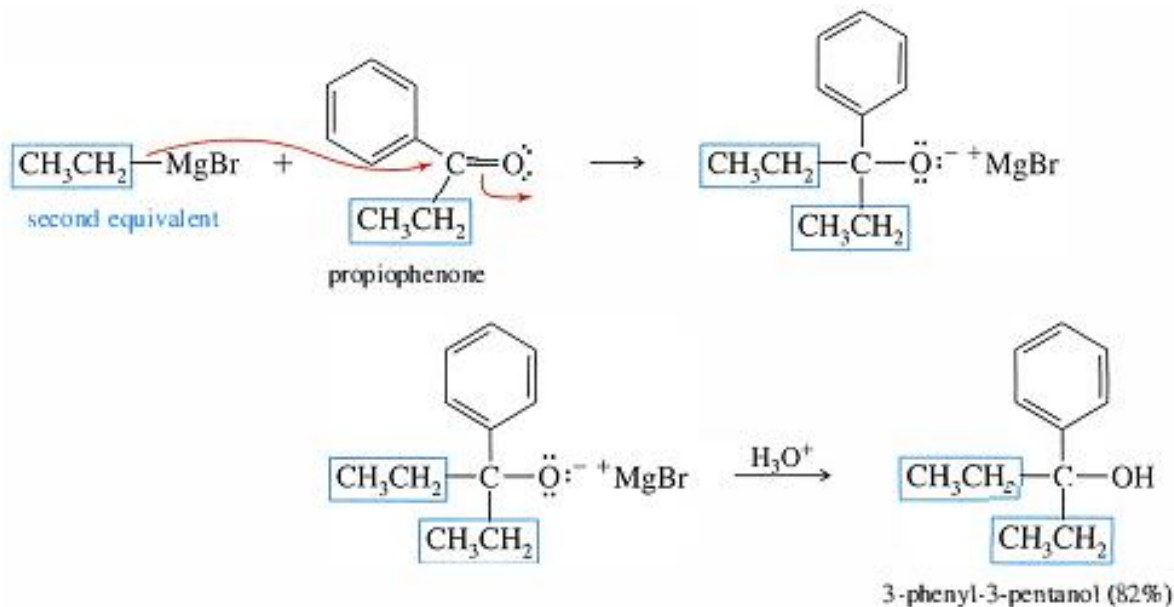


*Attack on an acid chloride*



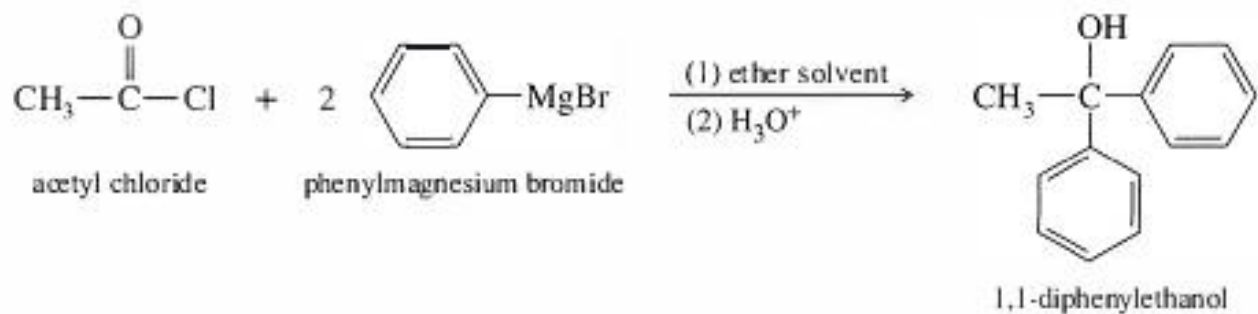
*Attack on an ester*



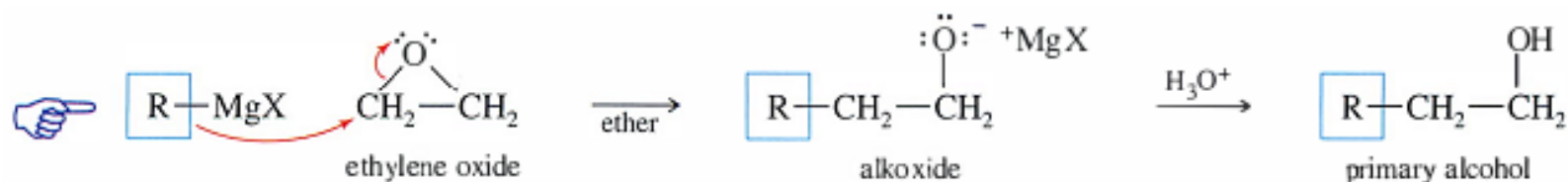


### PROBLEM 10-16

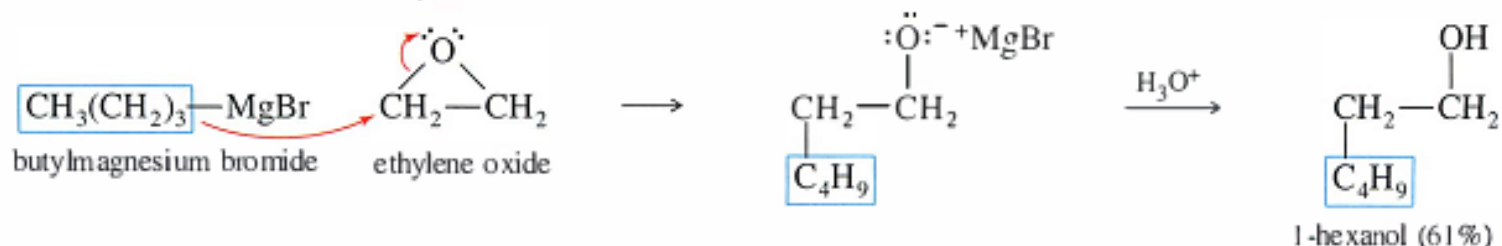
Propose a mechanism for the reaction of acetyl chloride with phenylmagnesium bromide to give 1,1-diphenylethanol.



## Addition to Ethylene Oxide



*Example*

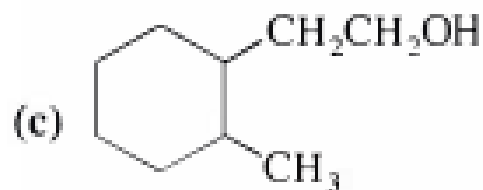


### PROBLEM 10-19

Show how you would synthesize the following alcohols by adding Grignard reagents to ethylene oxide.

(a) 2-phenylethanol

(b) 4-methyl-1-pentanol



## Reduction of the Carbonyl Group: Synthesis of 1° and 2° Alcohols

Grignard reagents convert carbonyl compounds to alcohols by adding alkyl groups. **Hydride reagents** add a hydride ion ( $\text{H}^-$ ), reducing the carbonyl group to an alkoxide ion with no additional carbon atoms. Subsequent protonation gives the alcohol. Converting a ketone or an aldehyde to an alcohol involves adding two hydrogen atoms across the  $\text{C}=\text{O}$  bond: a reduction. Mechanism 10-2 shows the mechanism for this reduction.

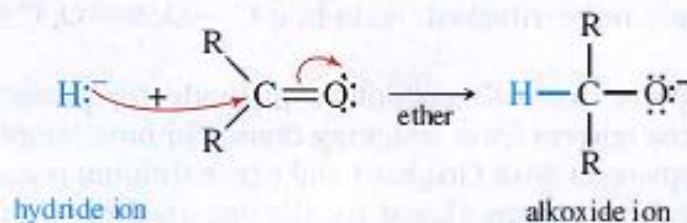
The two most useful hydride reagents, sodium borohydride ( $\text{NaBH}_4$ ) and lithium aluminum hydride ( $\text{LiAlH}_4$ ), reduce carbonyl groups in excellent yields. These reagents are called *complex hydrides* because they do not have a simple hydride structure such as  $\text{Na}^+\text{H}^-$  or  $\text{Li}^+\text{H}^-$ . Instead, their hydrogen atoms, bearing partial negative charges, are

### MECHANISM 10-2

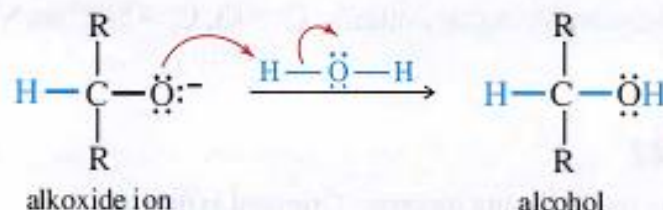
### Hydride Reduction of a Carbonyl Group

Sodium borohydride and lithium aluminum hydride reduce ketones and aldehydes to alcohols.

**Reaction 1:** Nucleophilic attack by hydride ion forms an alkoxide ion.

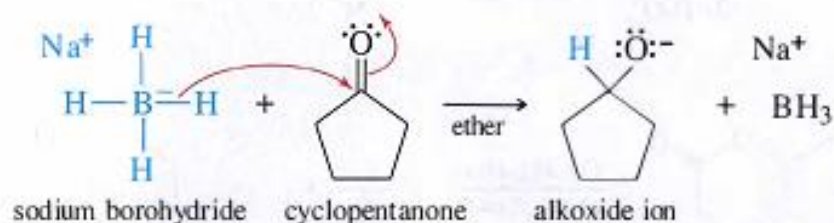


**Reaction 2:** After the first reaction is complete, water or dilute acid is added to protonate the alkoxide.

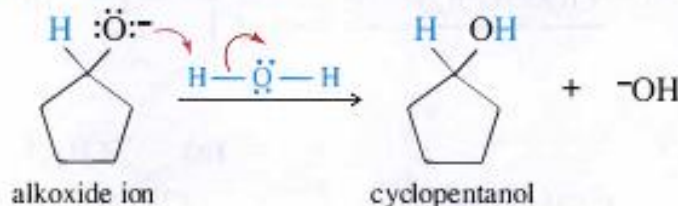


**EXAMPLE: Hydride reduction of cyclopentanone to cyclopentanol.**

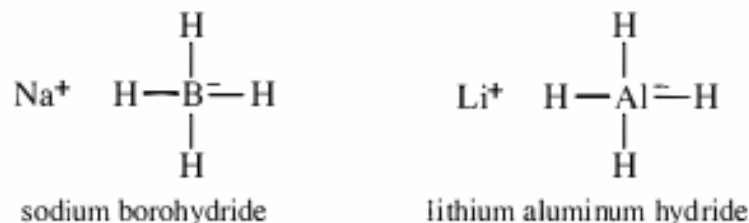
*Reaction 1:* Nucleophilic attack by hydride ion forms an alkoxide ion.



*Reaction 2:* After the first reaction is complete, water or dilute acid is added to protonate the alkoxide.



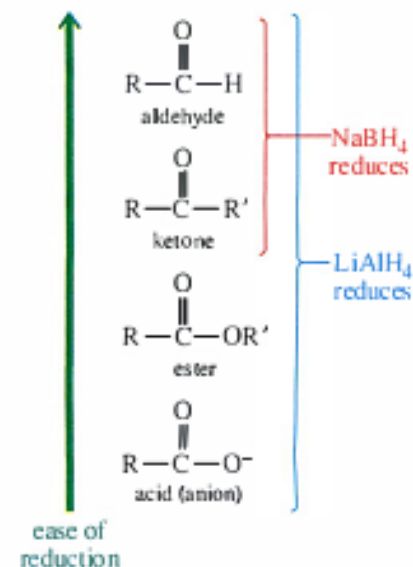
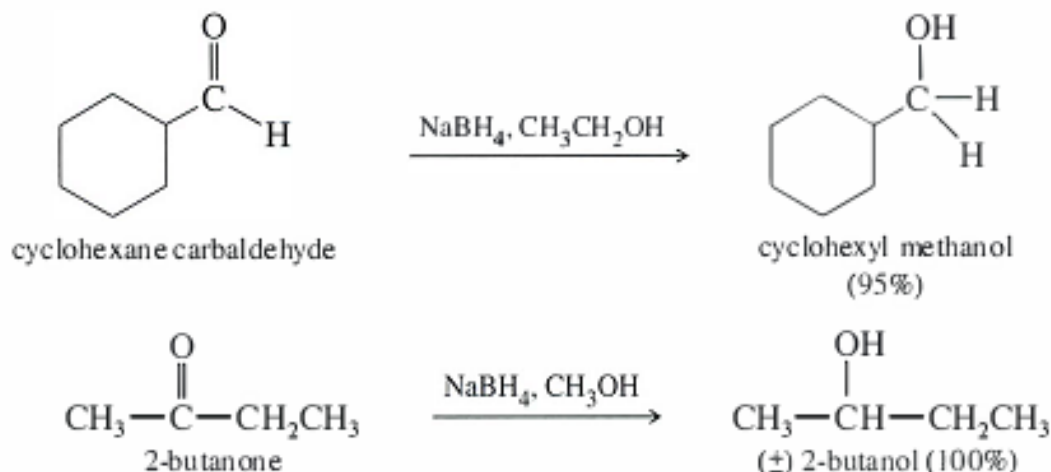
covalently bonded to boron and aluminum atoms. This arrangement makes the hydride a better nucleophile while reducing its basicity.



Aluminum is less electronegative than boron, so more of the negative charge in the  $\text{AlH}_4^-$  ion is borne by the hydrogen atoms. Therefore, lithium aluminum hydride is a much stronger reducing agent, and it is much more difficult to work with than sodium borohydride. LAH reacts explosively with water and alcohols, liberating hydrogen

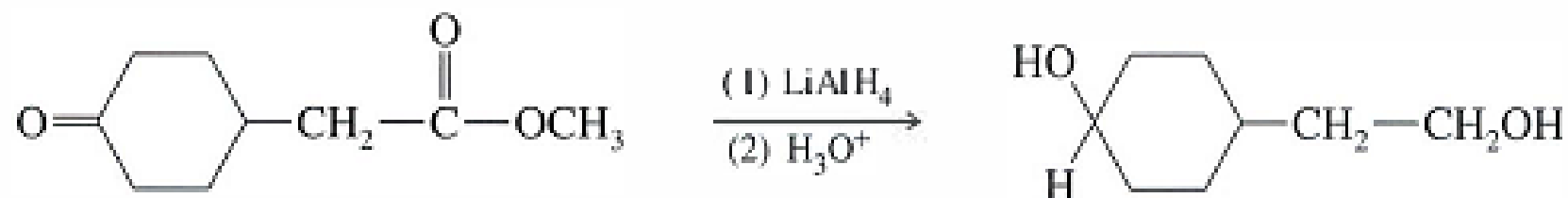
## Uses of Sodium Borohydride

Sodium borohydride ( $\text{NaBH}_4$ ) reduces aldehydes to primary alcohols, and ketones to secondary alcohols. The reactions take place in a wide variety of solvents, including alcohols, ethers, and water. The yields are generally excellent.



## Uses of Lithium Aluminum Hydride

Lithium aluminum hydride ( $\text{LiAlH}_4$ , abbreviated LAH) is a much stronger reagent than sodium borohydride. It easily reduces ketones and aldehydes and also the less-reactive carbonyl groups: those in acids, esters, and other acid derivatives (see Chapter 21). LAH reduces ketones to secondary alcohols, and it reduces aldehydes, acids, and esters to primary alcohols. The lithium salt of the alkoxide ion is initially formed, then the (cautious!) addition of dilute acid protonates the alkoxide. For example, LAH reduces both functional groups of the keto ester in the previous example.

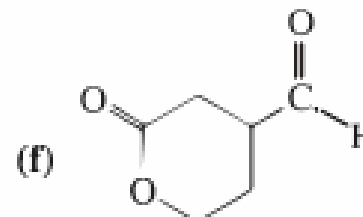
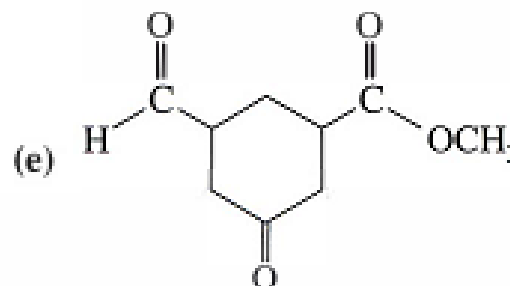
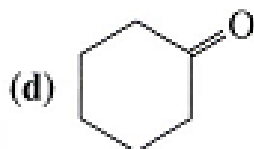
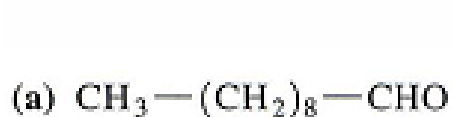


In summary, sodium borohydride is the best reagent for reduction of a simple ketone or aldehyde. Using  $\text{NaBH}_4$ , we can reduce a ketone or an aldehyde in the presence of an acid or an ester, but we do not have a method (so far) for reducing an acid or an ester in the presence of a ketone or an aldehyde. The sluggish acid or ester requires the use of  $\text{LiAlH}_4$ , and this reagent also reduces the ketone or aldehyde.



### PROBLEM 10-24

Predict the products you would expect from the reaction of  $\text{NaBH}_4$  with the following compounds.

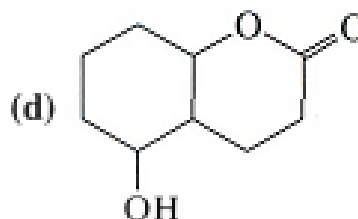


### PROBLEM 10-25

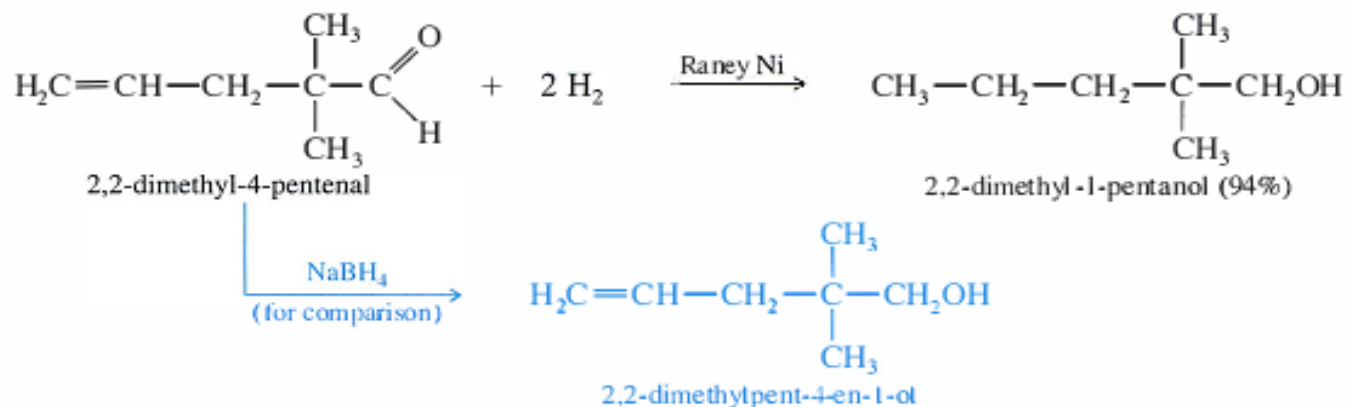
Repeat Problem 10-24 using  $\text{LiAlH}_4$  (followed by hydrolysis) as the reagent.

### PROBLEM 10-26

Show how you would synthesize the following alcohols by reducing appropriate carbonyl compounds.

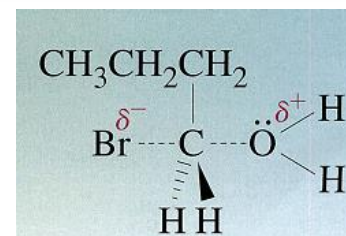


## Catalytic Hydrogenation of Ketones and Aldehydes



## Reactions of Alcohols

### Types of Reactions of Alcohols



$R-OH$	$\xrightarrow{\text{type of reaction}}$	Product
$R-OH$	dehydration	alkenes
$R-OH$	oxidation	ketones, aldehydes, acids
$R-OH$	substitution	$R-X$ halides
$R-OH$	reduction	$R-H$ alkanes
$R-OH$	esterification	$R-O-\overset{\text{O}}{\parallel}{C}-R'$ esters
$R-OH$	tosylation	$R-OTs$ tosylate esters (good leaving group)
$R-OH$	(1) form alkoxide (2) $R'X$	$R-O-R'$ ethers

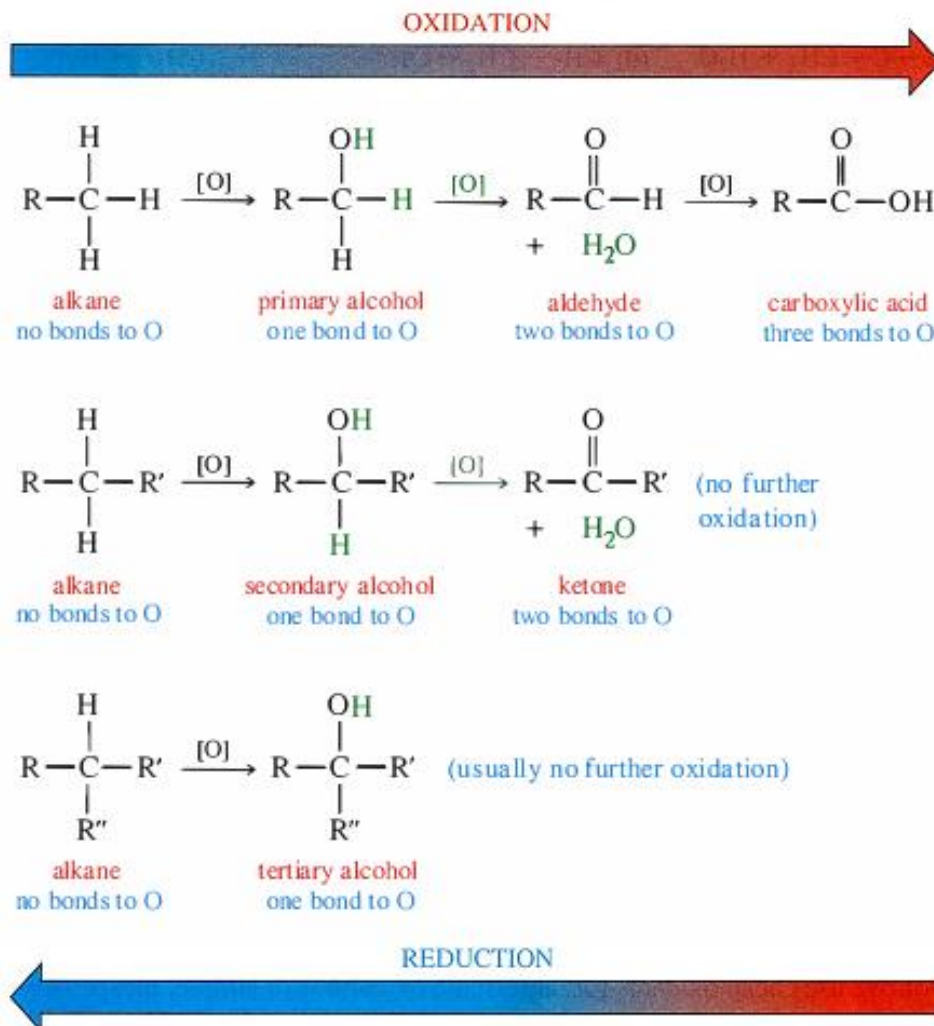
# Oxidation States of Alcohols and Related Functional Groups

Oxidation of alcohols leads to ketones, aldehydes, and carboxylic acids. These functional groups, in turn, undergo a wide variety of additional reactions. For these reasons, alcohol oxidations are some of the most common organic reactions.

**OXIDATION:** addition of O or O<sub>2</sub>; addition of X<sub>2</sub> (halogens); loss of H<sub>2</sub>.

**REDUCTION:** addition of H<sub>2</sub> (or H<sup>-</sup>); loss of O or O<sub>2</sub>; loss of X<sub>2</sub>.

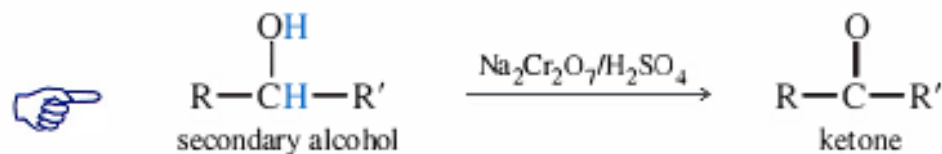
**NEITHER:** addition or loss of H<sup>+</sup>, H<sub>2</sub>O, HX, etc. is neither an oxidation nor a reduction.



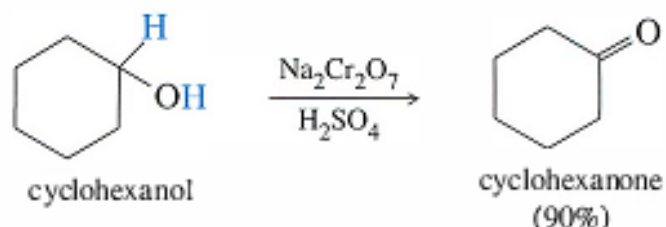
## Oxidation of Alcohols

### Oxidation of Secondary Alcohols

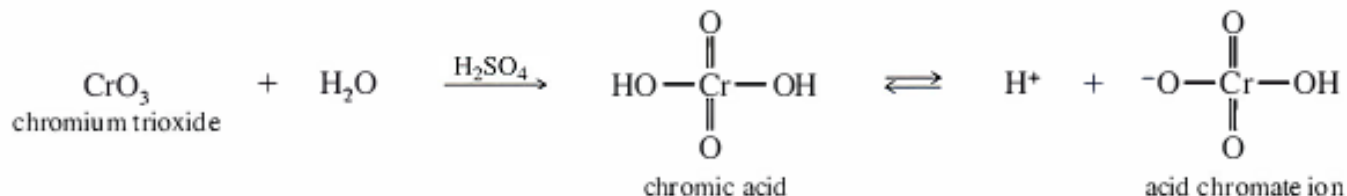
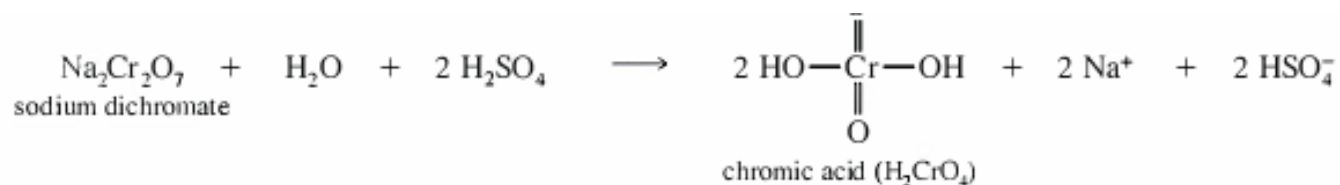
Secondary alcohols are easily oxidized to give excellent yields of ketones. The **chromic acid reagent** is often best for laboratory oxidations of secondary alcohols.



*Example*

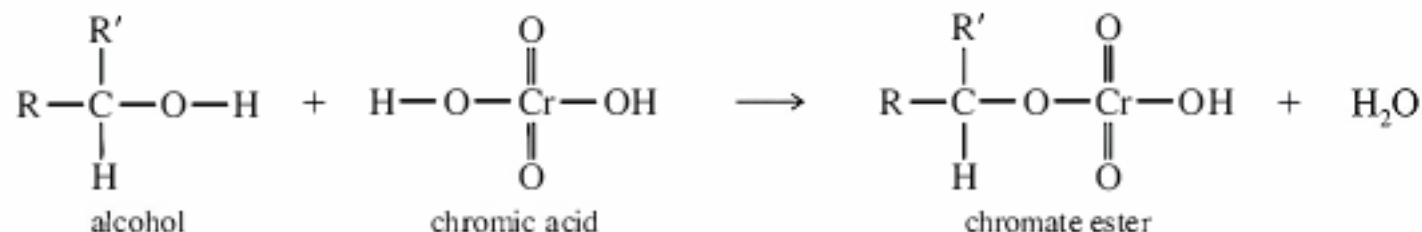


The chromic acid reagent is prepared by dissolving sodium dichromate, ( $\text{Na}_2\text{Cr}_2\text{O}_7$ ) in a mixture of sulfuric acid and water. The active species in the mixture is probably chromic acid,  $\text{H}_2\text{CrO}_4$ , or the acid chromate ion,  $\text{HCrO}_4^-$ . Adding chromium trioxide ( $\text{CrO}_3$ ) to dilute sulfuric acid achieves the same result.

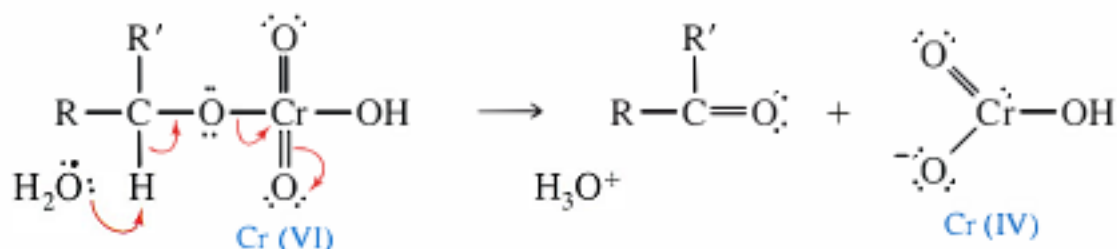


The mechanism of chromic acid oxidation probably involves the formation of a chromate ester. Elimination of the chromate ester gives the ketone. In the elimination, the carbinol carbon retains its oxygen atom but loses its hydrogen and gains the second bond to oxygen.

*Formation of the chromate ester*



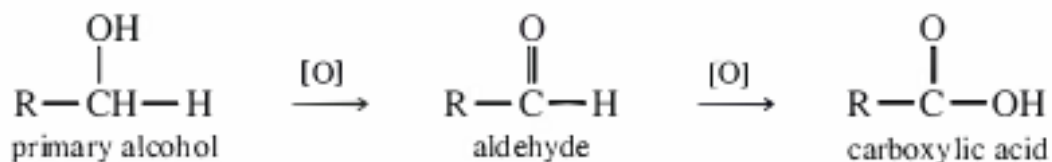
*Elimination of the chromate ester and oxidation of the carbinol carbon*



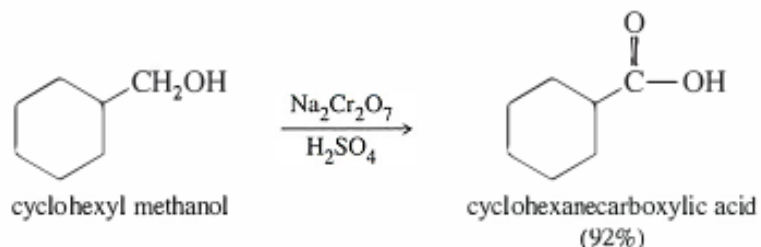
The chromium(IV) species formed reacts further to give the stable reduced form, chromium(III). Both sodium dichromate and chromic acid are orange, while chromic ion ( $\text{Cr}^{3+}$ ) is a deep blue. One can follow the progress of a chromic acid oxidation by observing the color change from orange through various shades of green to a greenish blue. In fact, the color change observed with chromic acid can be used as a test for the presence of an oxidizable alcohol.

## Oxidation of Primary Alcohols

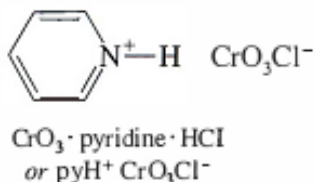
Oxidation of a primary alcohol initially forms an aldehyde. Unlike a ketone, however, an aldehyde is easily oxidized further to give a carboxylic acid.



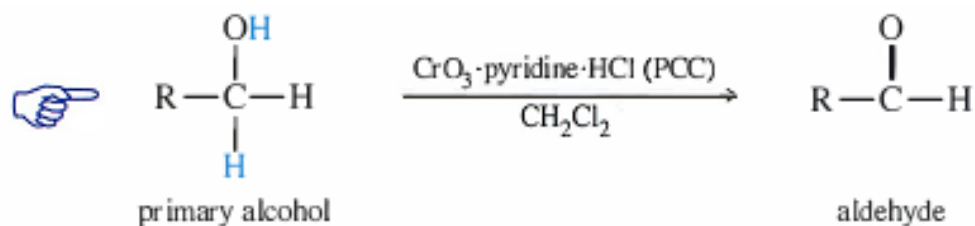
Obtaining the aldehyde is often difficult, since most oxidizing agents strong enough to oxidize primary alcohols also oxidize aldehydes. Chromic acid generally oxidizes a primary alcohol all the way to the carboxylic acid.



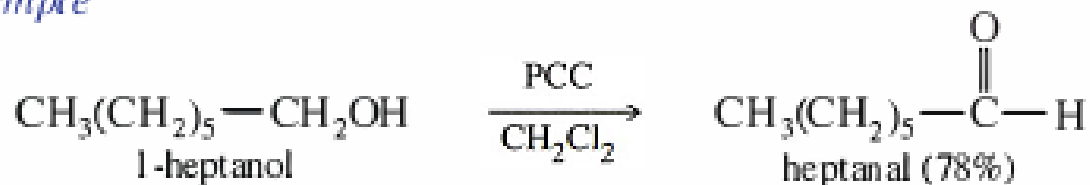
*Pyridinium chlorochromate (PCC):*



A better reagent for the limited oxidation of primary alcohols to aldehydes is **pyridinium chlorochromate (PCC)**, a complex of chromium trioxide with pyridine and HCl. PCC oxidizes most primary alcohols to aldehydes in excellent yields. Unlike most other oxidants, PCC is soluble in nonpolar solvents such as dichloromethane ( $\text{CH}_2\text{Cl}_2$ ), which is an excellent solvent for most organic compounds. PCC can also serve as a mild reagent for oxidizing secondary alcohols to ketones.



### Example



## Resistance of Tertiary Alcohols to Oxidation

### Summary of Alcohol Oxidations

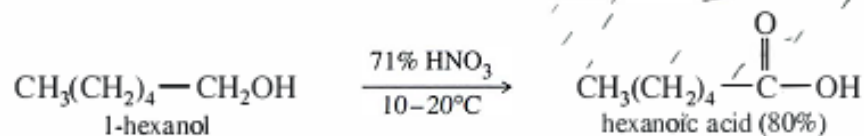
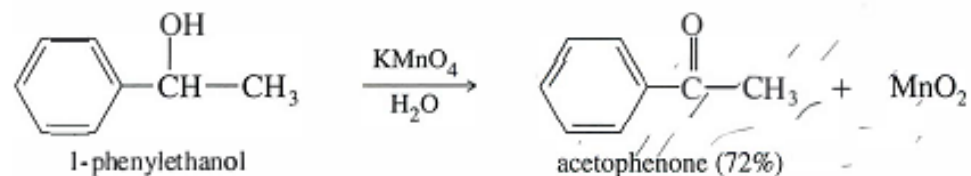
To Oxidize	Product	Reagent
2° alcohol	ketone	chromic acid (or PCC)
1° alcohol	aldehyde	PCC
1° alcohol	carboxylic acid	chromic acid

### PROBLEM 11-2

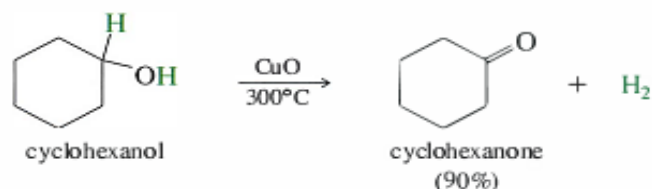
Predict the products of the reactions of the following compounds with chromic acid and also with PCC.

- |                          |   |
|--------------------------|---|
| (a) cyclohexanol         | (b) 1-methylcyclohexanol                  |
| (c) 2-methylcyclohexanol | (d) cyclohexanone                         |
| (e) cyclohexane          | (f) acetic acid, $\text{CH}_3\text{COOH}$ |
| (g) ethanol              | (h) acetaldehyde, $\text{CH}_3\text{CHO}$ |

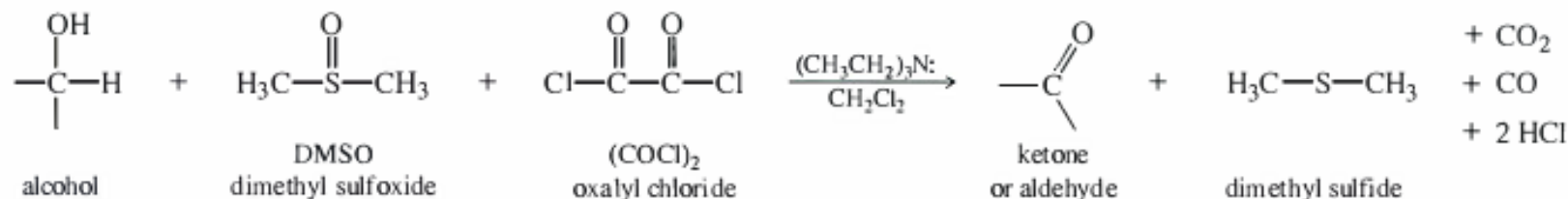
## Additional Methods for Oxidizing Alcohols



*Example*

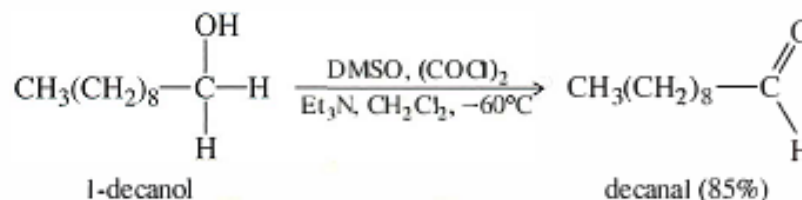
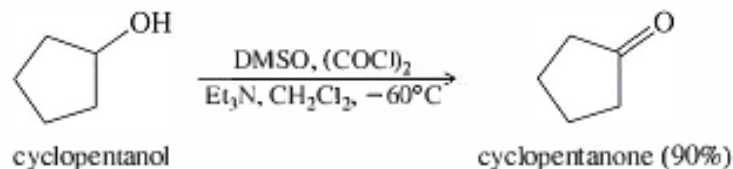


The **Swern oxidation** uses dimethyl sulfoxide (DMSO) as the oxidizing agent to convert alcohols to ketones and aldehydes. DMSO and oxalyl chloride are added to the alcohol at low temperature, followed by a hindered base such as triethylamine. Secondary alcohols are oxidized to ketones, and primary alcohols are oxidized only as far as the aldehyde. The byproducts of this reaction are all volatile and are easily separated from the organic products.

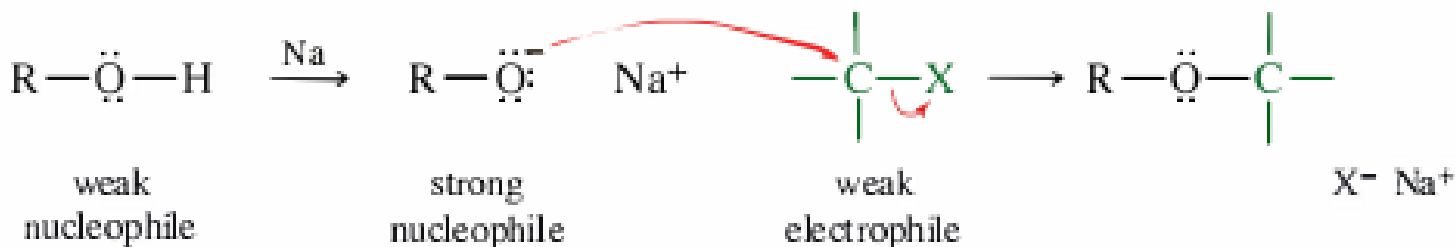
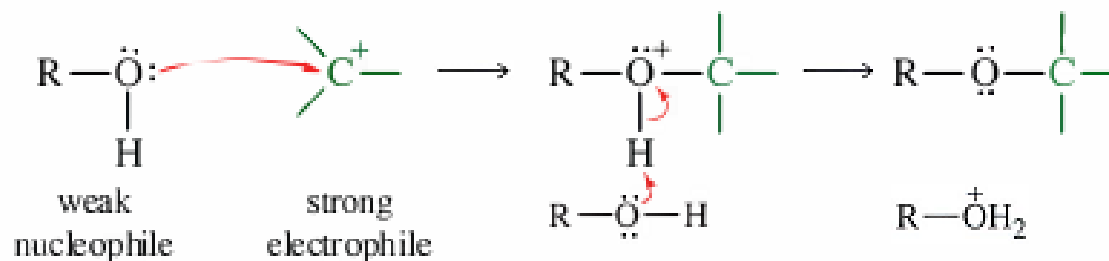




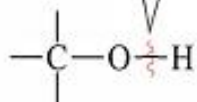
## Examples



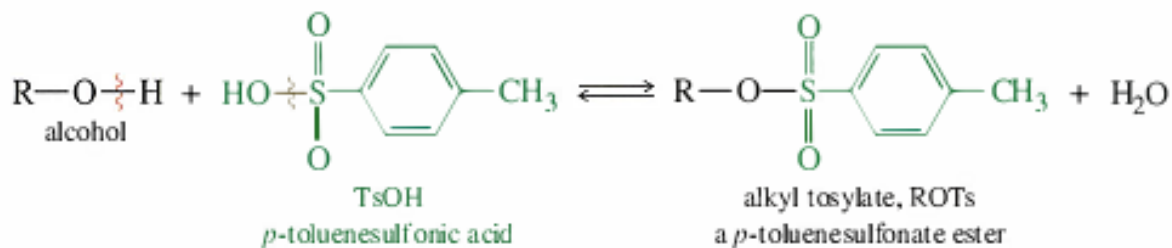
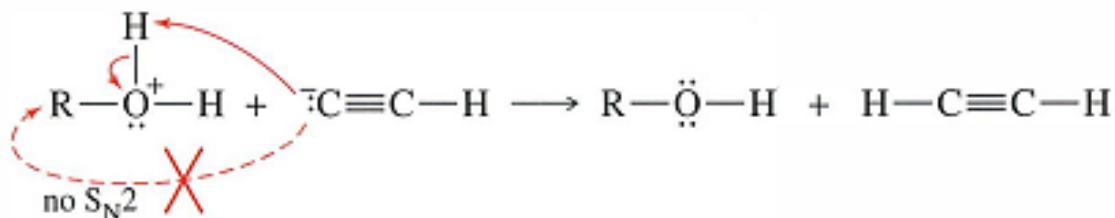
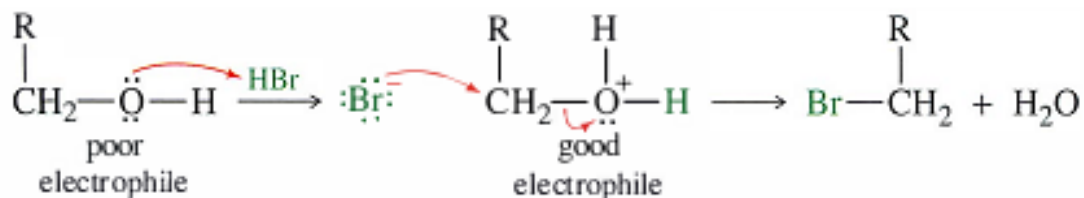
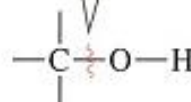
## Alcohols as Nucleophiles and Electrophiles: Formation of Tosylates



This bond is broken when alcohols react as nucleophiles.

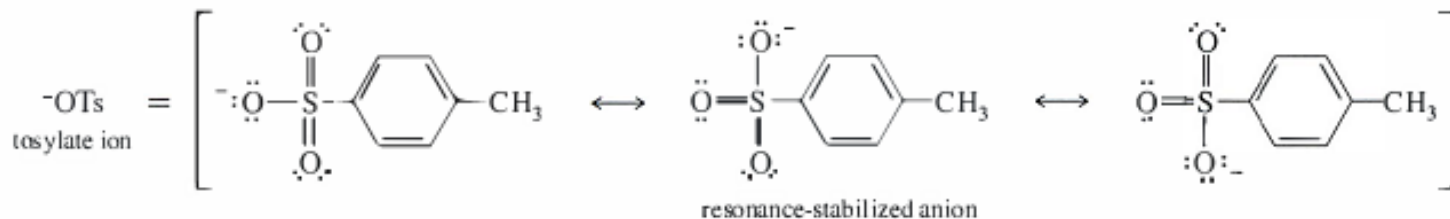
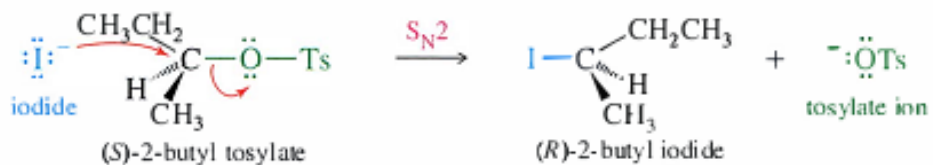
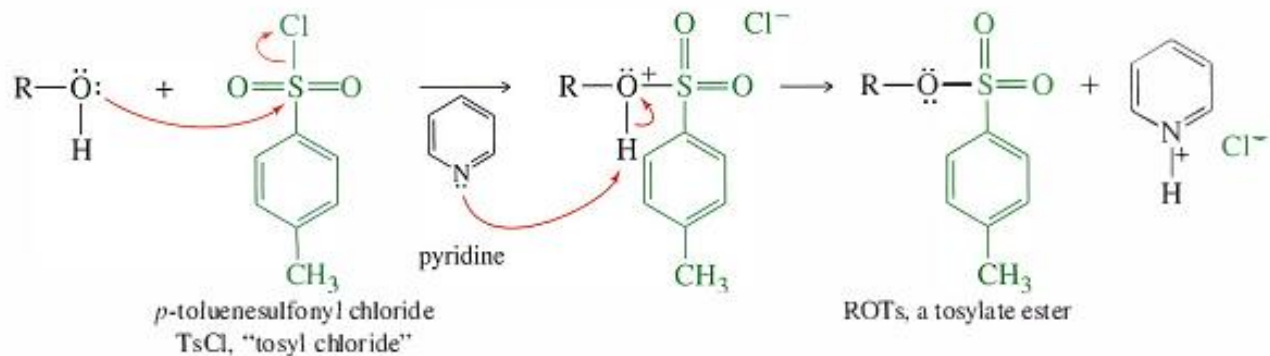
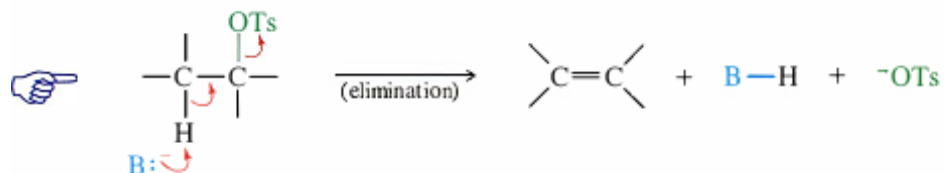


This bond is broken when alcohols react as electrophiles.

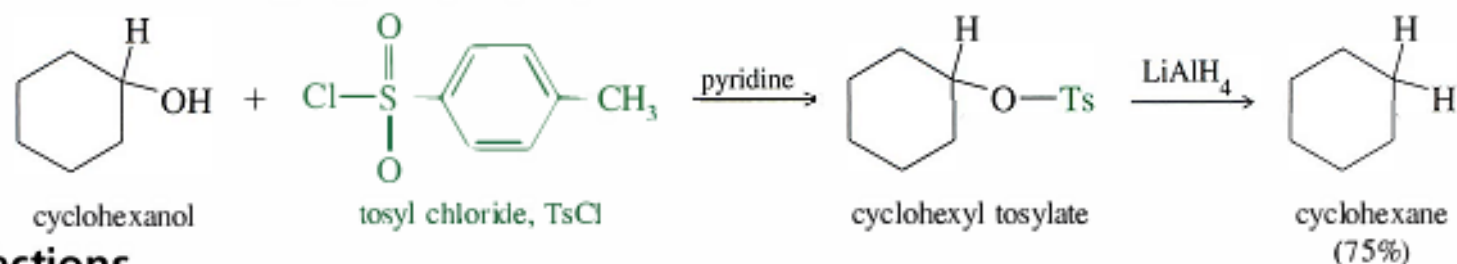
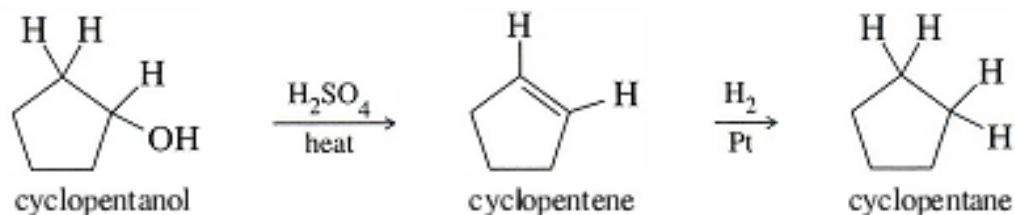




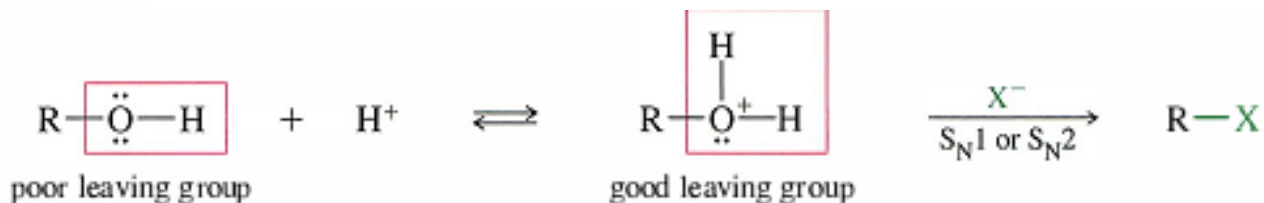
or elimination:



## Reduction of Alcohols



## Reactions of Alcohols with Hydrohalic Acids



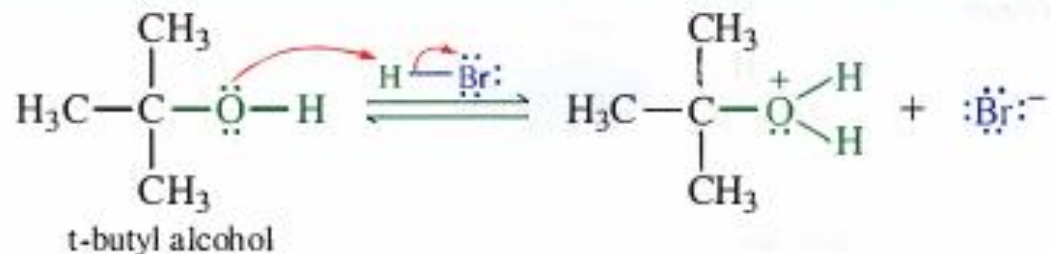
## Reactions with Hydrobromic Acid



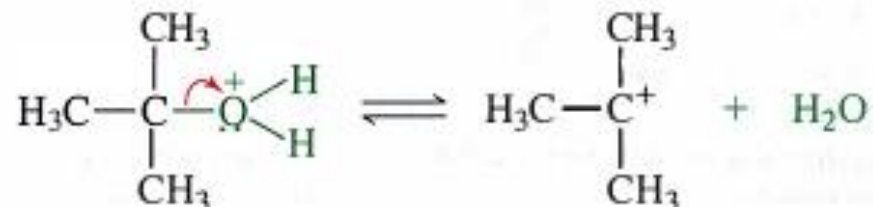
A tertiary alcohol reacts with HBr by the S<sub>N</sub>1 mechanism.

**EXAMPLE: Conversion of t-butyl alcohol to t-butyl bromide.**

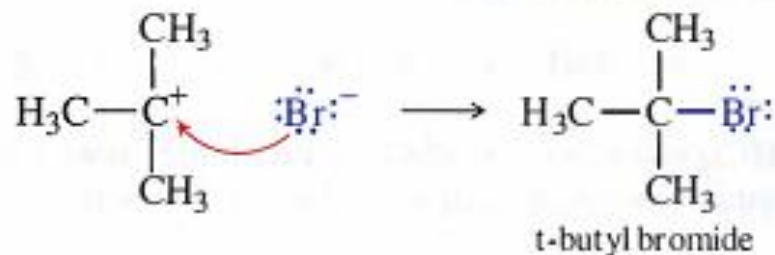
*Step 1:* Protonation converts the hydroxyl group to a good leaving group.



*Step 2:* Water leaves, forming a carbocation.



*Step 3:* Bromide ion attacks the carbocation.





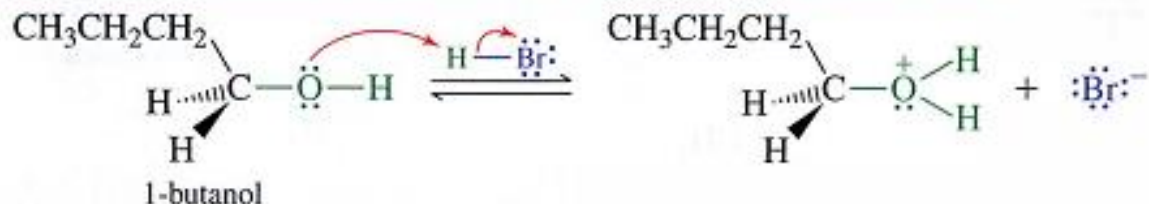
### MECHANISM 11-2

### Reaction of a Primary Alcohol with HBr ( $S_N2$ )

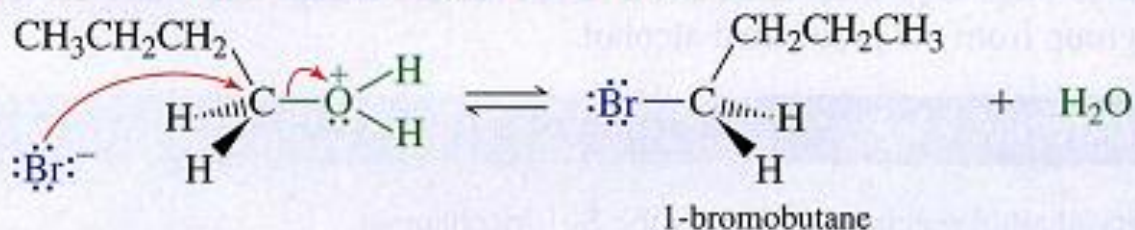
A primary alcohol reacts with HBr by the  $S_N2$  mechanism.

**EXAMPLE: Conversion of 1-butanol to 1-bromobutane.**

*Step 1:* Protonation converts the hydroxyl group to a good leaving group.



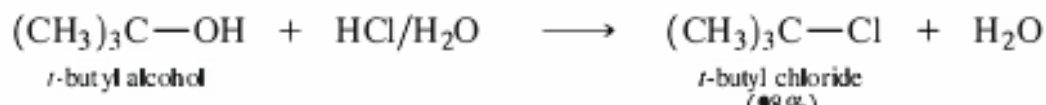
*Step 2:* Bromide displaces water to give the alkylbromide.



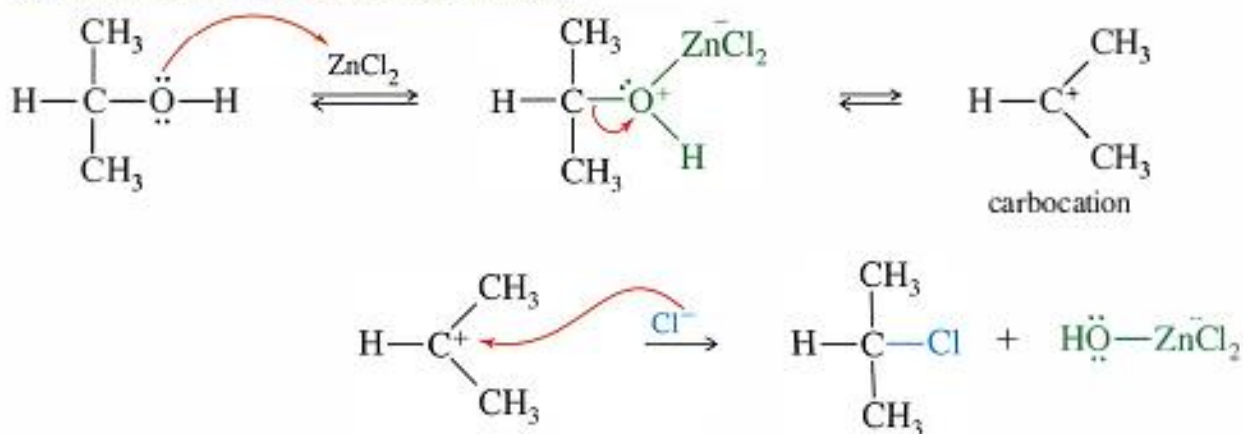
## Reactions with Hydrochloric Acid



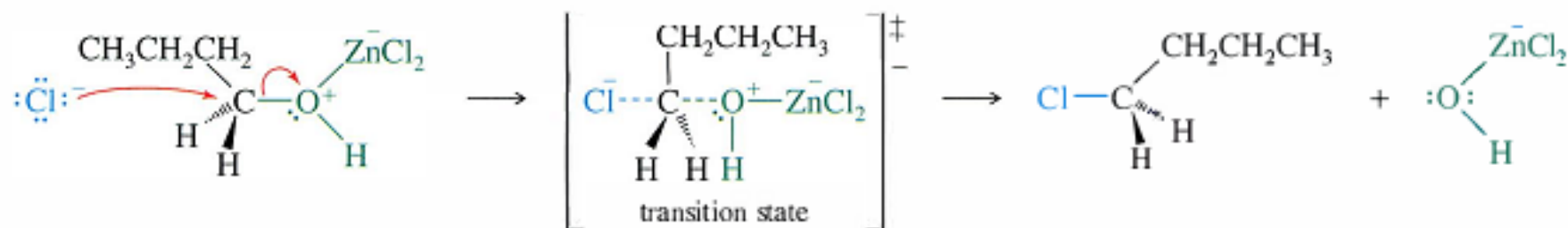
Hydrochloric acid (HCl) reacts with alcohols in much the same way that hydrobromic acid does. For example, concentrated aqueous HCl reacts with *t*-butyl alcohol to give *t*-butyl chloride.



*S<sub>N</sub>1* reaction with the Lucas reagent (fast)



*S<sub>N</sub>2* reaction with the Lucas reagent (slow)

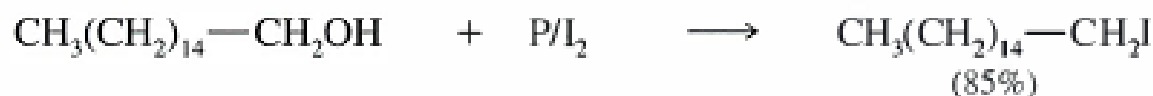
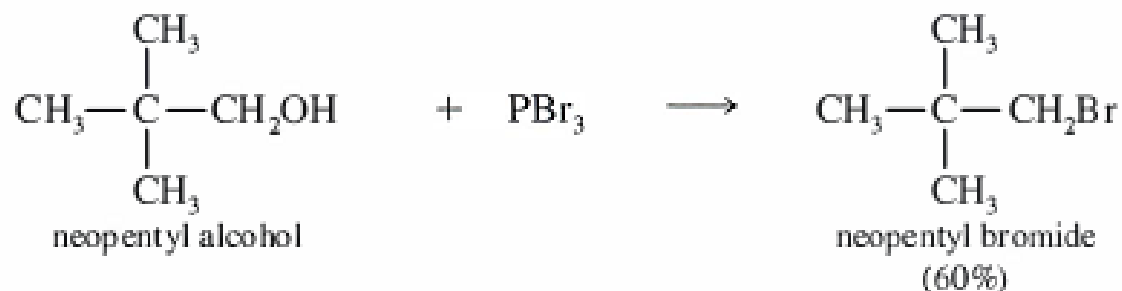


## Reactions of Alcohols with Phosphorus Halides

Several phosphorus halides are useful for converting alcohols to alkyl halides. Phosphorus tribromide, phosphorus trichloride, and phosphorus pentachloride work well and are commercially available.

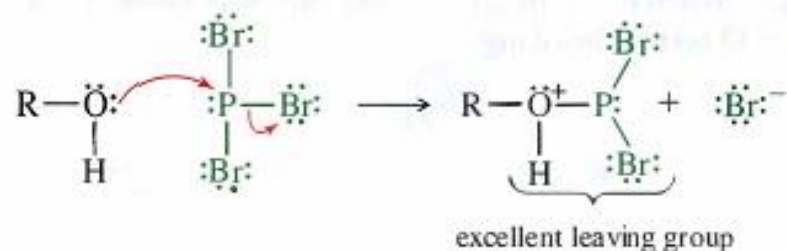


The following examples show the conversion of primary and secondary alcohols to bromides and iodides by treatment with  $\text{PBr}_3$  and  $\text{P/I}_2$ .

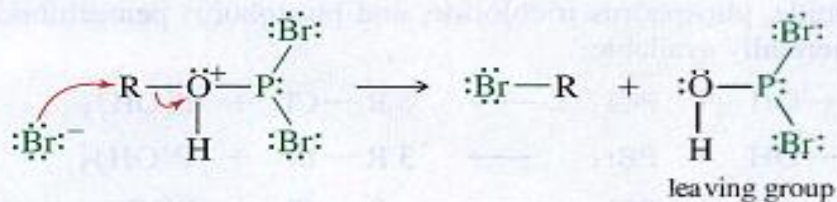




**Step 1:** PBr<sub>3</sub> is a strong electrophile. An alcohol displaces bromide ion from PBr<sub>3</sub> to give an excellent leaving group.

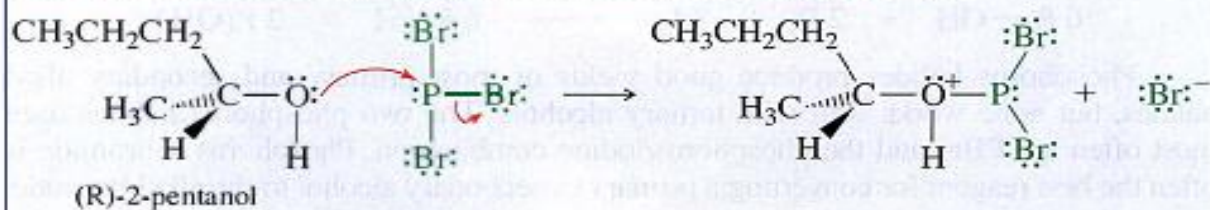


**Step 2:** Bromide displaces the leaving group to give the alkyl bromide.

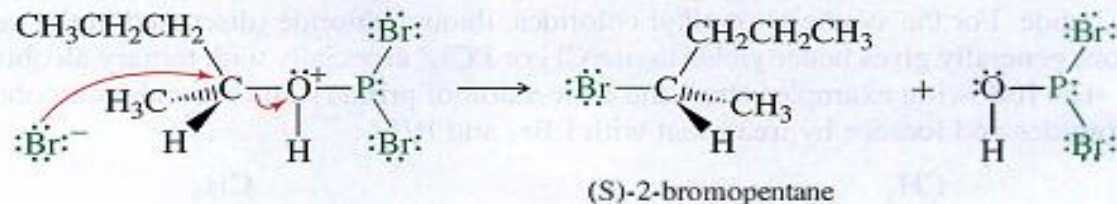


**EXAMPLE: Reaction of (R)-2-pentanol with PBr<sub>3</sub>.**

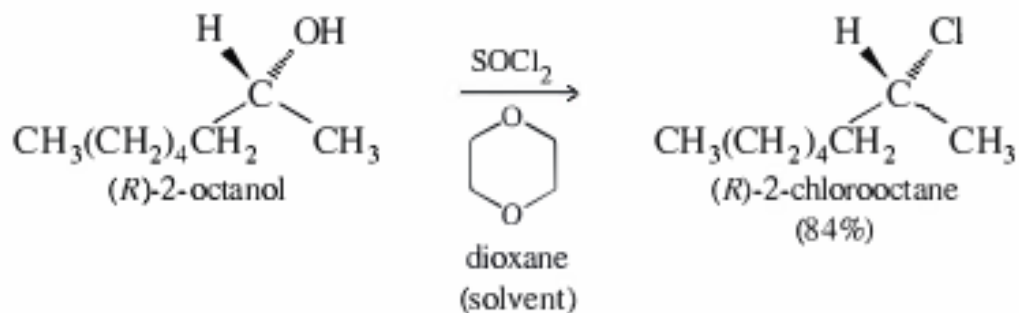
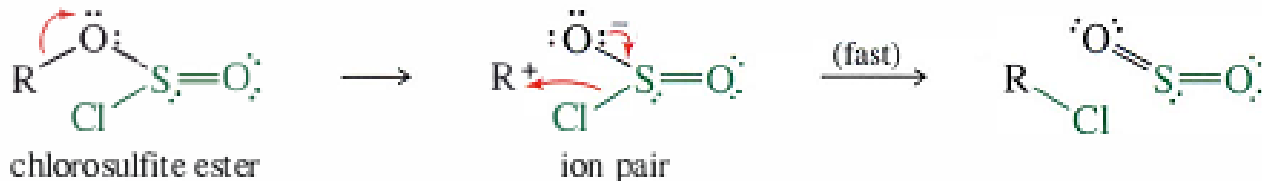
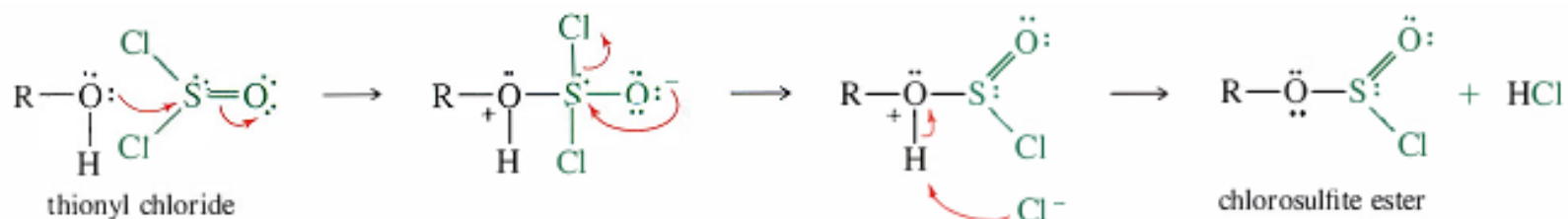
**Step 1:** Displacement of bromide and formation of a leaving group.



**Step 2:** Bromide displaces the leaving group to give (S)-2-bromopentane.



# Reactions of Alcohols with Thionyl Chloride



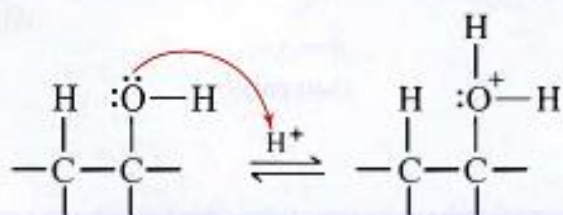
# Dehydration Reactions of Alcohols

## MECHANISM 11-4

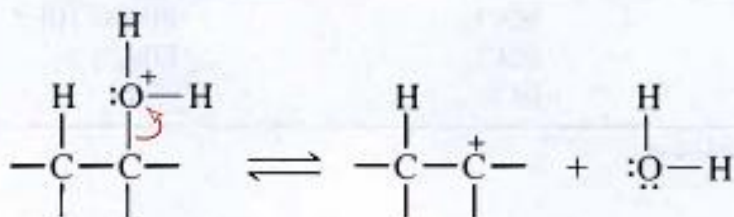
### (Review): Acid-Catalyzed Dehydration of an Alcohol

Dehydration results from E1 elimination of the protonated alcohol

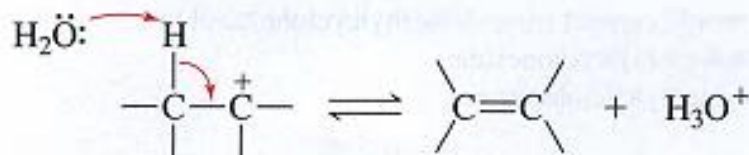
**Step 1:** Protonation converts the hydroxyl group to a good leaving group.

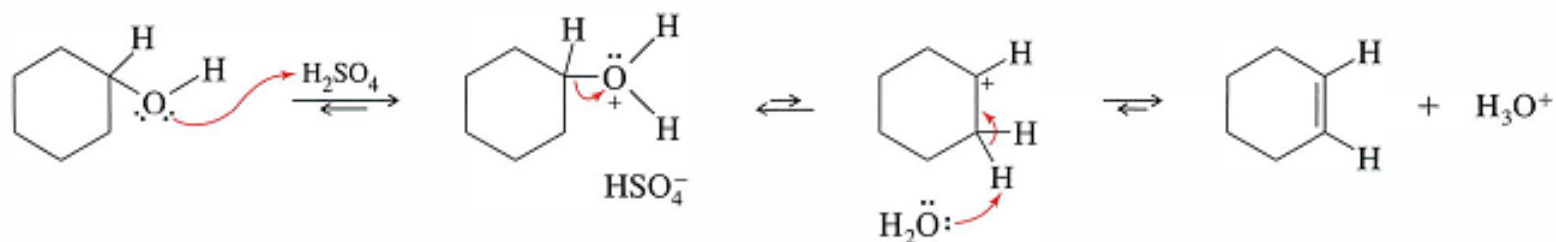
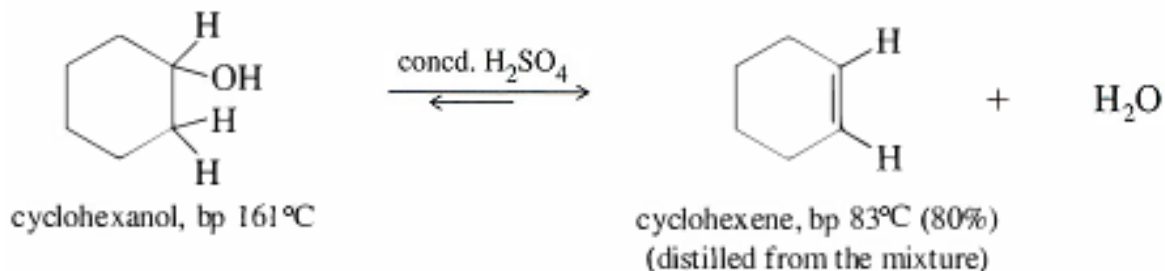


**Step 2:** Water leaves, forming a carbocation.

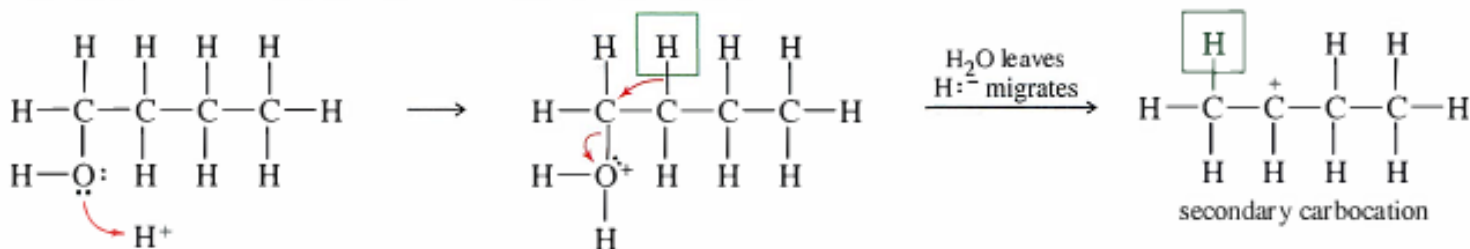


**Step 3:** Loss of a proton gives the alkene.

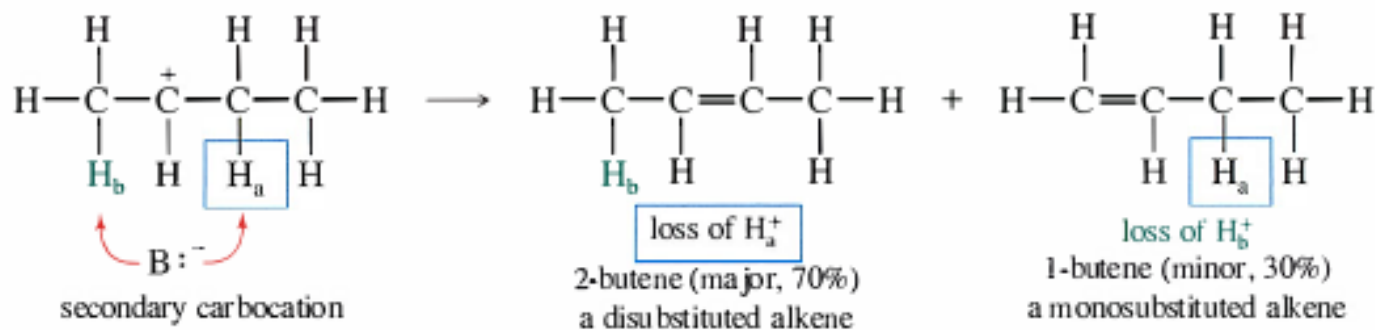




*Ionization of the protonated alcohol, with rearrangement*



*Loss of either proton to give two products*



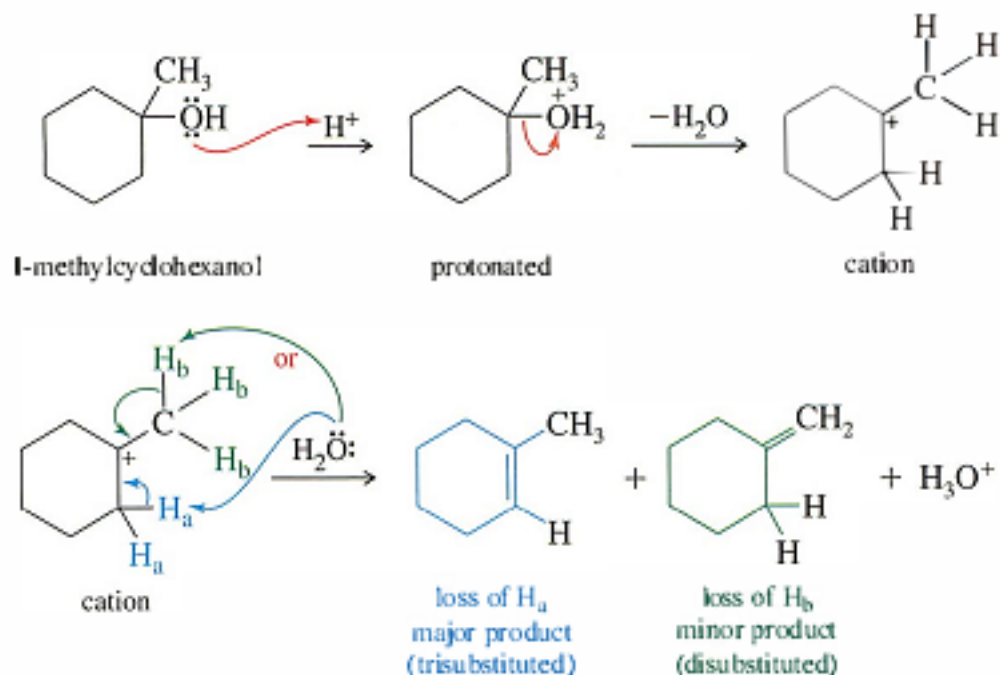
### SOLVED PROBLEM 11-3

Predict the products of sulfuric acid-catalyzed dehydration of the following alcohols.

- (a) 1-methylcyclohexanol                      (b) neopentyl alcohol

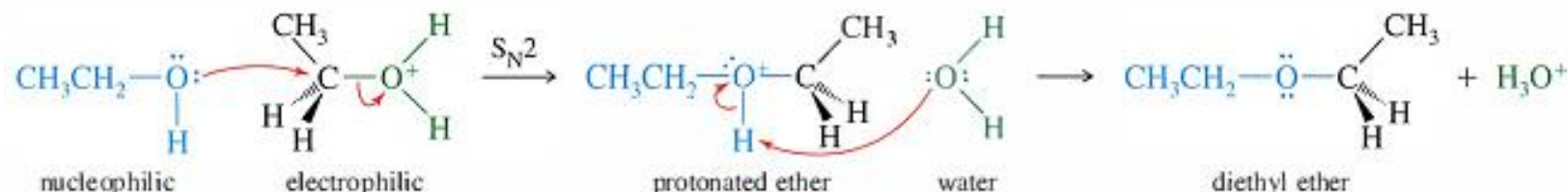
### SOLUTION

- (a) 1-Methylcyclohexanol reacts to form a tertiary carbocation. A proton may be abstracted from any one of three carbon atoms. The two secondary atoms are equivalent, and abstraction of a proton from one of these carbons leads to the trisubstituted double bond of the major product. Abstraction of a methyl proton leads to the disubstituted double bond of the minor product.



## Bimolecular Dehydration to Form Ethers (Industrial)

In some cases, a protonated primary alcohol may be attacked by another molecule of the alcohol and undergo an  $S_N2$  displacement. The net reaction is a bimolecular dehydration to form an ether. For example, the attack by ethanol on a protonated molecule of ethanol gives diethyl ether.



diethyl ether ( $\text{CH}_3\text{CH}_2-\text{O}-\text{CH}_2\text{CH}_3$ ) and dimethyl ether ( $\text{CH}_3-\text{O}-\text{CH}_3$ ). Under the acidic dehydration conditions, two reactions compete: Elimination (to give an alkene) competes with substitution (to give an ether).

*Substitution to give the ether; a bimolecular dehydration*



*Elimination to give the alkene, a unimolecular dehydration*

