

# Chapter 7: Alcohols, Phenols and Thiols

45

$\text{CH}_3\text{CH}_2\text{OH}$   
ethanol

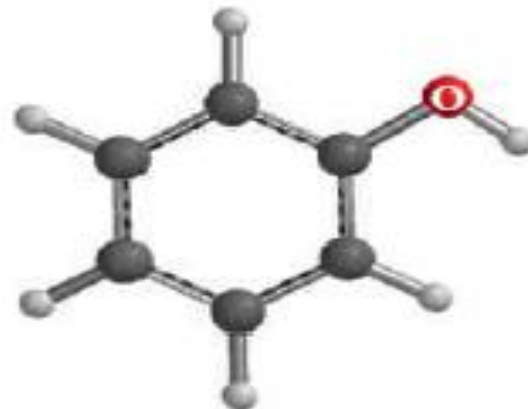




water



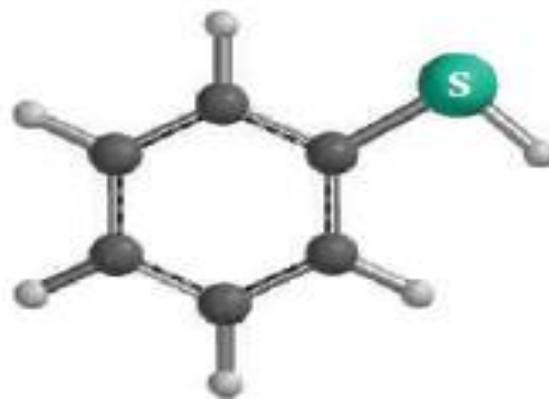
an alcohol



a phenol



a thiol



a thiophenol

**-Alcohols** have the general formula  $R-OH$  and are characterized by the presence of a **hydroxyl group,  $-OH$** .

**-Phenols** have a hydroxyl group attached directly to an aromatic ring.

**-Thiols** and thiophenols are similar to alcohols and phenols, except the oxygen is replaced by sulfur.

## 7.1 Nomenclature of Alcohols

In the IUPAC system, the hydroxyl group in alcohols is indicated by the ending **-ol**. In common names, the separate word *alcohol* is placed after the name of the alkyl group.



methanol

(methyl alcohol)



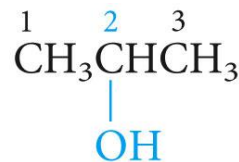
ethanol

(ethyl alcohol)



1-propanol

(*n*-propyl alcohol)



2-propanol

(isopropyl alcohol)



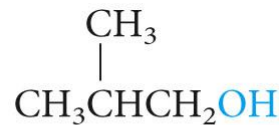
1-butanol

(*n*-butyl alcohol)



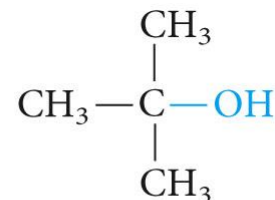
2-butanol

(*sec*-butyl alcohol)



2-methyl-1-propanol

(isobutyl alcohol)

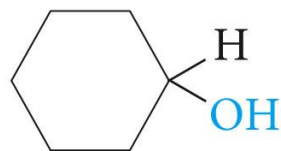


2-methyl-2-propanol

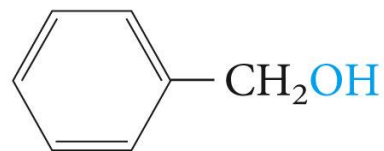
(*tert*-butyl alcohol)



2-propen-1-ol  
(allyl alcohol)



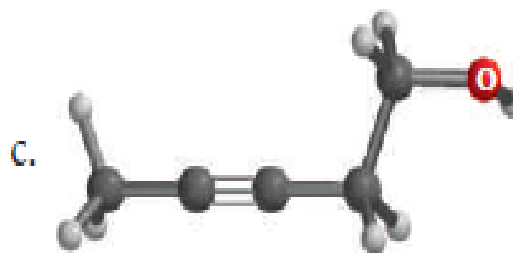
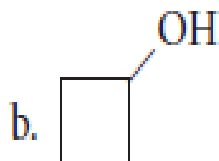
cyclohexanol  
(cyclohexyl alcohol)



phenylmethanol  
(benzyl alcohol)

### EXAMPLE 7.1

Name the following alcohols by the IUPAC system:



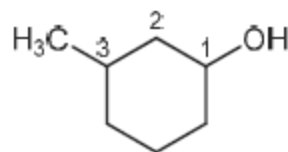
### Solution

- a. 3-bromopropanol (number from the hydroxyl-bearing carbon)
- b. cyclobutanol
- c. 3-pentyne-1-ol (*not* 2-pentyne-5-ol)

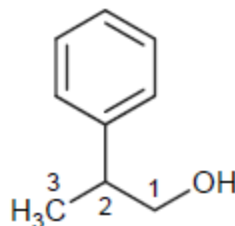
**PROBLEM 7.2** Write a structural formula for

- a. 3-methylcyclohexanol
- b. 2-phenylpropanol
- c. 3-pentyn-2-ol

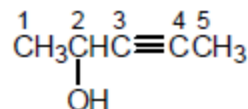
a.



b.



c.



## 7.2 Classification of Alcohols

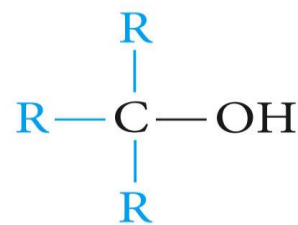
Alcohols are classified as primary ( $1^\circ$ ), secondary ( $2^\circ$ ), or tertiary ( $3^\circ$ ), depending on whether one, two, or three organic groups are connected to the hydroxyl-bearing carbon atom



primary ( $1^\circ$ )

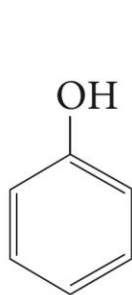


secondary ( $2^\circ$ )



tertiary ( $3^\circ$ )

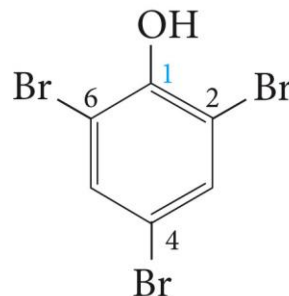
## 7.3 Nomenclature of Phenols



phenol

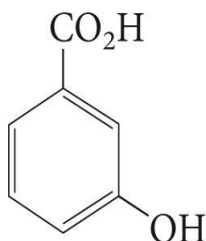


*p*-chlorophenol

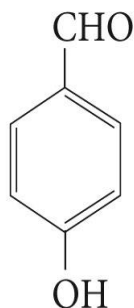


2,4,6-tribromophenol

The hydroxyl group is named as a substituent when it occurs in the same molecule with carboxylic acid, aldehyde, or ketone functionalities, which have priority in naming. Examples are



*m*-hydroxy  
benzoic acid



*p*-hydroxybenzaldehyde

but



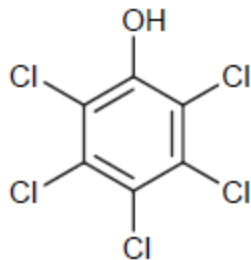
*p*-nitrophenol  
(not *p*-hydroxynitrobenzene)

## PROBLEM 7.4

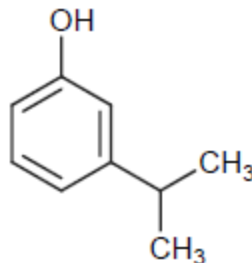
Write the structure for

- a. pentachlorophenol.
- b. *m*-isopropylphenol
- c. *o*-hydroxyacetophenone
- d. 3-hydroxy-5-nitrobenzaldehyde

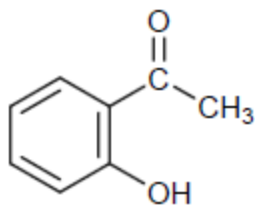
a.



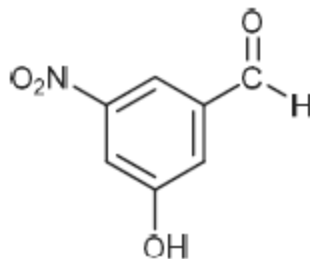
b.



c.



d.



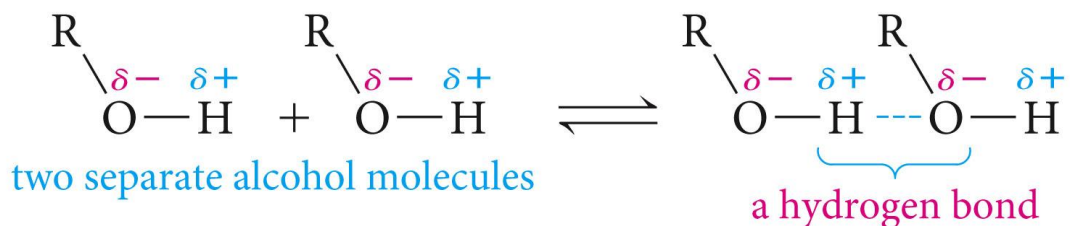


## 4.4 Hydrogen bonding in Alcohols and Phenols

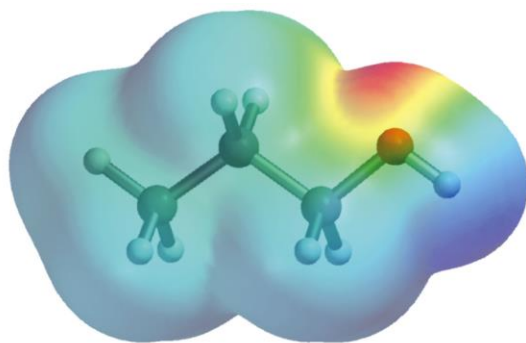
The boiling points of alcohols are much higher than those of ethers or hydrocarbons with similar molecular weights.

	$\text{CH}_3\text{CH}_2\text{OH}$	$\text{CH}_3\text{OCH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_3$
mol wt	46	46	44
bp	+78.5°C	-24°C	-42°C

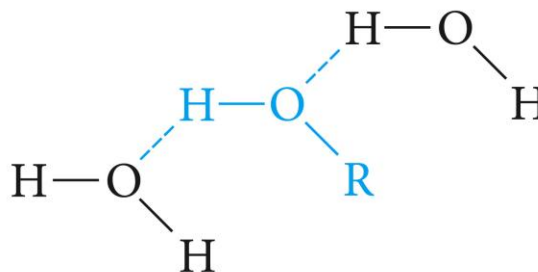
Why? Because alcohols form *hydrogen bonds* with one another



The lower-molecular-weight alcohols can readily replace water molecules in the hydrogen-bonded network. This accounts for the complete miscibility of such alcohols with water.



Electronic potential map for 1-propanol



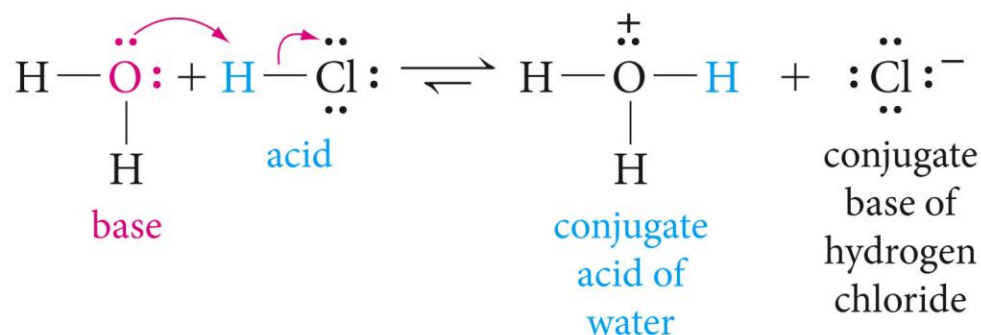
However, as the organic chain lengthens and the alcohol becomes relatively more hydrocarbon like, its water solubility decreases.

**Table 7.1**  **Boiling Point and Water Solubility of Some Alcohols**

<b>Name</b>	<b>Formula</b>	<b>bp, °C</b>	<b>Solubility in H<sub>2</sub>O g/100 g at 20°C</b>
methanol	CH <sub>3</sub> OH	65	completely miscible
ethanol	CH <sub>3</sub> CH <sub>2</sub> OH	78.5	completely miscible
1-propanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> OH	97	completely miscible
1-butanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	117.7	7.9
1-pentanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	137.9	2.7
1-hexanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	155.8	0.59

## 7.5 Acidity and Basicity reviewed

**Brønsted–Lowry acid** is a proton donor, **Brønsted–Lowry base** is a proton acceptor.



The strength of an acid (in water) is measured quantitatively by its acidity constant, or ionization constant,  $K_a$ .

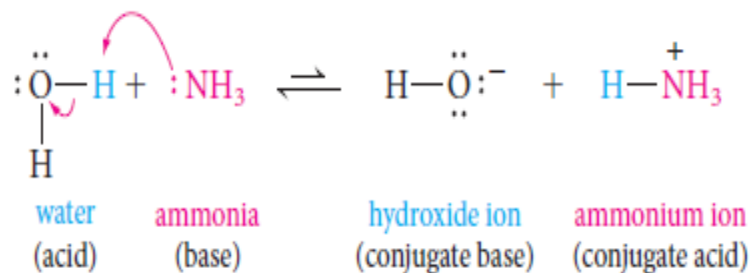
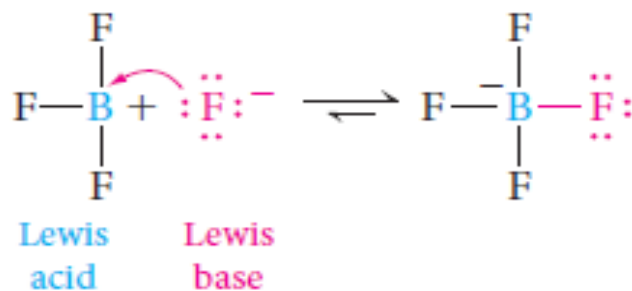
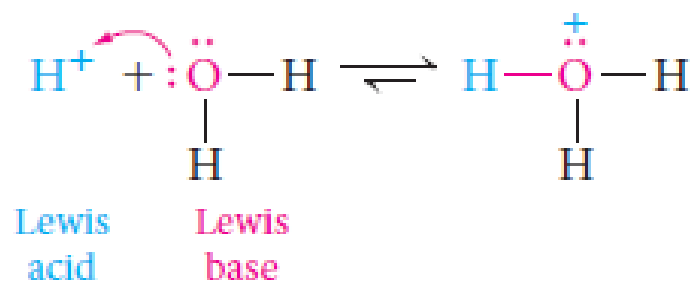


$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

A **Lewis acid** is an electron pair acceptor;

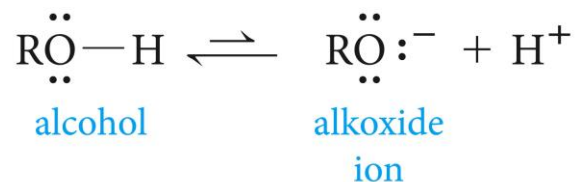
a **Lewis base** is an electron pair donor.

Examples

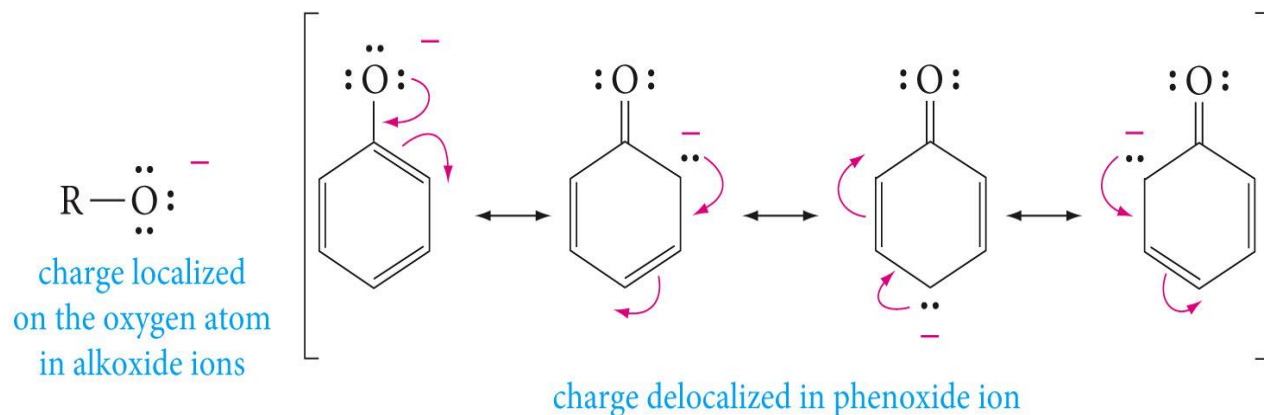


## 7.6 The Acidity of Alcohols and Phenols

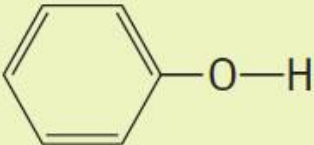

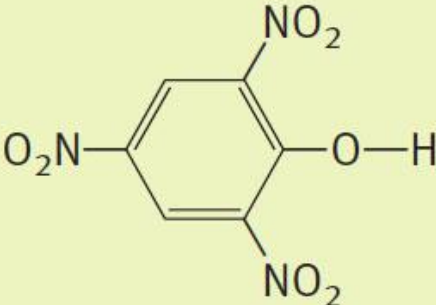
The hydroxyl group can act as a proton donor, and dissociation occurs in a manner similar to that for water:



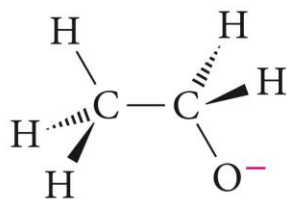
Phenols are much stronger acids than alcohols mainly because the corresponding phenoxide ions are stabilized by resonance. The negative charge of an alkoxide ion is concentrated on the oxygen atom, while the negative charge on the phenoxide ion can be delocalized to the *ortho* and *para* ring positions through resonance



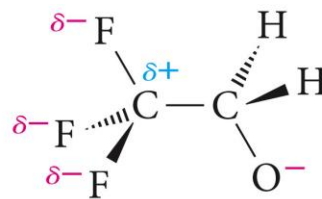
**Table 7.2**  **p  $K_a$ 's of Selected Alcohols and Phenols in Aqueous Aolution**

Name	Formula	p <i>K<sub>a</sub></i>
water	HO—H	15.7
methanol	CH <sub>3</sub> O—H	15.5
ethanol	CH <sub>3</sub> CH <sub>2</sub> O—H	15.9
<i>t</i> -butyl alcohol	(CH <sub>3</sub> ) <sub>3</sub> CO—H	18
2,2,2-trifluoroethanol	CF <sub>3</sub> CH <sub>2</sub> O—H	12.4
phenol		10.0
<i>p</i> -nitrophenol		7.2
picric acid		0.25

## Stabilization by inductive effect

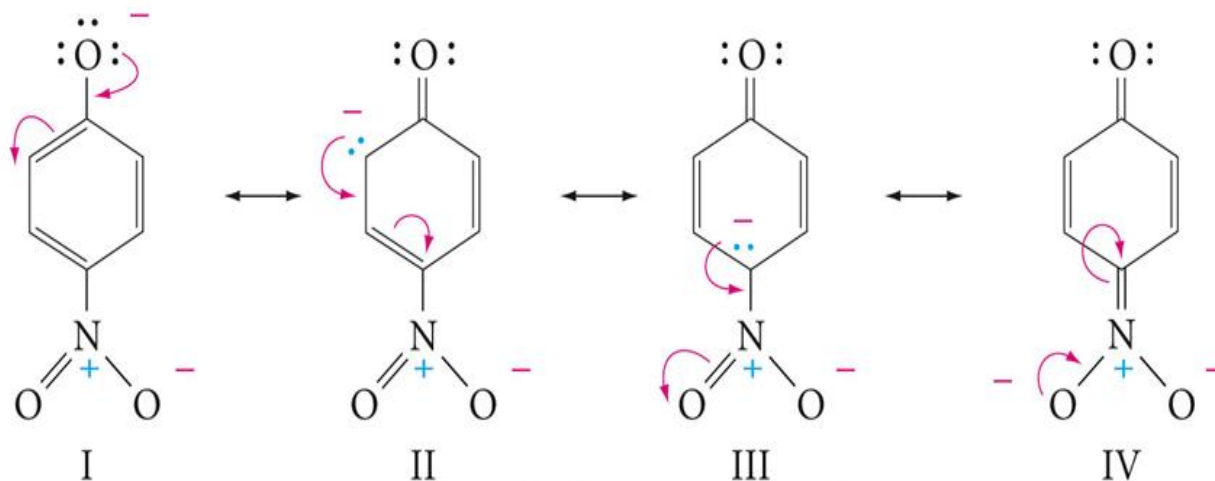


ethoxide ion



2,2,2-trifluoroethoxide ion

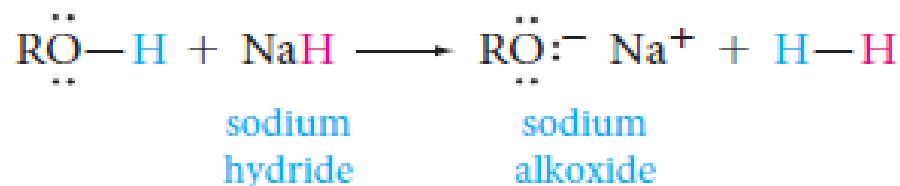
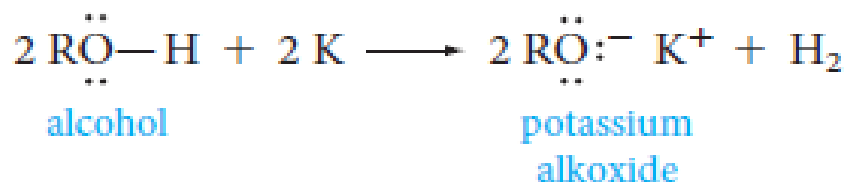
*All electron-withdrawing groups increase acidity by stabilizing the conjugate base. Electron-donating groups decrease acidity because they destabilize the conjugate base.*



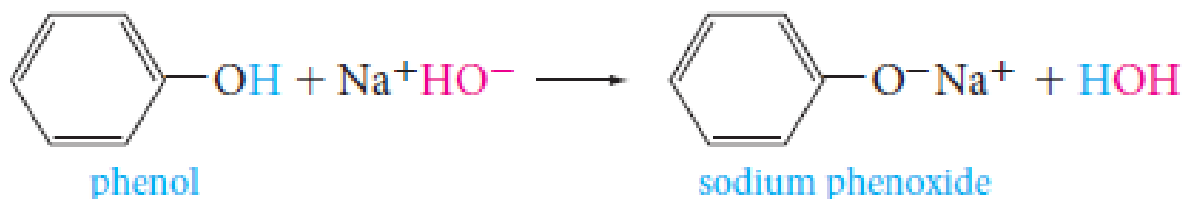
$p$ -nitrophenoxide ion resonance contributors



Alkoxides can be prepared by the reaction of an alcohol with sodium or potassium metal or with a metal hydride

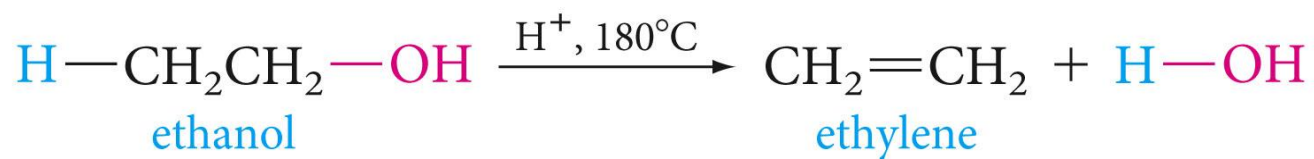


The treatment of alcohols with sodium hydroxide does not convert them to their alkoxides. This is because alkoxides are stronger bases than hydroxide ion. Phenols, however, can be converted to phenoxide ions in this way.



## 7.8 Dehydration of Alcohols to Alkenes

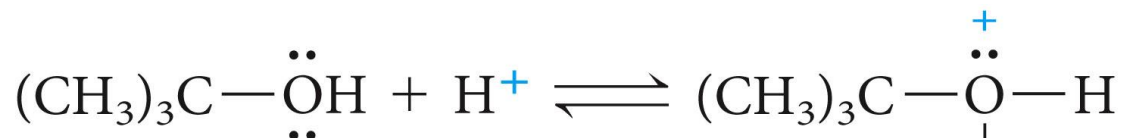
Alcohols can be dehydrated by heating them with a strong acid



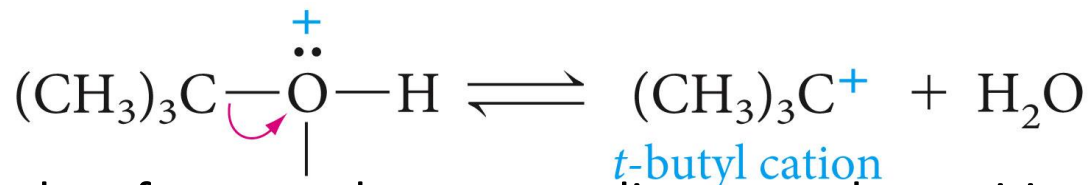
This type of reaction, which can be used to prepare alkenes, is the reverse of hydration . It is an *elimination reaction* and can occur by either an E1 or an E2 mechanism, depending on the class of the alcohol.

Tertiary alcohols dehydrate by the E1 mechanism.

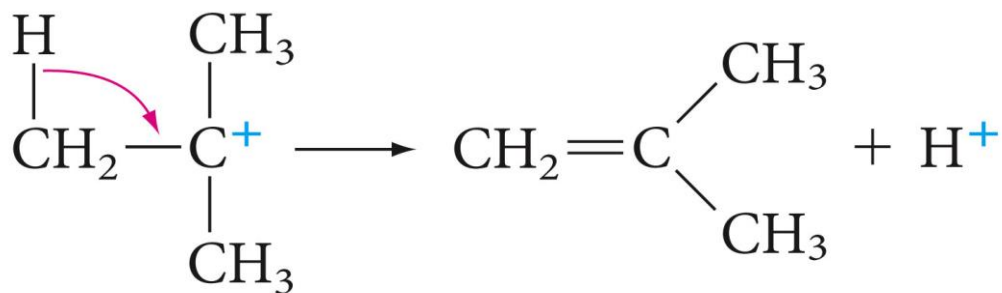
The first step involves rapid and reversible protonation of the hydroxyl group.



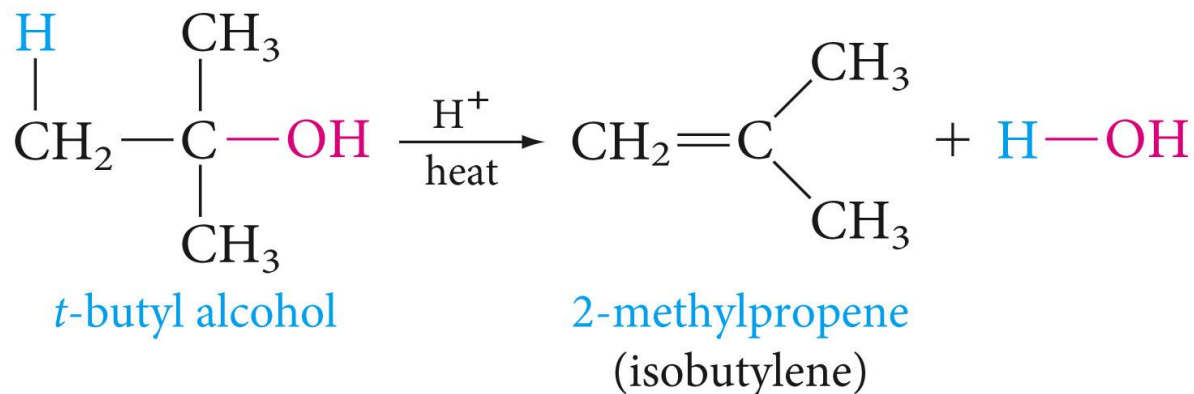
Ionization (the rate-determining step), with water as the leaving group, occurs readily because the resulting carbocation is tertiary.



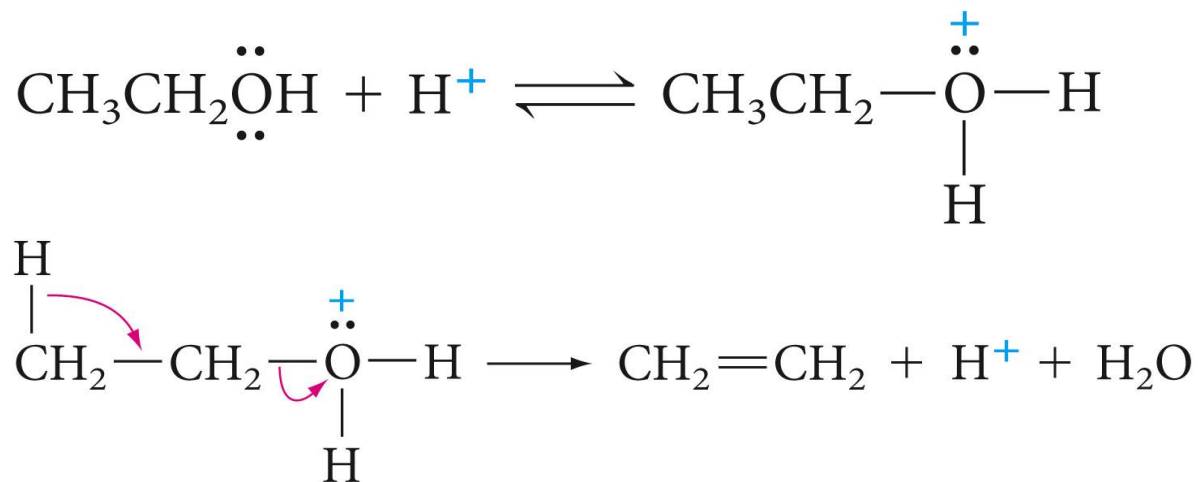
Proton loss from a carbon atom adjacent to the positive carbon completes the reaction.



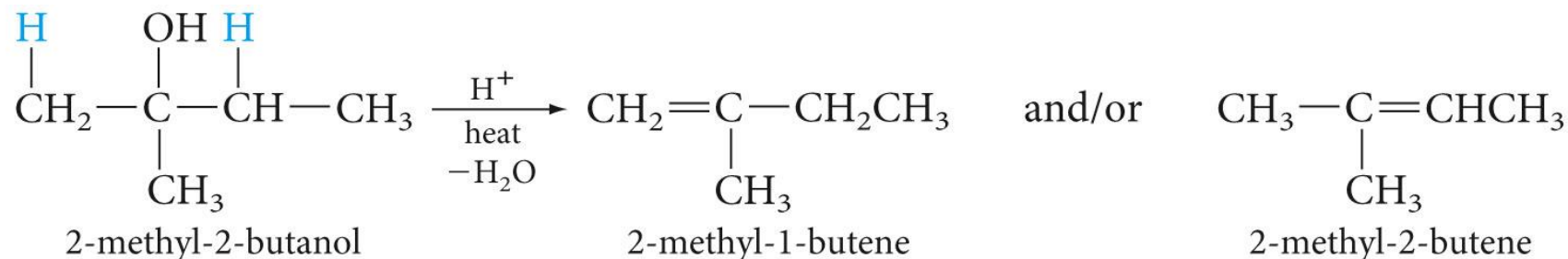
The overall reaction is



With a primary alcohol, a primary carbocation intermediate is avoided by combining the last two steps of the mechanism. The loss of water and an adjacent proton occurs simultaneously in an E2 mechanism.



Sometimes a single alcohol gives two or more alkenes



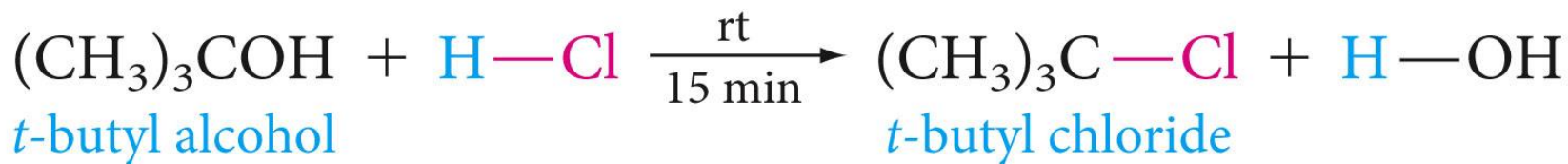
In these cases, *the alkene with the most substituted double bond usually predominates*. By “most substituted,” we mean the alkene with the greatest number of alkyl groups on the doubly bonded carbons.

## 7.9 The Reaction of Alcohols with Hydrogen Halides

Alcohols react with hydrogen halides (HCl, HBr, and HI) to give alkyl halides

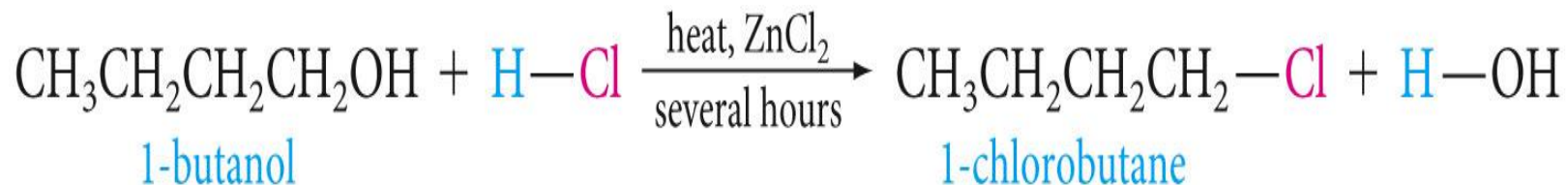


Because halide ions are good nucleophiles, we obtain mainly substitution products instead of dehydration. Once again, the reaction rate and mechanism depend on the class of alcohol (tertiary, secondary, or primary).

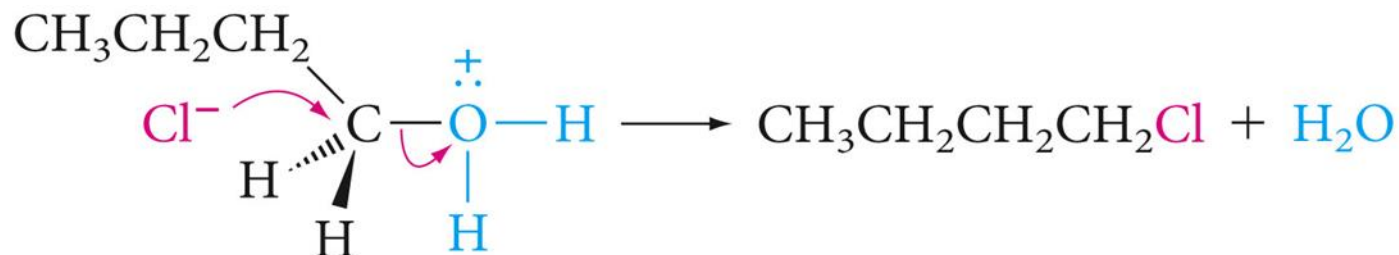


The reaction occurs by an S<sub>N</sub>1 mechanism and involves a carbocation intermediate.

On the other hand, 1-butanol, a primary alcohol, reacts slowly and must be heated for several hours with a mixture of concentrated hydrochloric acid and a Lewis acid catalyst such as zinc chloride to accomplish the same type of reaction.



The reaction occurs by an  $\text{S}_{\text{N}}2$  mechanism.

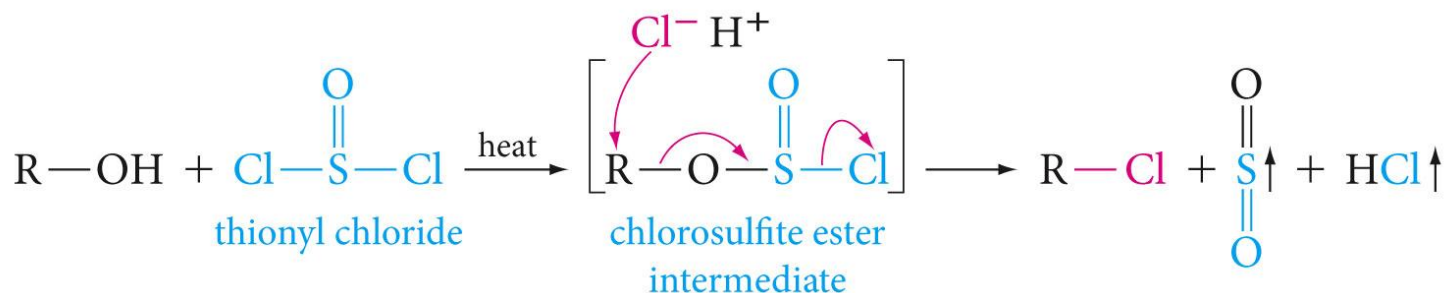


Secondary alcohols react at intermediate rates by both  $\text{S}_{\text{N}}1$  and  $\text{S}_{\text{N}}2$  mechanisms.

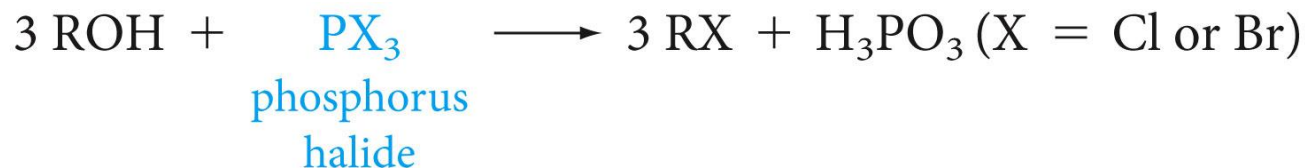
## 7.10 Other Ways to Prepare Alkyl Halides from Alcohols

Since alkyl halides are extremely useful in synthesis, it is not surprising that chemists have devised several ways to prepare them from alcohols.

1. Thionyl chloride reacts with alcohols to give alkyl chlorides.

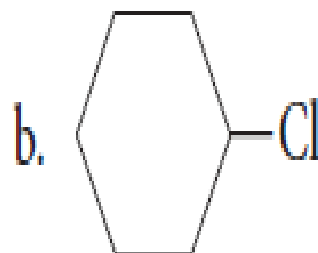
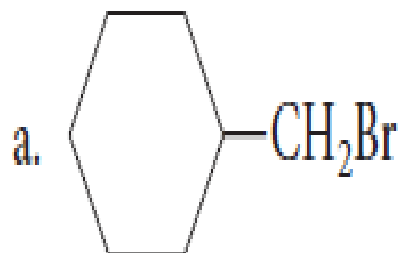


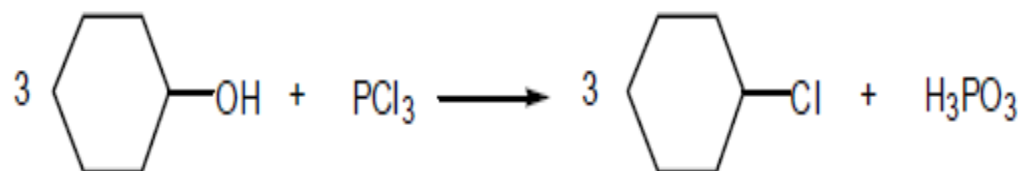
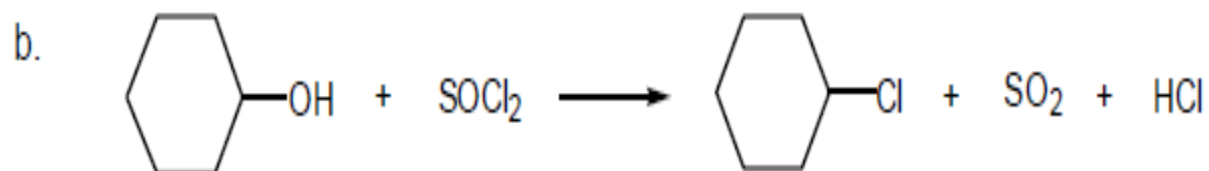
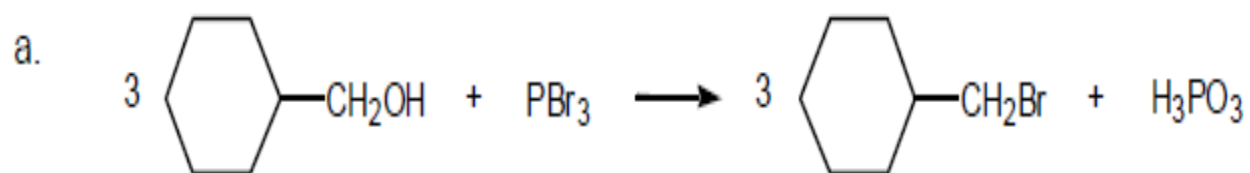
2. Phosphorus halides also convert alcohols to alkyl halides.



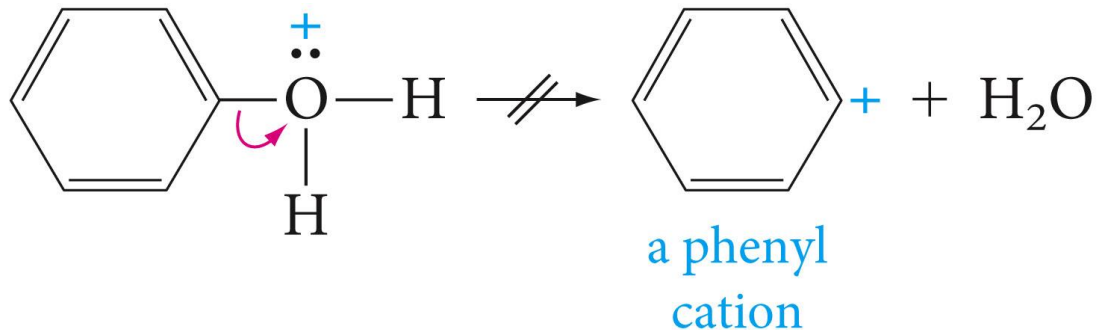


**PROBLEM 7.17** Write balanced equations for the preparation of the following alkyl halides from the corresponding alcohol and  $\text{SOCl}_2$ ,  $\text{PCl}_3$ , or  $\text{PBr}_3$ .





## 7.11 A Comparison of Alcohols and Phenols

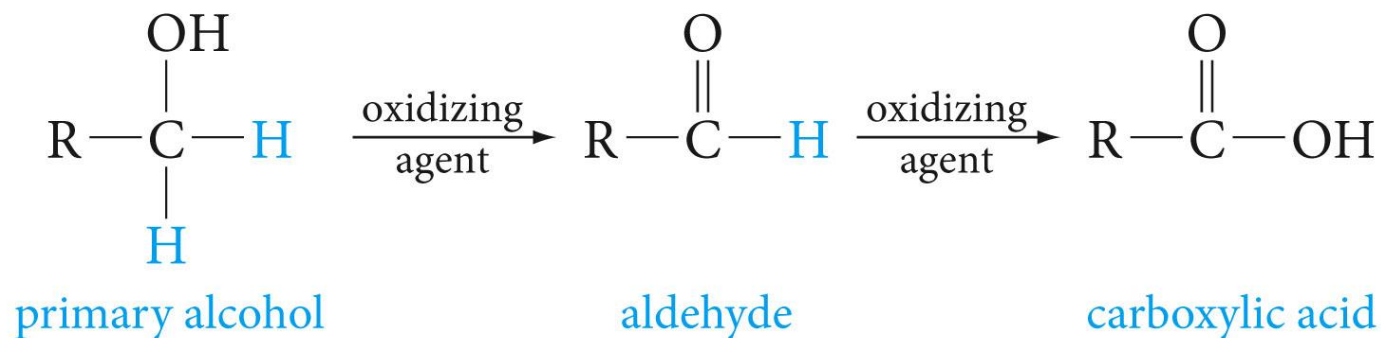


Phenyl cations are energetically unstable and are difficult to form. Phenols can also never undergo displacement by the S<sub>N</sub>2 mechanism

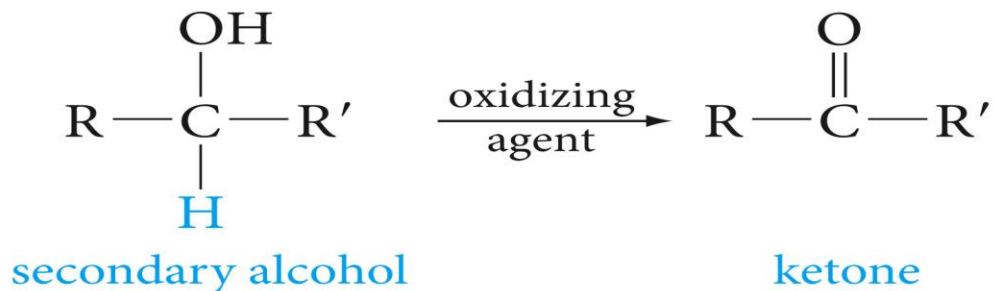
## 7.12 Oxidation of Alcohols to Aldehydes, Ketones, and Carboxylic Acids

Alcohols with at least one hydrogen attached to the hydroxyl-bearing carbon can be oxidized to carbonyl compounds.

Primary alcohols give aldehydes, which may be further oxidized to carboxylic acids.

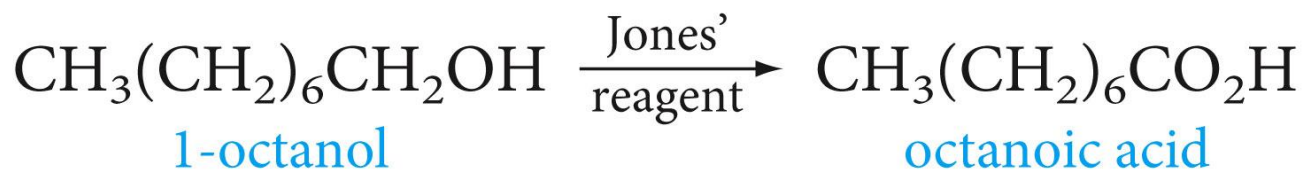
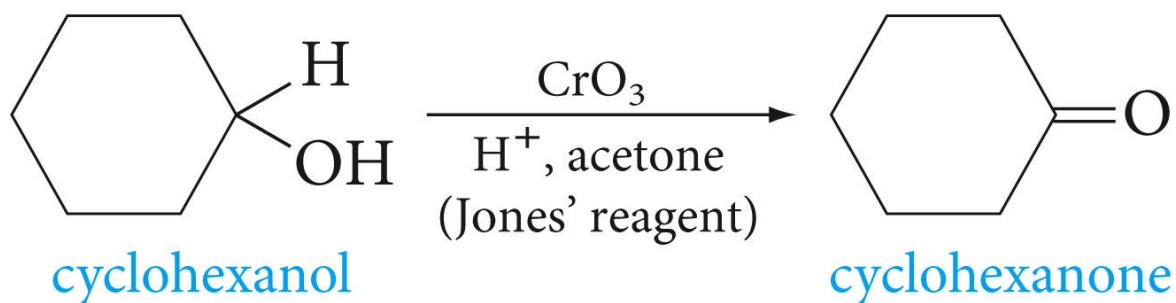


Secondary alcohols give ketones.

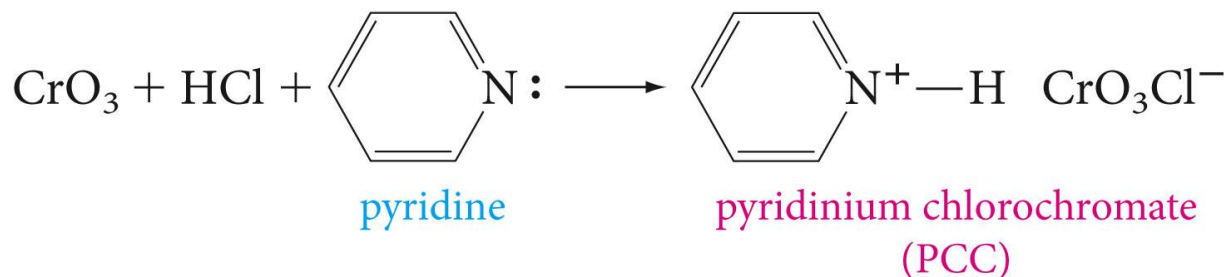
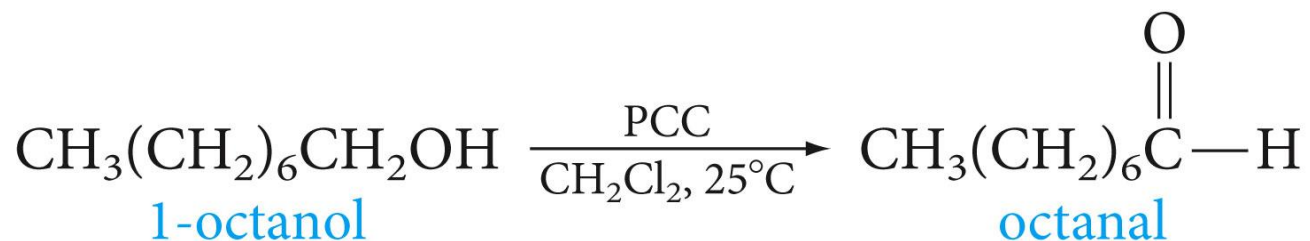


Tertiary alcohols, having no hydrogen atom on the hydroxyl-bearing carbon, do not undergo this type of oxidation.

A common laboratory oxidizing agent for alcohols is chromic anhydride,  $\text{CrO}_3$ , dissolved in aqueous sulfuric acid (**Jones' reagent**). Acetone is used as a solvent in such oxidations.



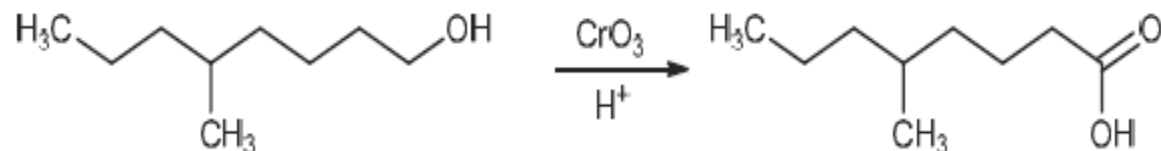
With primary alcohols, oxidation can be stopped at the aldehyde stage by special reagents, such as Pyridinium Chlorochromate (PCC)



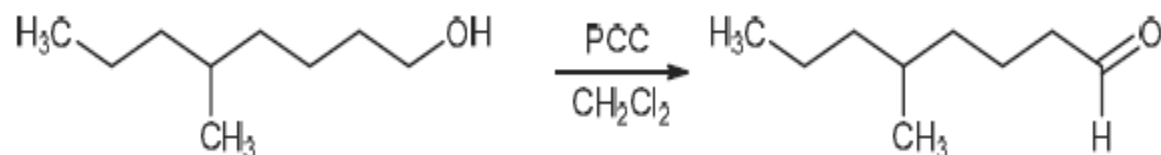
**PROBLEM 7.19** Write an equation for the oxidation of

- a. 4-methyl-1-octanol with Jones' reagent
- b. 4-methyl-1-octanol with PCC
- c. 4-phenyl-2-butanol with Jones' reagent
- d. 4-phenyl-2-butanol with PCC

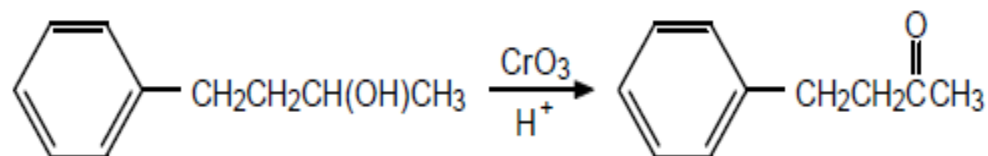
- a. The alcohol is primary and gives a carboxylic acid.



- b. The alcohol is primary and gives an aldehyde.



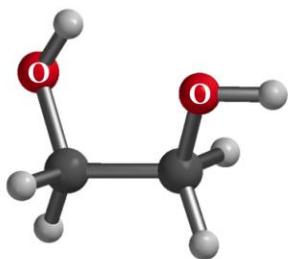
- c. The alcohol is secondary and gives a ketone.



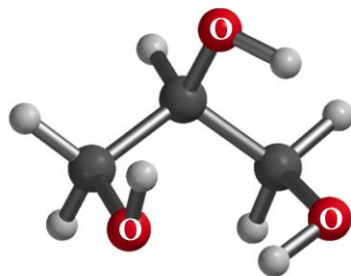
- d. The alcohol is secondary and gives a ketone, regardless of the oxidizing agent. The product is the same as in part c.



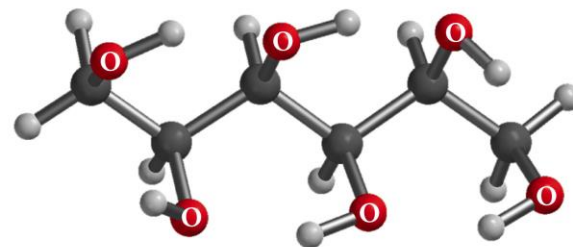
## 7.13 Alcohols with More Than One Hydroxyl Group



Ethylene glycol  
(1,2-ethanediol)  
bp 198 °C



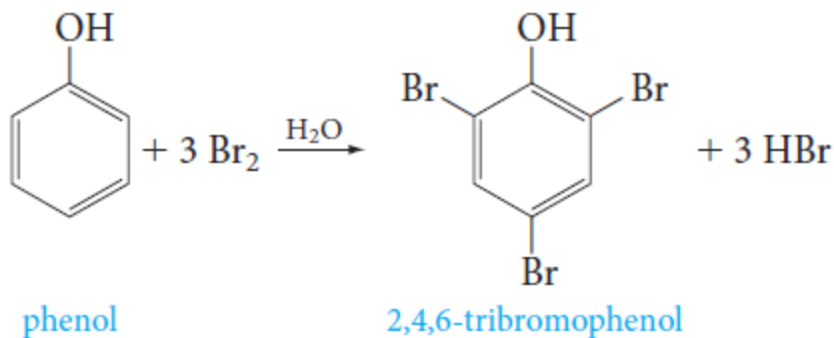
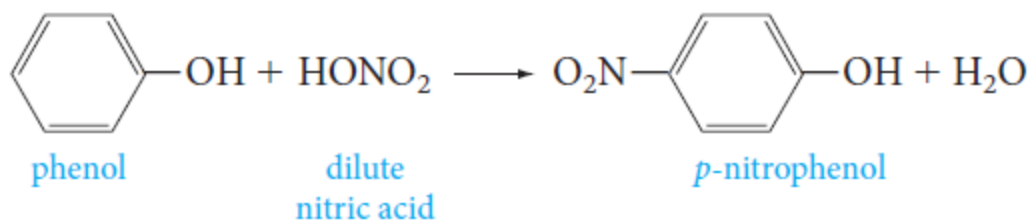
Glycerol (glycerine)  
1,2,3-propanetriol  
bp 290 °C



Sorbitol  
1,2,3,4,5,6-hexanehexaol  
Mp 110-112 °C

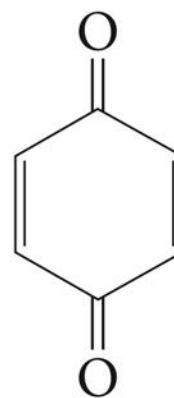
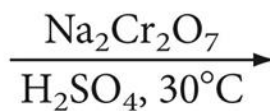
## 7.14 Aromatic Substitution in Phenols

Phenols undergo electrophilic aromatic substitution under very mild conditions because the hydroxyl group is strongly ring activating.





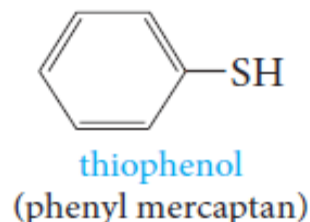
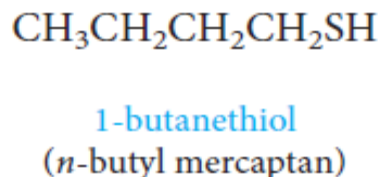
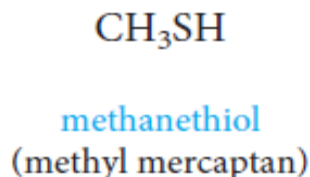
hydroquinone  
colorless, mp 171°C



1,4-benzoquinone  
yellow, mp 116°C

## 7.17 Thiols the Sulfur Analog of Alcohols and Phenols

- The **-SH** group, called the **sulfhydryl group**, is the functional group of thiols. Thiols are named as follows:



Thiols are sometimes called **mercaptans**, a name that refers to their reaction with mercuric ion to form mercury salts, called **mercaptides**.



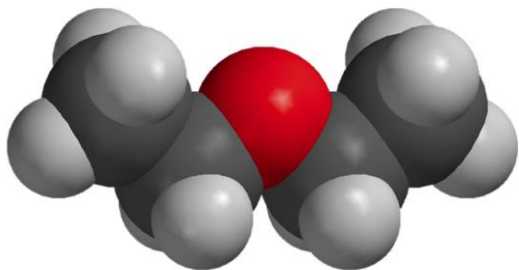
- Alkyl thiols can be made from alkyl halides by nucleophilic displacement with sulfhydryl ion



- Thiols are more acidic than alcohols. The  $pK_a$  of ethanethiol, for example, is 10.6 whereas that of ethanol is 15.9. Hence, thiols react with aqueous base to give thiolate



# Chapter 8: Ethers and Epoxides



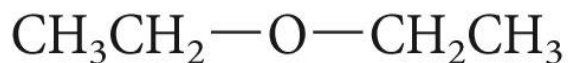
Diethyl ether in starting fluid

## 8.1 Nomenclature of Ethers

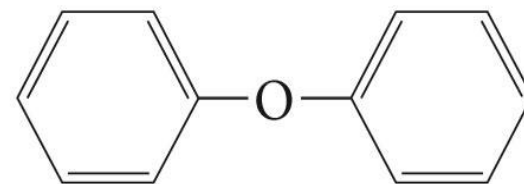
Ethers are usually named by giving the name of each alkyl or aryl group, in alphabetical order, followed by the word *ether*.



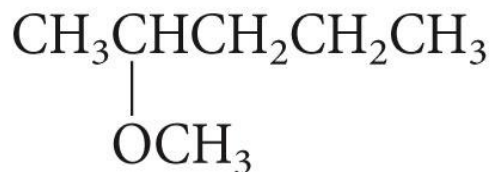
ethyl methyl ether



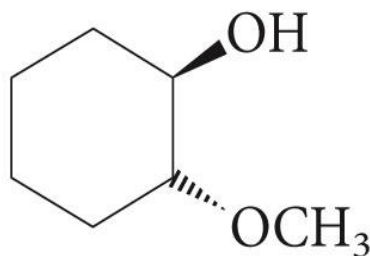
diethyl ether (the prefix *di-* is sometimes omitted)



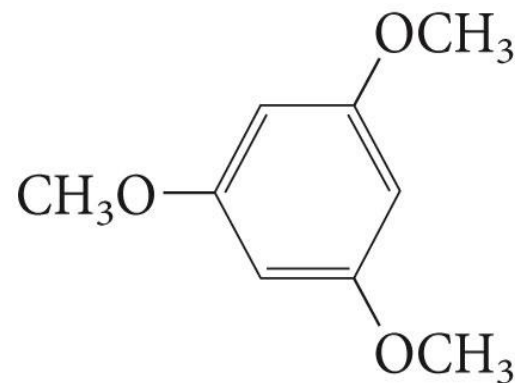
diphenyl ether



2-methoxypentane

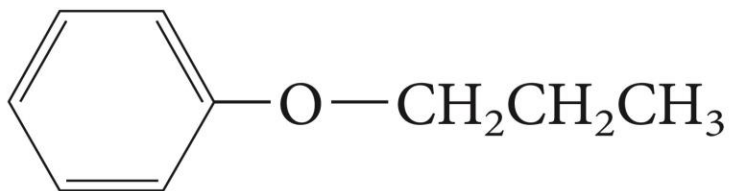
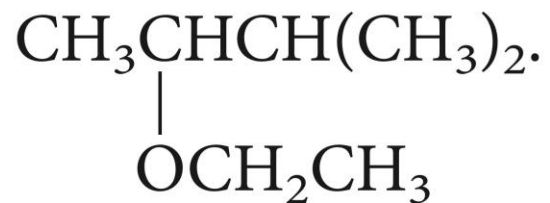


*trans*-2-methoxycyclohexanol



1,3,5-trimethoxybenzene

What are the correct names for the following ethers?



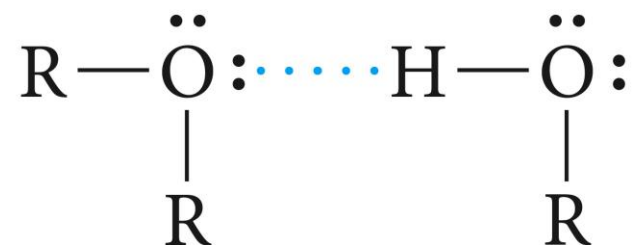


## 8.2 Physical Properties of Ethers

Ethers are colorless compounds with characteristic, relatively pleasant odors. They have lower boiling points (bp's) than alcohols with an equal number of carbon atoms. In fact, an ether has nearly the same bp as the corresponding hydrocarbon in which a  $\text{-CH}_2\text{-}$  group replaces the ether's oxygen.

**Table 8.1**  Properties of Alcohols, Ethers, and Hydrocarbons of Similar Molecular Weight

Compound	Formula	bp	mol wt	Water solubility (g/100 mL, 20°C)
1-butanol	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$	118°C	74	7.9
diethyl ether	$\text{CH}_3\text{CH}_2\text{—O—CH}_2\text{CH}_3$	35°C	74	7.5
pentane	$\text{CH}_3\text{CH}_2\text{—CH}_2\text{—CH}_2\text{CH}_3$	36°C	72	0.03



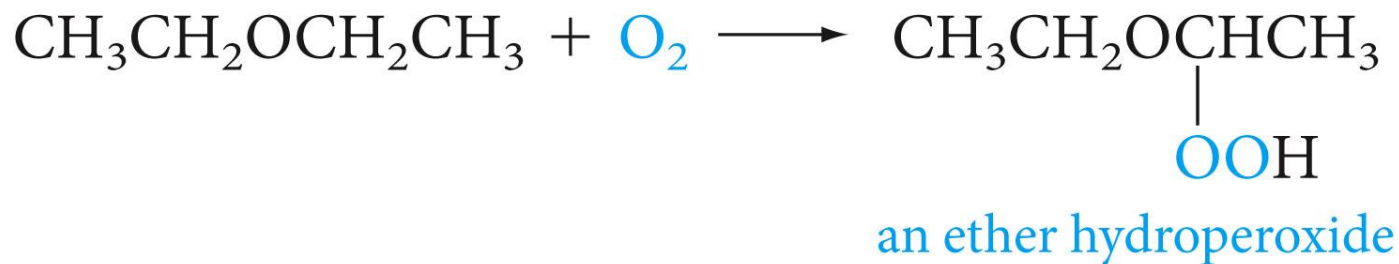
Because of their structures (no O-H bonds), ether molecules cannot form hydrogen bonds with one another. This is why they boil at much lower temperatures than their isomeric alcohols

Although ethers cannot form hydrogen bonds with one another, they do form hydrogen bonds with alcohols. This explains why ethers and alcohols are mutually soluble.

## Ethers as Solvents

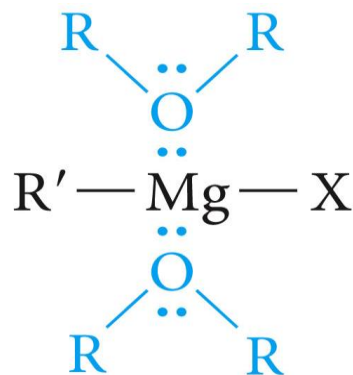
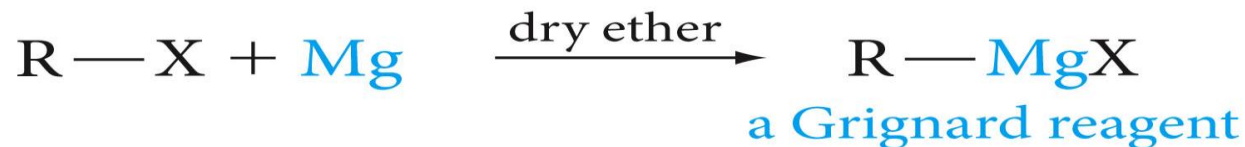
Ethers are relatively inert compounds. They do not usually react with dilute acids or bases or common oxidizing and reducing agents. They do not react with metallic sodium unlike alcohols. Their inert nature and the fact that most organic compounds are ether-soluble makes them excellent solvents for organic reactions.

When ethers are exposed to air for a long time, they form peroxides and may result to explosives.  $\text{FeSO}_4$  is usually added to destroy the peroxides.

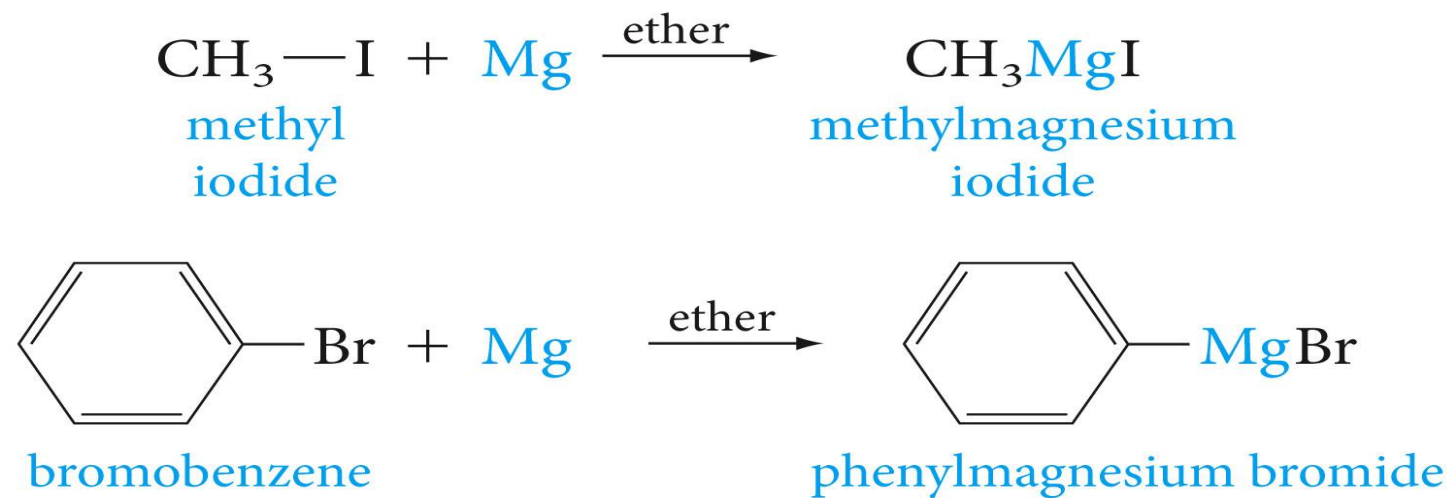


# The Grignard Reagent : an Organometallic Compound

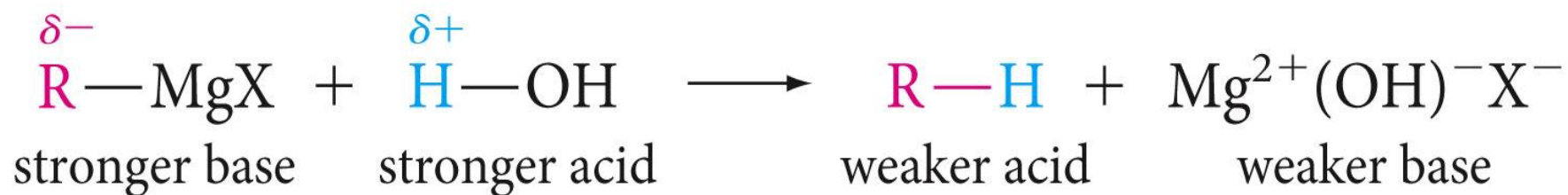
Pronounced greenyar(d)



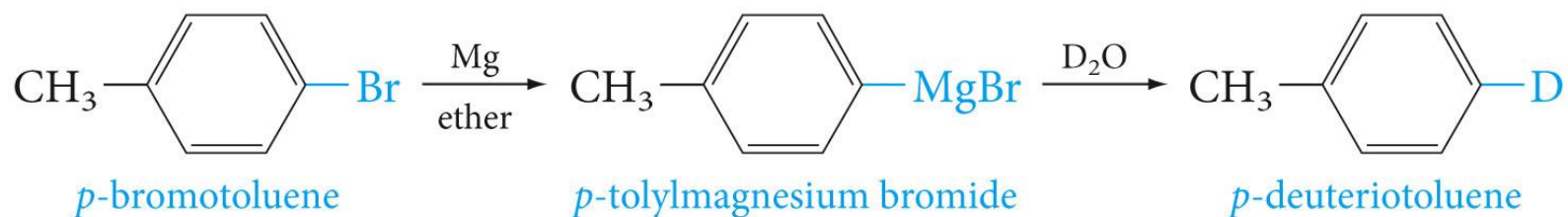
Acting as a Lewis base, ether stabilizes a Grignard reagent.



A carbanion is an alkyl or aryl group with a negatively charged carbon atom. Carbanions are strong bases

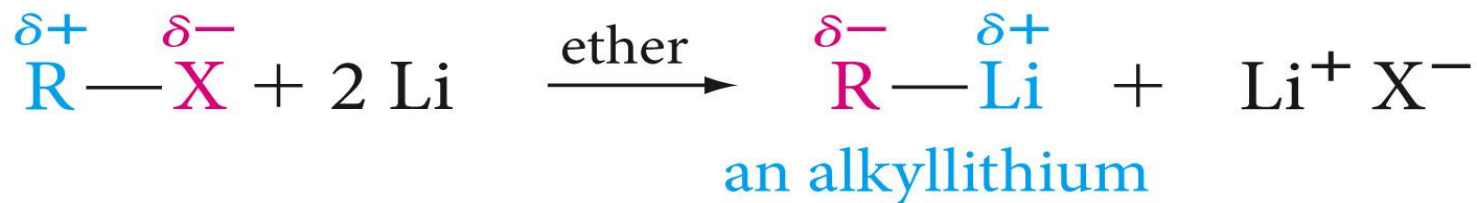
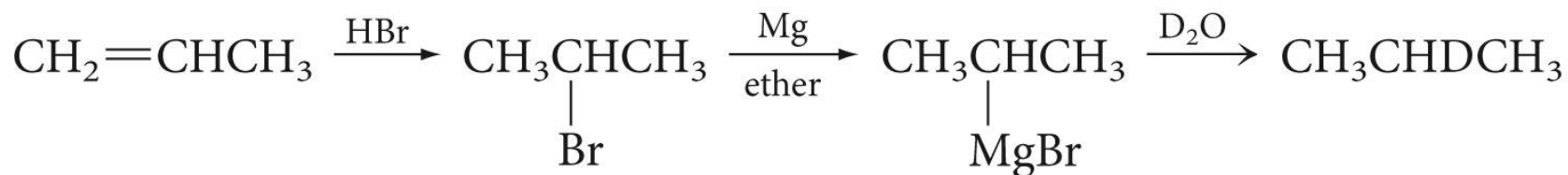


## Grignard reagent reaction with water



Reaction of Grignard reagent with water can be used to place deuterium isotopes by reacting them with heavy water ( $\text{D}_2\text{O}$ ), where the deuterium substitutes the halogen

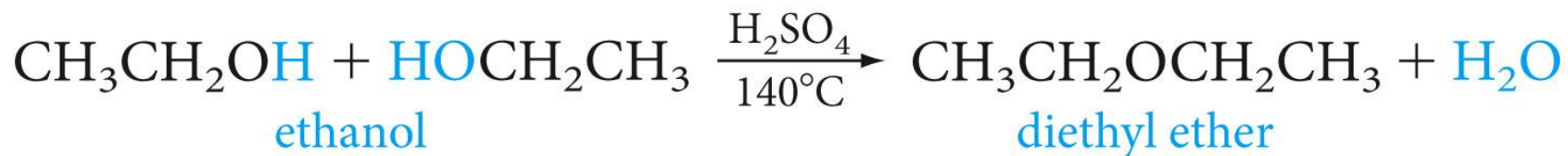
**Question:** Show how to prepare  $\text{CH}_3\text{CHDCH}_3$  from  $\text{CH}_2=\text{CHCH}_3$



These compounds contain carbon-metal (lithium) bond. They react in a similar manner to Grignard reagents, and are very useful in synthesis

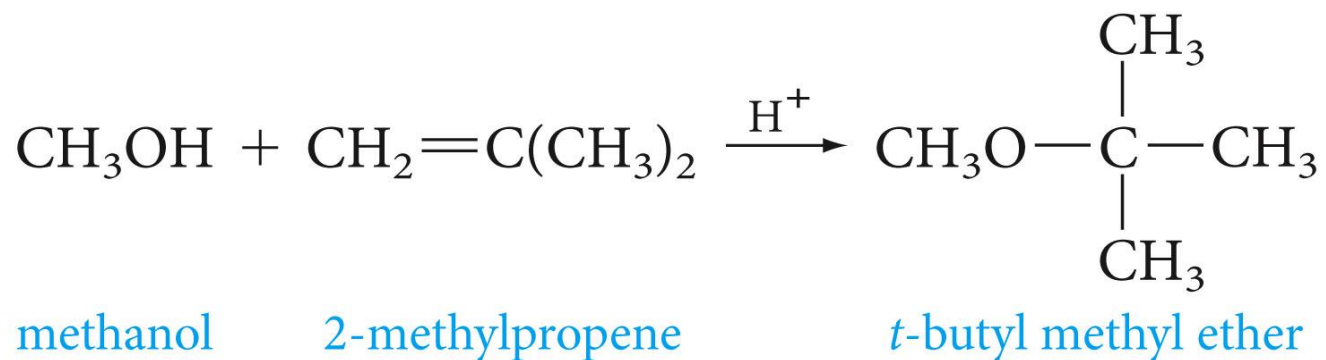
## 8.5 Preparation of Ethers

1. Commercial diethyl ether is prepared from ethanol and sulfuric acid.





2. Methyl *tert* Butyl Ether (MTBE) has a high octane value of about 110, it is used as an octane number enhancer in unleaded gasoline. It is prepared by the acid-catalyzed addition of methanol to 2-methylpropene



## Williamson Synthesis for unsymmetrical ether

This method has two:

The first step, an alcohol is converted to its alkoxide by treatment with a reactive metal (sodium or potassium) or metal hydride

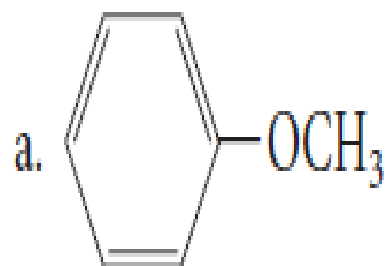


In the second step, an S<sub>N</sub>2 displacement is carried out between the alkoxide and an alkyl halide



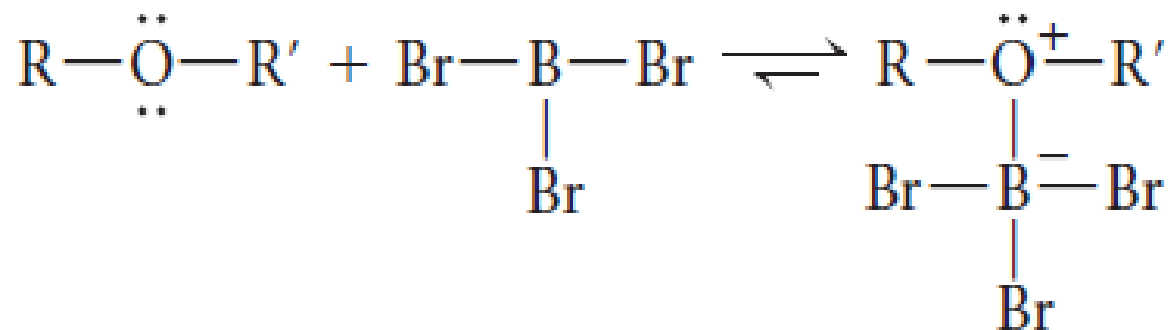
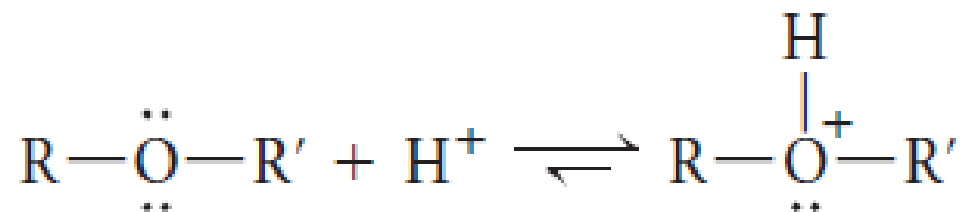
Since the second step is an S<sub>N</sub>2 reaction, it works best if R' in the alkyl halide is primary and not well at all if R' is tertiary

**PROBLEM 8.11** Write equations for the synthesis of the following ethers by the Williamson method:

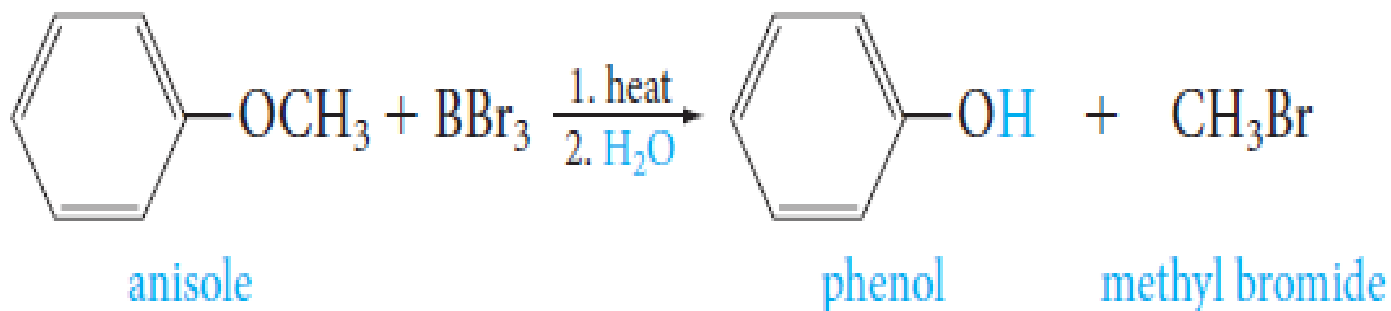
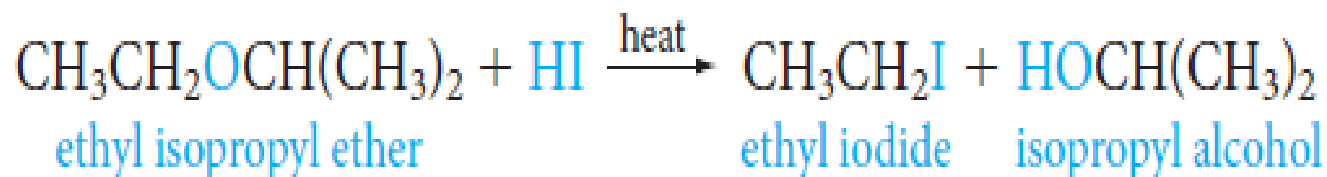


## 8.6 Cleavage of Ethers

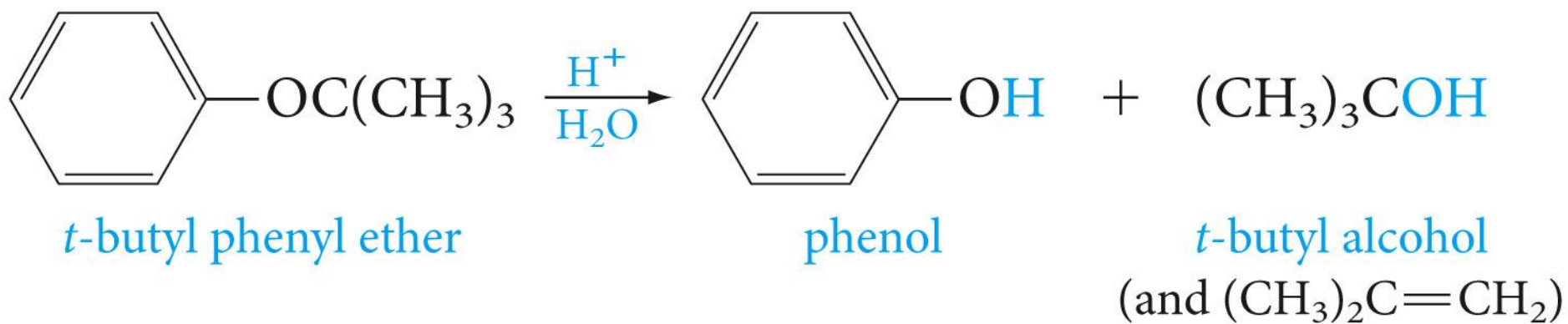
Ethers have unshared electron pairs on the oxygen atom and are therefore Lewis bases. They react with strong proton acids and with Lewis acids such as the boron halides.



These reactions are similar to the reaction of alcohols with strong acids . If the alkyl groups R and/or R' are primary or secondary, the bond to oxygen can be broken by reaction with a strong nucleophile such as I<sup>-</sup> or Br<sup>-</sup> (by an S<sub>N</sub>2 process)

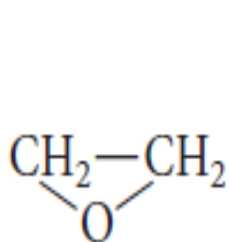


If R or R' is tertiary, a strong nucleophile is not required since reaction will occur by an S<sub>N</sub>1 (or E1) mechanism.

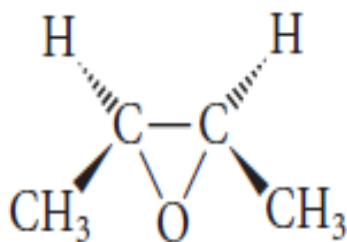


## 8.7 Epoxides ( Oxiranes)

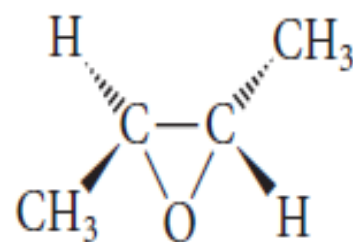
*Epoxides* (or oxiranes) are cyclic ethers with a three-membered ring containing one oxygen atom.



ethylene oxide  
(oxirane)  
bp 13.5°C

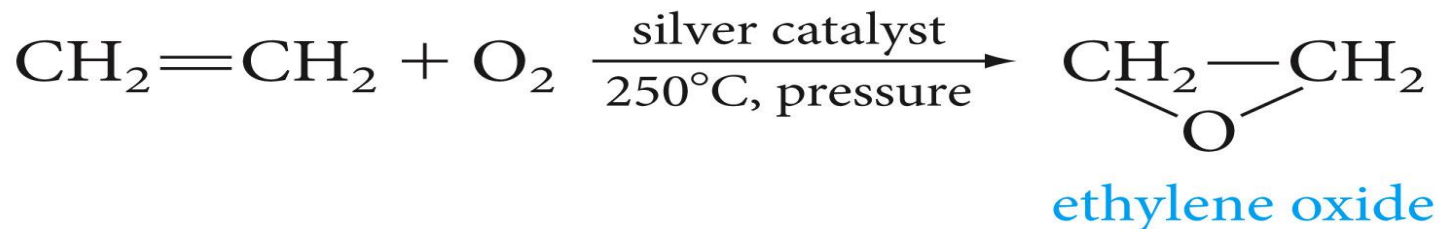


*cis*-2-butene oxide  
(*cis*-2,3-dimethyloxirane)  
bp 60°C

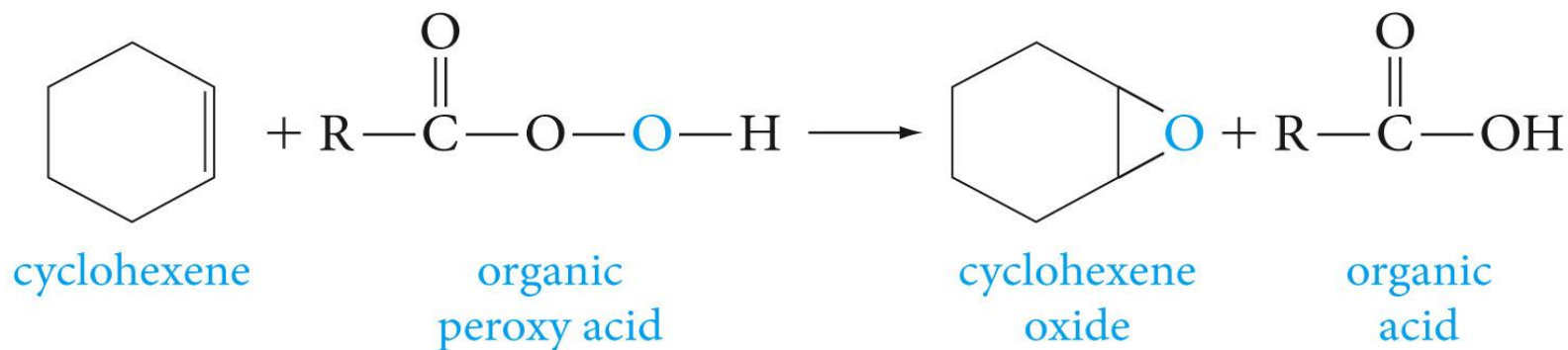


*trans*-2-butene oxide  
(*trans*-2,3-dimethyloxirane)  
bp 54°C

The most important commercial epoxide is ethylene oxide, produced by the silver-catalyzed air oxidation of ethylene.



Other epoxides are usually prepared by the reaction of an alkene with an organic peroxyacid (often called simply a *peracid*)

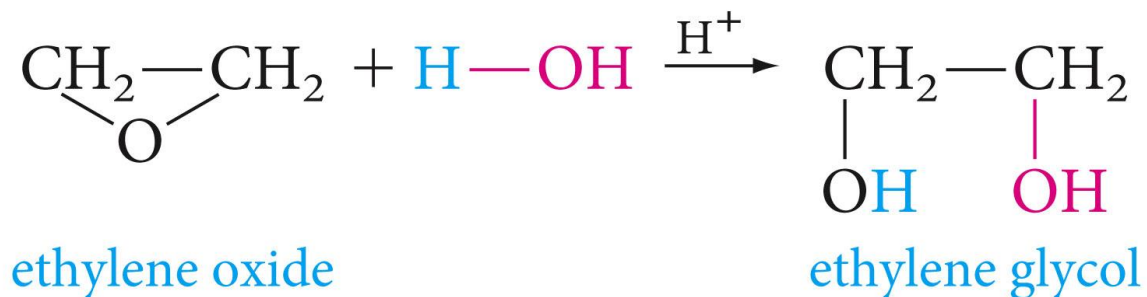




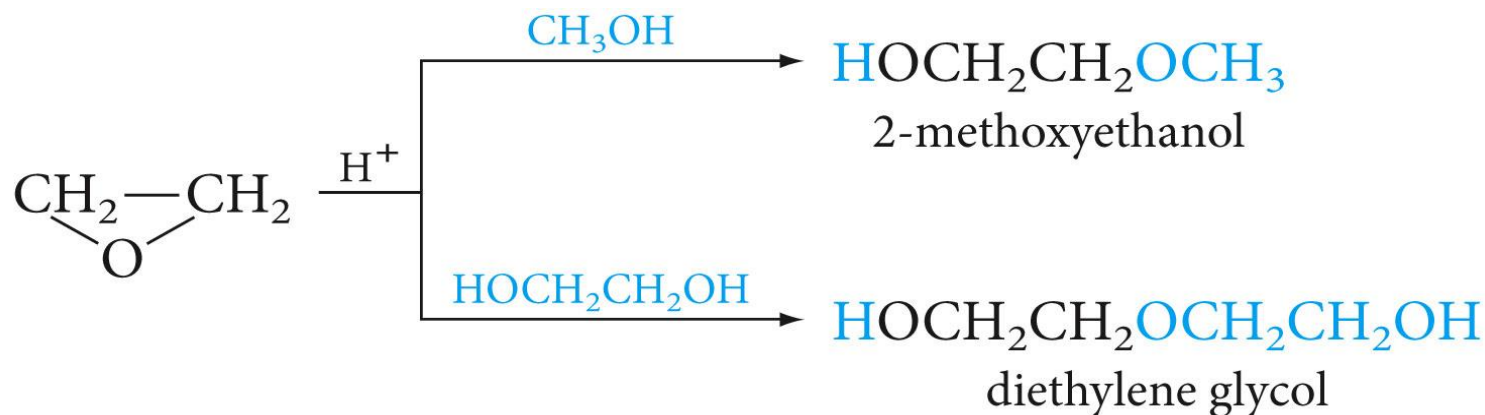
## 8.8 Reactions of Epoxides

Because of the strain in the three-membered ring, epoxides are much more reactive than ordinary ethers and give products in which the ring has opened.

1. Reaction with water they undergo acid-catalyzed ring opening to give glycols.



2. Other nucleophiles add to epoxides in a similar way.



Grignard reagents and organolithium compounds are strong nucleophiles capable of opening the ethylene oxide (epoxide) ring. The initial product is a magnesium alkoxide or lithium alkoxide, but after hydrolysis, we obtain a primary alcohol with two carbon atoms than the organometallic reagent.



- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{MgCl}$  followed by hydrolysis
- $\text{C}_6\text{H}_5\text{CH}_2\text{MgBr}$  followed by hydrolysis
- $\text{H}_2\text{C}=\text{CHLi}$  followed by hydrolysis
- $\text{CH}_3\text{C}\equiv\text{C}^-\text{Na}^+$  followed by hydrolysis

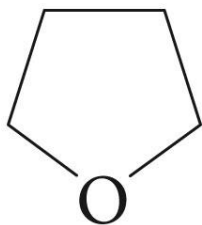
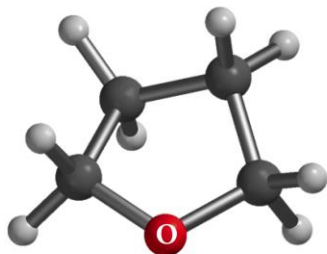
a.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{MgCl}$  followed by hydrolysis

b.  $\text{C}_6\text{H}_5\text{CH}_2\text{MgBr}$  followed by hydrolysis

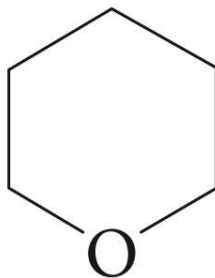
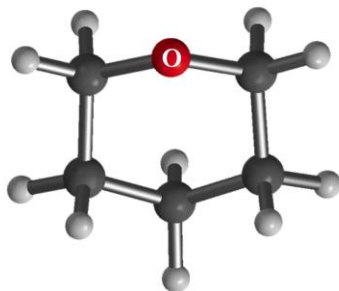
c.  $\text{H}_2\text{C}=\text{CHLi}$  followed by hydrolysis

d.  $\text{CH}_3\text{C}\equiv\text{C}^-\text{Na}^+$  followed by hydrolysis

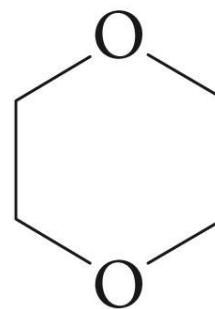
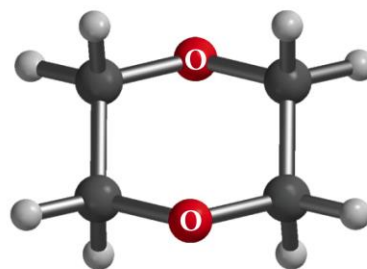
## 8.9 Cyclic Ethers



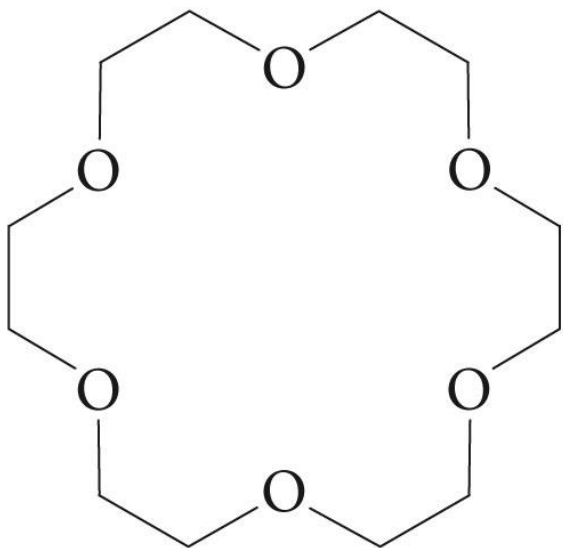
tetrahydrofuran  
(oxolane)  
bp 67°C



tetrahydropyran  
(oxane)  
bp 88°C

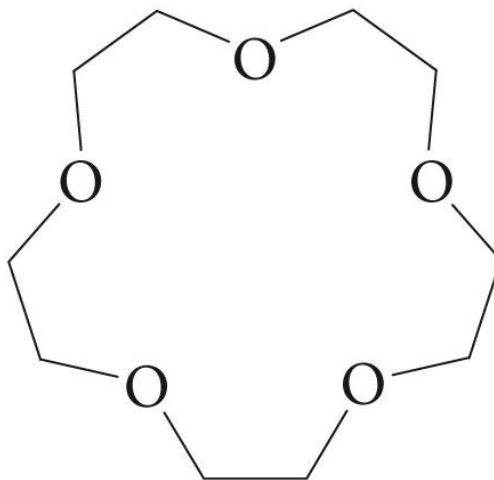


1,4-dioxane  
bp 101°C



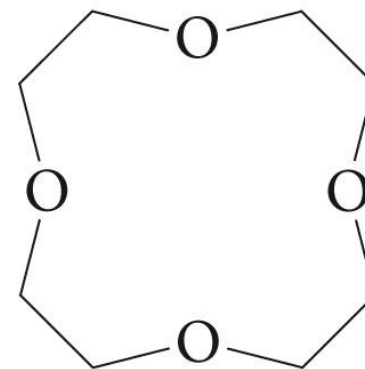
[18]crown-6

mp 39–40°C



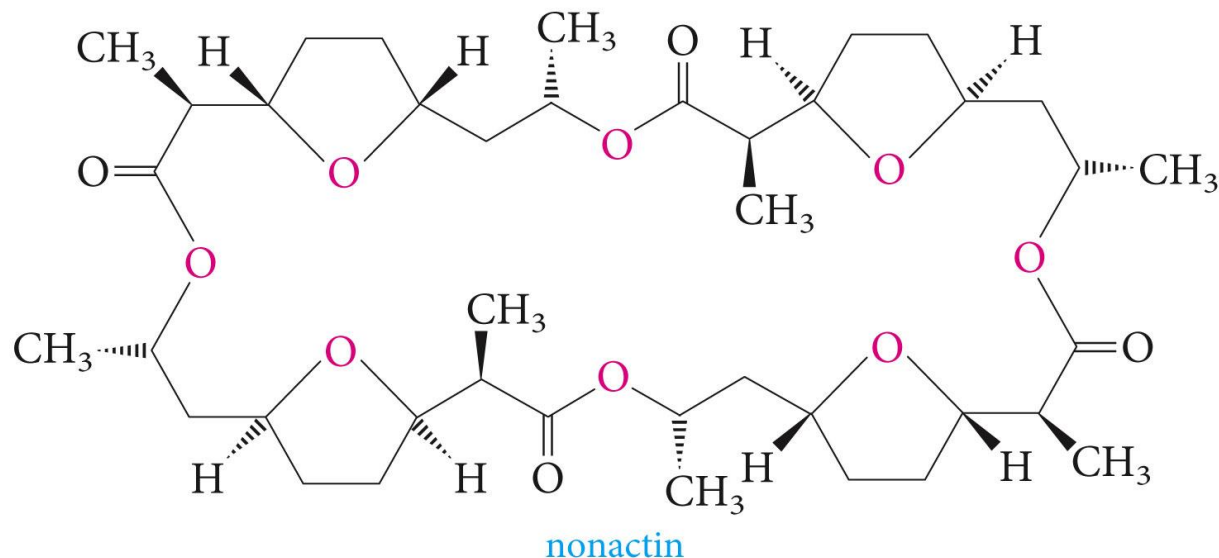
[15]crown-5

(liquid)



[12]crown-4

These compounds are called **Crown ethers** because their molecule have a crown-like shape. The bracket number represents the ring size and the terminal numbers gives the number of oxygens. The oxygens are usually separated by two carbons.



The selective binding of metallic ions by macrocyclic compounds is important in nature. Several antibiotics, such as **nonactin**, have large rings that contain regularly spaced oxygen atoms. Nonactin (which contains four tetrahydrofuran rings joined by four ester links) selectively binds  $K^+$  (in the presence of  $Na^+$ ) in aqueous media. Thus allowing selective transport of  $K^+$  (but not  $Na^+$ ) through the cell membranes

## Homework 7

26,29,33,34,36,38,40,47,48,52

## Homework 8

17,21,23,27,31,33,42