# Alcohols and Phenols

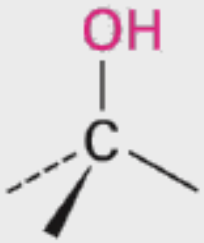
By

Idrees AL-Mashkoor

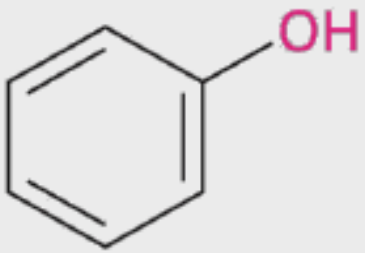
# • Alcohols and Phenols

Assist proff: idries Muhson al mashkor

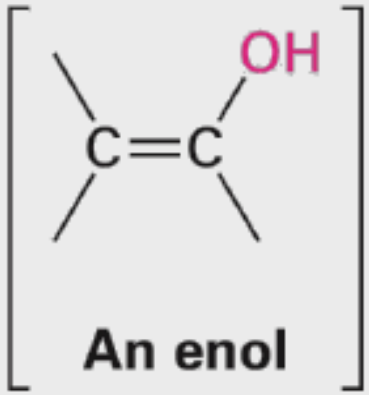
- Alcohols contain an OH group connected to a saturated C ($sp^3$)
- They are important solvents and synthesis intermediates
- Phenols contain an OH group connected to a carbon in a benzene ring
- Methanol, $CH_3OH$, called methyl alcohol, is a common solvent, a fuel additive, produced in large quantities
- Ethanol, $CH_3CH_2OH$, called ethyl alcohol, is a solvent, fuel, beverage
- Phenol, $C_6H_5OH$ ("phenyl alcohol") has diverse uses - it gives its name to the general class of compounds
- OH groups bonded to vinylic $sp^2$-hybridized carbons are called **enols**




**An alcohol**



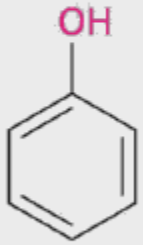

**A phenol**



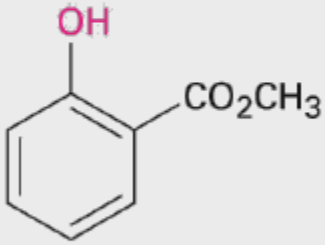

**An enol**

- To begin to study oxygen-containing functional groups

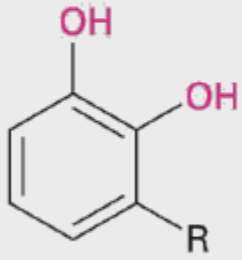
- These groups lie at the heart of biological chemistry




**Phenol (also known as carbolic acid)**




**Methyl salicylate**

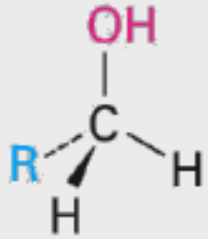



**Urushiols (R = different $C_{15}$ alkyl and alkenyl chains)**

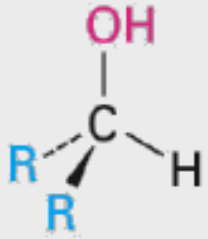
Idries AL-mashkor

# Naming Alcohols and Phenols

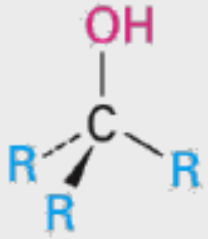
- General classifications of alcohols based on substitution on C to which OH is attached
- Methyl (C has 3 H's), Primary (1°) (C has two H's, one R), secondary (2°) (C has one H, two R's), tertiary (3°) (C has no H, 3 R's)




**A primary (1°) alcohol**



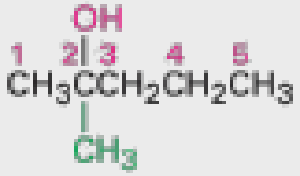

**A secondary (2°) alcohol**



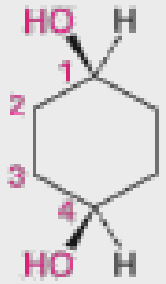

**A tertiary (3°) alcohol**

# IUPAC rules for Naming Alcohol

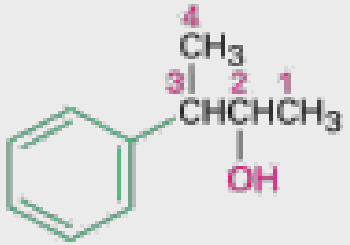
- Select the longest carbon chain containing the hydroxyl group, and derive the parent name by replacing the *-e* ending of the corresponding alkane with *-ol*
- Number the chain from the end nearer the hydroxyl group
- Number substituents according to position on chain, listing the substituents in alphabetical order




**2-Methyl-2-pentanol**
**(New: 2-Methylpentan-2-ol)**




***cis*-1,4-Cyclohexanediol**
**(New: *cis*-Cyclohexane-1,4-diol)**




**3-Phenyl-2-butanol**
**(New: 3-Phenylbutan-2-ol)**

# Naming Phenol

- Use "phenol" (the French name for benzene) as the parent hydrocarbon name, not benzene
- Name substituents on aromatic ring by their position from OH


Benzyl alcohol
(phenylmethanol)


Allyl alcohol
(2-propen-1-ol)

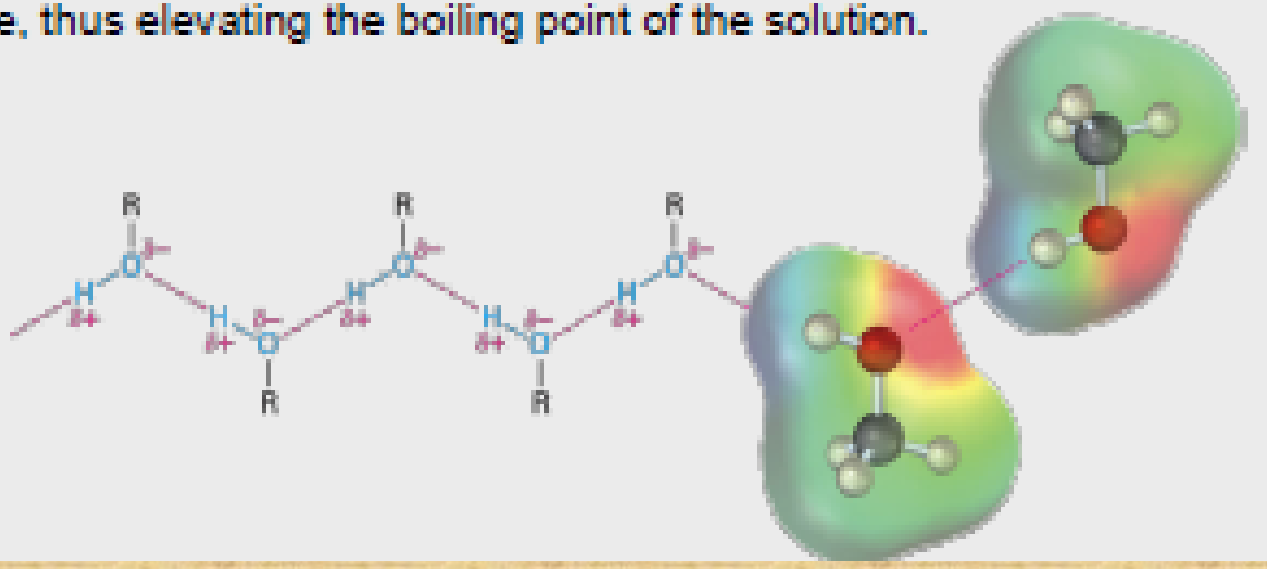

*tert*-Butyl alcohol
(2-methyl-2-propanol)


Ethylene glycol
(1,2-ethanediol)


Glycerol
(1,2,3-propanetriol)

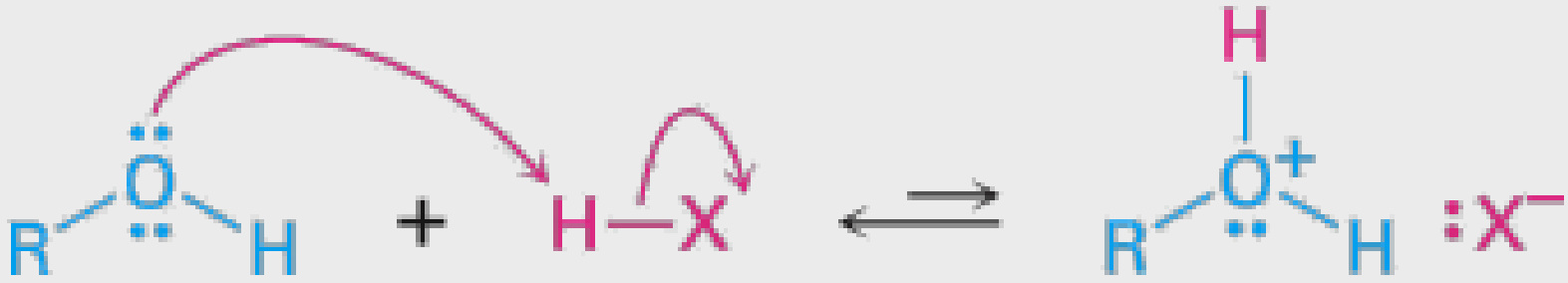
# Properties of Alcohols and Phenols

- The structure around O of the alcohol or phenol is similar to that in water, $sp^3$ hybridized.
- Alcohols and phenols have much higher boiling points than similar alkanes and alkyl halides.
- A positively polarized —OH hydrogen atom from one molecule is attracted to a lone pair of electrons on a negatively polarized oxygen atom of another molecule.
- This produces a force that holds the two molecules together
- These intermolecular attractions are present in solution but not in the gas phase, thus elevating the boiling point of the solution.



# Properties of Alcohols and Phenols: Acidity and Basicity

- Weakly basic and weakly acidic
- Alcohols are weak Brønsted bases
- Protonated by strong acids to yield oxonium ions, $ROH_2^+$

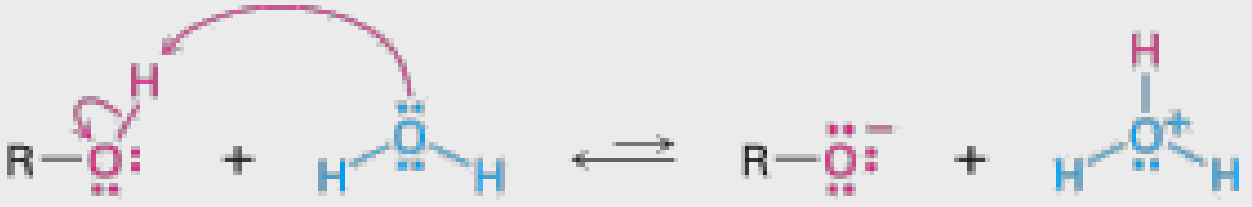



**An alcohol** **An oxonium ion**

$$\left[\text{or ArOH} + \text{HX} \rightleftharpoons \text{ArOH}_2^+\ X^-\right]$$

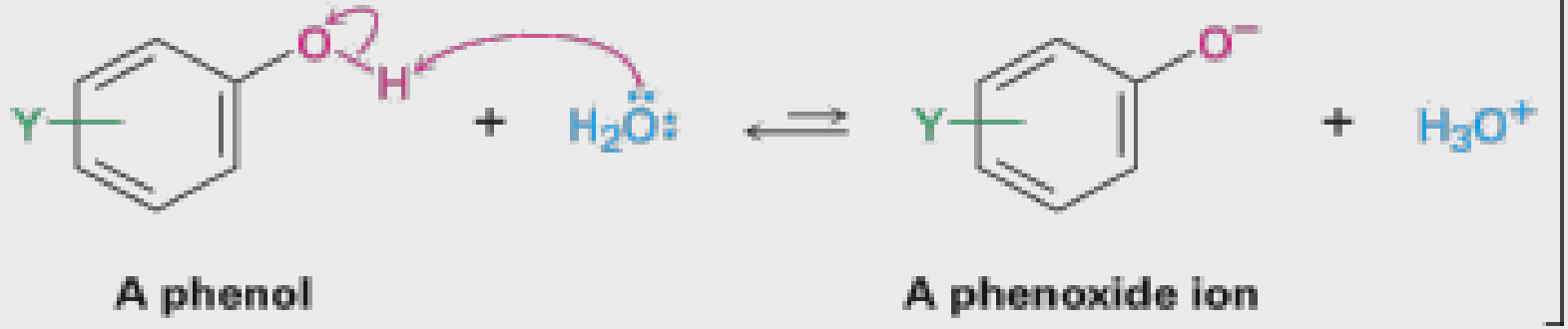
# Alcohols and Phenols are Weak Brønsted Acids

- Can transfer a proton to water to a very small extent
- Produces $H_3O^+$ and an **alkoxide ion, $RO^-$**, or a **phenoxide ion, $ArO^-$**



**An alcohol** **An alkoxide ion**

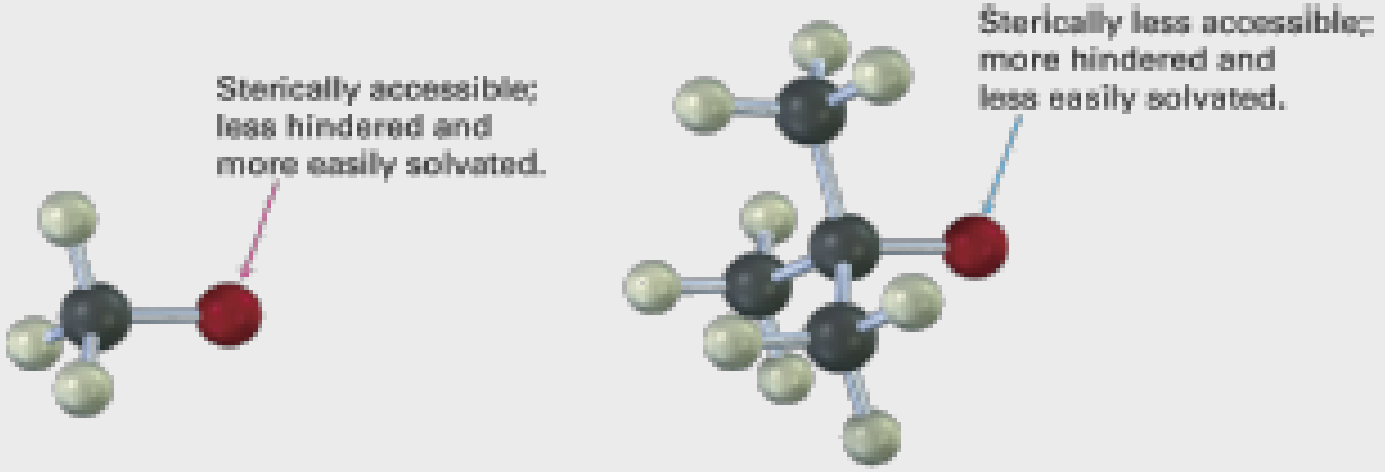
or



**A phenol** **A phenoxide ion**

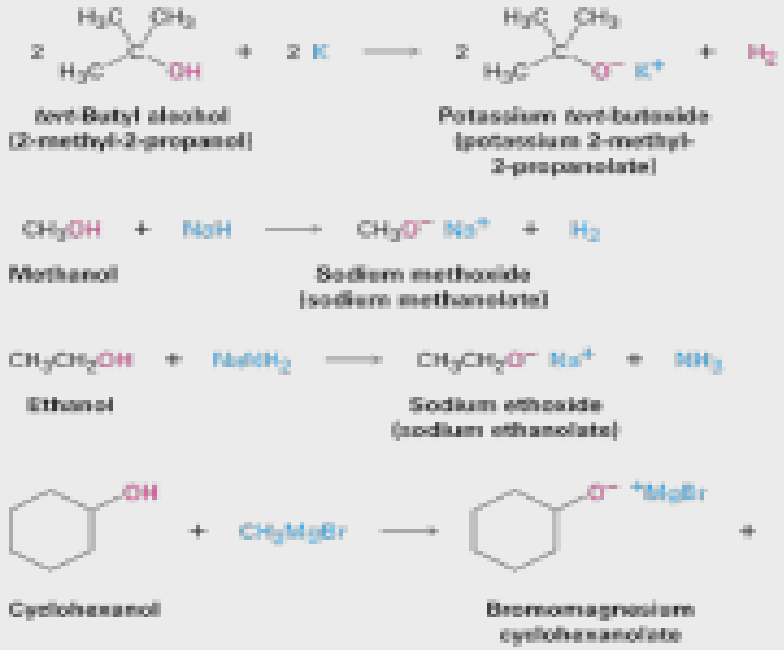
# Relative Acidities of Alcohols

- Simple alcohols are about as acidic as water
- Alkyl groups make an alcohol a weaker acid
- The more easily the alkoxide ion is solvated by water the more its formation is energetically favored
- Steric effects are important



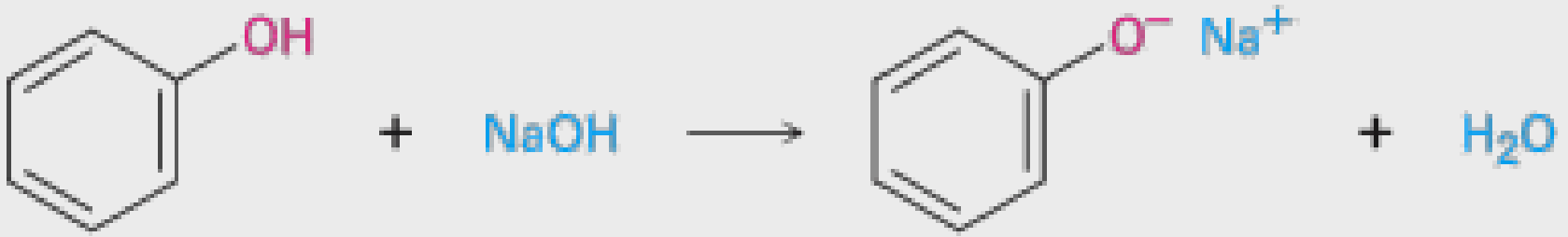
# Generating Alkoxides from Alcohols

- Alcohols are weak acids – requires a strong base to form an alkoxide such as NaH, sodium amide $NaNH_2$, and Grignard reagents (RMgX)
- Alkoxides are bases used as reagents in organic chemistry



# Phenol Acidity

- Phenols ($pK_a$ ~10) are much more acidic than alcohols ($pK_a$ ~ 16) because of resonance stabilization of the phenoxide ion
- Phenols react with NaOH solutions (but alcohols do not), forming salts that are soluble in dilute aqueous solution
- A phenolic component can be separated from an organic solution by extraction into basic aqueous solution and is isolated after acid is added to the solution

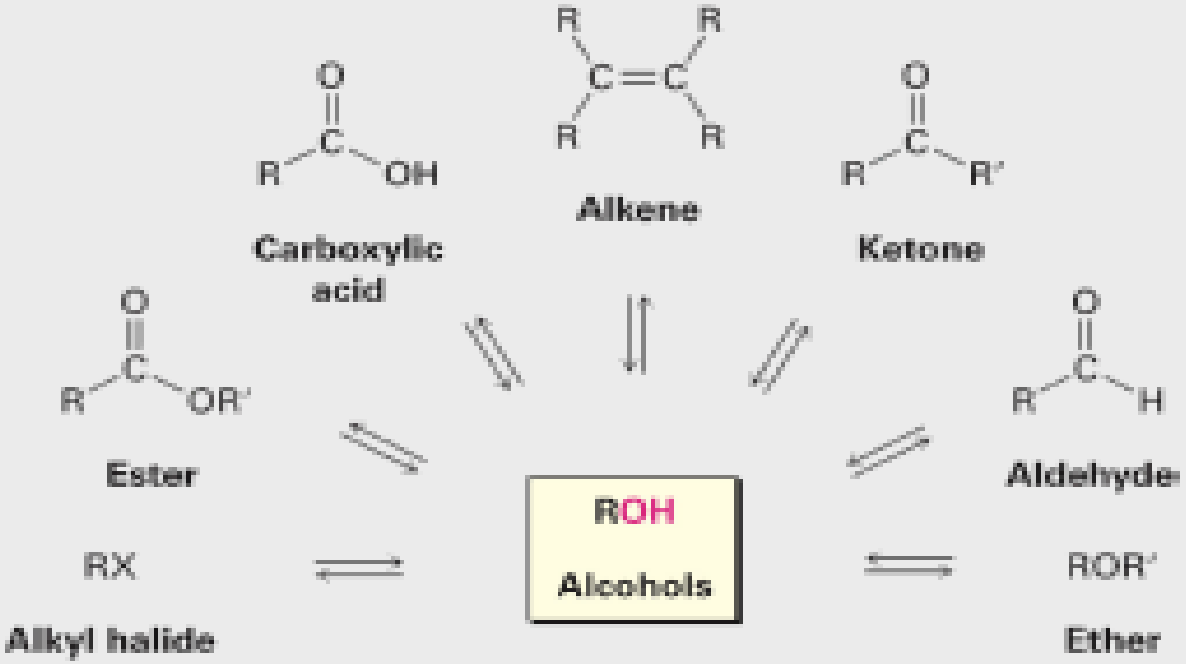



**Phenol**

**Sodium phenoxide (sodium phenolate)**

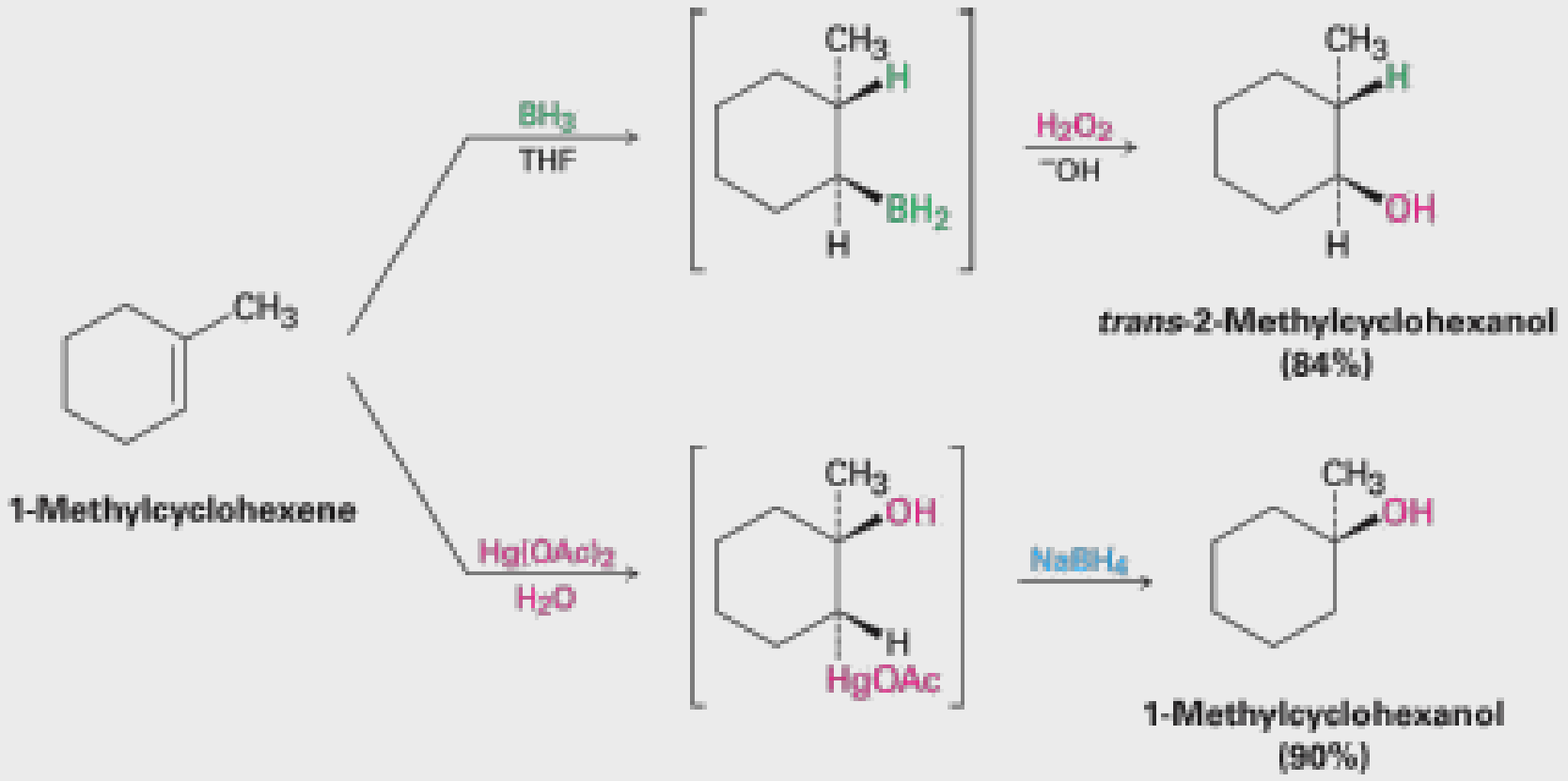
# Preparation of Alcohols:

- Alcohols are derived from many types of compounds
- The alcohol hydroxyl can be converted to many other functional groups
- This makes alcohols useful in synthesis



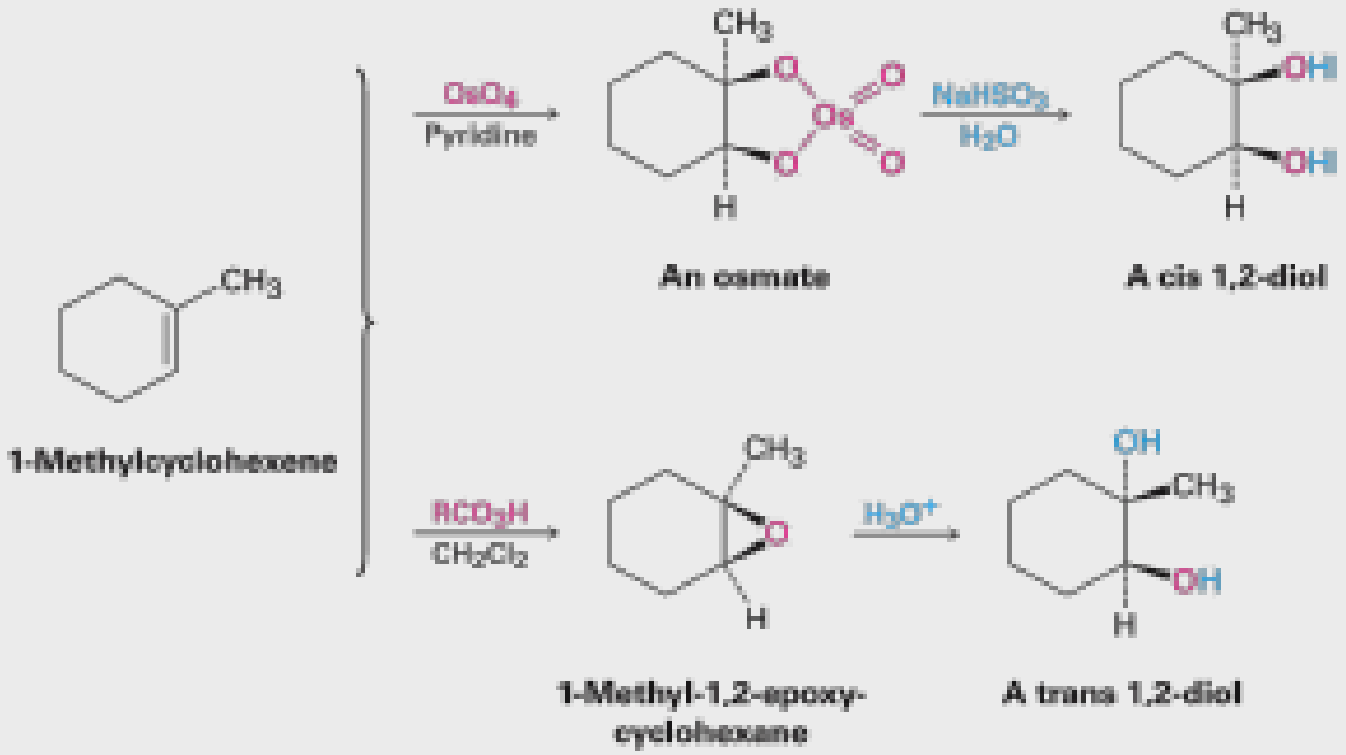
# Review: Preparation of Alcohols by Regiospecific Hydration of Alkenes

- Hydroboration/oxidation: *syn*, *anti*-Markovnikov hydration
- Oxymercuration/reduction: Markovnikov hydration



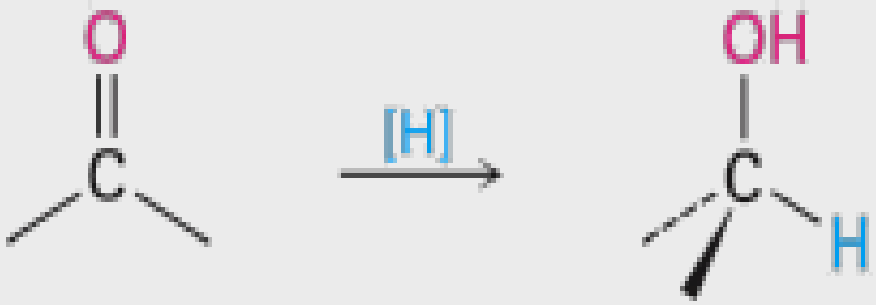
# 1,2-Diols

- Review: *Cis*-1,2-diols from hydroxylation of an alkene with $OsO_4$ followed by reduction with $NaHSO_3$
- *Trans*-1,2-diols from acid-catalyzed hydrolysis of *epoxides*



# 17.4 Alcohols from Carbonyl Compounds: Reduction

- Reduction of a carbonyl compound in general gives an alcohol
- Note that organic reduction reactions add the equivalent of $H_2$ to a molecule




where [H] is a reducing agent

**A carbonyl compound** **An alcohol**

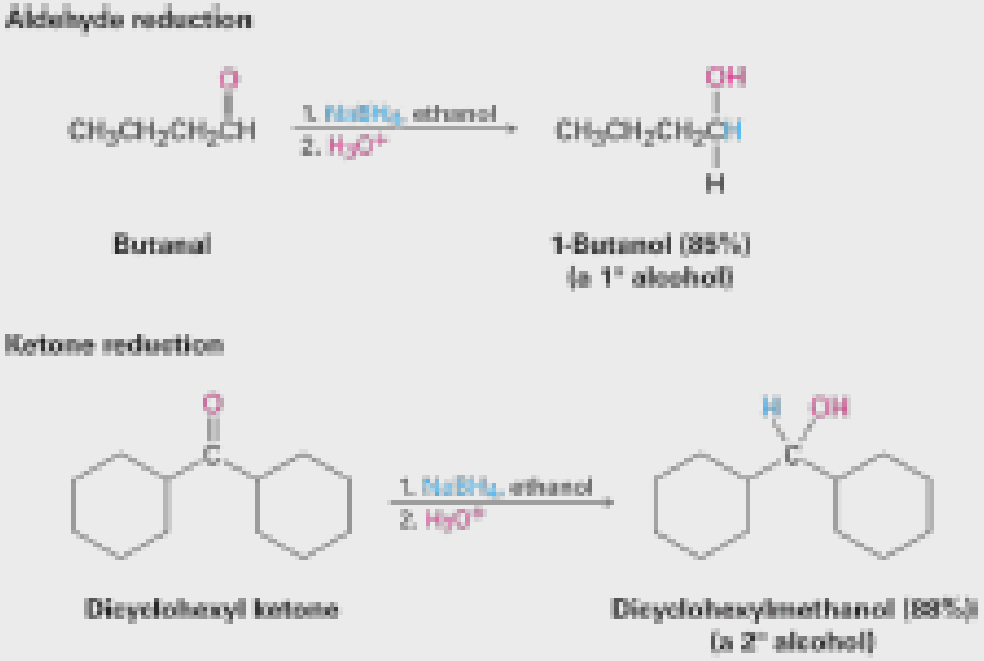
# Reduction of Aldehydes and Ketones

- Aldehydes gives primary alcohols
- Ketones gives secondary alcohols


An aldehyde | A primary alcohol | A ketone | A secondary alcohol

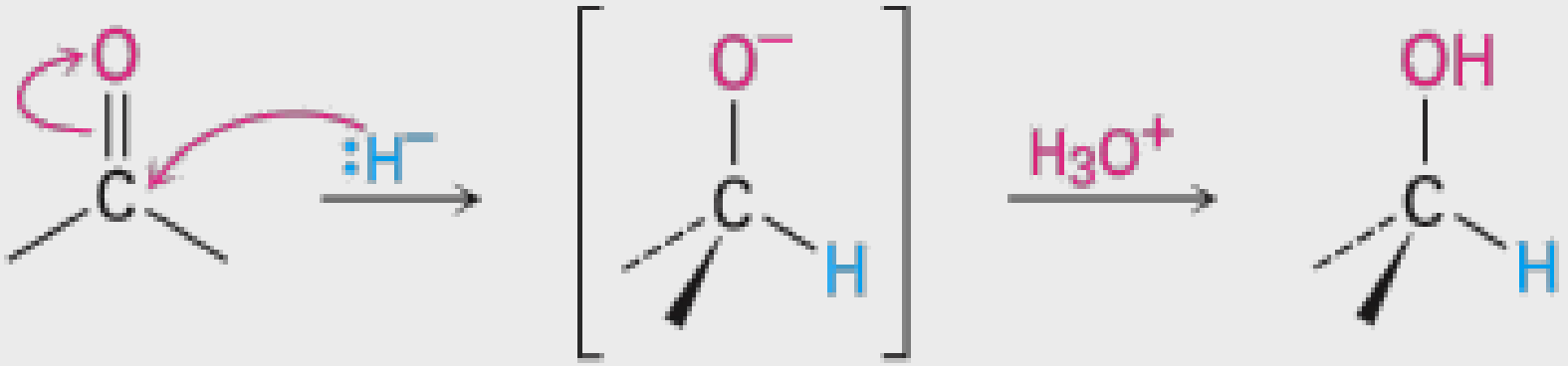
# Reduction Reagent: Sodium Borohydride

- $NaBH_4$ is not sensitive to moisture and it does not reduce other common functional groups
- Lithium aluminum hydride ($LiAlH_4$) is more powerful, less specific, and very reactive with water
- Both add the equivalent of "$H^-$"



# Mechanism of Reduction

- The reagent adds the equivalent of hydride to the carbon of C=O and polarizes the group as well




**A carbonyl compound**

**An alkoxide ion intermediate**

**An alcohol**

# Reduction of Carboxylic Acids and Esters

- Carboxylic acids and esters are reduced to give primary alcohols
- $LiAlH_4$ is used because $NaBH_4$ is not effective

**Carboxylic acid reduction**


**9-Octadecenoic acid (oleic acid)**

**9-Octadecen-1-ol (87%)**

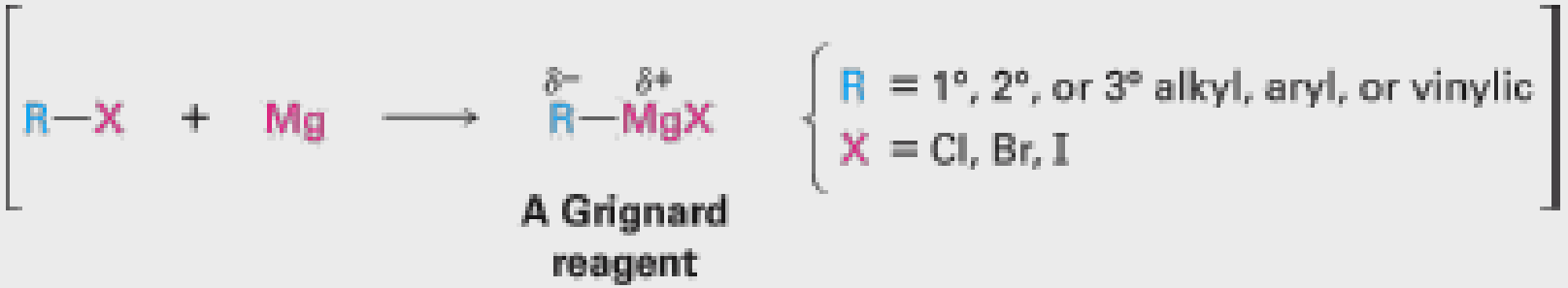
**Ester reduction**


**Methyl 2-pentenoate**

**2-Penten-1-ol (91%)**

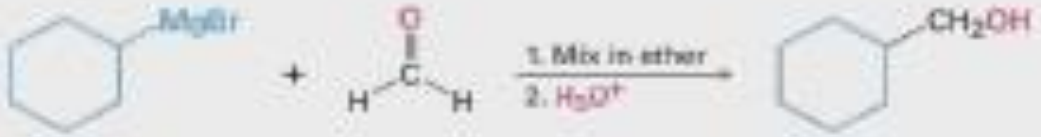
# 17.5 Alcohols from Carbonyl Compounds: Grignard Reagents

- Alkyl, aryl, and vinylic halides react with magnesium in ether or tetrahydrofuran to generate Grignard reagents, RMgX
- Grignard reagents react with carbonyl compounds to yield alcohols




# Reactions of Grignard Reagents with Carbonyl Compounds

**Formaldehyde reaction**




Cyclohexyl-magnesium bromide + Formaldehyde → Cyclohexylmethanol (65%) (a 1° alcohol)

**Aldehyde reaction**


Phenylmagnesium bromide + 3-Methylbutanal → 3-Methyl-1-phenyl-1-butanol (73%) (a 2° alcohol)

**Ketone reaction**


Ethylmagnesium bromide + Cyclohexanone → 1-Ethylcyclohexanol (89%) (a 3° alcohol)

# Reactions of Esters and Grignard Reagents

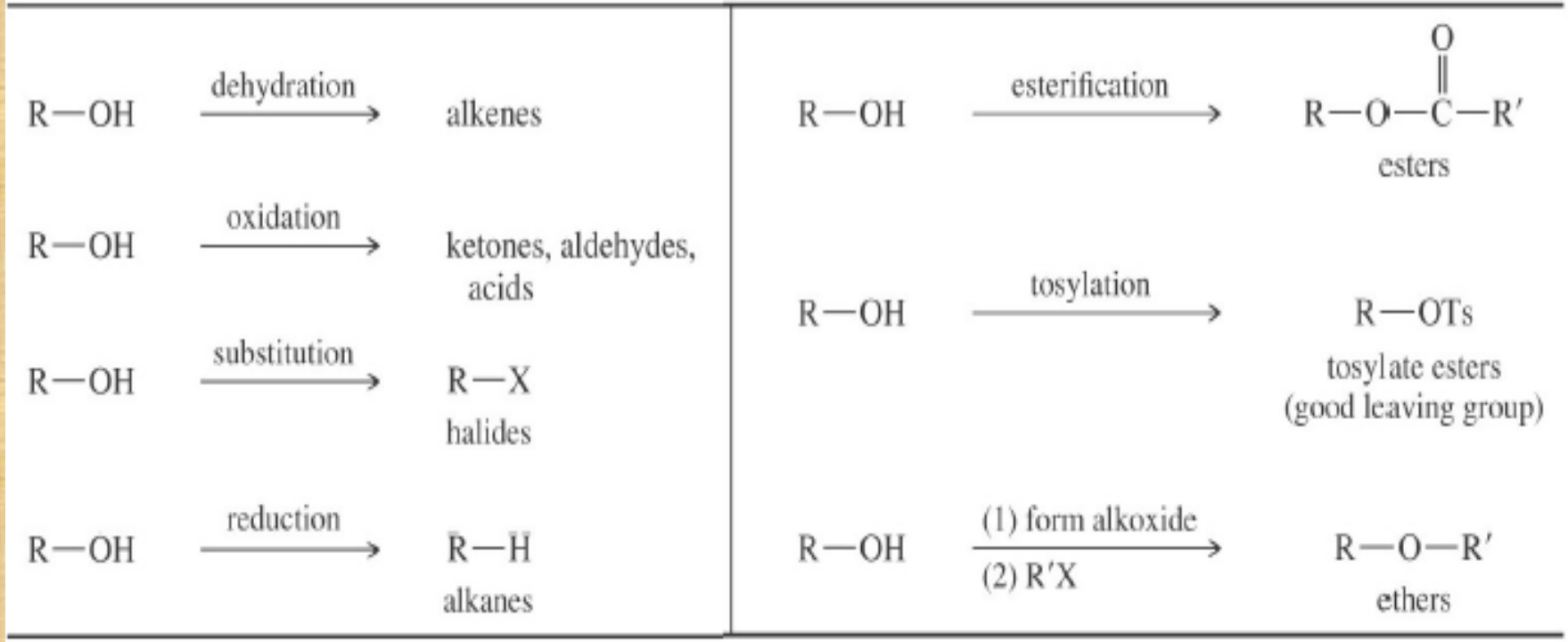
- Yields tertiary alcohols in which *two* of the carbon substituents come from the Grignard reagent
- Grignard reagents do not add to carboxylic acids – they undergo an acid-base reaction, generating the hydrocarbon of the Grignard reagent


**Ethyl pentanoate**

**2-Methyl-2-hexanol (85%)**
**(a 3° alcohol)**

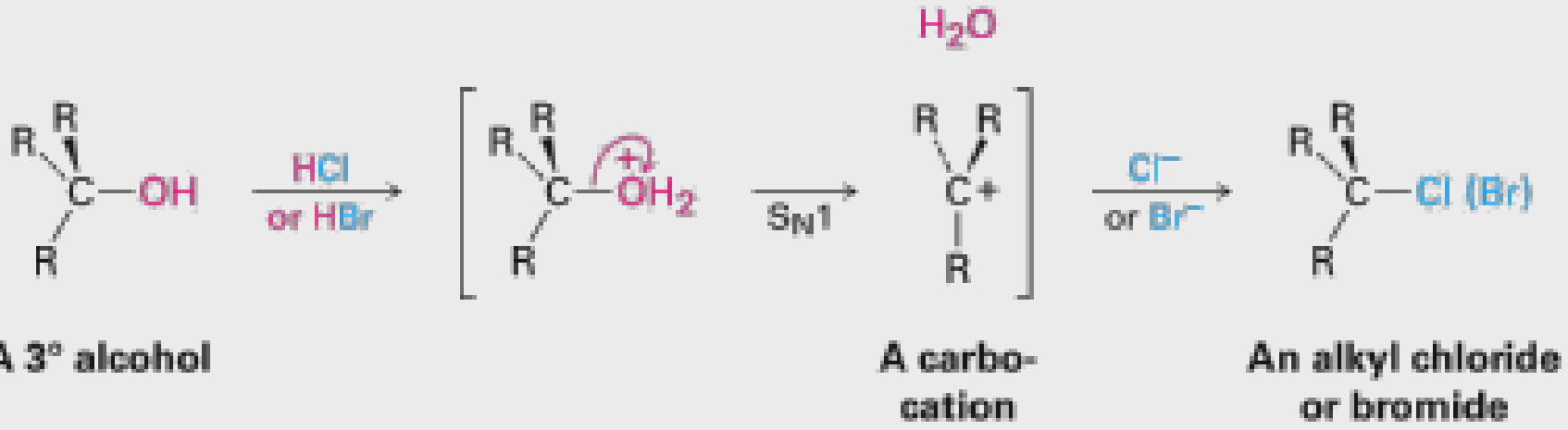
# Reaction of Alcohols

## Types of Alcohol Reactions



# Reaction of Alcohols

- Conversion of alcohols into alkyl halides:
- 3° alcohols react with HCl or HBr by $S_N1$ through carbocation intermediate
- 1° and 2° alcohols converted into halides by treatment with $SOCl_2$ or $PBr_3$ via $S_N2$ mechanism

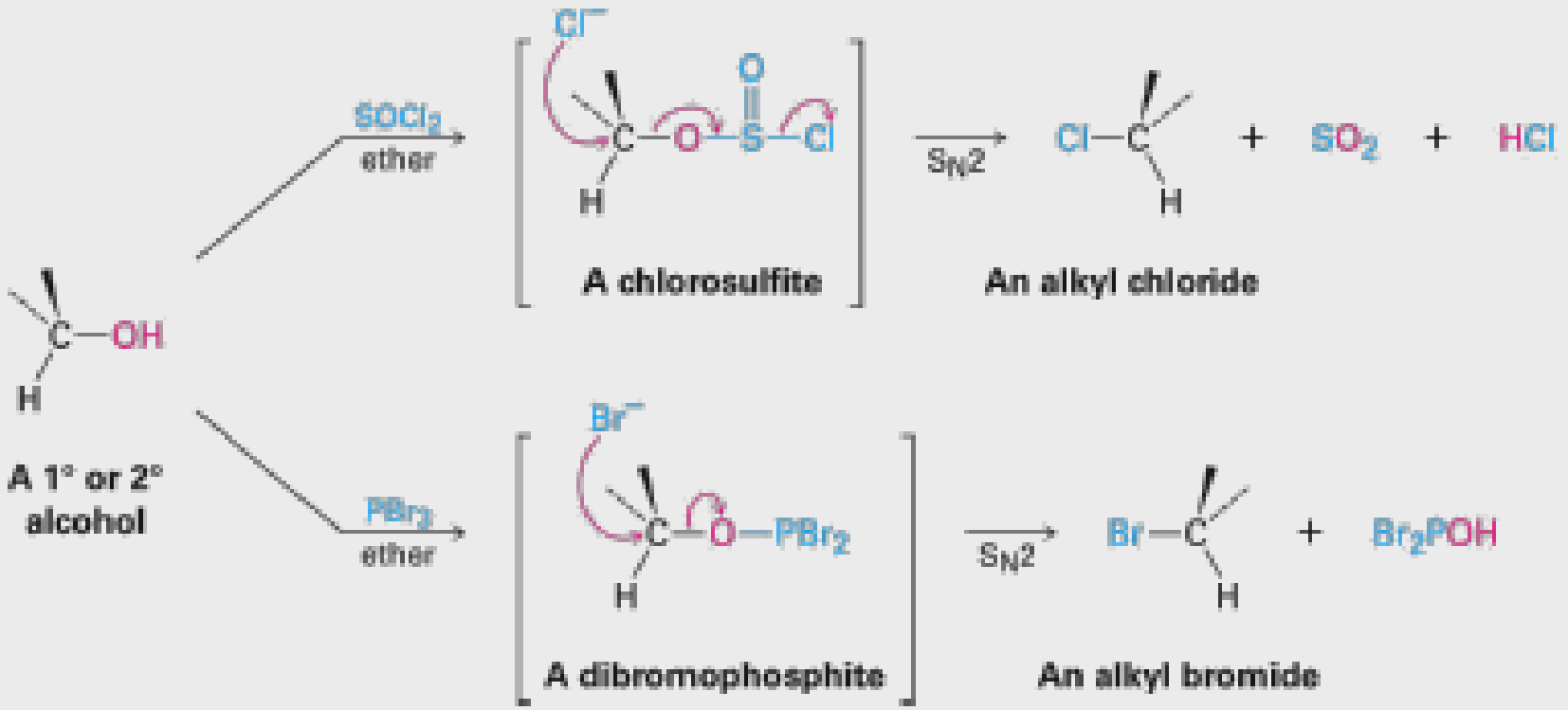


# Reaction of Alcohols

## Reactions with HCl

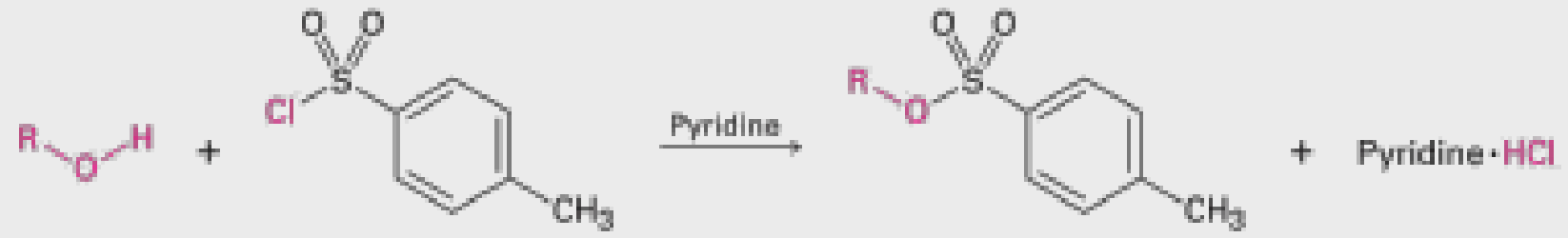
- Chloride is a weaker nucleophile than bromide.
- $ZnCl_2$ is added to promote the reactions
  - it bonds more strongly than proton.
- The reagent composed of HCl and $ZnCl_2$ = Lucas reagent.
- Lucas test: $ZnCl_2$ in conc. HCl
  - 1° alcohols react slowly or not at all.
  - 2° alcohols react in 1-5 minutes.
  - 3° alcohols react in less than 1 minute.

# Reactions of 1° and 2° alcohols



# Conversion of Alcohols into Tosylates

- Reaction with *p*-toluenesulfonyl chloride (tosyl chloride, *p*-TosCl) in pyridine yields alkyl tosylates, ROTos
- Formation of the tosylate does not involve the C–O bond so configuration at a chirality center is maintained
- Alkyl tosylates react like alkyl halides



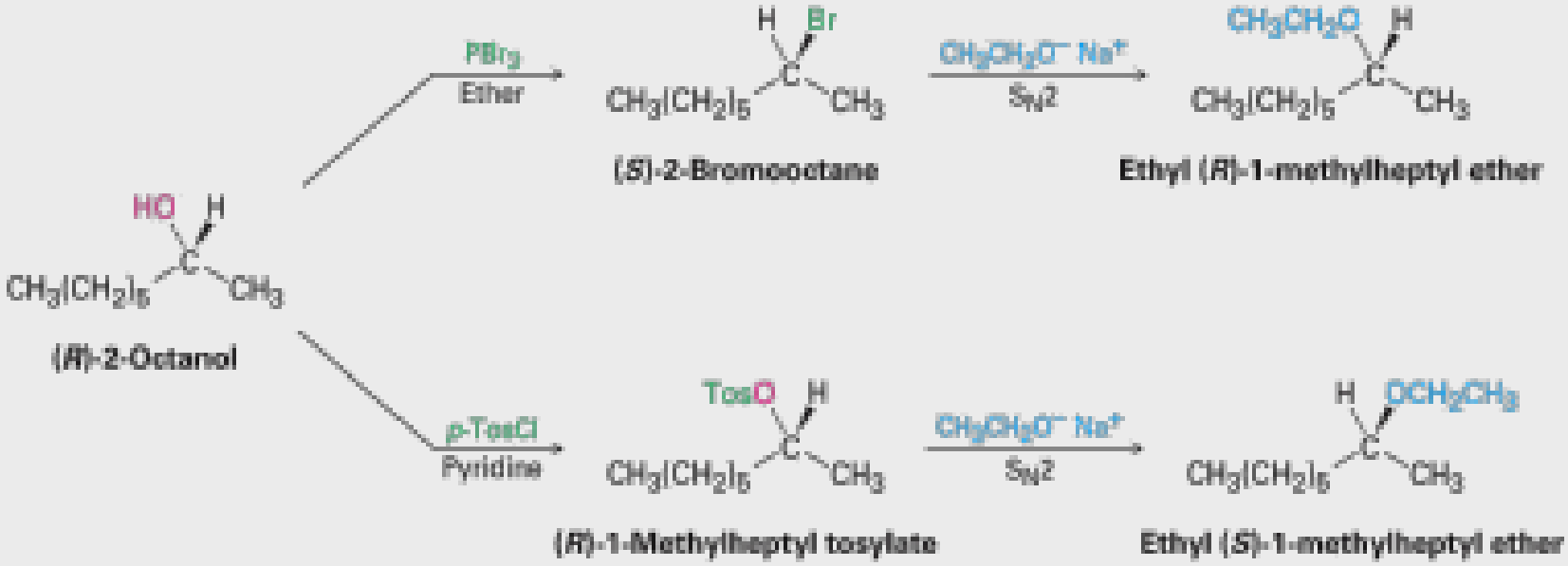

An alcohol

*p*-Toluenesulfonyl chloride

A tosylate (ROTos)

# Stereochemical Uses of Tosylates

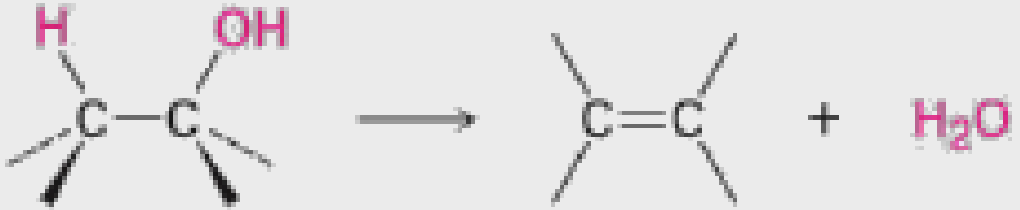
- The $S_N2$ reaction of an alcohol via an alkyl halide proceeds with *two* inversions, giving product with same arrangement as starting alcohol
- The $S_N2$ reaction of an alcohol via a tosylate, produces inversion at the chirality center



# Dehydration of Alcohols to Yield Alkenes

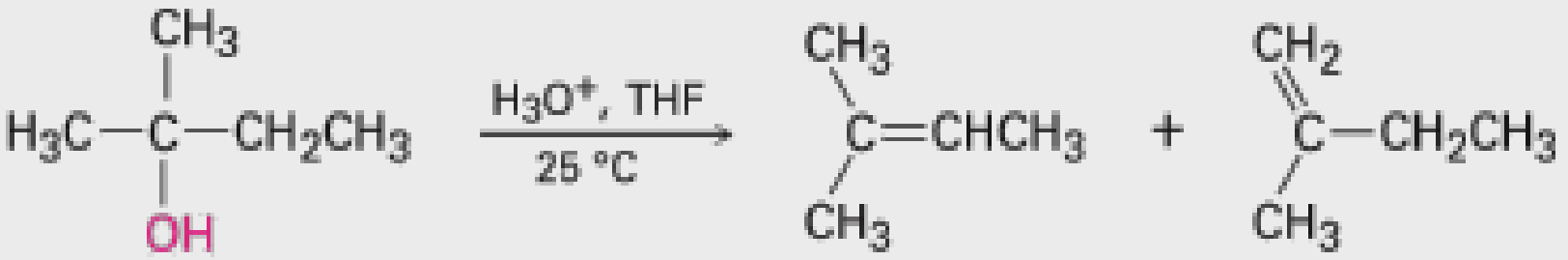
- The general reaction: forming an alkene from an alcohol through loss of O-H and H (hence dehydration) of the neighboring C–H to give π bond
- Specific reagents are needed

**A dehydration reaction**



# Acid- Catalyzed Dehydration

- Tertiary alcohols are readily dehydrated with acid
- Secondary alcohols require severe conditions (75% $H_2SO_4$, 100°C) - sensitive molecules do not survive
- Primary alcohols require very harsh conditions – impractical
- Reactivity is the result of the nature of the carbocation intermediate




**2-Methyl-2-butanol**

**2-Methyl-2-butene (trisubstituted)**

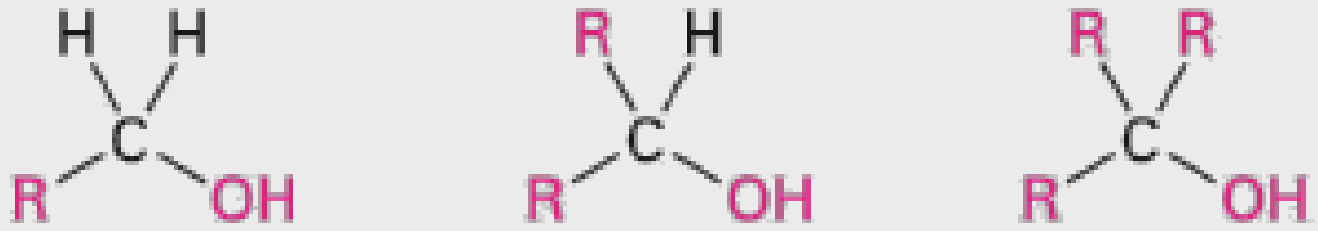
**Major product**

**2-Methyl-1-butene (disubstituted)**

**Minor product**

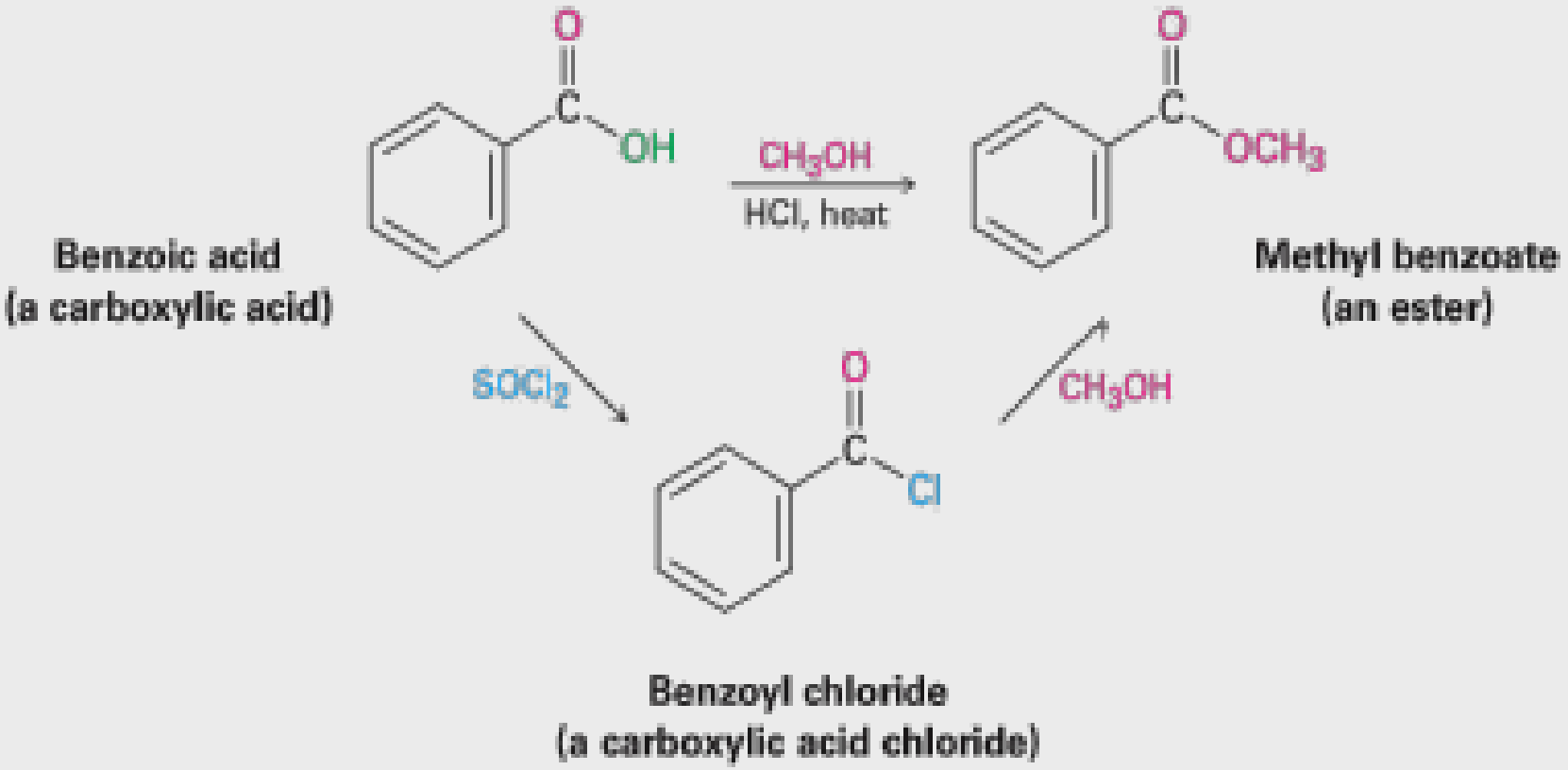
# Dehydration with $POCl_3$

- Phosphorus oxychloride in the amine solvent pyridine can lead to dehydration of secondary and tertiary alcohols at low temperatures
- An E2 reaction via an intermediate ester of $POCl_2$ (see Figure 17.7)



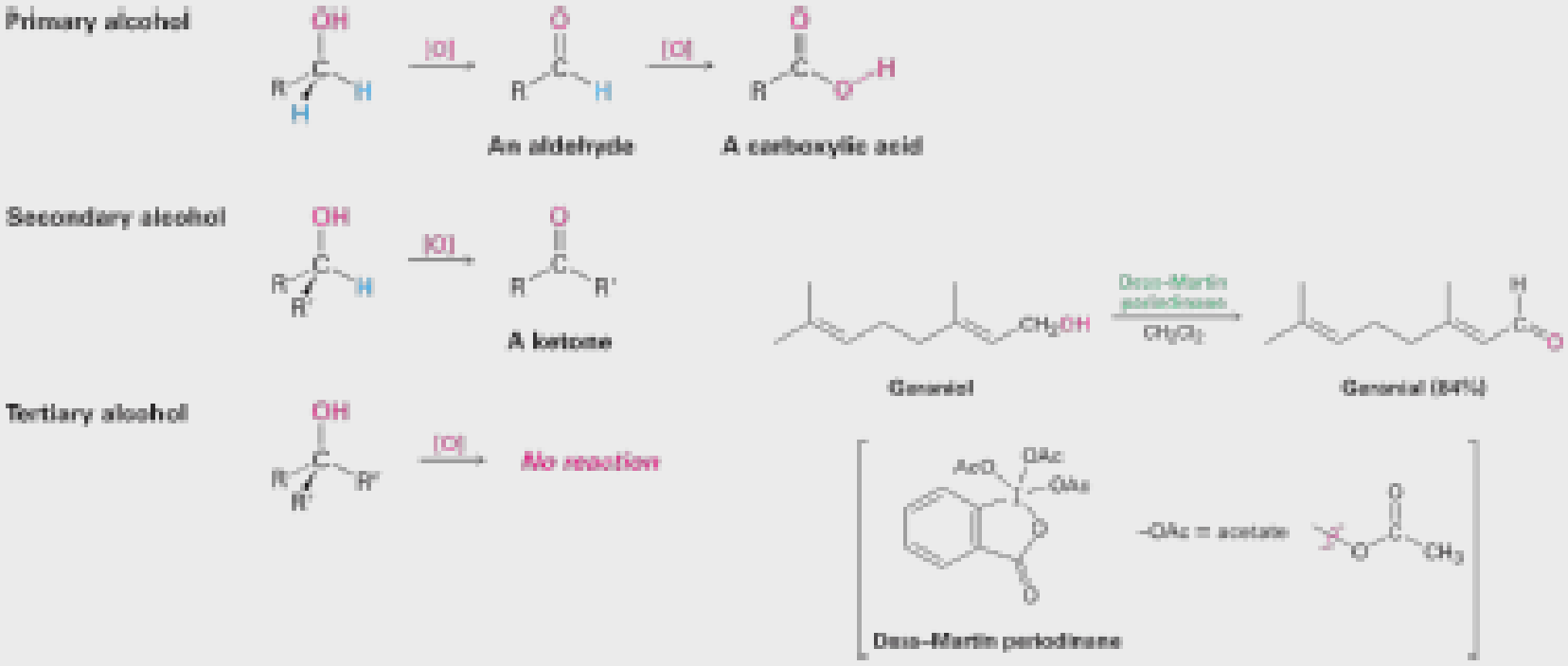

**Primary** < **Secondary** < **Tertiary**

# Incorporation of Alcohols into Esters



# Oxidation of Alcohols

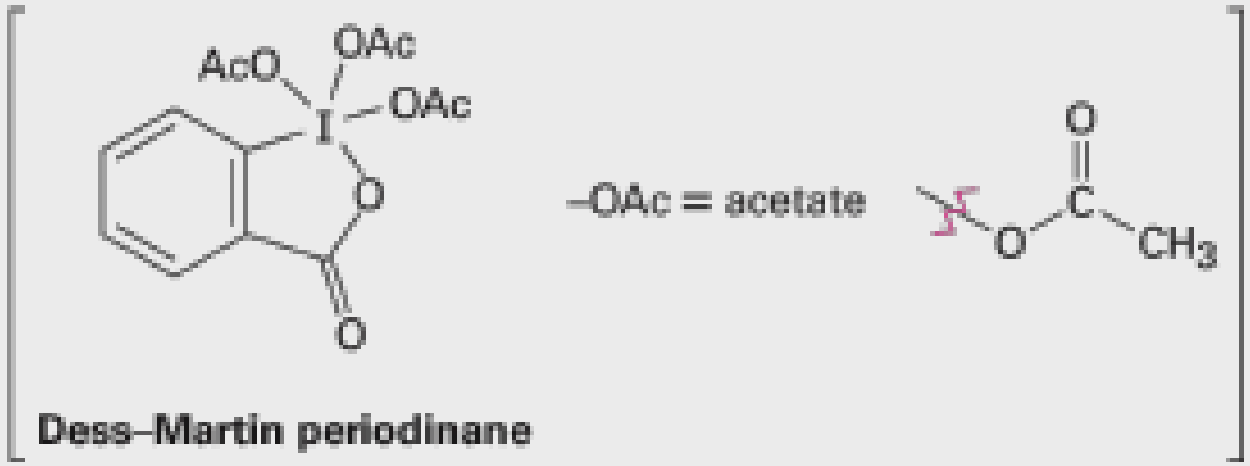
- Can be accomplished by inorganic reagents, such as $KMnO_4$, $CrO_3$, and $Na_2Cr_2O_7$ or by more selective, expensive reagents



# Oxidation of Primary Alcohols

- To aldehyde: pyridinium chlorochromate (PCC, $C_5H_6NCrO_3Cl$) in dichloromethane
- Other reagents produce carboxylic acids


**Geraniol** **Geranial (84%)**




**Dess–Martin periodinane**

# Oxidation of Secondary Alcohols

- Effective with inexpensive reagents such as $Na_2Cr_2O_7$ in acetic acid
- PCC is used for sensitive alcohols at lower temperatures

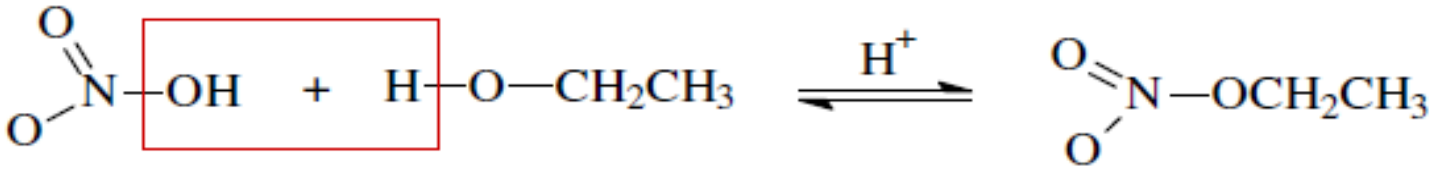

**Testosterone**
**(male sex hormone)**

**4-Androstene-3,17-dione (82%)**

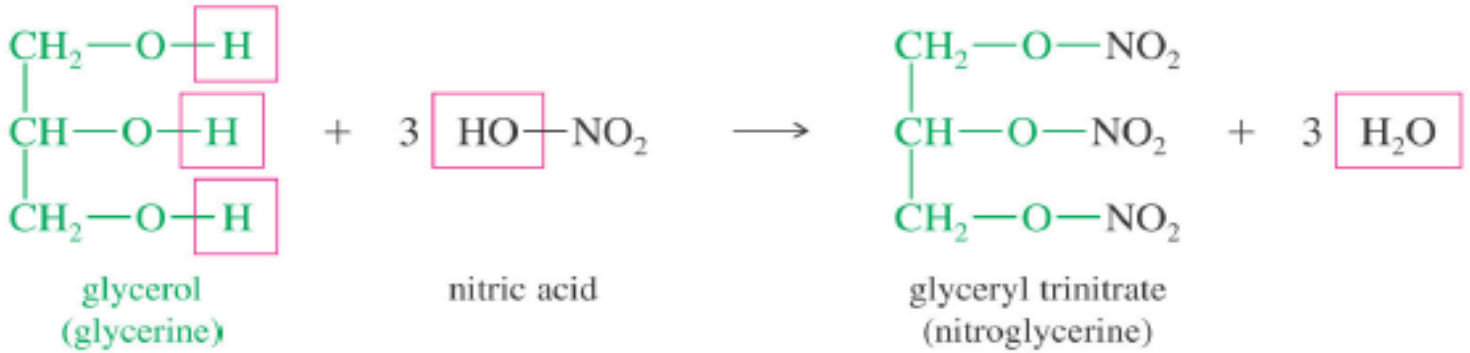
# Reaction of alcohols

## Nitrate Esters

- Alcohols + nitric acid.



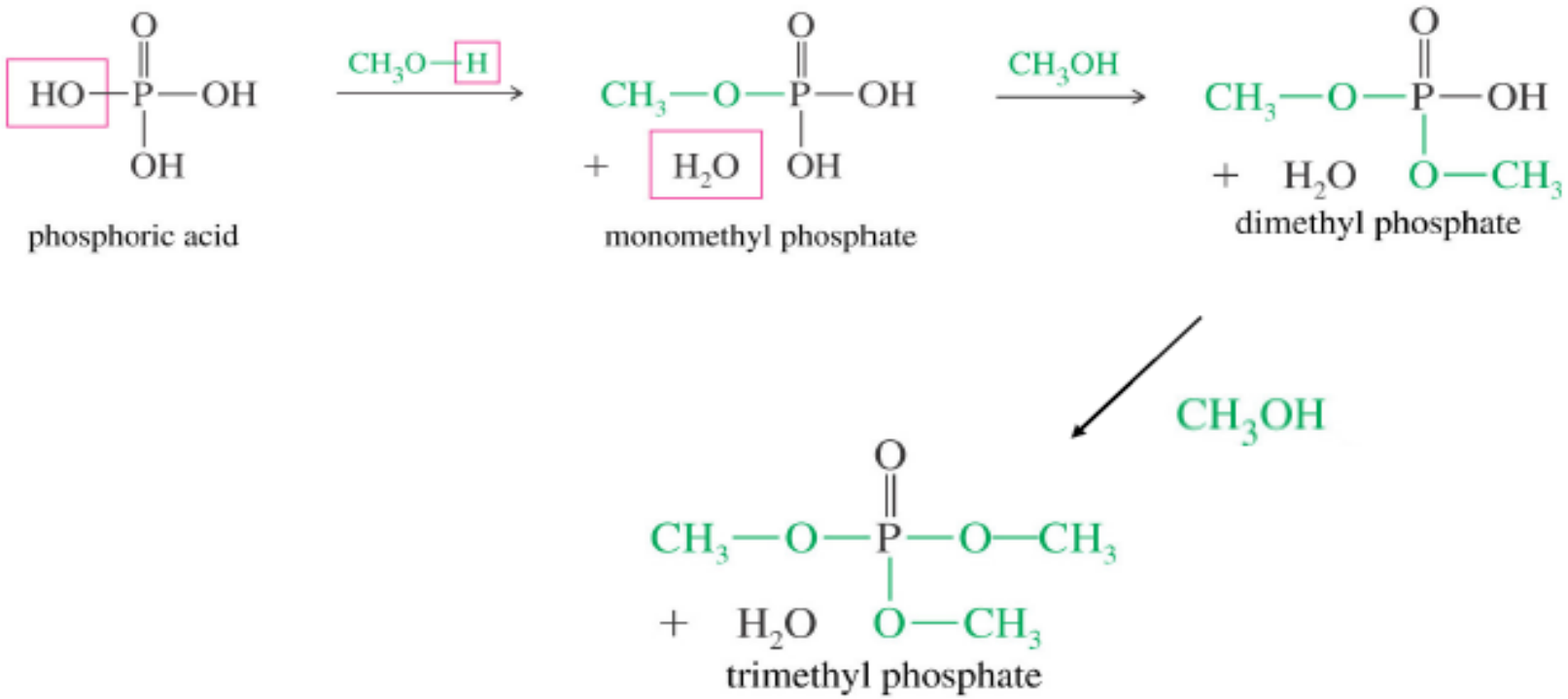

Glyceryl nitrate results from the reaction of glycerol (1,2,3-propanetriol) with three molecules of nitric acid.



# Reaction of al cohols

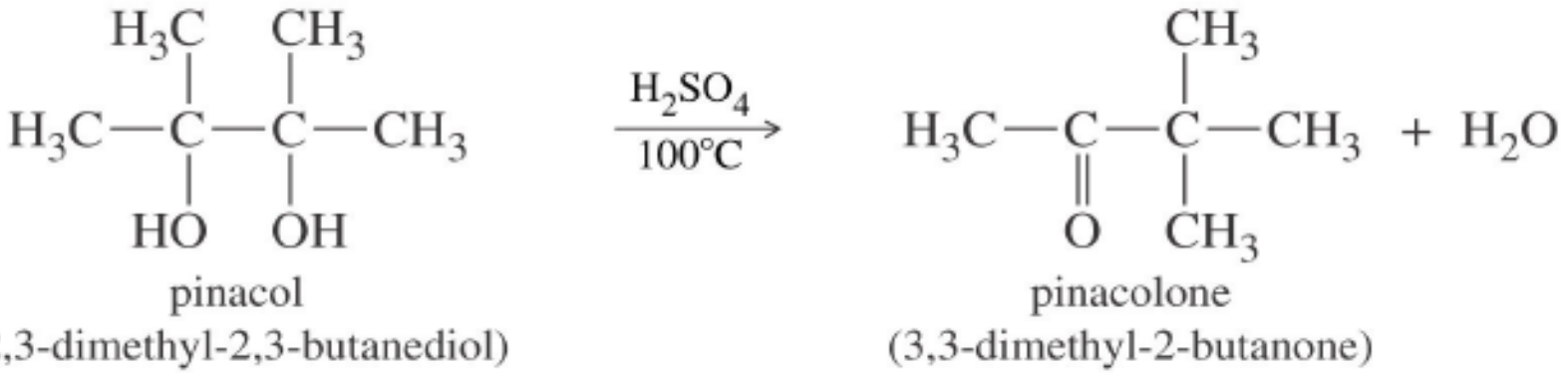
## Phosphate Esters

- Alcohol + phosphoric acid.



# Reaction of alcohol

## Pinacol Rearrangement



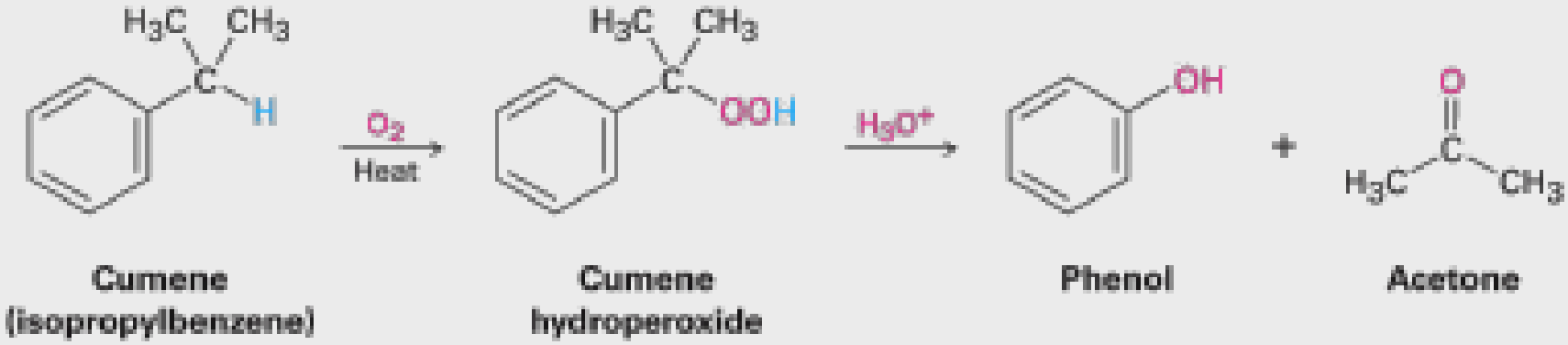

pinacol
(2,3-dimethyl-2,3-butanediol)

pinacolone
(3,3-dimethyl-2-butanone)

- vicinal diol converts to the ketone (pinacolone) under acidic conditions and heat.
- Formally an acid-catalyzed dehydration.

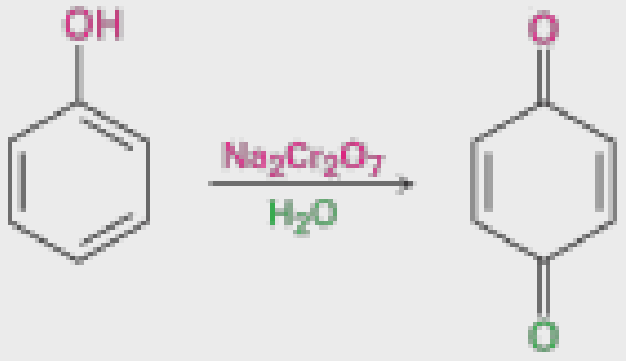
# Phenols and Their Uses

- Industrial process from readily available cumene
- Forms cumene hydroperoxide with oxygen at high temperature
- Converted into phenol and acetone by acid

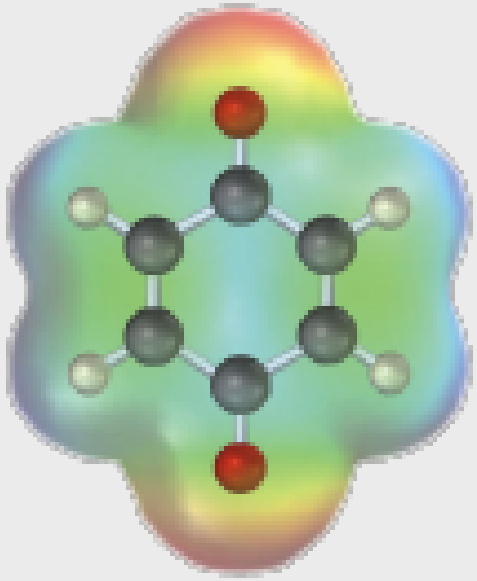


# Reactions of Phenols

- The hydroxyl group is a strongly activating, making phenols substrates for electrophilic halogenation, nitration, sulfonation, and Friedel–Crafts reactions
- Reaction of a phenol with strong oxidizing agents yields a quinone
- Fremy's salt [$(KSO_3)_2NO$] works under mild conditions through a radical mechanism



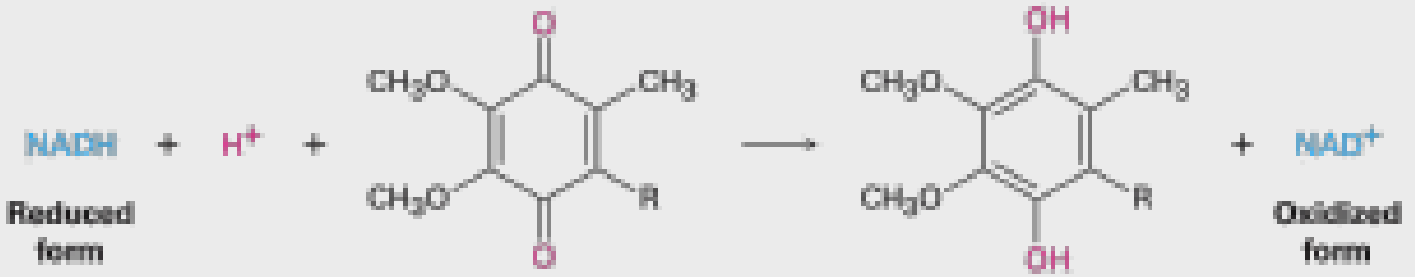

**Phenol** **Benzoquinone (79%)**



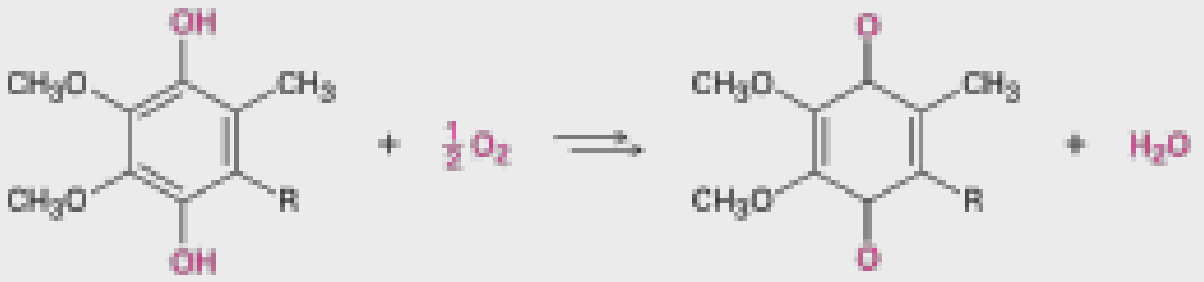
# Quinones in Nature

- *Ubiquinones* mediate electron-transfer processes involved in energy production through their redox reactions

**Step 1**




**Step 2**




Net change: $NADH + \frac{1}{2}O_2 + H^+ \longrightarrow NAD^+ + H_2O$

# Thank you for attention

**Assist proff: idries Muhson al mashkor**