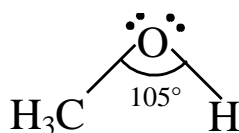
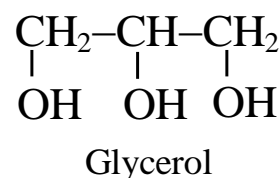
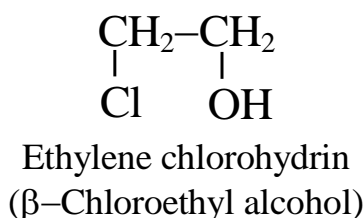
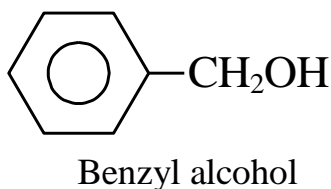
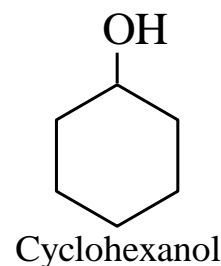
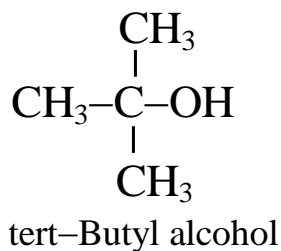


Alcohols

The organic compounds containing one or more than one hydroxyl group(s) attached to sp^3 hybridised carbon atom(s) are called alcohols. Alcohols are bent shaped molecules. In alcohols, the carbon atom linked with 'O' atom of $-OH$ group is sp^3 hybridised. The central 'O' atom is also sp^3 hybridised and the $C-O-H$ bond angle is 105° .

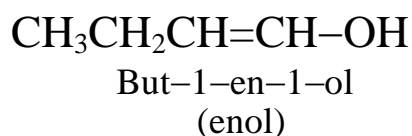
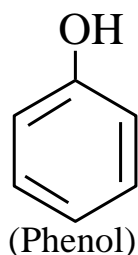


Some examples of alcohols are:



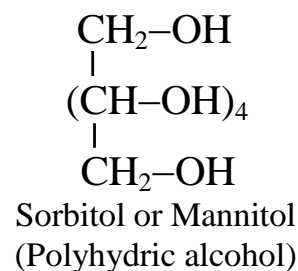
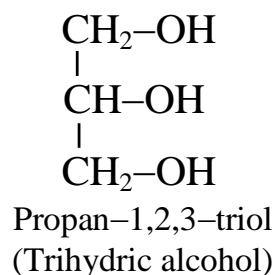
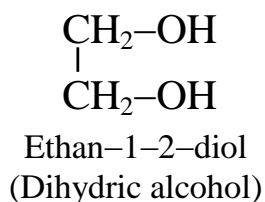
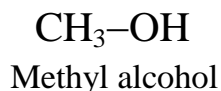
Compounds in which the hydroxyl group is attached directly to a sp^2 hybridised carbon atom are known as enols or phenols (in case of aromatic compounds).

For example,

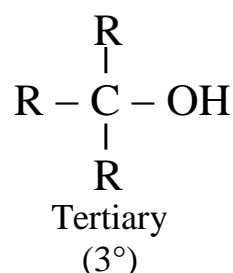
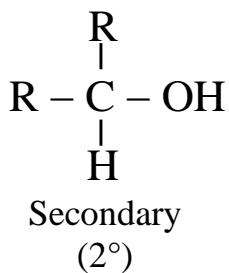
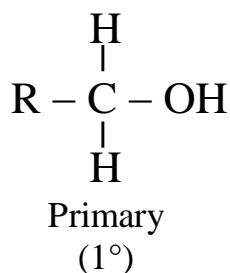


Classification of Alcohols

Alcohols are classified as mono, di and trihydric alcohols depending upon the number of -OH groups present in them. Alcohols with one, two and three -OH groups are called mono, di and trihydric alcohols respectively. Alcohols, which contain four or more hydroxyl groups attached to the sp^3 hybridised carbon atoms are called polyhydric alcohols.



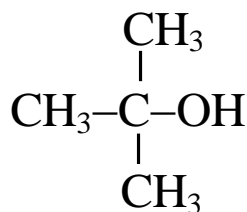
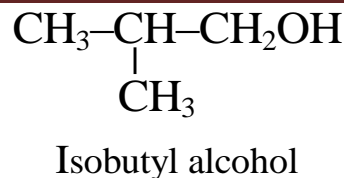
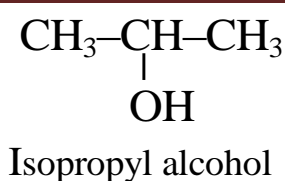
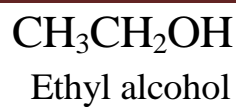
The monohydric alcohols can further be classified according to the type of carbon that bears the -OH group. An alcohol in which OH group is attached to carbon atom, which in turn is linked to only one carbon atom, is called primary (1°) alcohol. Similarly, an alcohol in which OH group is attached a carbon atom which is linked to two carbon atoms is called secondary (2°) alcohol and an alcohol in which the carbon atom bearing OH group is attached to three carbon atoms is called tertiary (3°) alcohol. For example,



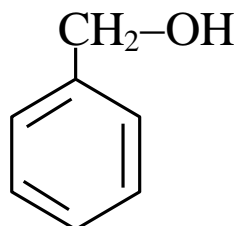
IUPAC Nomenclature of Alcohols

For certain alcohols, common names are used extensively with respect to their IUPAC names. The common names are derived by adding the suffix alcohol to the name of alkyl group. Common names of few alcohols are

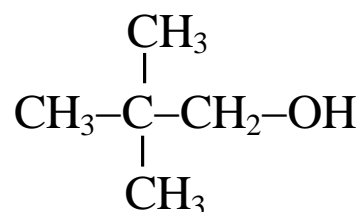
ALCOLHOLS, PHENOLS AND ETHERS



tert-butyl alcohol



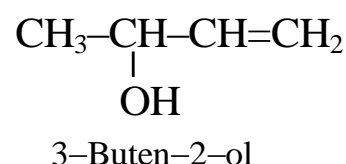
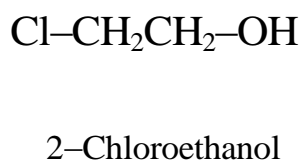
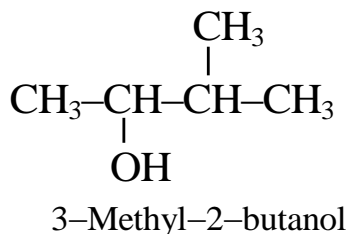
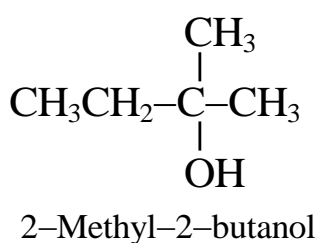
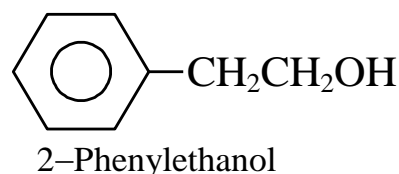
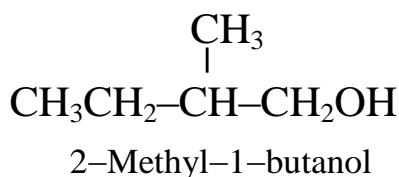
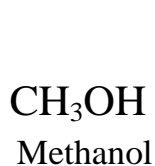
Benzyl alcohol



Neo-pentyl alcohol

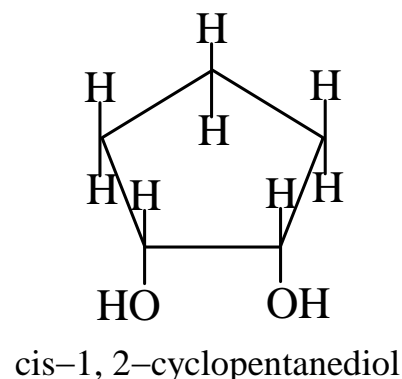
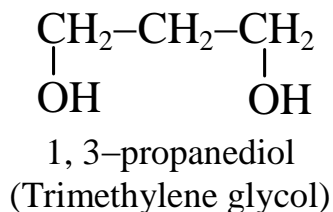
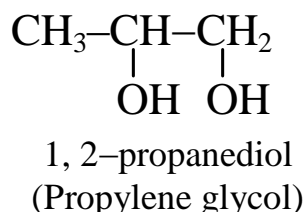
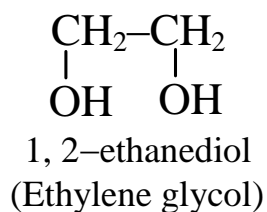
The IUPAC rules of naming alcohols are as follows:

- Select the parent chain structure as the longest continuous carbon chain that contains the $-\text{OH}$ group, then consider the compound to have been derived from this structure by replacement of hydrogen by various groups. The parent structure is known as ethanol, propanol, butanol etc. depending on the number of carbon atoms. Each name is derived by replacing the terminal $-e$ of the corresponding alkane by $-ol$.
- Indicate by a number, the position of the $-\text{OH}$ group in the parent chain, using the lowest possible number.
- Indicate by numbers, the positions of other groups attached to the parent chain.



ALCOLHOLS, PHENOLS AND ETHERS

Alcohols containing two hydroxyl groups are called glycols. They have both common name and IUPAC names. Common names are given in parenthesis.

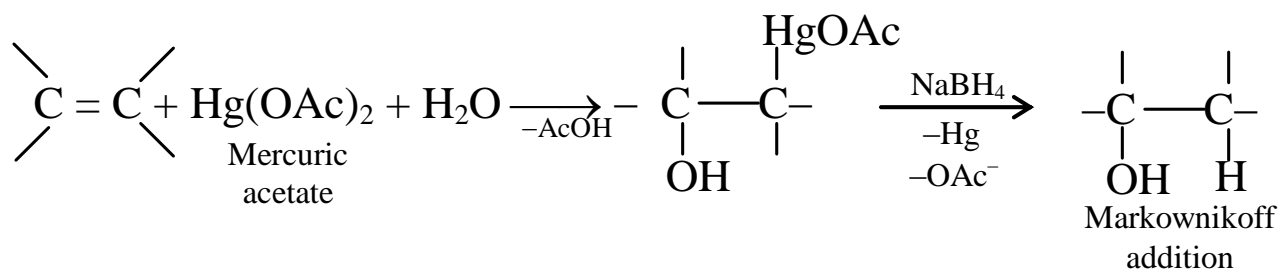


Methods Of Preparation Of Alcohols

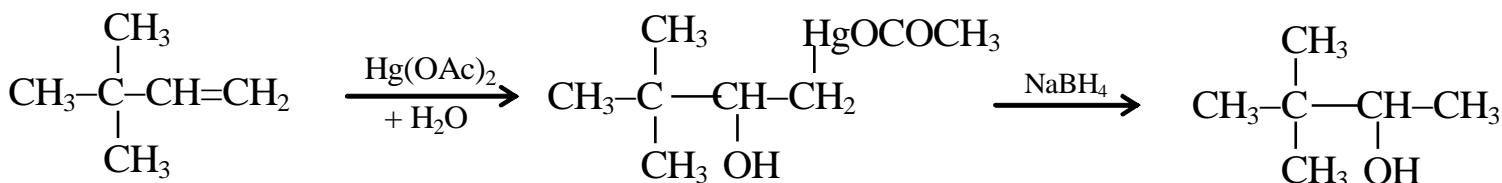
Monohydric alcohols can be prepared by the following methods:

Oxymercuration-Demercuration

Alkenes can be converted into alcohols by oxymercuration–demercuration reaction. In this reaction, addition of water takes place according to Markownikov's rule.



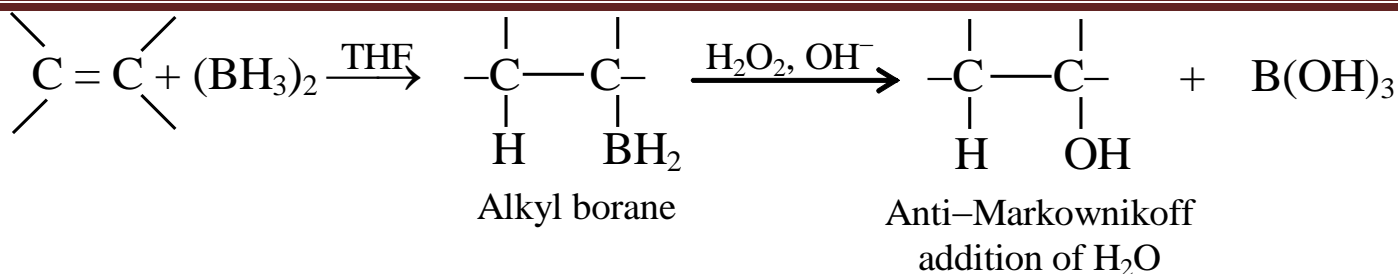
For example,



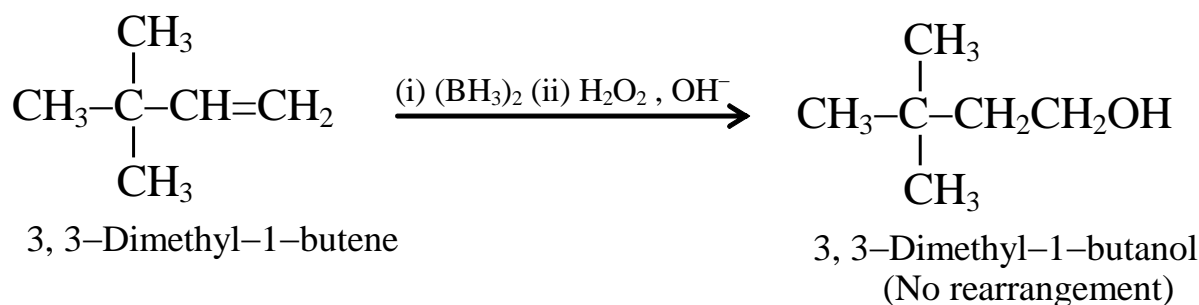
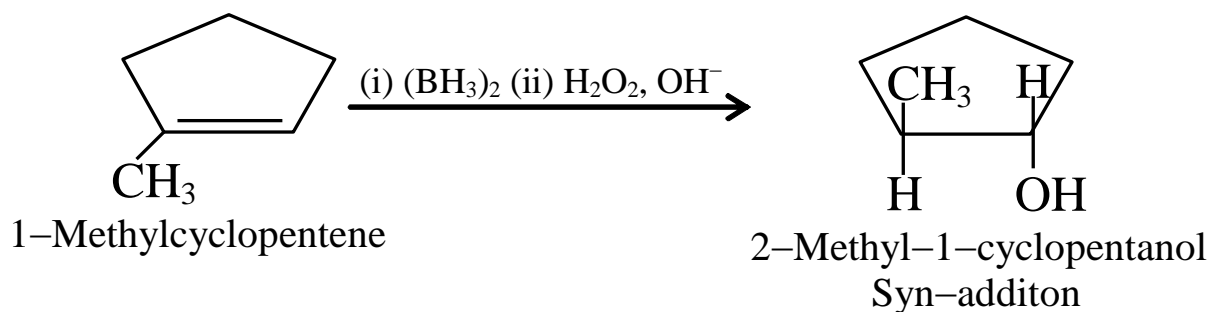
Hydroboration-Oxidation

Alkenes react with diborane to form trialkyl boranes, which upon treatment with alkaline H_2O_2 give alcohols via anti-Markownikoff's addition of water.

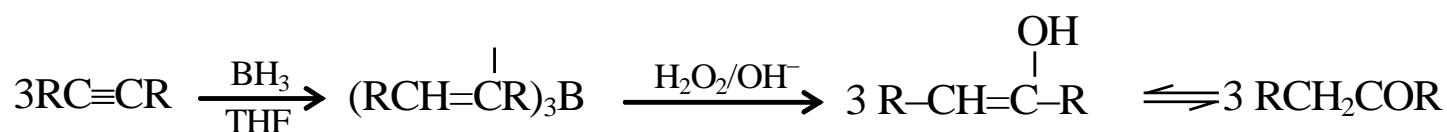
ALCOLHOLS, PHENOLS AND ETHERS



For example,



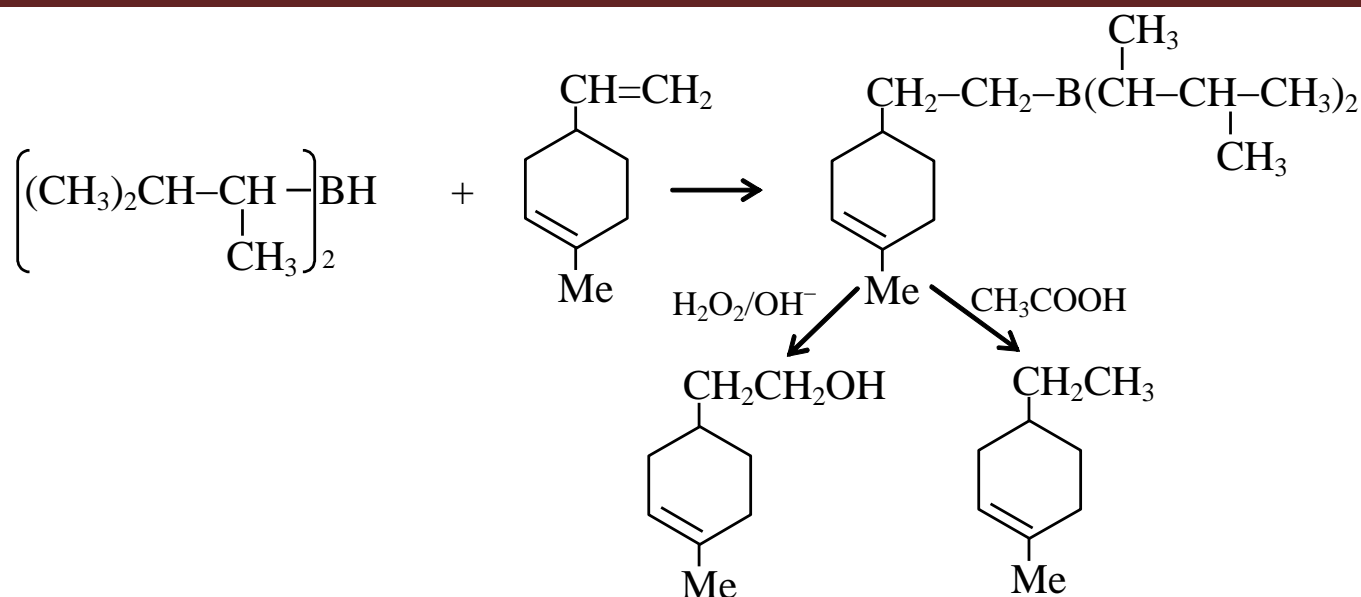
(i) Hydroboration-oxidation of non-terminal alkynes leads to the formation of ketones. For example,



(ii) Non-catalytic hydrogenation: Hydroboration-oxidation can be used to reduce double bonds in alkene without using molecular hydrogen and a transition metal catalyst. For example,

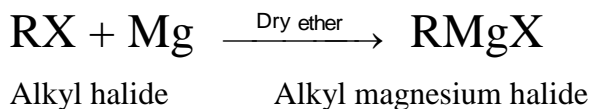


(iii) Selective reduction: Less hindered double bonds can be selectively reduced by hydroboration-oxidation. For example,



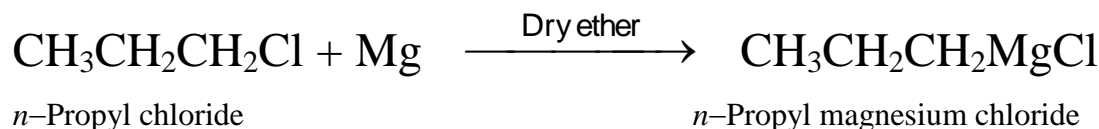
Synthesis from Grignards Reagent

When a solution of an alkyl halide in dry ethyl ether, $(\text{C}_2\text{H}_5)_2\text{O}$, is allowed to stand over turnings of metallic magnesium, a vigorous reaction takes place. The solution turns cloudy, begins to boil and the magnesium metal gradually disappears. The resulting solution is known as Grignard reagent. It is one of the most useful and versatile reagents known to the organic chemists.

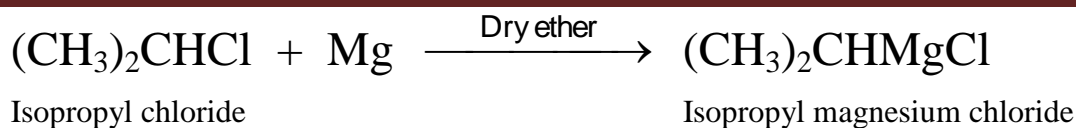


The Grignard reagent has the general formula RMgX , and the general name alkyl magnesium halide. The carbon–magnesium bond is covalent but highly polar, with carbon pulling away electrons from electropositive magnesium but the magnesium–halogen bond is essentially ionic, $\text{R}^{\ominus} \text{Mg}^{\oplus} \text{X}$.

Since magnesium becomes bonded to the same carbon that previously held halogen, the alkyl group remains intact during the preparation of the reagent. Thus, *n*-propyl chloride yields *n*-propyl magnesium chloride and isopropyl chloride yields isopropyl magnesium chloride.



ALCOLHOLS, PHENOLS AND ETHERS



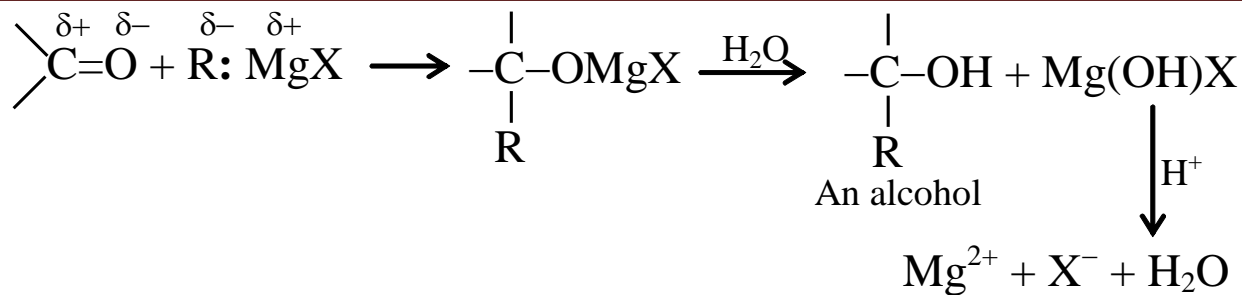
The Grignard reagent belongs to a class of compounds called organometallic compounds, in which carbon is bonded to a metal like lithium, potassium, sodium, zinc, mercury, lead, thallium or to almost any metal known. Each kind of organometallic compound has its own set of properties and its particular uses depend on these. But whatever the metal, it is less electronegative than carbon and the carbon–metal bond is always highly polar. Although the organic group is not a full–fledged carbanion but has considerable carbanionic characters. Thus, organometallic compounds can serve as a source of carbon bearing negative charge.

The Grignard reagent has the formula RMgX and is prepared by the reaction of metallic magnesium with the appropriate organic halide. This halide can be alkyl (1° , 2° , 3°), allylic, aryl alkyl (e.g. benzyl), or aryl (phenyl) or substituted phenyl. The halogen may be $-\text{Cl}$, $-\text{Br}$ or $-\text{I}$, (Aryl magnesium chlorides must be made in the cyclic ether tetrahydrofuran instead of ethyl ether). Aldehydes and ketones resemble each other closely in most of their reactions. The carbonyl group is also unsaturated and like the carbon–carbon bond, it also undergoes addition. One of the typical reaction is cis addition of the Grignard reagent.

The electrons of the carbonyl double bond hold together atoms of different electronegativity, thus, the electrons are not equally shared, the mobile π –cloud is pulled strongly towards the more electronegative atom, oxygen. The addition of an unsymmetrical reagent happens such that the nucleophilic (basic) portion attaches itself to carbon and the electrophilic (acidic) portion attaches itself to oxygen.

The carbon–magnesium bond of the Grignard reagent is a highly polar bond, carbon being negative relative to electropositive magnesium. When Grignard reagent is added to carbonyl compounds, the organic group attaches to carbon and magnesium to oxygen.

ALCOLHOLS, PHENOLS AND ETHERS



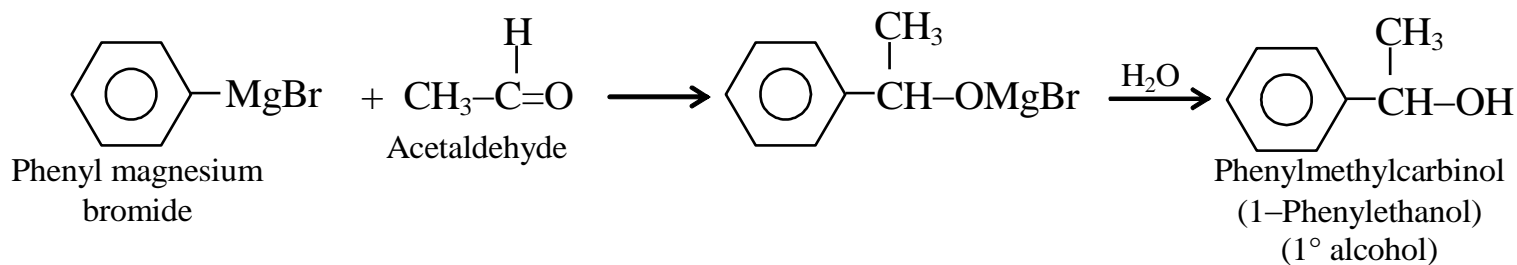
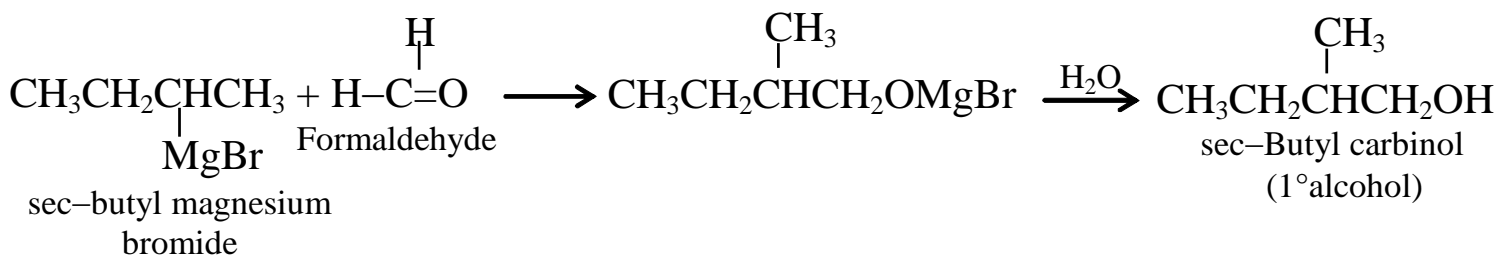
The product is a magnesium salt of the weakly acidic alcohol and is easily converted into the alcohol by the addition of the stronger acid, water. The $\text{Mg}(\text{OH})\text{X}$ thus formed is a gelatinous material, which forms coating over carbonyl compound, thus dilute mineral acid (HCl , H_2SO_4) is commonly used instead of water, so that water-soluble magnesium salts are formed.

Products Of The Grignard Synthesis:

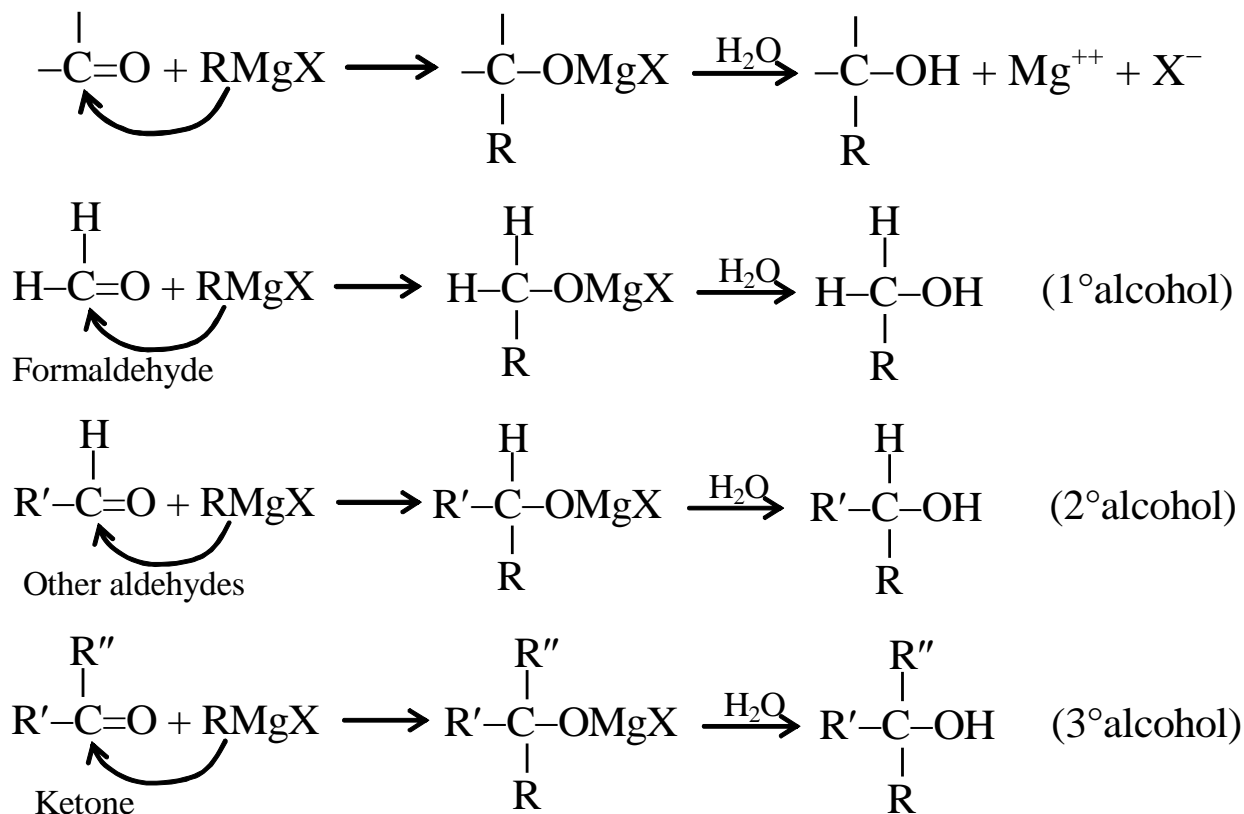
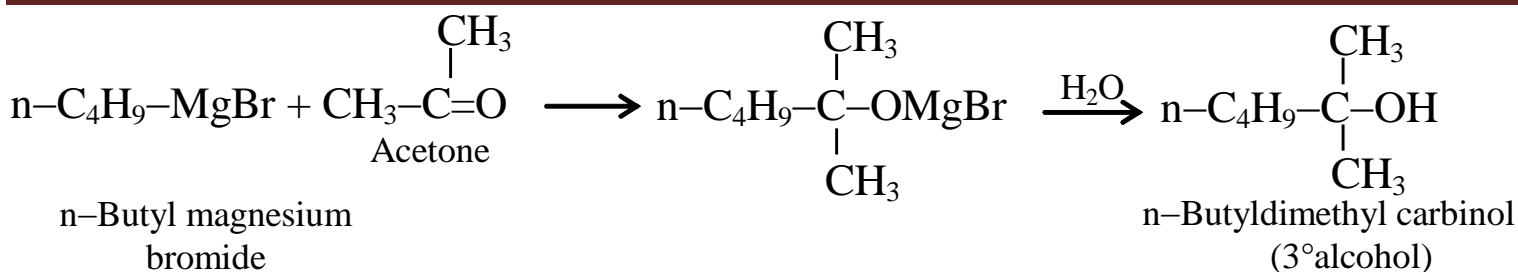
The type of alcohol that is obtained from a Grignard synthesis depends upon the type of carbonyl compound used. Formaldehyde (HCHO) yields primary alcohols, other aldehydes (RCHO) yield secondary alcohols and ketones (R_2CO) yield tertiary alcohols.

The number of hydrogens attached to the carbonyl carbon defines the carbonyl compound as formaldehyde, higher aldehydes or ketone. The carbonyl carbon is the one that finally bears the -OH group in the product and the number of hydrogen defines the alcohol as primary, secondary, or tertiary.

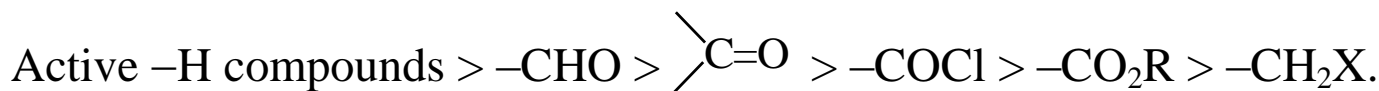
For example,



ALCOLHOLS, PHENOLS AND ETHERS



Reactivity order of the substrates with a Grignard reagent is

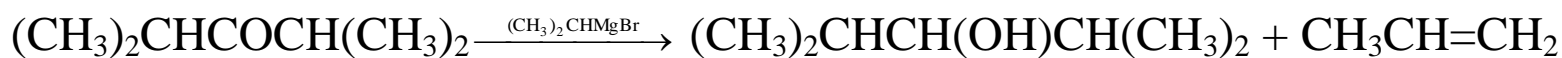


Exceptional Behaviour Of Grignard Reagent:

Sometimes, Grignard reagent does not react with compounds containing functional group normally capable of undergoing reaction. Generally, branching of the carbon chain near the functional group prevents the reaction. For example, methyl magnesium bromide or iodide does not react with hexamethyl acetone $(\text{CH}_3)_3\text{CCOC}(\text{CH}_3)_3$. It has also been found that if Grignard reagent contains large alkyl groups, reaction may be prevented. For example, isopropyl methyl acetone reacts with methyl magnesium iodide but not with t-butyl magnesium

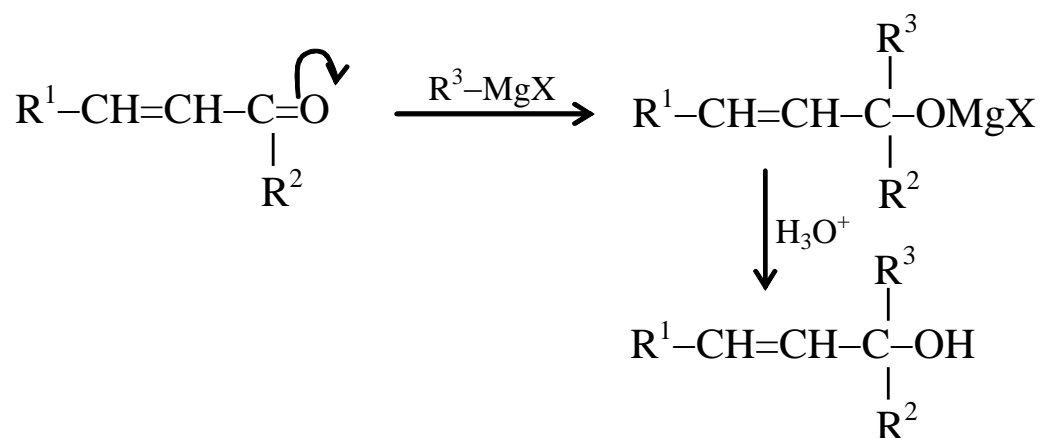
ALCOLHOLS, PHENOLS AND ETHERS

iodide. In other cases, abnormal reaction may take place. For example, when isopropyl magnesium bromide is added to diisopropyl ketone, the expected tertiary alcohol is not formed, instead the secondary alcohol, di-isopropyl carbinol is obtained resulting from the reduction of the ketone.

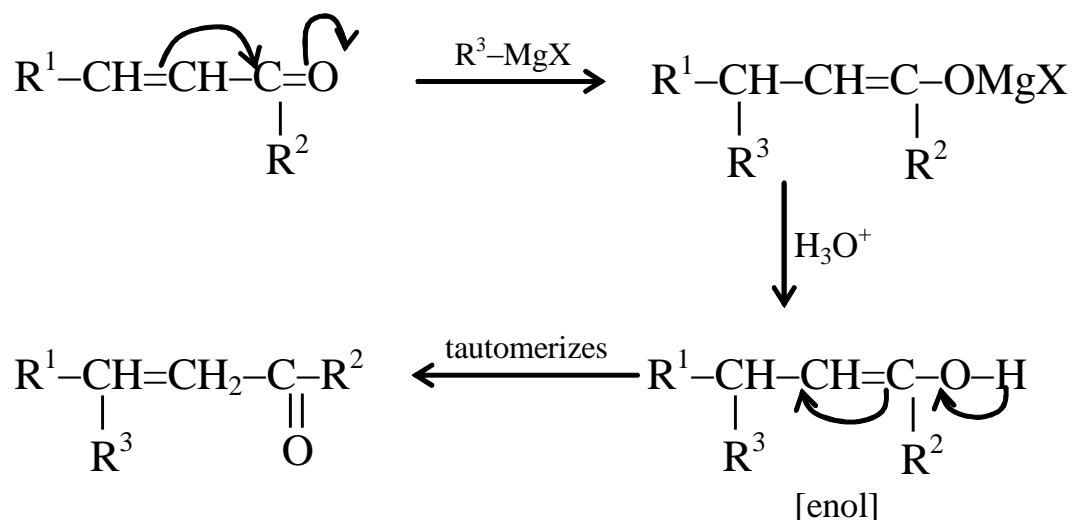


α , β -unsaturated carbonyl compounds adds on Grignard reagents at the 1,2 or 1,4-positions.

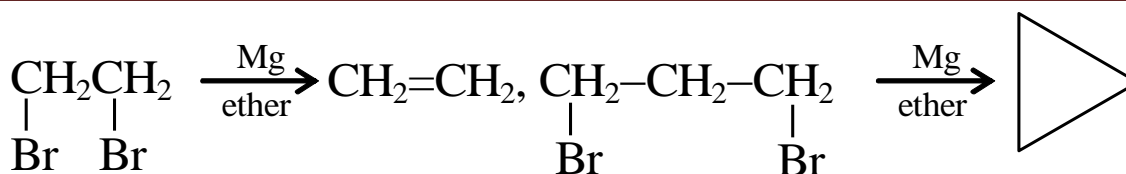
1,2-addition:



1,4-addition:



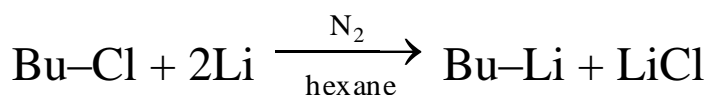
The reaction of dihalides of the type $\text{Br}(\text{CH}_2)_n\text{Br}$ with magnesium depends on the value of n . For $n = 1$, no Grignard reagent is formed. For example,



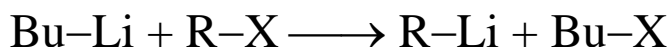
When $n \geq 4$, the Grignard reagent can be possibly made with dibromo compound i.e, $\text{Br}(\text{CH}_2)_n\text{Br}$.

Organolithium Compounds:

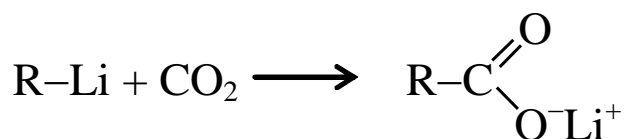
Alkyl lithium compounds can be prepared by direct displacement, the chlorides give best yields. For example,



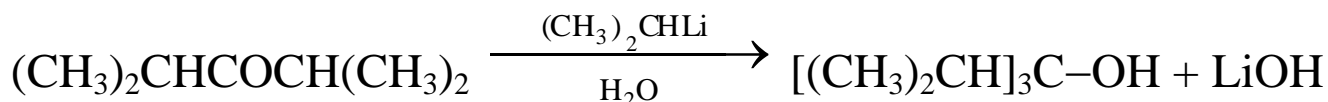
Other organolithium compounds can be prepared by the halogen-metal exchange with the butyl lithium compound.



Organolithium compounds behave like the Grignard reagent but the lithium compounds are usually more reactive and the yield of the product is often better. Because of their sensitivity to oxygen and to water, reaction with lithium alkyls is best carried out in an atmosphere of dry nitrogen. Alkyl lithium reacts with CO_2 to give carboxylate salt.

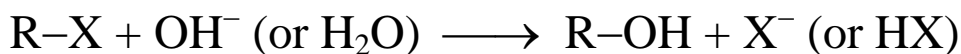


It has been found that sterically hindered t-alcohols cannot be prepared by the Grignard reaction. On the other hand, many of these alcohols can be prepared by means of lithium alkyls. For example,



Hydrolysis Of Alkyl Halides

Alkyl halides on hydrolysis gives alcohols either by S_N1 or S_N2 route depending upon the structure of alkyl halide and the reaction conditions employed.

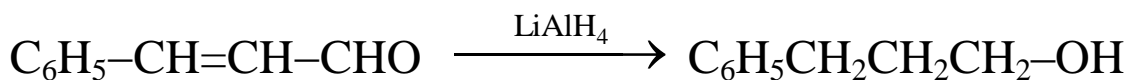


Reduction Of Carbonyl Compounds

Aldehydes can be reduced to primary alcohols and ketones to secondary alcohols, either by catalytic hydrogenation or by the use of chemical reducing agents like lithium aluminium hydride (LiAlH₄), H₂/Ni, B₂H₆/THF etc.

Reduction By LiAlH₄

It can reduce all functional groups of column 'A' into Column 'B'. Generally, it is unable to reduce double bond, which are in conjugation with >C=O group the double bond is reduced when a phenyl group is attached to the β-carbon. E.g.



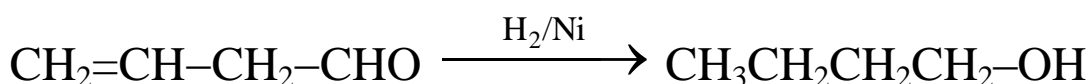
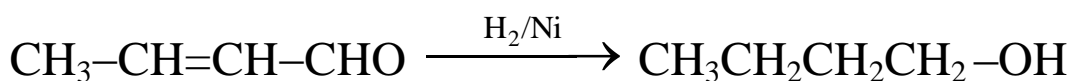
"A"	"B"
>CHO	$\text{-CH}_2\text{-OH}$
>C=O	>CH-OH
-COOH	$\text{-CH}_2\text{-OH}$
-COOR	$\text{-CH}_2\text{-OH} + \text{ROH}$
-COCl	$\text{-CH}_2\text{-OH}$
$(\text{RCO})_2\text{O}$	$\text{RCH}_2\text{-OH}$
lactone	Diol
epoxide	Alcohol

Reduction By NaBH_4

It can reduce all the above groups of column 'A' into groups of column 'B' except, $-\text{COOH}$ and $-\text{COOR}$. NaBH_4 is able to reduce the double bonds, which are in conjugation with >C=O group.

Reduction By H_2/Ni

It can reduce all the above groups of column 'A' into groups of column 'B'. It can also reduce double and triple bond present in carbonyl compounds irrespective of the position in carbon chain whether it is in conjugation with carbonyl group or not.



Reduction By $\text{B}_2\text{H}_6/\text{THF}$

It can reduce all above groups of column 'A' into groups of column 'B' except, $-\text{COCl}$.

Reduction By LiAlH_4 OR NaBH_4

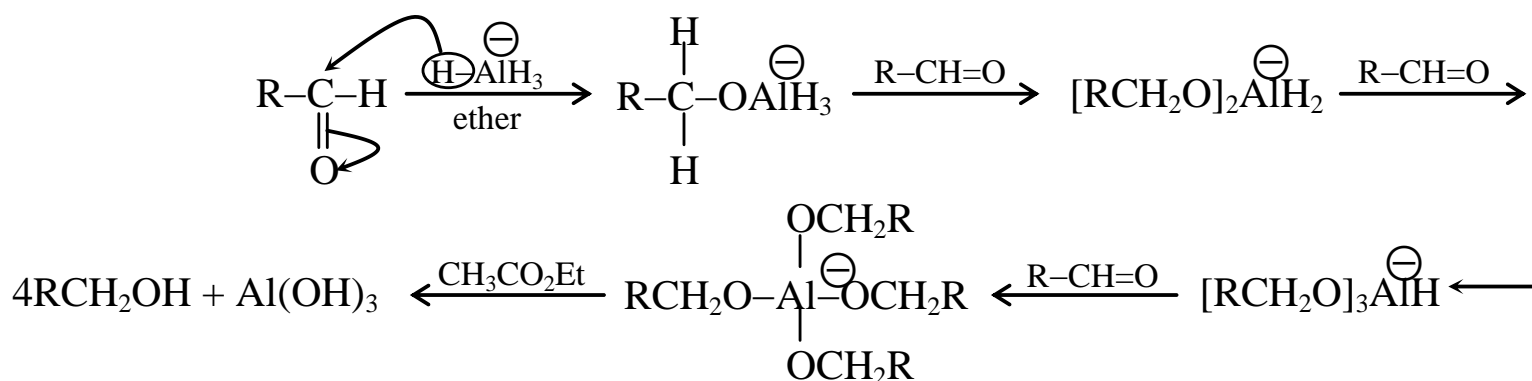
The commonly used reagent for the reduction of aldehydes and ketones are LiAlH_4 or NaBH_4 . The reaction proceeds by successive transfer of hydride ions (H^-) from boron or aluminium to four different carbonyl carbons. As all four of the hydrides are transferred, there are distinct reducing agent used in every step of reduction. In the first step, the reducing agent is AlH_4^- (I), while in the second step, the reducing agent is $\text{RCH}_2\text{OAlH}_3^-$ (II).

In the same manner, species $[\text{RCH}_2\text{O}]_2\text{AlH}_2^-$ (species III) and $[\text{RCH}_2\text{O}]_3\text{AlH}^-$ (species IV) will be obtained. Reduction with NaBH_4 is usually done in water or in alcohol which are used as the solvent. The solvent destroys the intermediate alkoxide ion and yields alcohol. If water or an alcohol is not used as the solvent, aqueous acid can be added after the reduction to convert the alkoxide to alcohol.

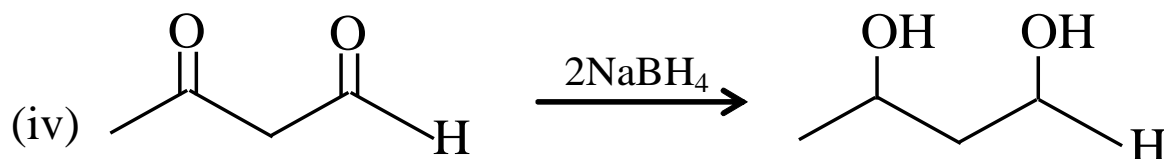
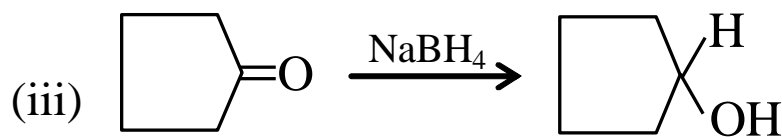
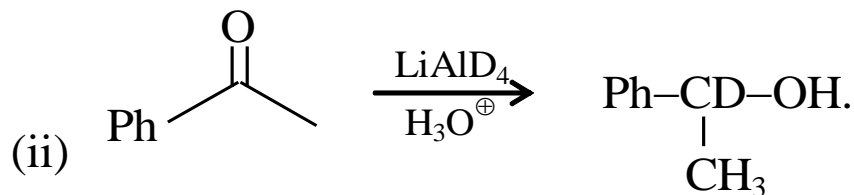
ALCOLHOLS, PHENOLS AND ETHERS

The mechanism for reduction with lithium aluminium hydride is very similar to that of NaBH_4 . As LiAlH_4 violently reacts with water and other polar protic solvents to give molecular hydrogen, reduction with LiAlH_4 are done in aprotic solvents like anhydrous ether. Ethyl acetate is added to decompose the aluminium complex. But reduction with NaBH_4 can be carried out in water or ethanol solution.

Mechanism Of Reduction By LiAlH_4 :

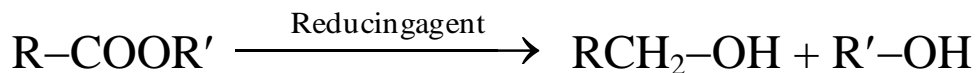


Aldehydes are reduced to primary alcohols by both LiAlH_4 and NaBH_4 while these reducing agents reduce ketones to secondary alcohols.

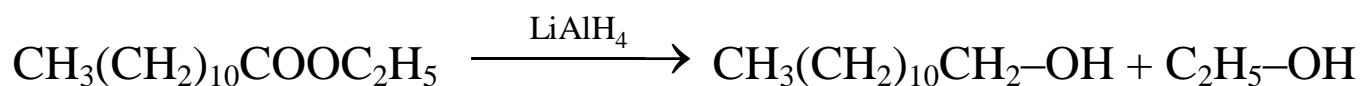
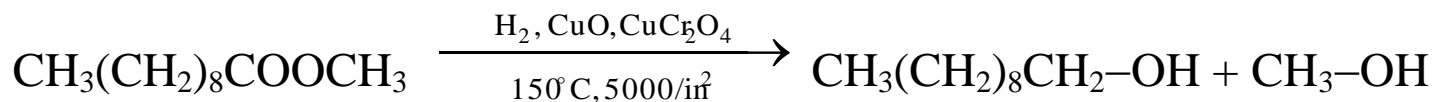


Reduction Of Esters

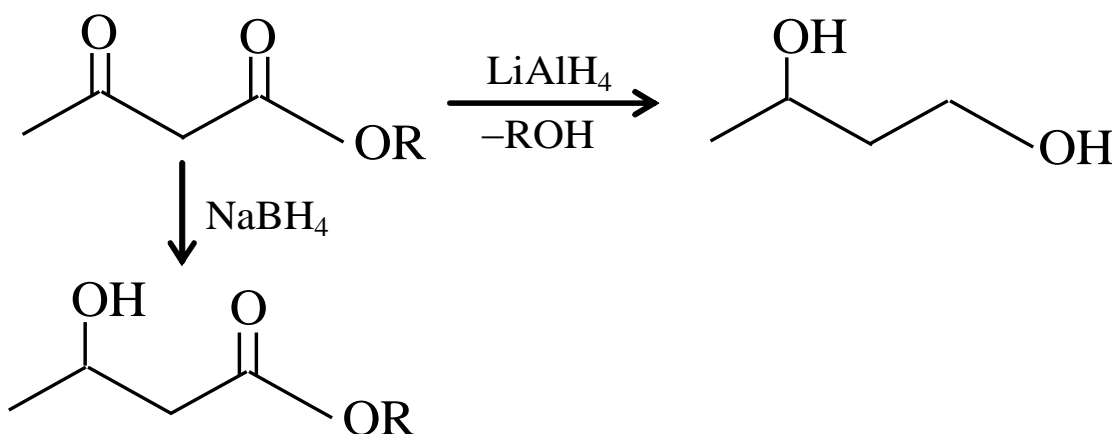
In chemical reduction of esters, the acid portion of ester is converted into primary alcohol.



For example,



Carboxylic acids and esters produce alcohols by LiAlH_4 but not by NaBH_4 .



General Physical Properties Of The Alcohols

The properties of the alcohols are largely determined by OH group. However, the alkyl group (which is inert) also plays important role to explain some of the physical properties like boiling point and solubility in water.

Boiling Point

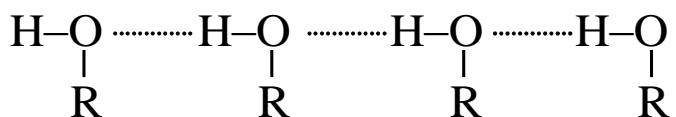
The lower members like methanol, ethanol, 1-propanol have higher boiling points. The boiling point rises as the molecular weights of the alcohol increases. It is quite evident that within the homologous series, the alcohols of normal chain show a rise in the boiling points with the increase in molecular weights.

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Like alkanes, the branched chain isomers of alcohol have lower boiling points. Thus among the four isomeric butyl alcohols, t-butyl has the lowest boiling points (80°C). The order of boiling points of isomeric butyl alcohols is

n-Butyl alcohol, $\text{CH}_3(\text{CH}_2)_3\text{OH}$ > iso-butyl alcohol, $(\text{CH}_3)_2\text{CHCH}_2\text{OH}$ > sec-butyl alcohol, $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$ > t-butyl alcohol, $(\text{CH}_3)_3\text{COH}$

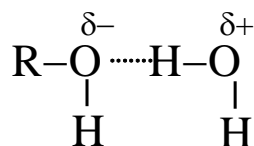
Compactness of t-butyl alcohol reduces the surface area and hence lowers the boiling point. The boiling point of alcohols are much higher than alkanes of comparable molecular weights. The high boiling point of the alcohols is due to hydrogen bonding by which the alcohol molecules remain associated in the liquid state.



The hydrogen of one (OH) group forms a loose bond with the oxygen of OH group of another molecule i.e. they remain in the molecular association through inter-molecular hydrogen bonding, which accounts for their high boiling points. But the hydrogen bonding is not so extensive as in water molecules. So, water boils at a higher temperature than methyl and ethyl alcohols.

Solubility In Water

The lower members of alcohols are highly soluble in water but as the size of the alkyl group increases, the solubility decreases. This phenomenon is common with other organic compounds having atleast one electronegative atom or group like ethers, aldehydes, ketones, acids, amides, sugars etc. and they all are soluble in water. The solubility of alcohols is attributed to its ability to form hydrogen bonds with water.



But as the molecular weight increases, the solubility decreases. For example, methanol is infinitely soluble but only 0.6 g of n-hexyl alcohol dissolves in 100

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ml of water. In general, organic compounds having atleast one electronegative element become gradually insoluble in water as the hydrocarbon chain increases. However, branching of the alcohol increases the solubility. Thus, t-butyl alcohol is infinitely soluble but 1-butanol is slightly soluble in water. This is again due to the compactness of the molecule. Better and easy surrounding by water increases the solubility. Increase in the number of OH groups increases the solubility. For example, glycol (two OH groups) and glycerol (three OH groups) are more soluble in water than methanol and ethanol.

General Chemical Properties Of The Alcohols

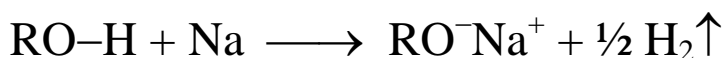
Chemical reactions are mainly based on –OH group of alcohol. The oxygen atom of –OH group polarize both the C–O bond and the O–H bond of any alcohol. Polarization of the O–H bond makes the hydrogen partially positive and explain why alcohols are weak acids. Polarization of the C–O bond makes the carbon atoms partially positive. The polarization of C–O bond is responsible for the weak basic character of alcohols.

On the basis of the above explanation of polarization of C–O and O–H bonds, we can classify the reaction of alcohols into two parts, first due to breaking of the C–O bond, with removal of –OH group and second due to the breaking of O–H bond, with removal of ‘H’. Except these reactions, alcohols show some other reactions like oxidation, reduction, elimination etc. Alkyl group of alcohols is also responsible for some chemical reactions.

Reaction Due To O–H Bond Cleavage

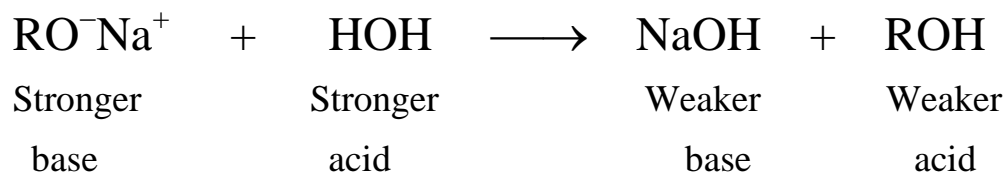
Reaction With Alkali Metals:

Active metals (Na, K, Mg, Al etc) when treated with alcohols give hydrogen gas. In this reaction, order of reactivity of alcohols is $\text{CH}_3\text{OH} > 1^\circ > 2^\circ > 3^\circ$. This reaction exhibits acidic character of alcohols.

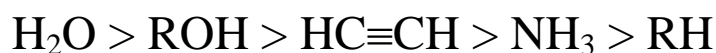


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In –OH group of alcohols, oxygen is more electronegative than hydrogen, this results in polarization of O–H bond due to which acidic nature arises in alcohols. Reaction of active metals with alcohols shows that alcohols are acidic in nature.



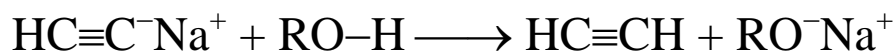
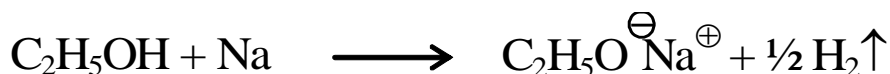
The order of acidity for some compounds is



The order of basicity is

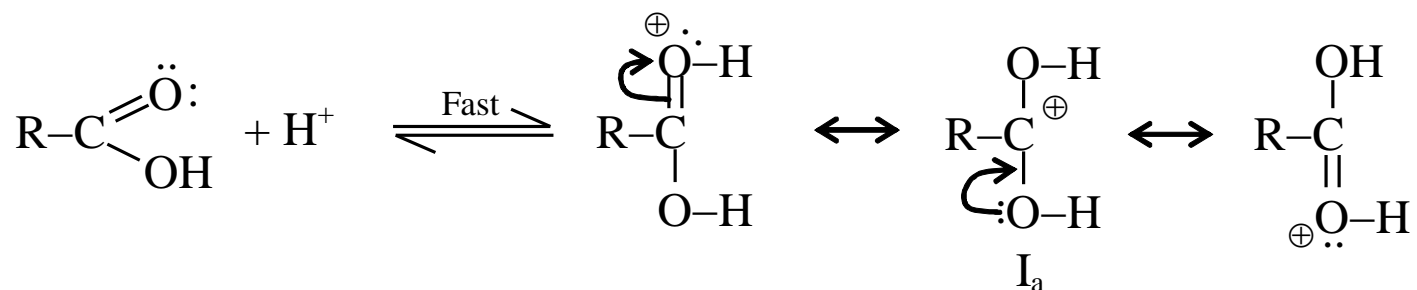


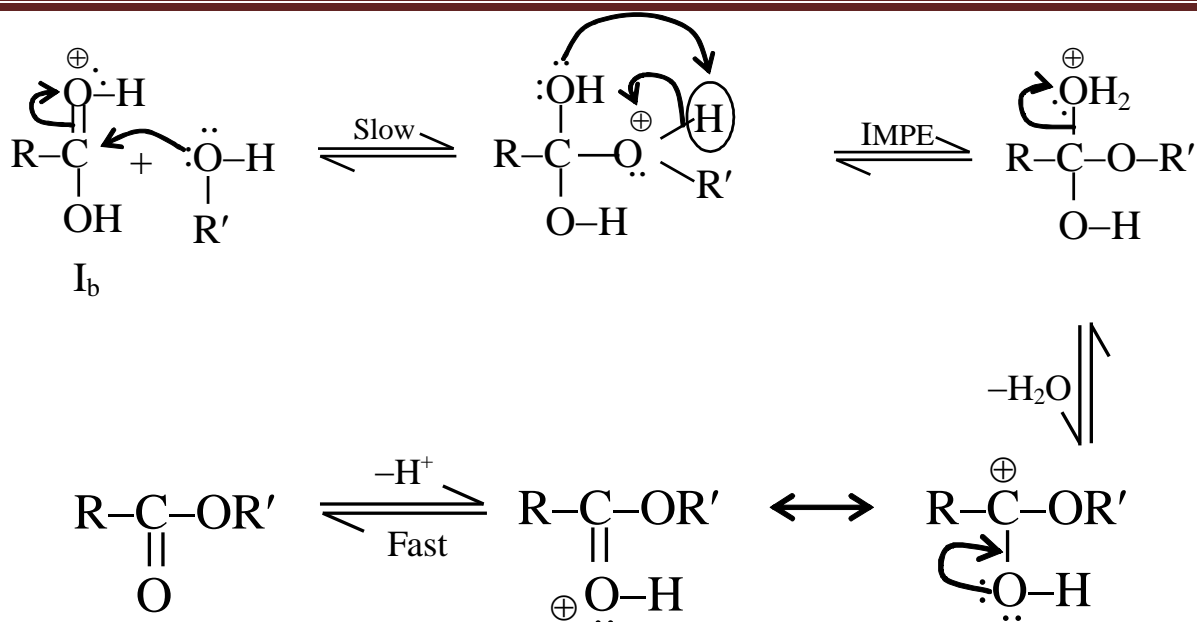
The above order is based on the reactions of alcohols with other species.



Esterification:

A direct reaction between a carboxylic acid and alcohol under the catalytic effect of sulphuric acid yields an ester. This is a reversible reaction and is known as the “**Fischer esterification**”.



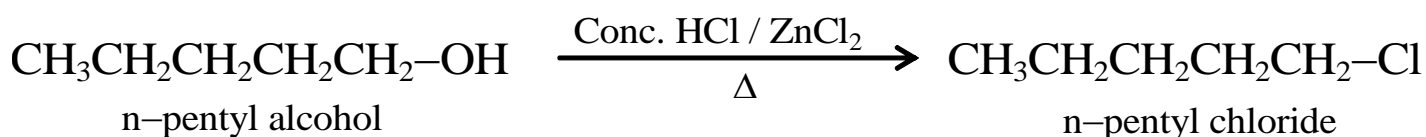
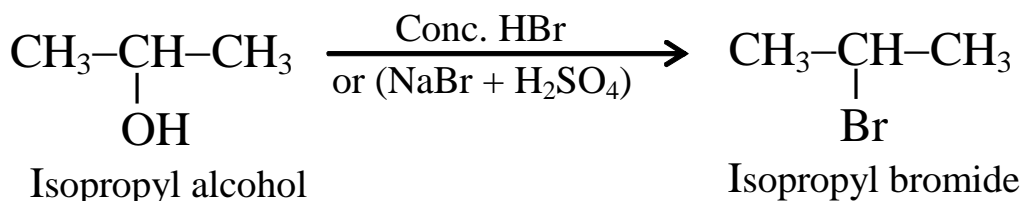


Reactions Due To C–O Bond Cleavage

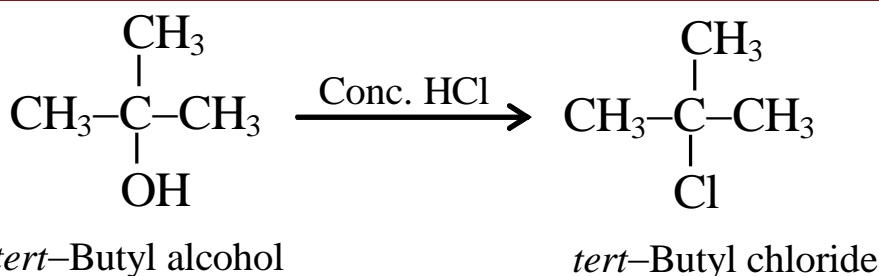
Polarization of the C–O bond makes the carbon atom partially positive, so this carbon would be susceptible to the nucleophilic attack and if it were not for the fact that OH^- is a strong base and they are very poor leaving group. Protonation of the alcohol converts a poor leaving group (OH^-) into a good one. It also make the carbon atom even more positive (because $-\text{OH}_2^+$ is more electron withdrawing than $-\text{OH}$) and therefore, even more susceptible to nucleophilic attack. Now, nucleophilic substitution reactions are possible in alcohols according to the given mechanism.

Reaction With H–X:

For example,

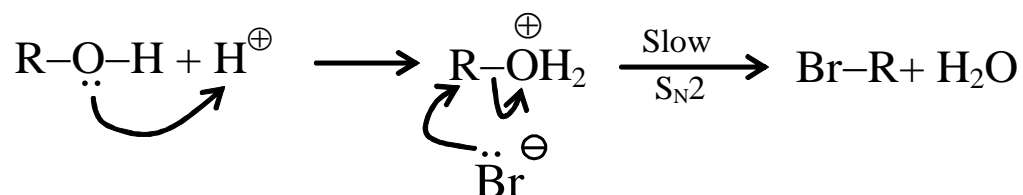


ALCOLHOLS, PHENOLS AND ETHERS



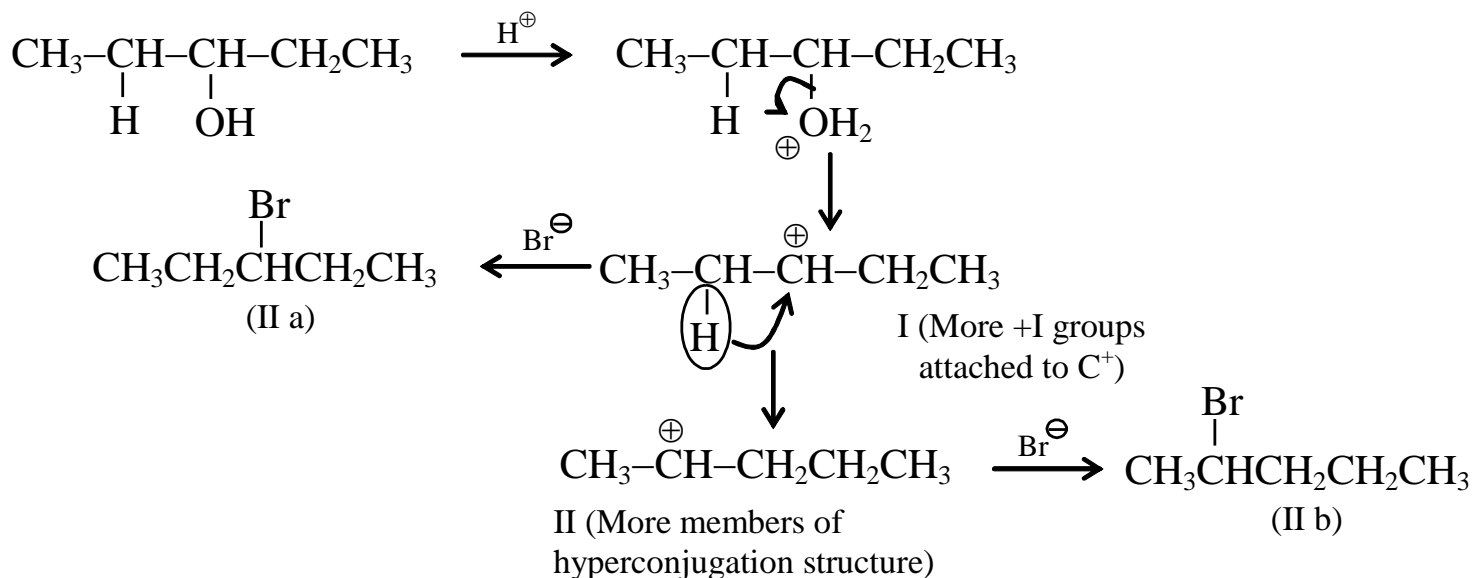
In S_N1 reactions of alcohol (when R group is 3°), R may rearrange. Primary alcohols and methanol apparently react through a mechanism that we recognize as an S_N2 type.

With HBr, alcohols produce alkyl bromide.



or for stable carbocation R^{\oplus} , racemic mixture will be obtained for optically active alcohol by S_N1 mechanism.

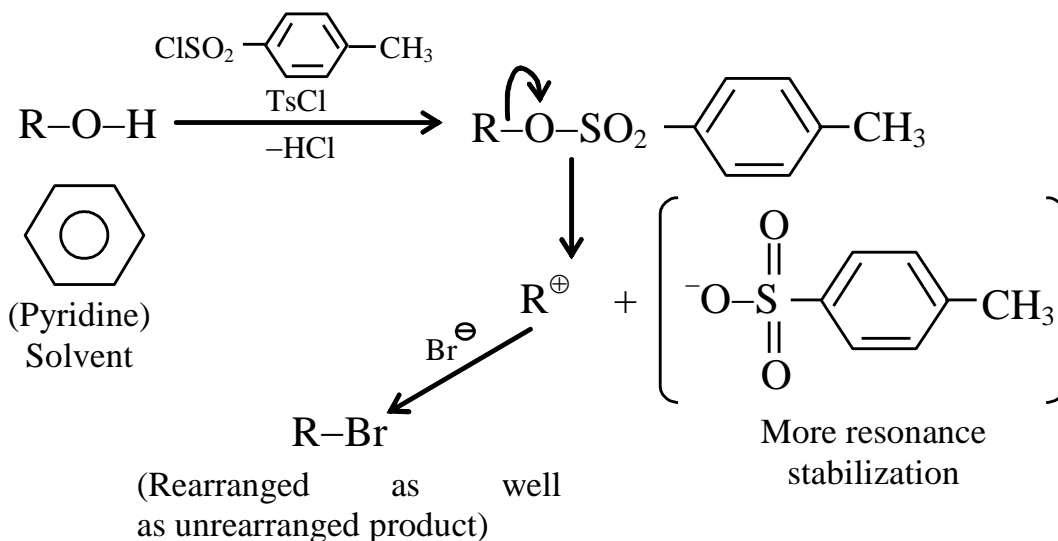
But 3-pentanol reacts with HBr to produce 2 and 3-bromopentane derivatives.



In S_Ni reaction, retention of configuration is observed & mechanism operates through intimate ion-pair formation.

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With PBr_3 , PBr_5 also alkyl bromide results with no rearrangement. Sometimes alcoholic OH is made good leaving group by converting O–H into –OTs group.



For the compound like $\text{CH}_3\text{-CH(OH)-CH=CH}_2$, double bond shifts and resultant bromide is a mixture as shown below.

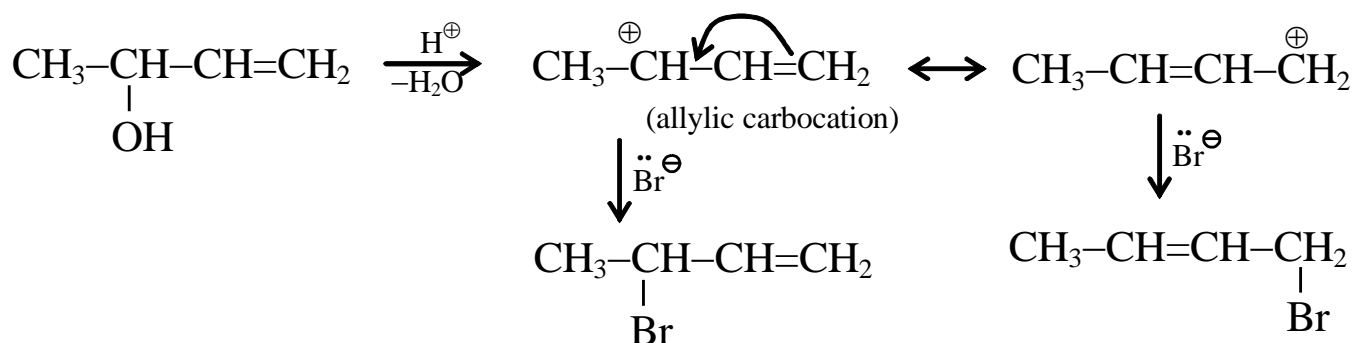


Illustration 1.

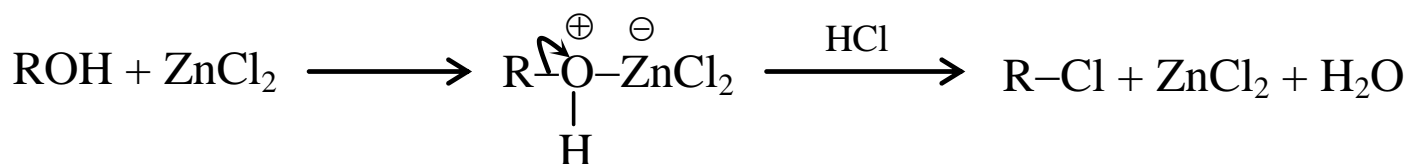
Secondary and tertiary alcohol can be converted into the corresponding alkyl halide with concentrated HBr or HI , but to convert primary alcohol into corresponding primary alkyl chloride, ZnCl_2 is needed. Why?

Solution:

We have discussed earlier that the reactivity of primary alcohol is least among different types of alcohols namely primary, secondary and tertiary. Thus, protonation of –OH group is not sufficient enough to increase polarity of C – O bond to the level of being attacked by the nucleophile. Lewis acid like ZnCl_2 is

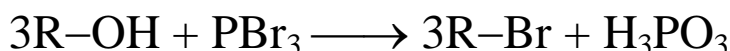
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used as a catalyst to increase the polarity of the C – O bond, leading to the formation of carbonium ion.



Reaction With PX_3 And PX_5 :

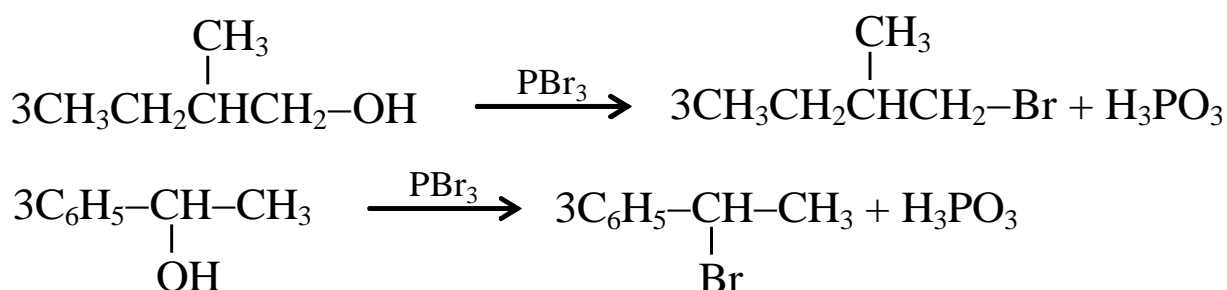
Alcohols react with PX_3 and PX_5 to yield alkyl halides ($\text{PX}_3 = \text{PBr}_3, \text{PI}_3$)



(1° or 2°)

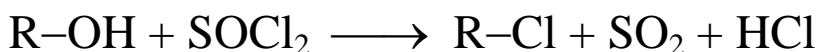


For example,



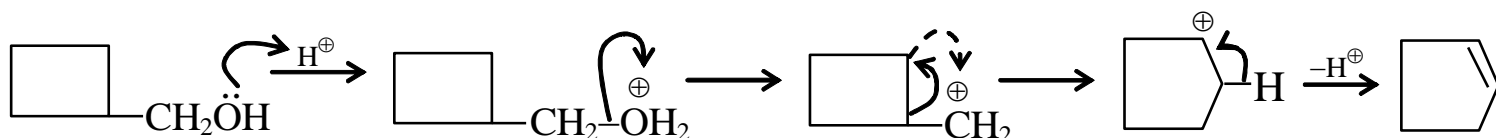
Reaction With SOCl_2 :

Alcohols react with thionyl chloride in presence of pyridine to give alkyl chloride with inverted configuration, while in absence of pyridine, an alkyl chloride with retention of configuration is obtained via $\text{S}_{\text{N}}\text{i}$ mechanism.



Acid Catalysed Dehydration Of Alcohols:

Alcohols in presence of dilute acid undergo dehydration forming alkenes. The reaction proceeds by E_1 mechanism.



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Dehydration of cyclic alcohol is accompanied by expansion in the above reaction. Stability of the ring is given by Baeyer strain theory, according to which the stability order of the rings is $6 > 7, 5 > 8, 9 \gg 4 > 3$.

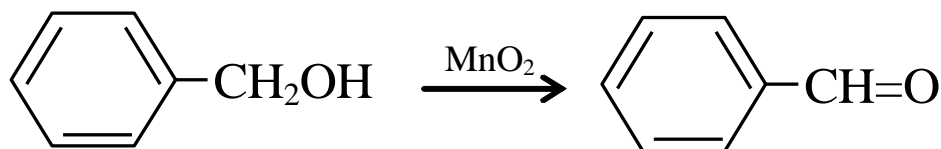
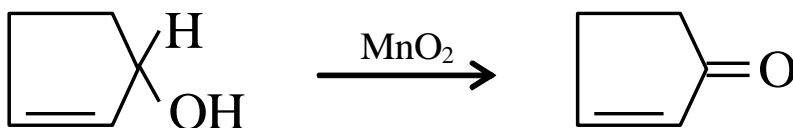
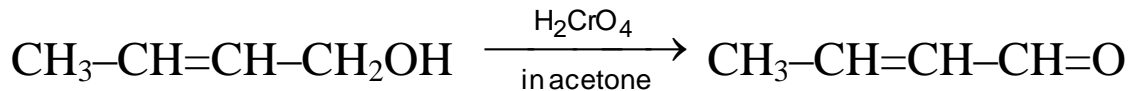
Oxidation Of 1°, 2°, 3° Alcohols With CrO_3 OR $\text{K}_2\text{Cr}_2\text{O}_7$ In Acid

Alcohols with atleast one hydrogen atom on 1° and 2° carbinol are oxidised to carbonyl compounds (aldehydes and ketones). PCC (Mixture of pyridine, HCl and CrO_3) oxidises 1° alcohol to aldehydes but $\text{K}_2\text{Cr}_2\text{O}_7$ or KMnO_4 in acid converts 1° alcohol directly to carboxylic acids. Under mild conditions, 3° alcohols are not oxidised.

Jone's reagent (chromic acid in aqueous acetone solution):

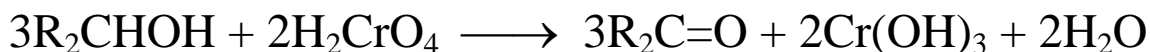
This is a sufficiently mild oxidising agent, so that it oxidises alcohols without oxidising or rearranging double bonds. MnO_2 can oxidise 1° allylic or 1° benzylic alcohols selectively into aldehydes.

For example,



Chromic Acid (Jones Reagent)

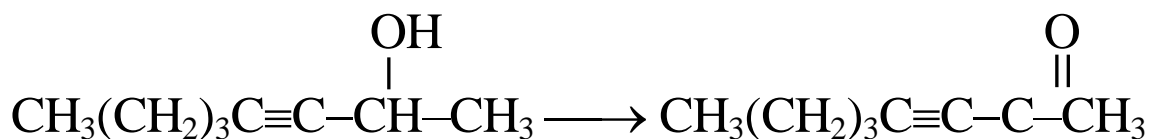
The most convenient reagent for the oxidation of alcohols is 8N chromic acid in sulphuric acid (Jones reagent). Two millimoles of this reagent oxidizes 3 millimoles of monohydric alcohol according to the equation:



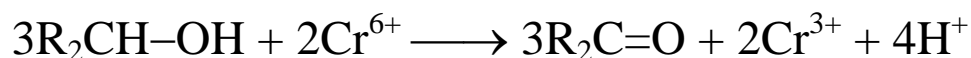
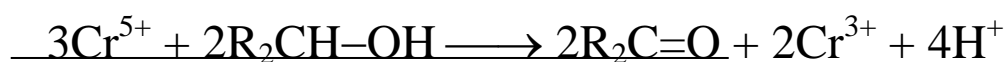
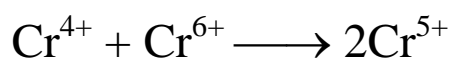
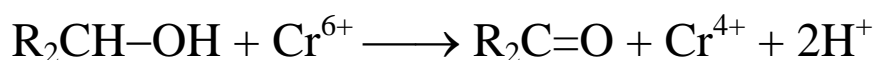
The function of sulphuric acid is to prevent complex formation of Cr(VI) with its reduced form Cr (III) to a salt having much less oxidation potential. This

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ensures that all the Cr(VI) is used in oxidation, which thus becomes rapid and complete. Acetone is the usual solvent used at ice bath temperature. Alcohols having double or triple bonds in the molecule can be selectively oxidized to ketones in good yields. For example,



The most likely mechanism for the oxidation of alcohols by Jones reagents has been shown to be

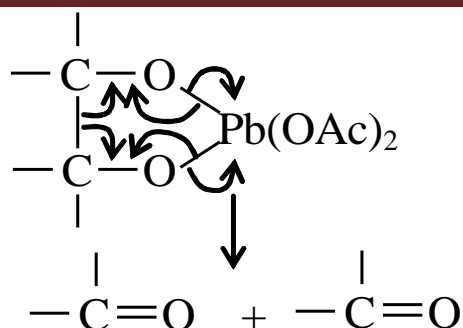
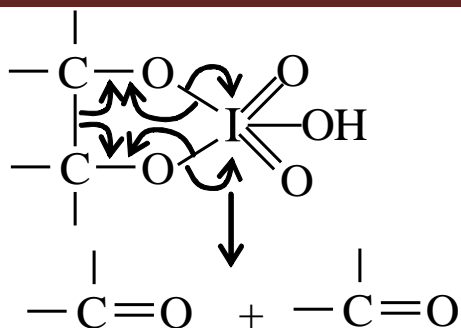


Thus, apparently, 3 moles of alcohols react with 2 moles of Cr(VI) to give 3 moles of ketone and 2 moles of Cr(III). It is clear, however, that only one mole of the alcohol is oxidized directly by Cr(VI) and the other two part in the oxidation with Cr (V).

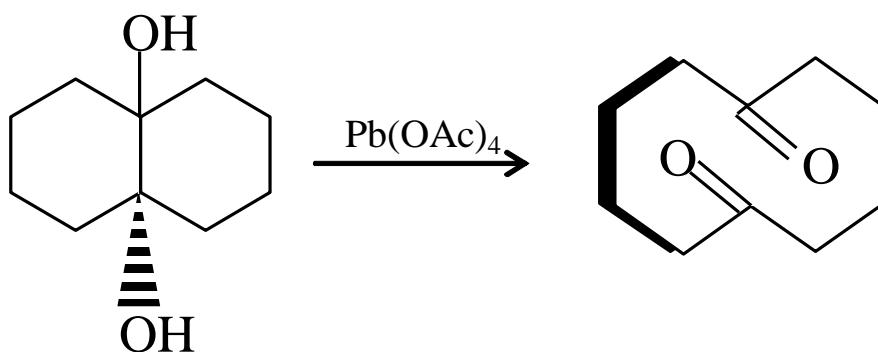
Cleavage Of 1, 2–Glycols

Lead tetraacetate or periodic acid are commonly used for the cleavage of 1, 2–glycols. The former reagent is used in anhydrous solvent, whereas the later in organic solvent. Periodic acid is more selective and readily cleaves 1, 2–glycols at room temperature. But cleavage of an α –hydroxy ketone or acid by this reagent even at higher temperature is slow. Lead tetraacetate, however, oxidizes α –hydroxyketone or acid as well as 1, 2–glycols more easily. This is explained on the basis of a five–membered cyclic intermediate.

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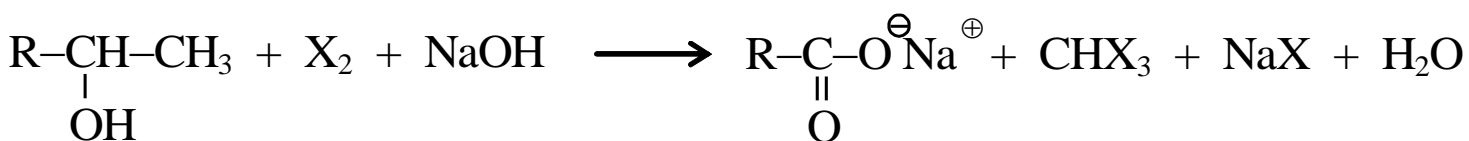


A 1,2-glycol need not necessarily be cis to undergo cleavage with lead tetraacetate. For instance, trans-9,10-decalindiol undergoes cleavage to cyclodecane-1,6-dione.



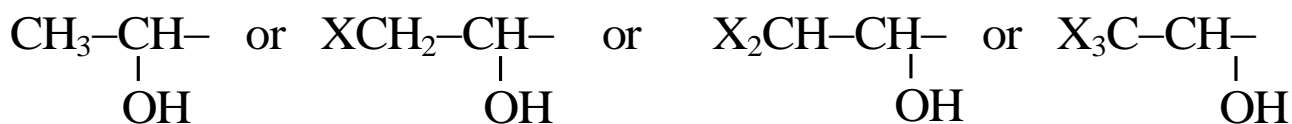
Haloform Reaction

The general reaction is represented as

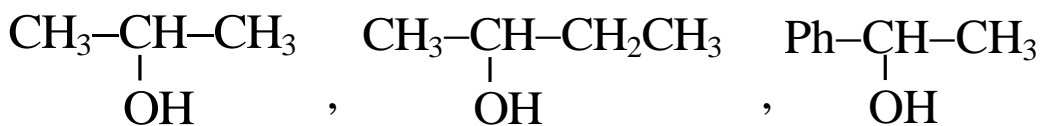


The CH_3 carbon is lost as CHX_3 and the remaining part exists as acid salt, which can be acidified to liberate free acid.

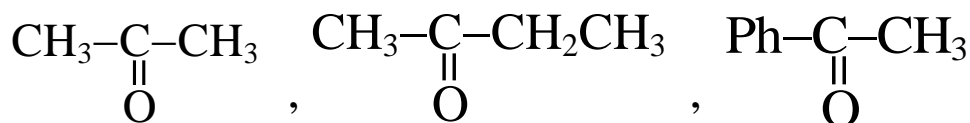
The structural feature essential in the compound to show haloform reaction is that any of the following moieties should be present in the molecule attached to some electron-withdrawing group or electron donating group by +I only.



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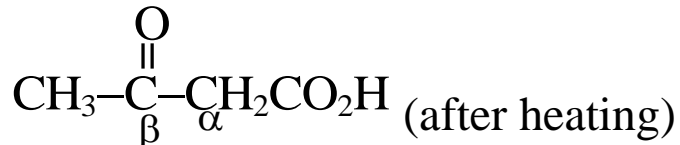
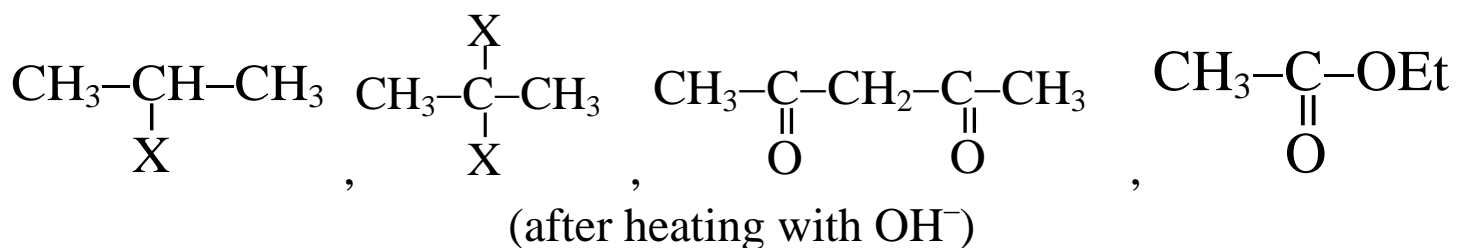


Ketones: Most Methyl Ketones

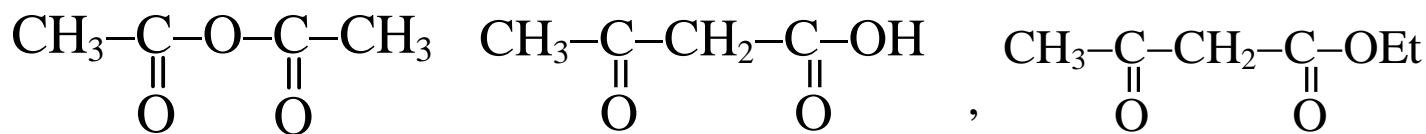
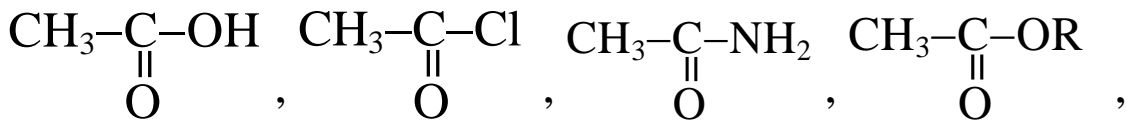


Aldehydes: only acetaldehyde $\begin{array}{c} \text{CH}_3-\text{C}-\text{H} \\ || \\ \text{O} \end{array}$

Other Compounds:



The compounds that respond negatively to iodoform test are

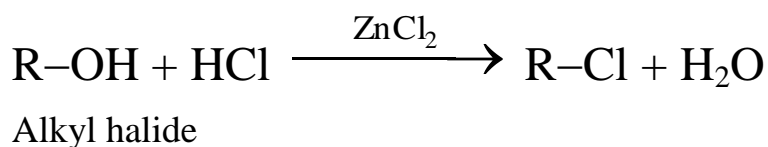


Distinguishing Primary, Secondary And Tertiary Alcohols

The following methods are used for distinguishing three types of monohydric alcohols.

Lucas Test

Alcohols react with concentrated hydrochloric acid in the presence of anhydrous zinc chloride to form alkyl chlorides. The alkyl chlorides appear as cloudiness because of its insolubility in Lucas reagent.



The three types of alcohols undergo this reaction at different rates. The rates of reaction with **Lucas reagent** [conc. HCl + ZnCl₂ (anhydrous)] follow the given order:

Tertiary alcohol > Secondary alcohol > Primary alcohol

An unknown alcohol (monohydric) is mixed with conc. HCl and anhydrous ZnCl₂ at room temperature. The alkyl chloride formed is insoluble in the medium, thus the solution becomes cloudy before it separates out as a distinct layer. The following observations are made,

- (a) If cloudiness (white turbidity) appears immediately, the alcohol is tertiary.
- (b) If cloudiness appears within 5 minutes, the alcohol is secondary.
- (c) If the solution remains clear, i.e., no cloudiness is formed the alcohol is primary.

Remember that the benzyl and allyl alcohol react as rapidly as tertiary alcohol with Lucas reagent because their cations are resonance stabilised and as stable as 3° carbocations.

Dichromate Test (Oxidation Test)

This test is based on the fact that three types of monohydric alcohols give different oxidation products on oxidation.

The unknown alcohol is treated with sodium dichromate in dilute sulphuric acid (orange solution) at room temperature. Then the oxidation products are identified.

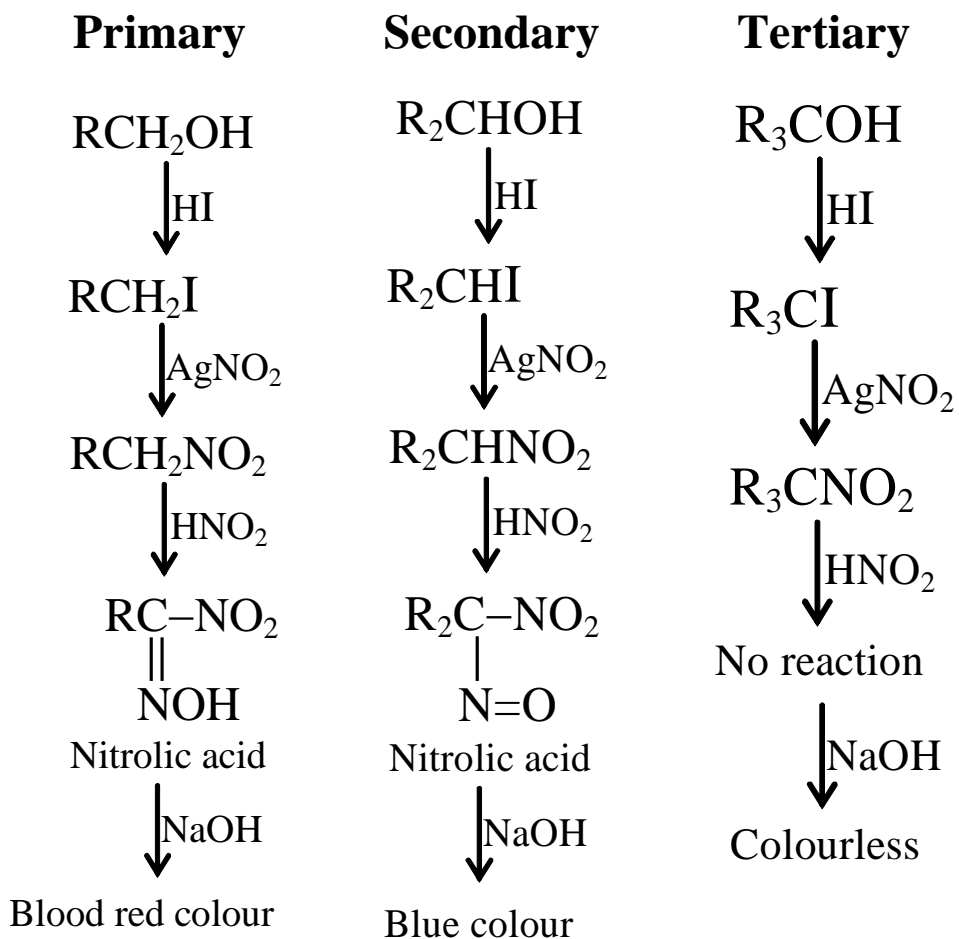
- (i) A carboxylic acid with same number of carbon atoms as in the alcohol, if formed confirms the primary alcohol. The colour of the solution changes from orange to green.
- (ii) A ketone with same number of carbon atoms as in the alcohol if formed confirms the secondary alcohol. The colour of the solution also changes from orange to green.
- (iii) In case the colour of the solution does not change, i.e. it remains same, then it is 3° alcohol.

Victor Meyer's Test

In this test, the following steps are involved,

- (i) Alcohol is reacted with conc. HI or red phosphorous and iodine to form corresponding alkyl iodide.
- (ii) Alkyl iodide is then treated with silver nitrite when corresponding nitroalkanes is formed.
- (iii) Nitro alkane is treated with nitrous acid ($\text{NaNO}_2 + \text{H}_2\text{SO}_4$) and the solution is made alkaline by addition of excess of caustic soda.

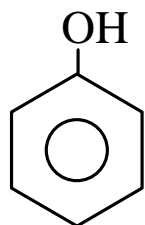
ALCOLHOLS, PHENOLS AND ETHERS



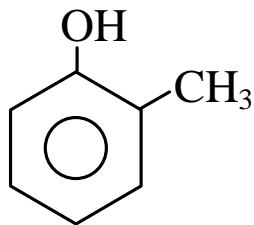
Phenols

Compounds having hydroxyl groups directly attached to a benzene ring are called phenols. A phenolic OH is characterized by the formation of violet, red or green colouration when treated with neutral FeCl_3 solution.

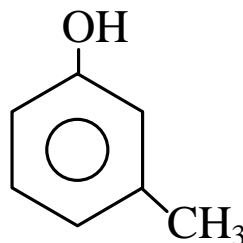
Some examples of phenolic compounds are given below.



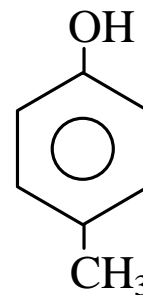
Phenol
(Carbolic acid)



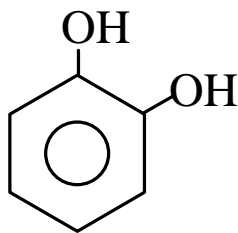
o-methylphenol
(o-cresol)



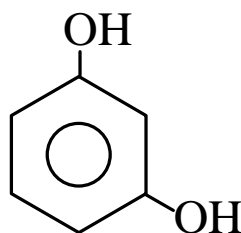
m-methyl phenol
(m-cresol)



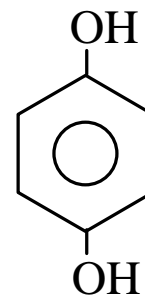
p-methyl phenol
(p-cresol)



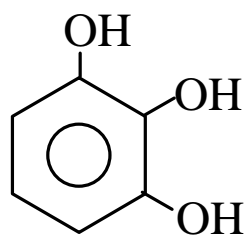
o-dihydroxybenzene
(catechol)



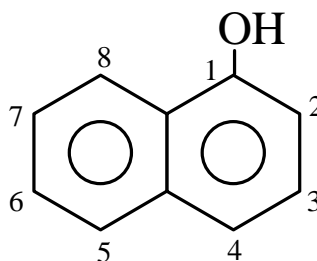
m-dihydroxybenzene
(resorcinol)



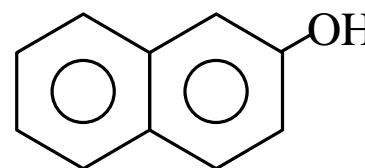
p-dihydroxybenzene
(Hydroquinone)



1, 2, 3-trihydroxybenzene
(pyrogallol)



1-naphthol
(α -naphthol)

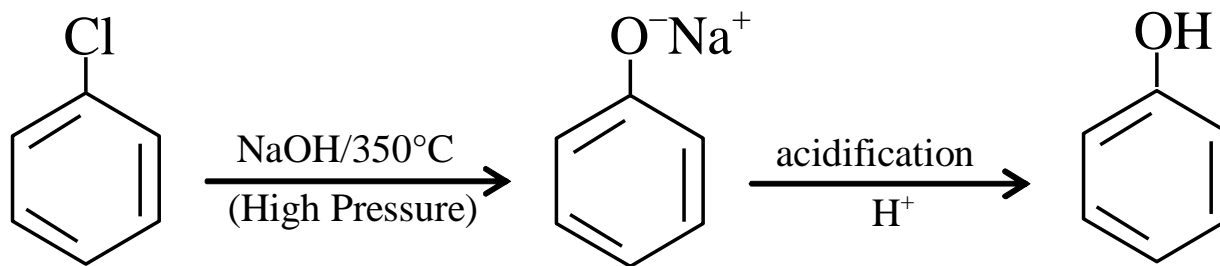


2-naphthol
(β -naphthol)

Methods For Preparation Of Phenols

Dow's Process

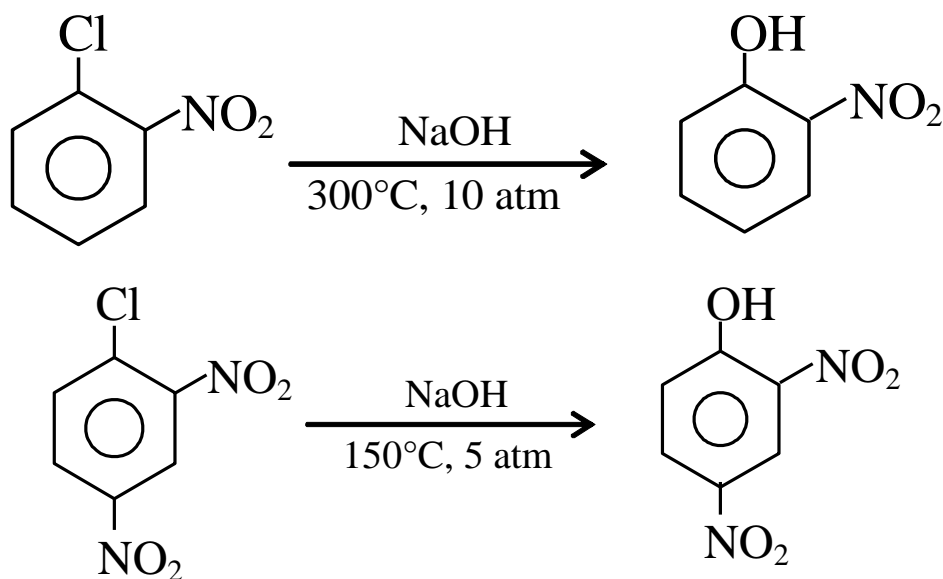
When chlorobenzene is heated with aqueous NaOH at 350°C under high pressure, sodium phenoxide is obtained which on acidification produces phenol.



The above reaction takes place through benzyne mechanism.

By Nucleophilic Substitution Of Aryl Halides

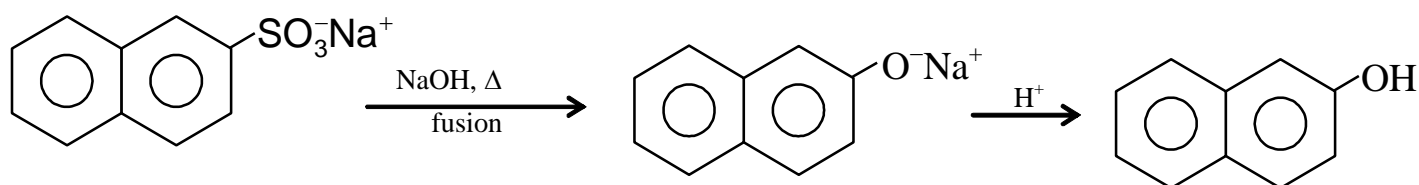
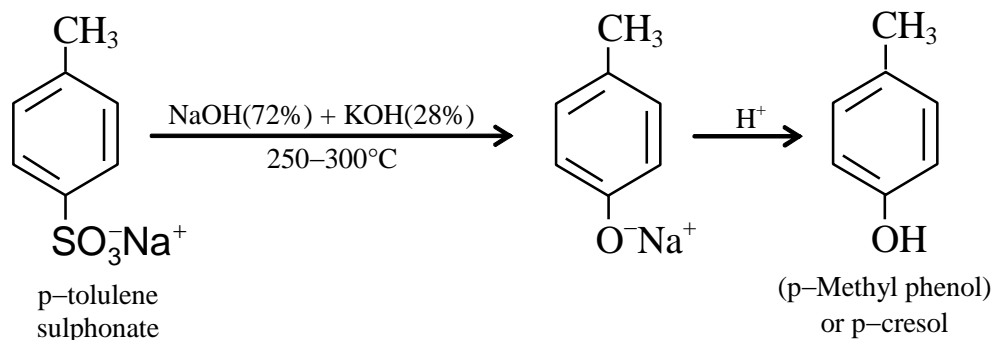
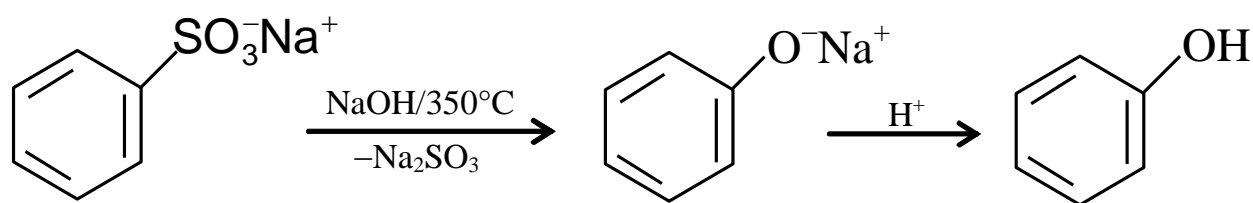
Highly activated aryl halides containing electronwithdrawing groups at ortho & para positions when treated with NaOH undergo $\text{S}_{\text{N}}\text{Ar}$ mechanism to form substituted phenols.



By Fusing Sodium Arylsulphonates With NaOH

The fusion of aromatic sulphonates with caustic alkali at high temperatures gives phenols by displacement of sulphite ion.

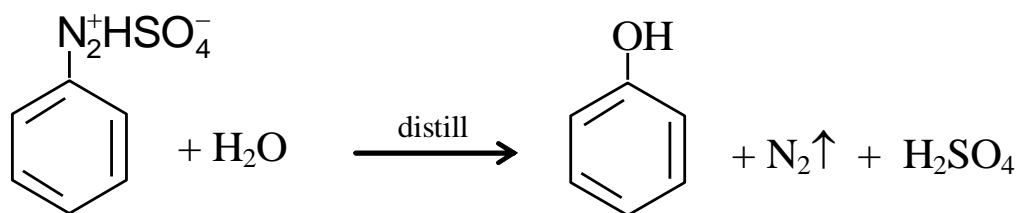
ALCOLHOLS, PHENOLS AND ETHERS



There are limitations to this method. Firstly, halophenols cannot be prepared in this way because at high temperatures OH^- displaces the halogens more readily than the replacement of SO_3^{2-} ion. Secondly, a substituent of $-\text{R}$ type, which is meta to the sulphonic acid group activates the ortho and para positions for hydride displacement. For example, nitrophenol cannot be obtained from m-nitrobenzene sulphonic acid.

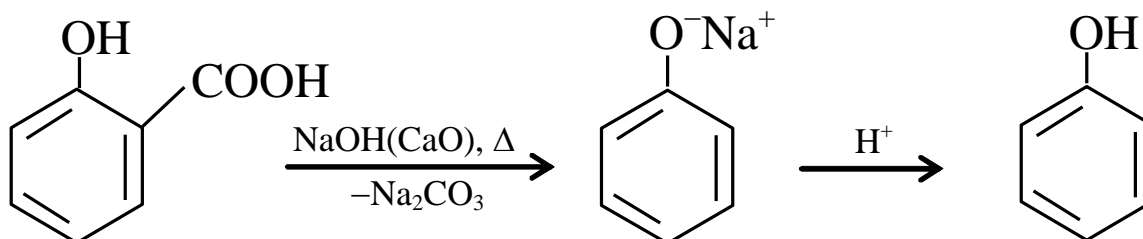
By Steam Distillation Of Diazonium Salts

Benzene or arene diazonium salts on distillation with steam forms phenol or substituted phenols respectively, with the liberation of nitrogen.



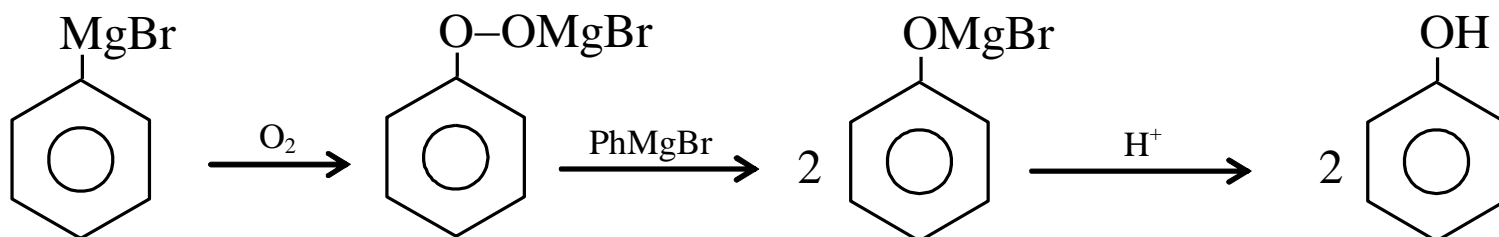
By Distillation Of Phenolic Acids With Soda Lime

Phenolic carboxylic acids (ortho, meta or para) on heating with sodalime undergo decarboxylation to give sodium phenoxide, which on acidification gives phenol.



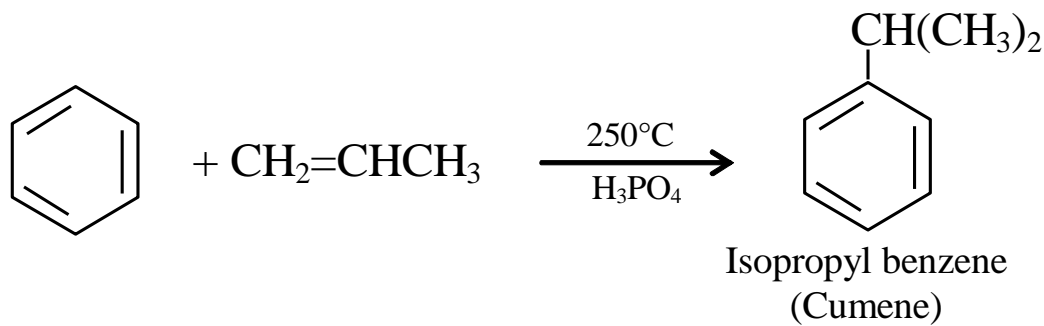
From Grignard Reagents

Phenyl magnesium halide or reaction with electrophilic O_2 gives a peroxide salt, which on reaction with another mole of phenyl magnesium halide gives 2 moles of magnesium salt of phenol. This on acidification gives 2 moles of phenol.

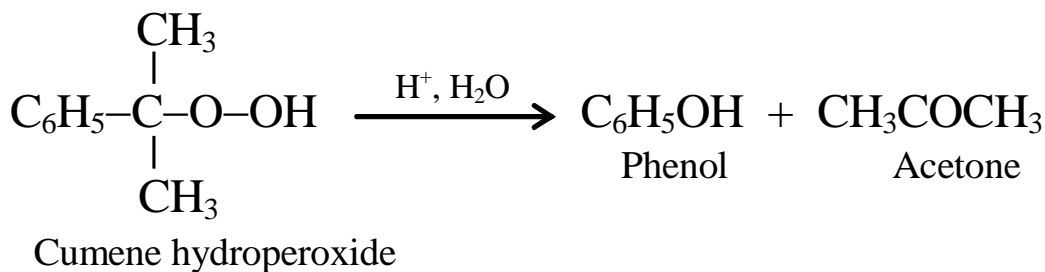
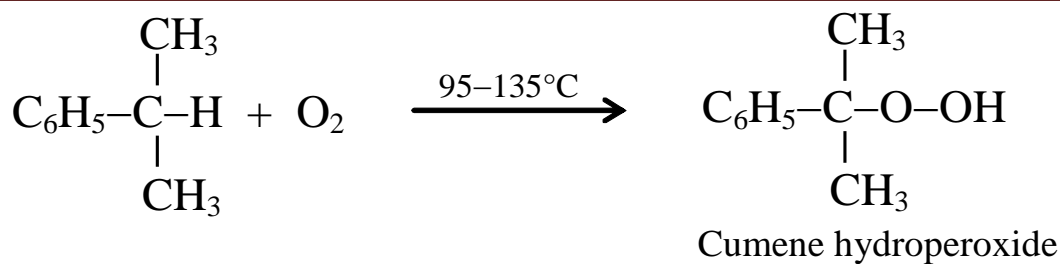


From Cumene Hydroperoxide

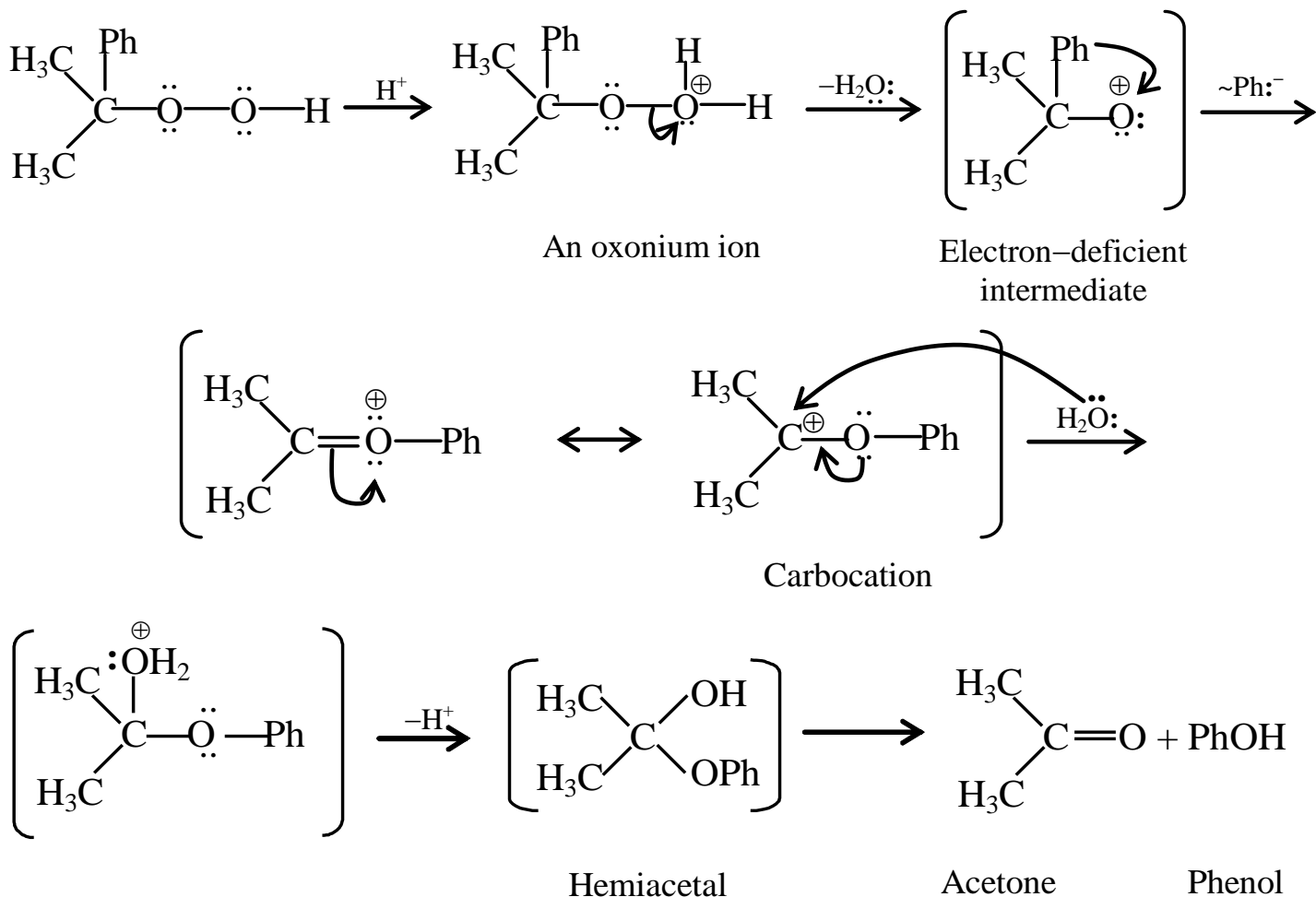
This is carried out by oxidising cumene to its hydroperoxide and subsequently decomposing it with acid into phenol and acetone. The mechanism involves 1, 2-shift of phenyl group.



ALCOLHOLS, PHENOLS AND ETHERS



In the rearrangement, Ph migrates from carbon to oxygen. Most acid-catalyzed rearrangements require the intermediacy of a positively charged atom to which the group migrates, most of these positively charged sites were carbocations but in this case it is an O^+ .



The rearrangement of Ph may be synchronous with the loss of H₂O.

Physical Characteristics Of Phenols

Phenol is a colourless crystalline solid, melting point 43° and boiling point 182°C, which turns pink when exposed to air and light. It is moderately soluble in cold water due to formation of intermolecular hydrogen bonding with water.

Chemical Properties Of Phenols

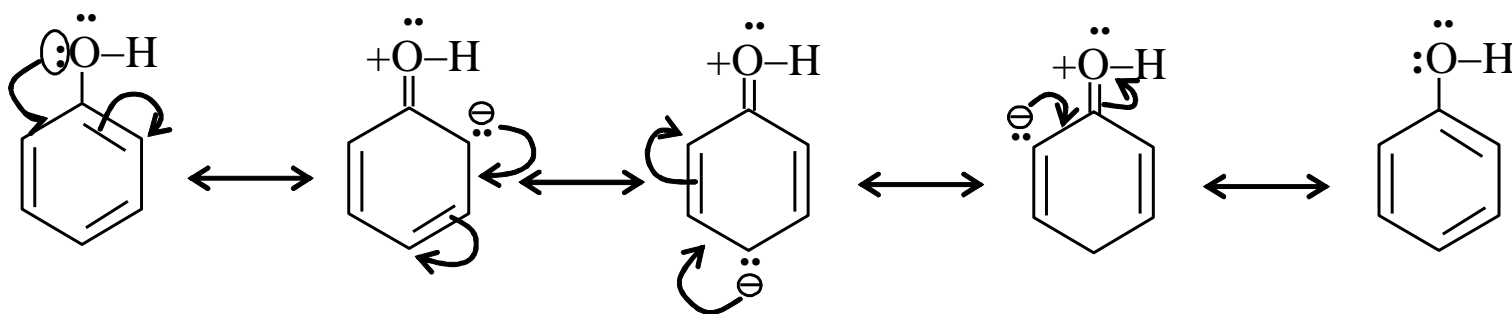
Phenol shows two types of reactions:

(i) due to –OH group (ii) due to benzene ring.

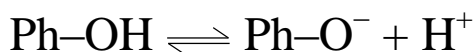
Reactions Due To –OH Group

Acidic Nature:

Phenol is weaker acid than carbonic acid but stronger than alcohols. Because of resonance, the oxygen atom of the –OH group acquires a positive charge, which facilitates the release of proton.



The C-atom in phenol is sp²-hybridised. So it is more electron withdrawing than the sp³-hybridised carbon atom of alcohols.

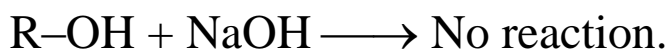
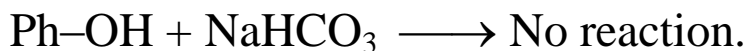
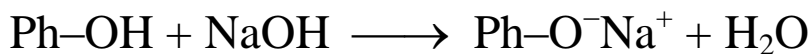


When phenol ionizes, the resulting phenoxide ion is more stabilised by resonance than phenol itself because of delocalisation of a negative charge only and subsequently the equilibrium lies more towards forward side. Unlike phenols, alkoxides ions are not stabilised.

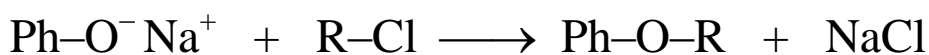
ALCOLHOLS, PHENOLS AND ETHERS

In general, electron-withdrawing groups increases the acidic strength whereas electron-releasing groups diminishes the acidic nature of phenols.

Phenol dissolves in NaOH, but it is insoluble in sodium bicarbonate solution as phenol is stronger acid than H₂O but weaker than carbonic acid. In general, strong acid displaced weak acid and strong base displaces weak base.



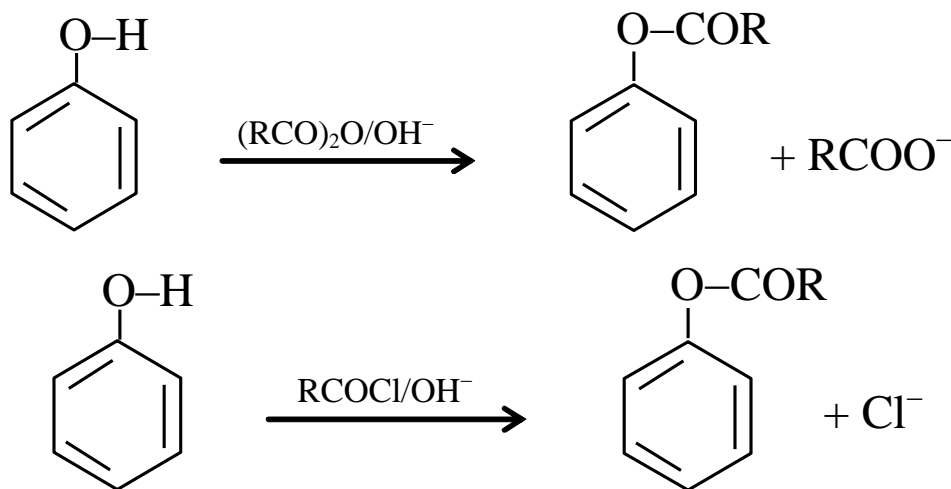
Phenoxides react with alkyl halides to form phenolic ethers.



Sodium phenoxide

Acylation:

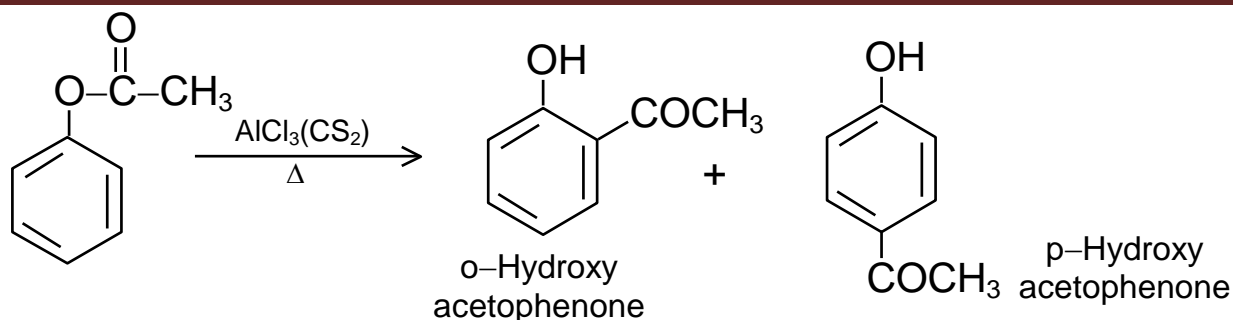
Phenols react with carboxylic acid anhydrides or acid chlorides to yield phenyl esters.



Fries Rearrangement:

The phenyl ester formed from the reaction of phenol and acid anhydride undergoes rearrangement when treated with anhydrous AlCl₃ to yield ortho and para-hydroxyketones. The o-isomer is separated from the mixture by steam-distillation.

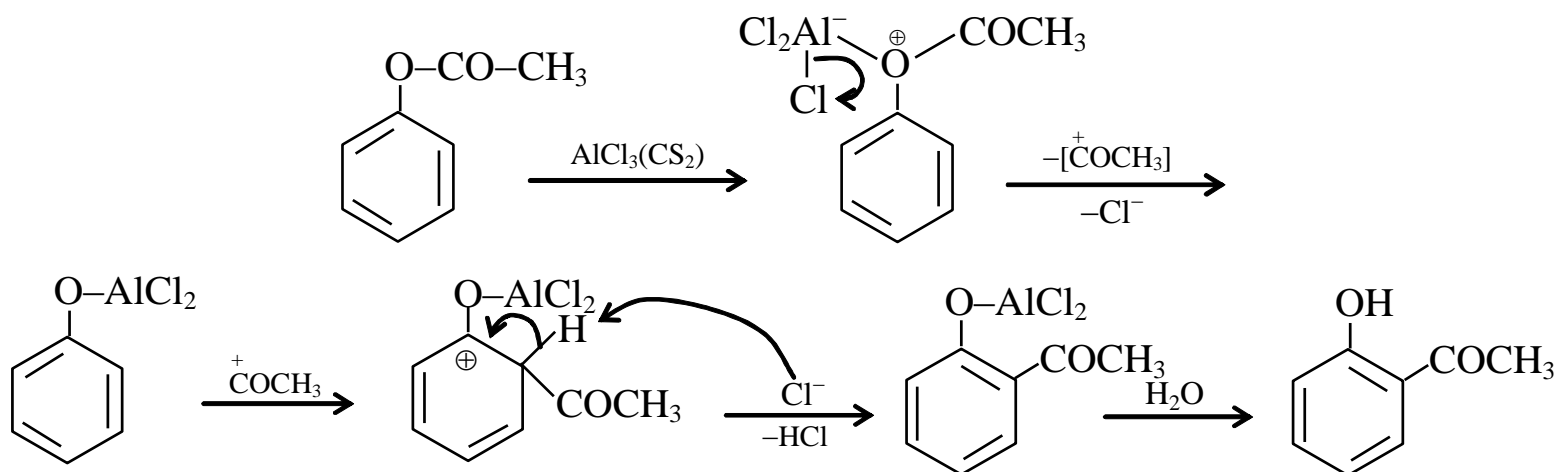
ALCOLHOLS, PHENOLS AND ETHERS



Generally low temperature (60°C or less) favours the formation of the p-isomer whereas high temperature (above 160°C) favours the o-isomer.

Mechanism:

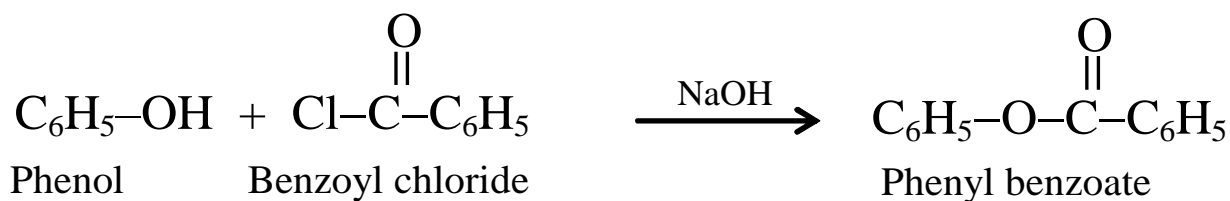
The reaction proceeds as Friedel–Crafts acylation, acylium ion being supplied by the substrate itself.



Similarly, if the electrophile attacks at p-position, p-isomer is formed.

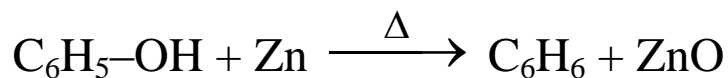
Reaction With Benzoyl Chloride:

Alkaline solution of phenol when treated vigorously with benzoyl chloride yields phenylbenzoate. The reaction is known as Schotten–Baumann reaction.



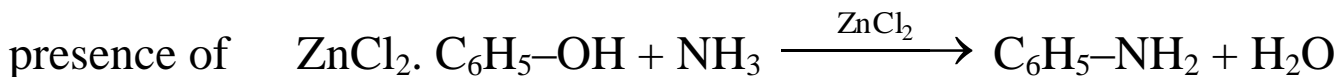
Reaction With Zn–Dust:

Phenol yields benzene when heated with Zn–dust.



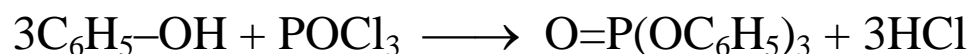
Reaction With Ammonia:

Phenol is converted into aniline when heated with ammonia under pressure or in

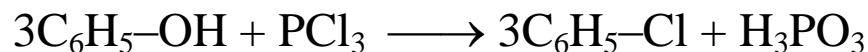


Reaction With PCl_5 :

Phenol reacts with PCl_5 to give chlorobenzene along with POCl_3 and HCl . Further with POCl_3 , phenol reacts to produce triphenyl phosphate. With PCl_3 , phenol reacts to give chlorobenzene and H_3PO_3 .



(Triphenyl phosphate)



Test For Phenol:

Phenol and its derivatives give a violet, red, blue or green colouration with ferric chloride solution. This reaction is characteristics of all compounds containing --C(OH)=C group.

Reactions Due To Benzene Ring

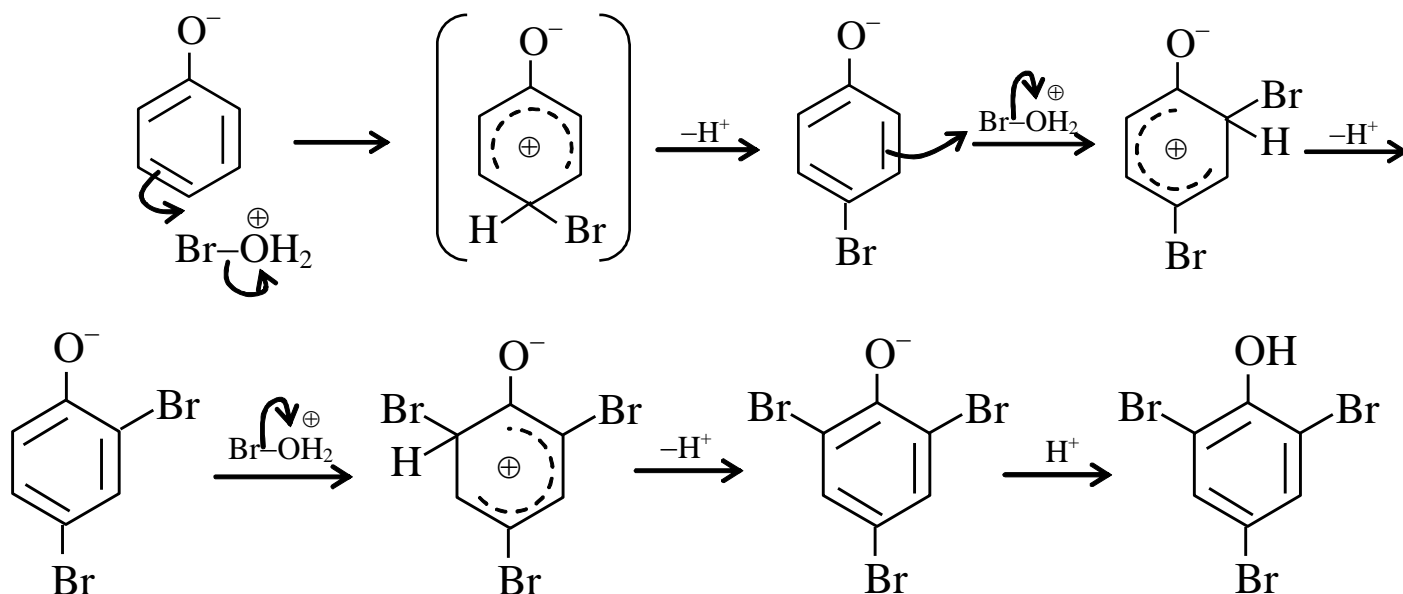
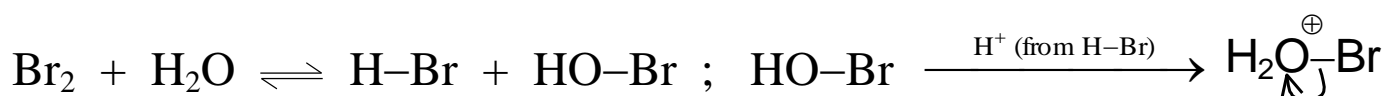
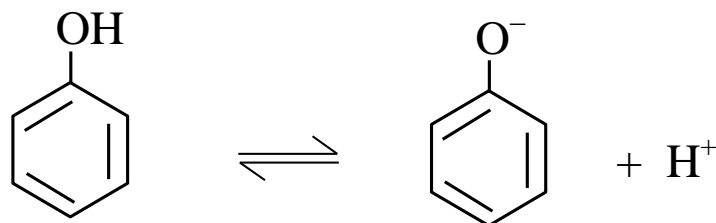
Phenols give electrophilic aromatic substitution, as the hydroxyl group is o– & p–directing.

Bromination:

Phenol on treatment with chlorine or bromine water gives an immediate precipitate of 2,4,6–trihalogen derivative. Phenol in aqueous medium is partially ionised and the phenoxide ion thus obtained is much more reactive than phenol itself towards electrophilic attack. Moreover, halogen reacts with water forming

ALCOLHOLS, PHENOLS AND ETHERS

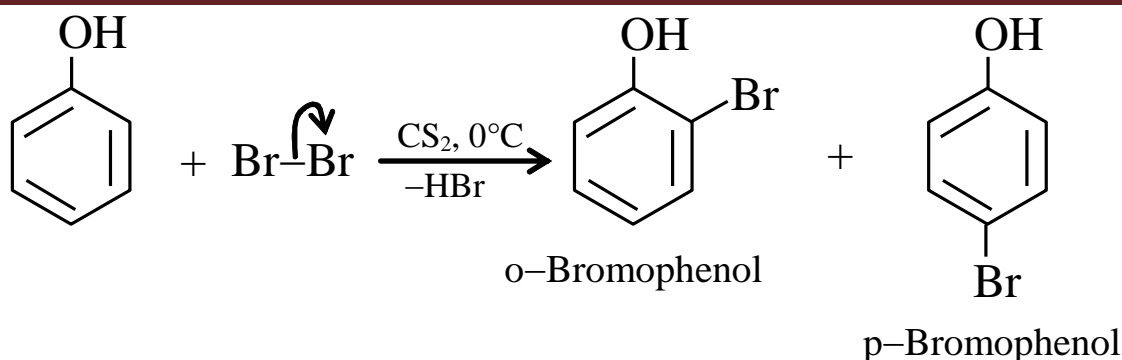
halogen acid and hypohalous acid. The proton attacks at the OH group of hypohalous acid to give $\text{H}_2\text{O}^{\oplus}-\text{X}$, which acts as a stronger electrophile. Therefore, halogenation takes place at all the ortho and para positions.



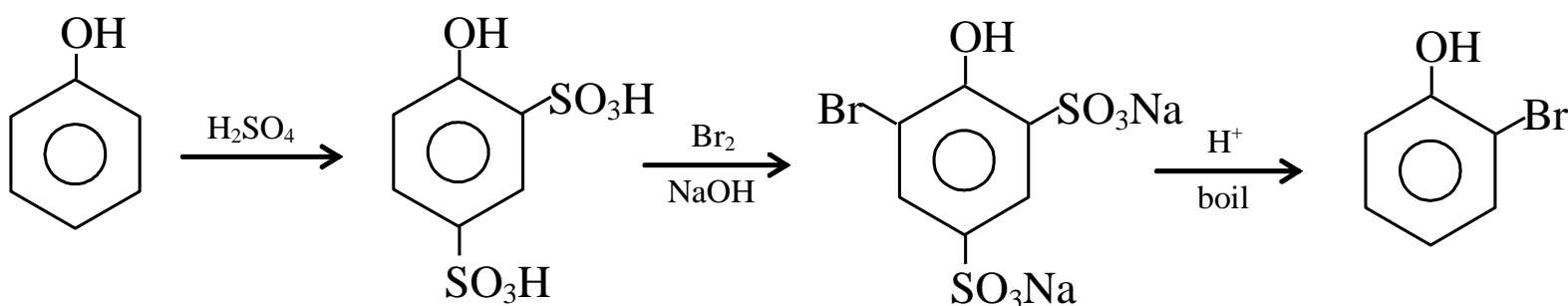
(Yellow ppt.) 2,4,6-Tribromophenol

If the halogenation is carried out in non-aqueous medium like CS_2 or CCl_4 , only mono-substitution takes place. This is because the ionisation of phenol does not occur in non-aqueous medium. The benzene ring of phenol is less activated than that of phenoxide ion as well as the bromine in Br_2 molecule is not as electrophilic as in $\text{Br-}\text{OH}_2^{\oplus}$.

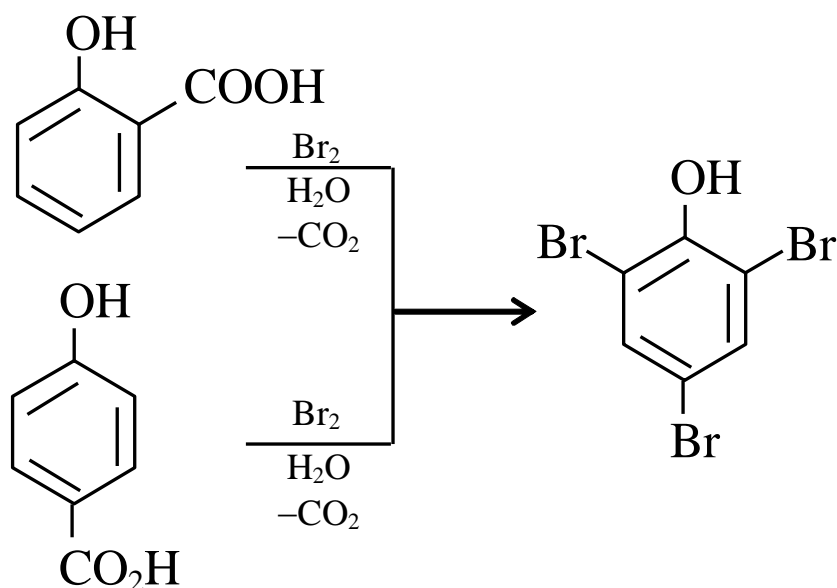
ALCOLHOLS, PHENOLS AND ETHERS

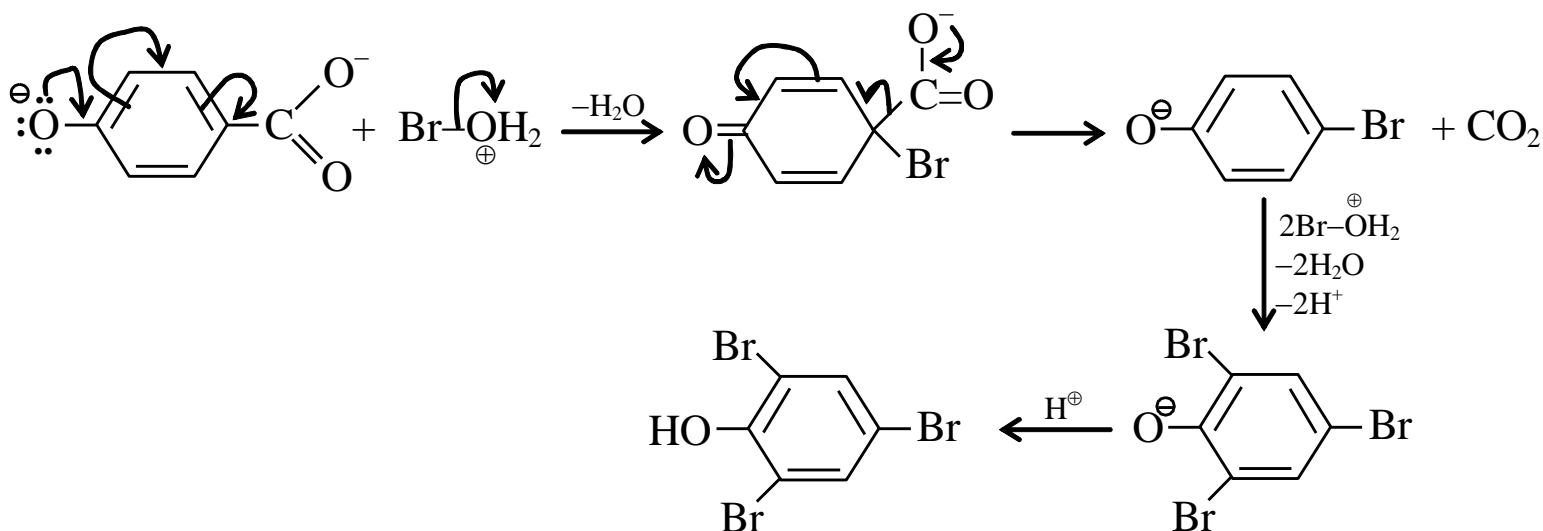


o-Bromophenol is also prepared by protecting one ortho and the para positions by sulphonation.



So strong is the activation of benzene ring in aqueous medium that derivatives of phenol containing $-\text{COOH}$ group or $-\text{SO}_3\text{H}$ group either at the ortho or at the para position are displaced by Br in bromination reaction. This is an example of brominative decarboxylation. For example, salicylic acid when treated with bromine water gives 2,4,6-trisubstituted phenol.



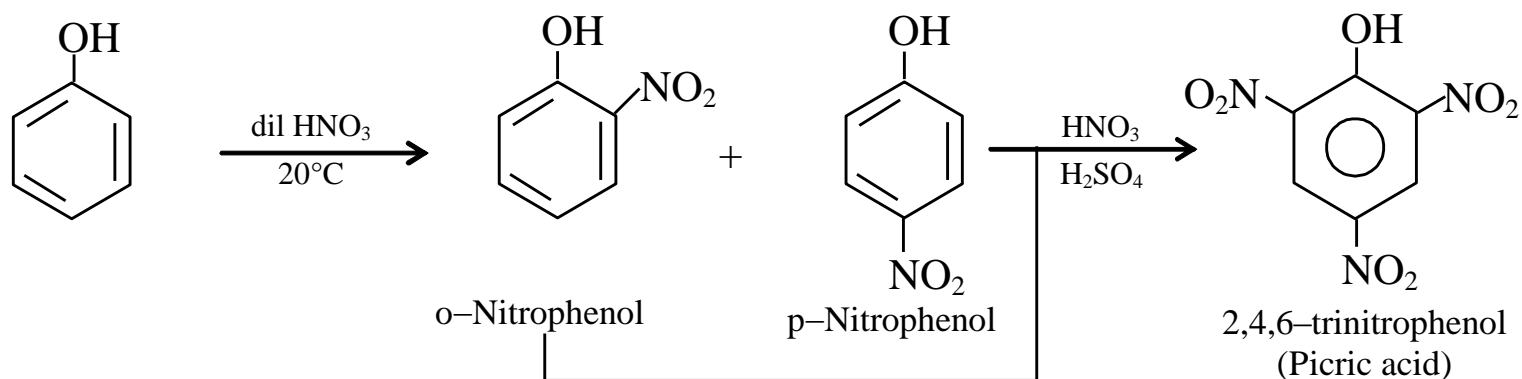


In case when SO_3H group is present at ortho and para positions, desulphonation takes place liberating SO_3 gas.

Trisubstitution of benzene is also observed when aniline is treated with bromine because the reactivity of aniline is same as that of phenoxide ion towards electrophilic attack.

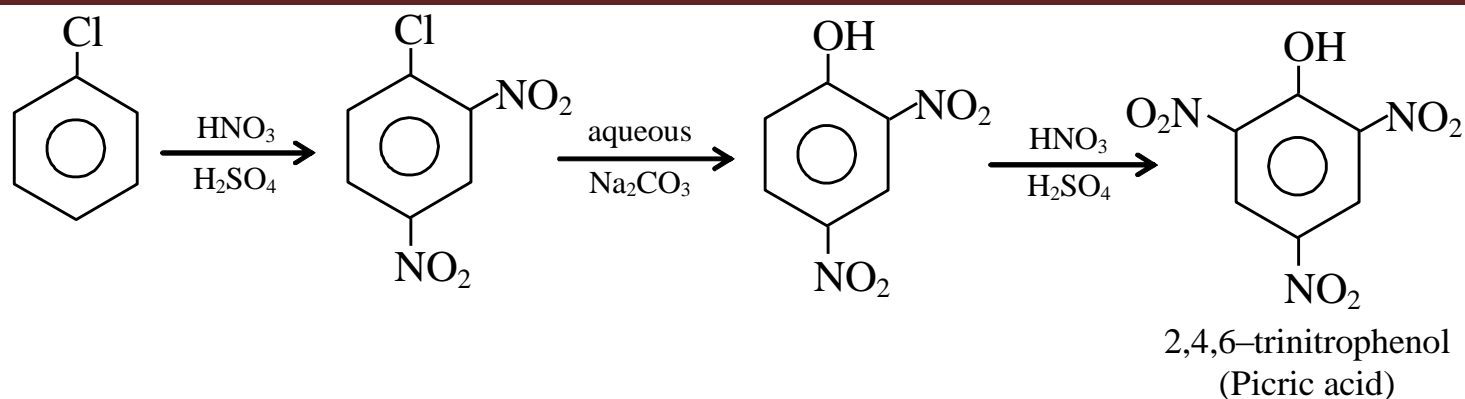
Nitration:

When treated with dilute HNO_3 , phenol gives o and p-nitrophenol. When treated with nitrating mixture, phenol gives 2, 4, 6- trinitrophenol (picric acid) but the yield is poor.

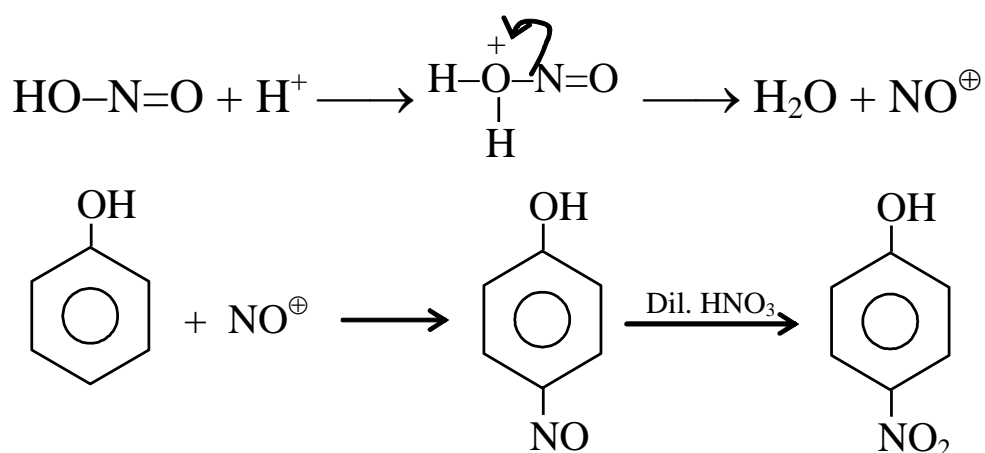


Picric acid can be alternatively prepared as follows:

ALCOLHOLS, PHENOLS AND ETHERS

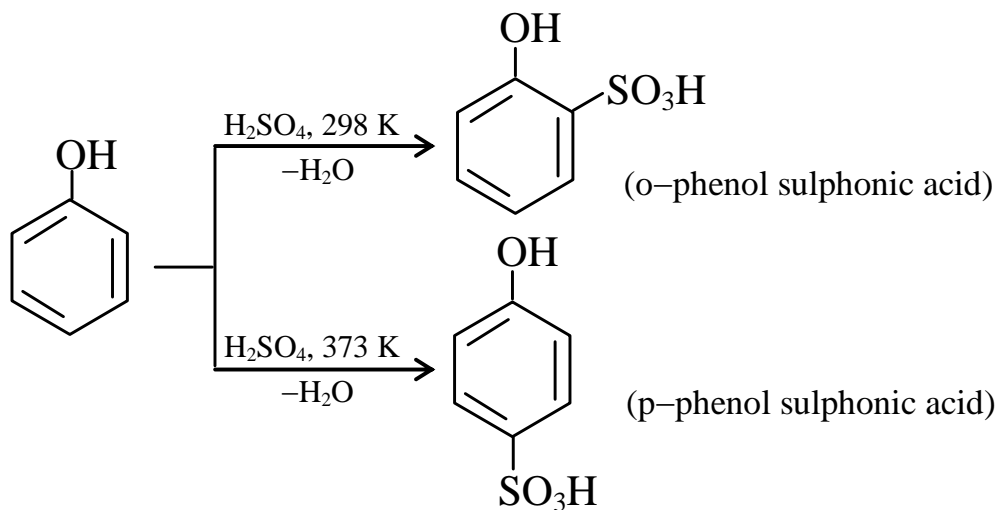


Pure p-nitrophenol is prepared in good yield when phenol is treated with nitrous acid and the product, p-nitrosophenol is oxidised to p-nitrophenol.



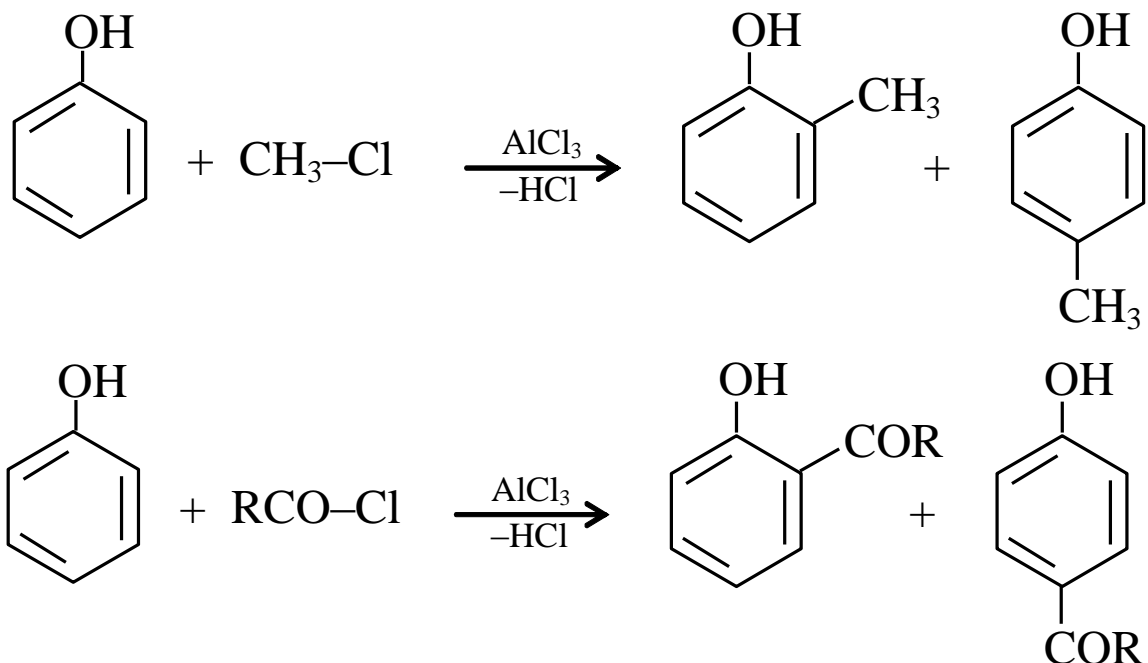
Sulphonation:

When treated with concentrated sulphuric acid, phenol gives either o or p-sulphonated derivatives. Low temperature yields o-isomer whereas high temperature yields p-isomer in greater yield.

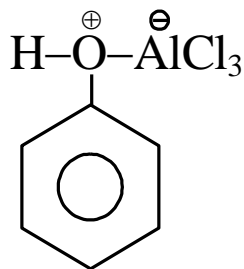


Friedel–Crafts Reaction:

Phenol undergoes alkylation and acylation to form mainly p-derivative along with some o-derivative.

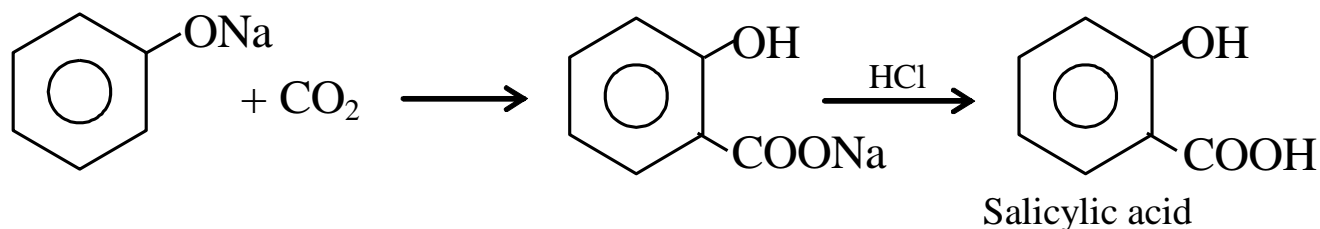


The yield is not good as the reactivity of phenol is diminished by the formation of a complex with Lewis acid AlCl_3 .



Kolbe's Reaction:

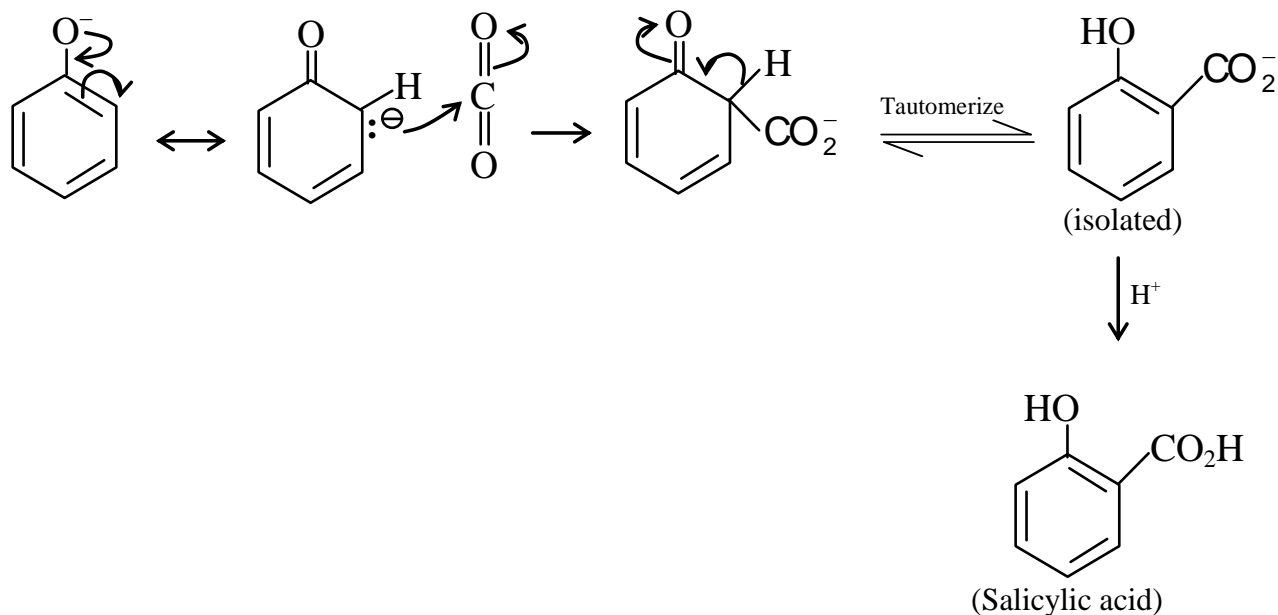
Sodium phenoxide is heated with carbon dioxide at $120\text{--}140^\circ\text{C}$ under pressure to yield sodium salicylate, which upon acidification produces salicylic acid.



ALCOLHOLS, PHENOLS AND ETHERS

A small amount of p-derivative is also formed. If the temperature rises above 140°C , the p-isomer is the main product.

Mechanism:



Salicylic acid is used for the preparation of Aspirin, oil of winter green (methyl salicylate) and salol (phenyl salicylate).

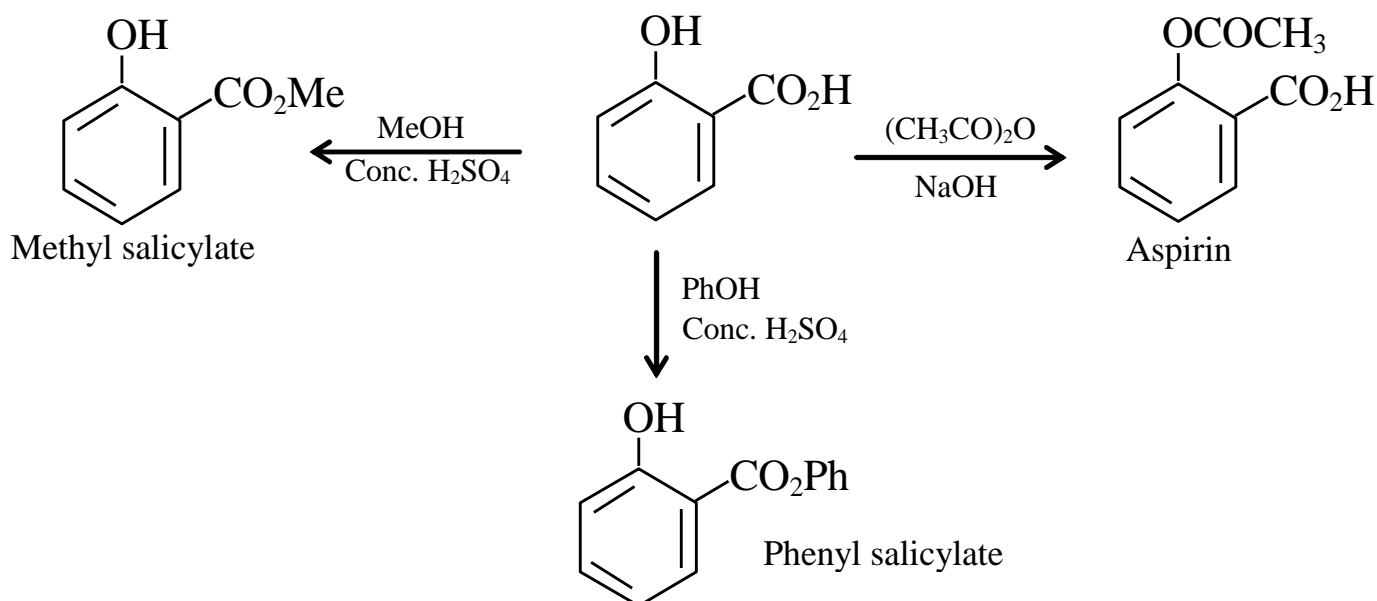
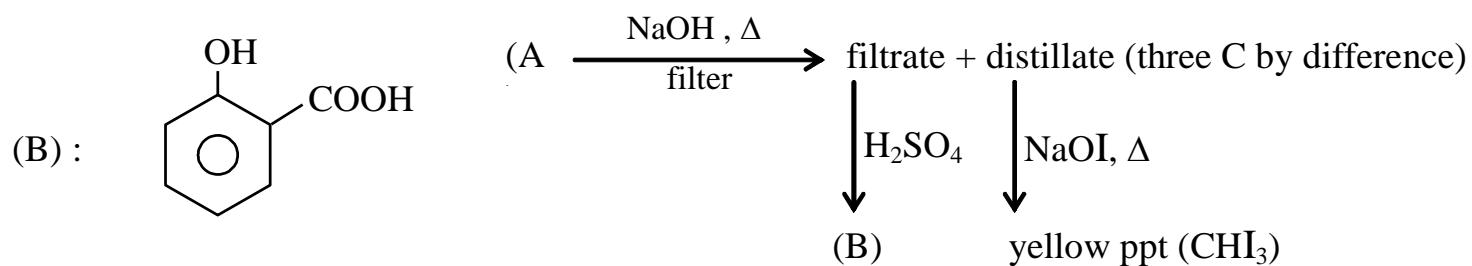


Illustration 2.

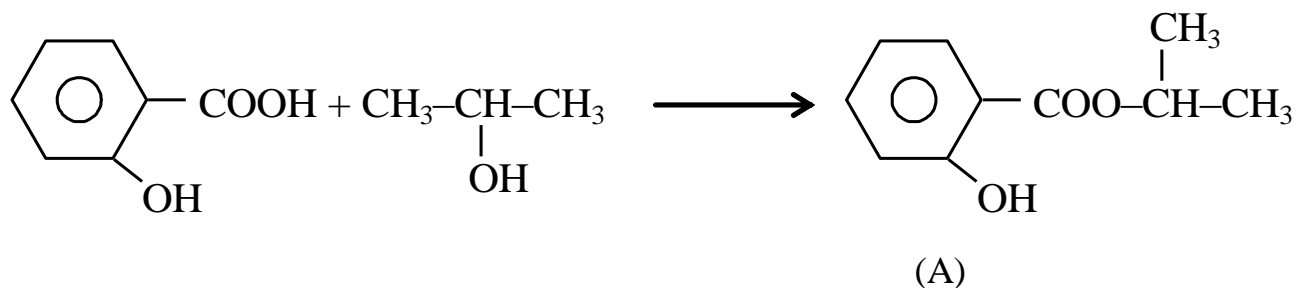
Compound (A) having molecular formula $C_{10}H_{12}O_3$ is insoluble in H_2O , dilute HCl and dilute aqueous $NaHCO_3$ but soluble in $NaOH$. A solution of (A) in dilute $NaOH$ was boiled and the distillate was collected in a solution of $NaOI$, where a yellow precipitate is formed. Filtrate on acidification forms (B) with molecular formula $C_7H_6O_3$, which is steam-distilled. (B) dissolves in aqueous $NaHCO_3$ with evolution of gas. Assign structures to (A) and (B), and explain the reactions.

Solution:

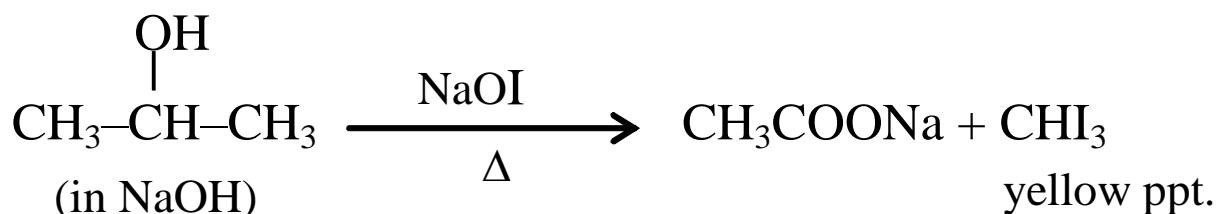
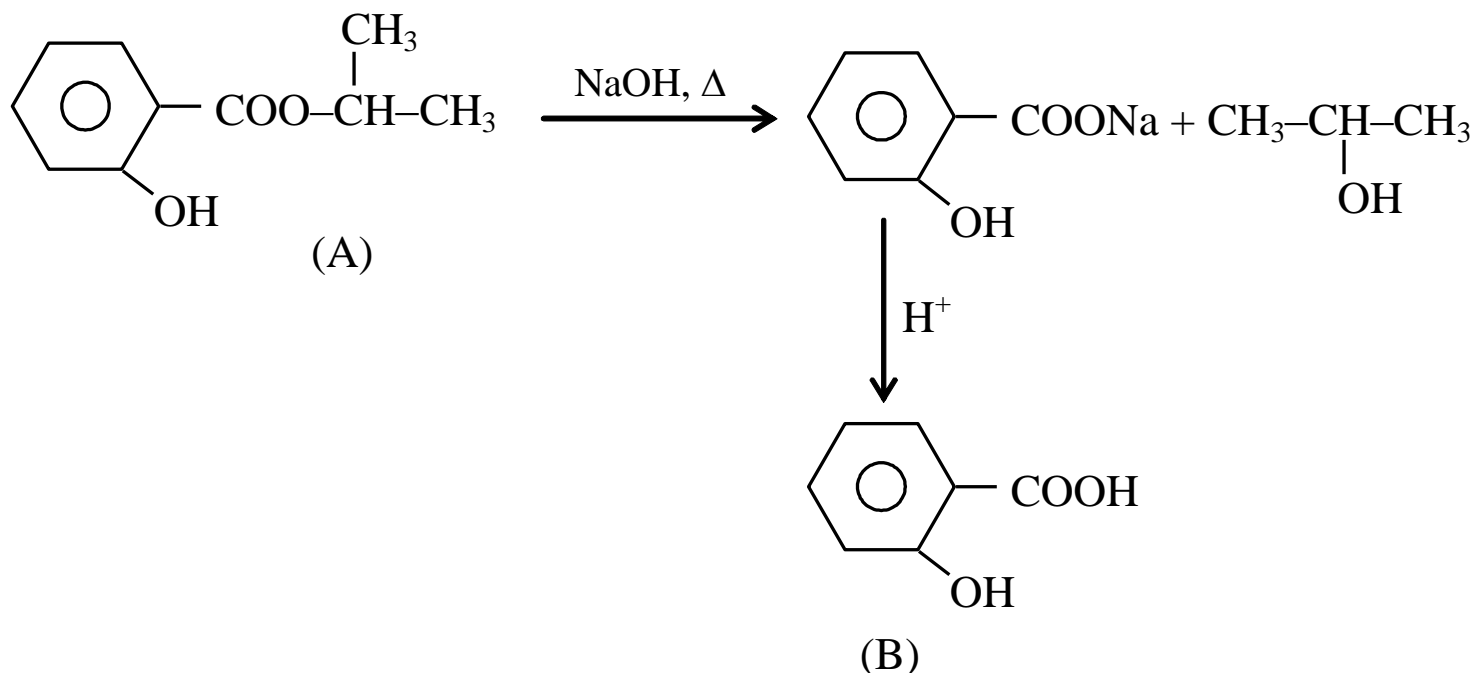
(B) gives a gas with $NaHCO_3$. Hence, (B) has $-COOH$ group. Since (B) is steam distilled, hence (B) is o-hydroxybenzoic acid (salicylic acid)



Distillate gives iodoform test. Hence, distillate is isopropyl alcohol and (A) is an ester of salicylic acid (B) and isopropyl alcohol

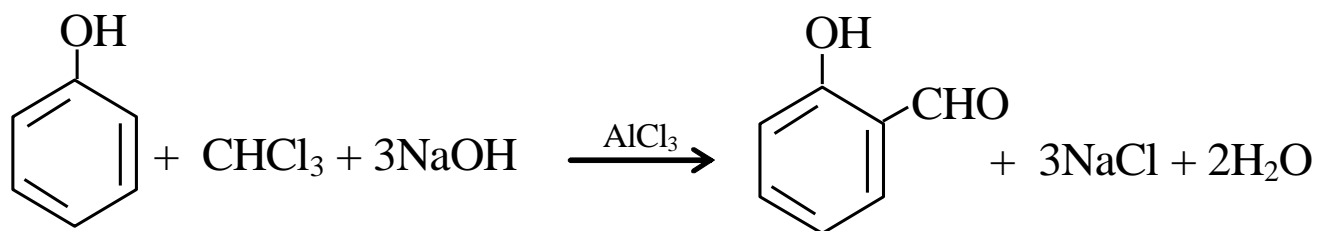


Explanation

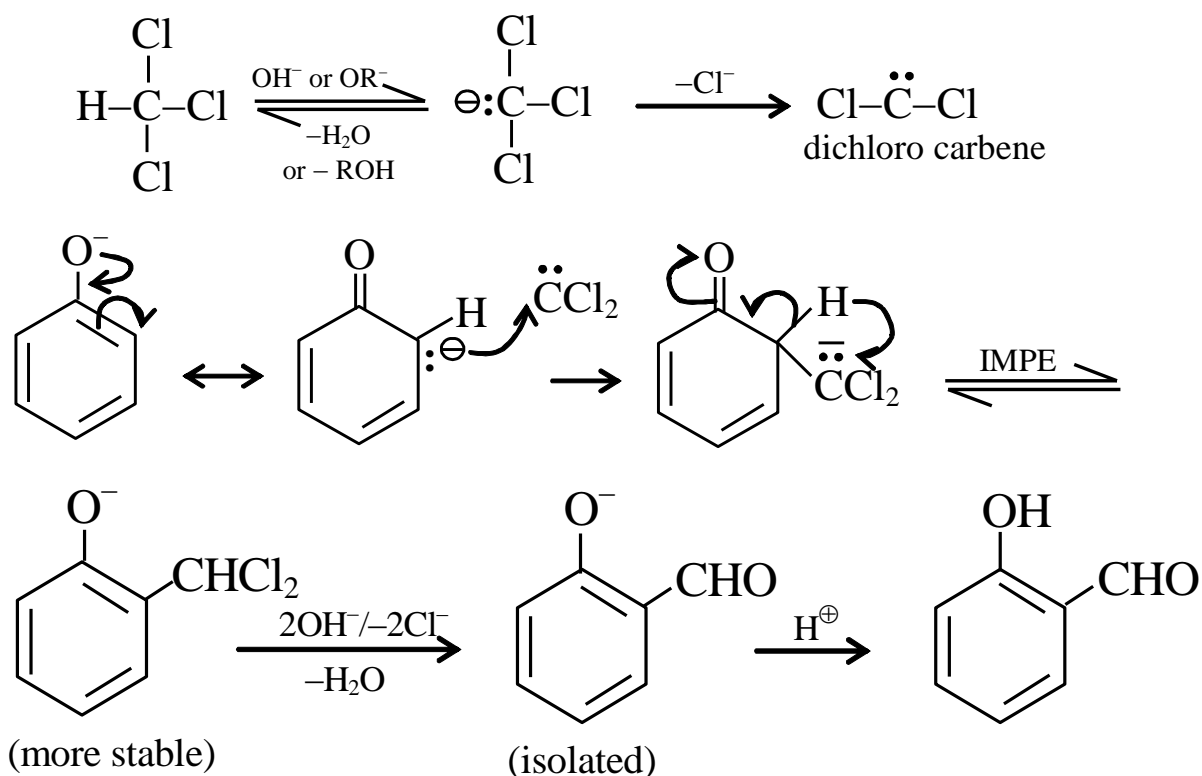


Reimer–Tiemann Reaction:

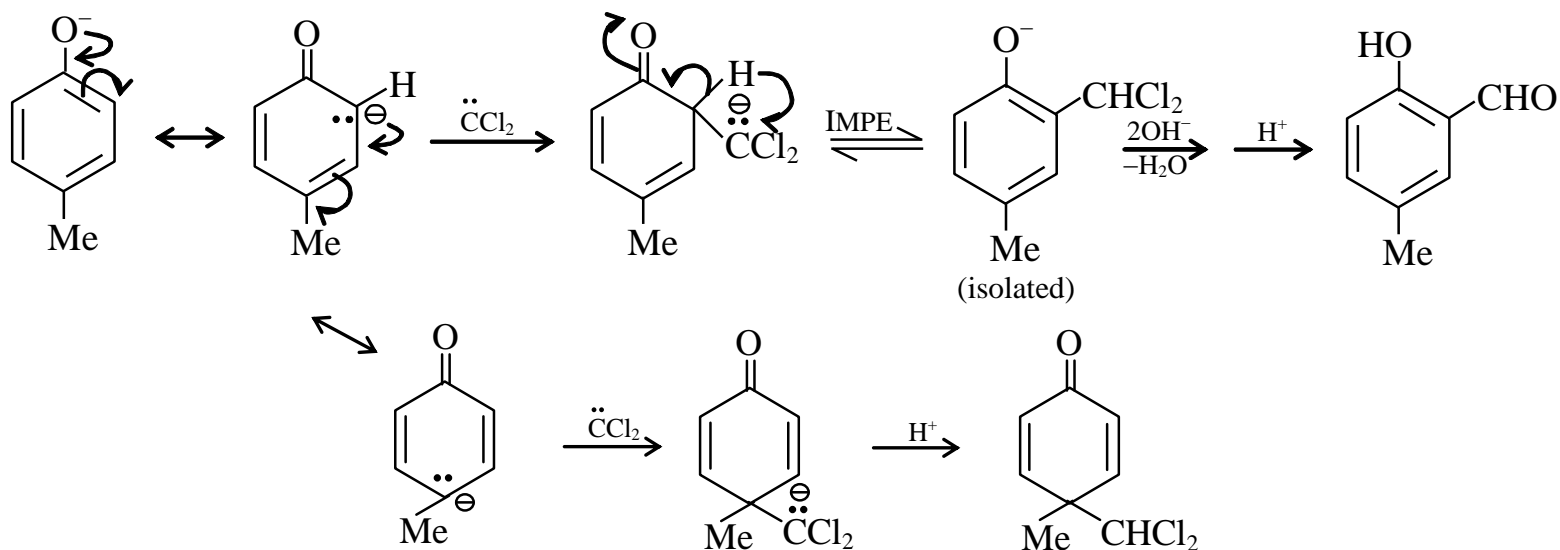
An alkaline solution of phenol is refluxed with chloroform at 60°C, distilling off the excess of chloroform and acidifying the residual liquid with sulphuric acid. As a result, o-hydroxy and p-hydroxy benzaldehyde are formed, which are separated by steam-distillation.



Mechanism:



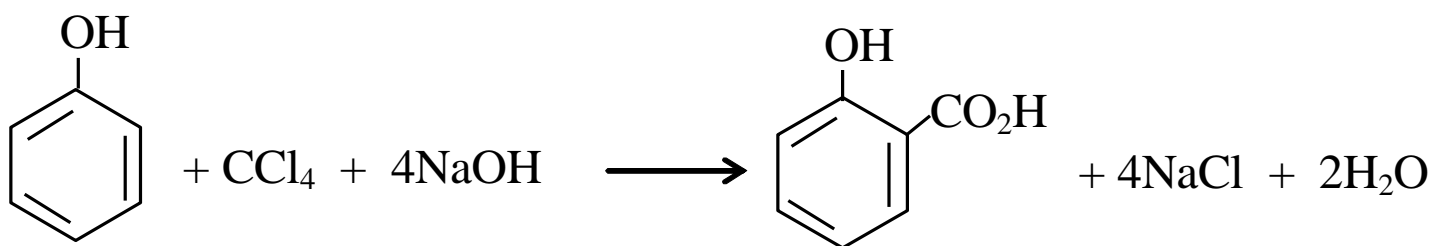
If 'o' both the o-positions are blocked, p-hydroxy benzaldehyde is the main product. With blocked p-position, o-hydroxy benzaldehyde and cyclohexadienones are formed.



Cyclohexadienone derivative remains unhydrolysed as it has a neopentyl system, which involves lot of steric crowding.

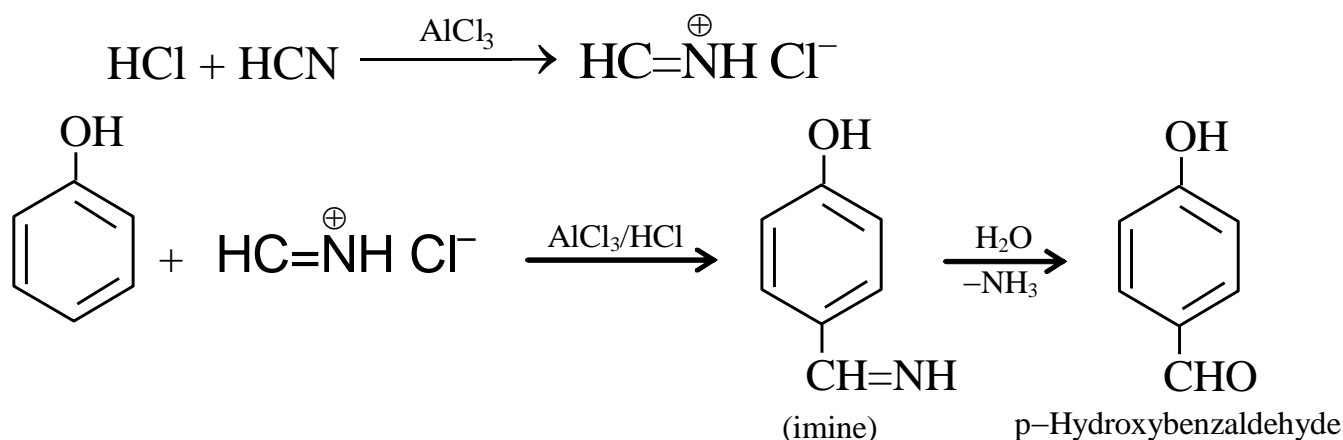
ALCOLHOLS, PHENOLS AND ETHERS

When phenol is refluxed with CCl_4 in alkaline medium, salicylic acid is formed.



Gattermann's Reaction:

When phenol is treated with liquid HCN and gaseous HCl in the presence of anhydrous AlCl_3 and the product formed is hydrolysed, p-hydroxy benzaldehyde is formed.

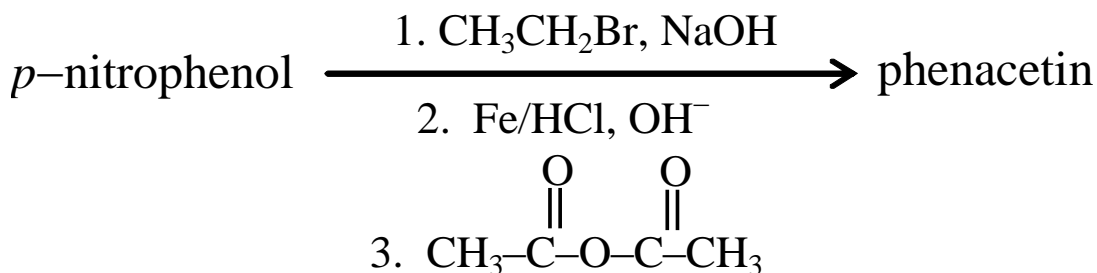


Liebermann Test:

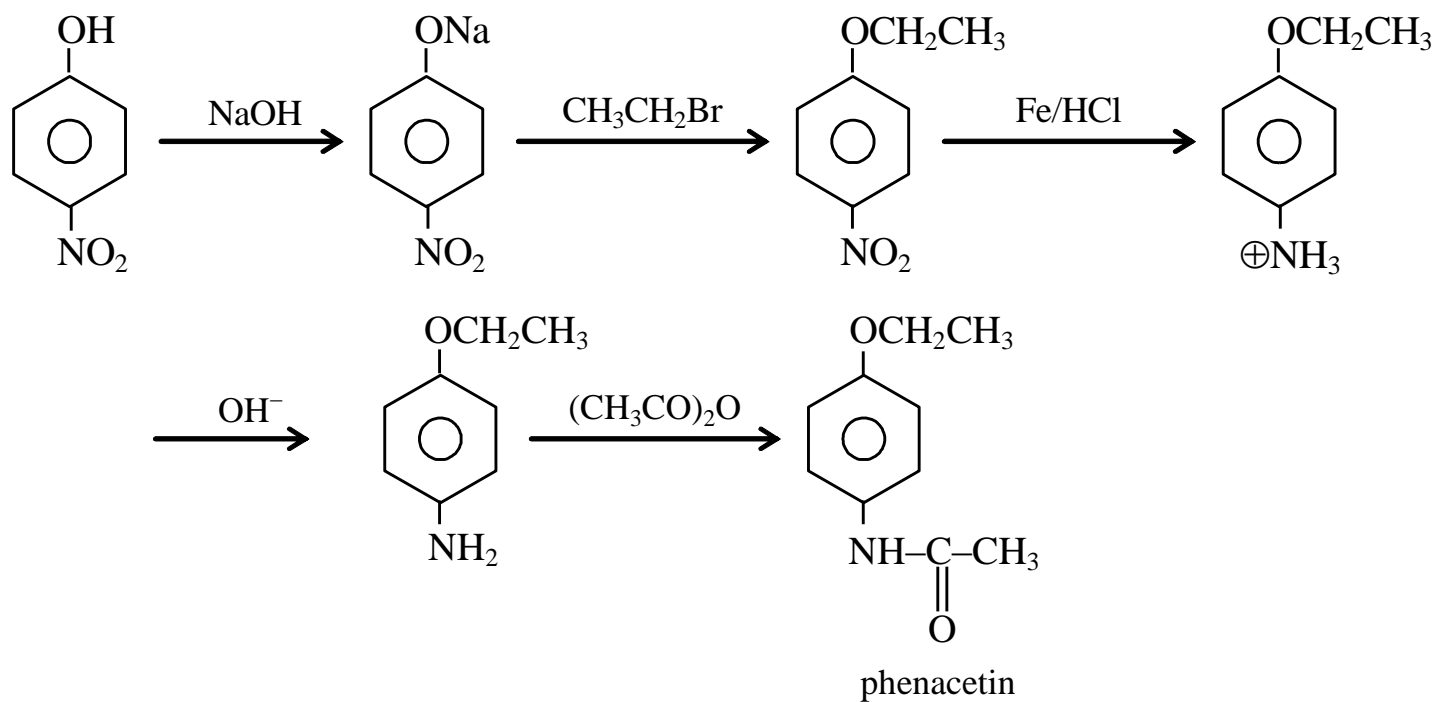
When phenol is dissolved in concentrated sulphuric acid and a few drops of aqueous sodium nitrite is added, a red colour is obtained on dilution and turns blue when aqueous sodium hydroxide is added.

Illustration 3.

A synthesis of the analgesic substance phenacetin is outlined in the following equation. What is the structure of phenacetin?

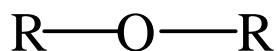


Solution:

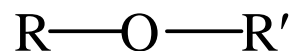


Aliphatic Ethers

Ethers are compounds in which oxygen is bonded to two alkyl substituents. If the alkyl substituents are identical, the ether is symmetrical or simple ether and if they are different, the ether is unsymmetrical ether.



A symmetrical or simple ether



An unsymmetrical or mixed ether.

The groups R and R' can be alkyl or aryl. When both the R groups are alkyl, they are called alkyl ether and when at least one of the R group is an aryl, they are called aryl ethers.

IUPAC Nomenclature Of Ethers

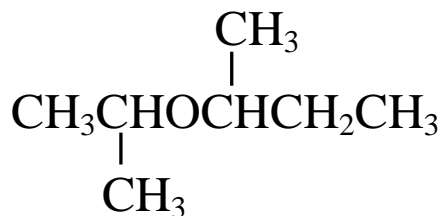
The common name of ether is obtained by citing the names of the two alkyl substituents in alphabetical order, followed by the word “ether”. The smallest ether is almost always named by their common names.



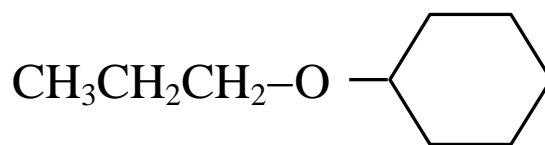
Ethyl methyl ether



diethyl ether



sec-butyl isopropyl ether



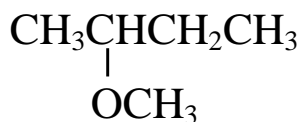
cyclohexyl *n*-propyl ether

The IUPAC system names ether as an alkane that contains an alkoxy substituent. The alkyl part with greater number of carbon atoms is named as alkane while the other alkyl part is named as alkoxy by removing the “yl” from the name of the alkyl substituent and adding “oxy”. For example, CH_3O — is called methoxy,

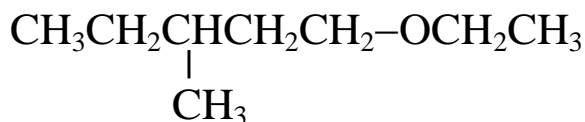
$\text{CH}_3\text{CH}_2\text{O}$ — is called ethoxy, $\begin{array}{c} \text{CH}_3\text{CH} \text{---} \text{O} \text{---} \\ | \\ \text{CH}_3 \end{array}$ is called isopropoxy, $\begin{array}{c} \text{CH}_3\text{CH}_2\text{CH} \text{---} \text{O} \text{---} \\ | \\ \text{CH}_3 \end{array}$

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is called *sec*-butoxy and $(\text{CH}_3)_3\text{C}-\text{O}-$ is called *tert*-butoxy. Thus, IUPAC name for ether is alkoxyalkane.



2-methoxybutane



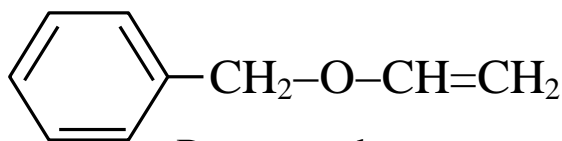
1-ethoxy-3-methylpentane



1, 4-diisopropoxybutane



1-chloro-2-methoxyethane

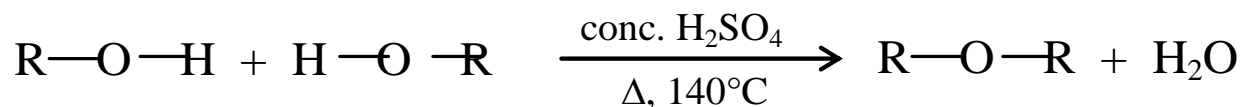


Benzoxymethane

General Methods Of Preparation Of Ethers

Intermolecular Dehydration Of Alcohols

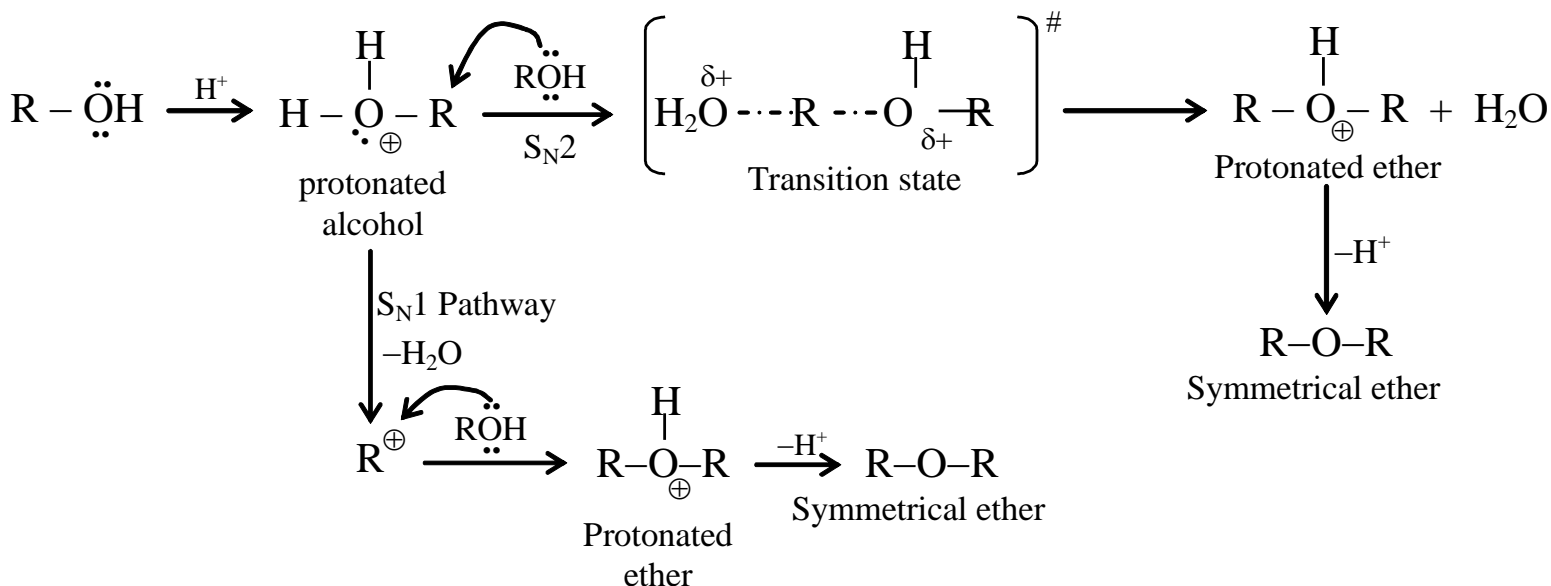
When alcohols are treated with H_2SO_4 or H_3PO_4 at 140°C , a molecule of water is eliminated from two alcohol molecules to give ether. This reaction is called intermolecular dehydration of alcohols. Alcohols on dehydration intramolecularly, give alkene. Thus, dehydration of alcohols to ether can be achieved by controlling the reaction conditions i.e. reaction is carried out at low temperature (it should not increase beyond 140°C). Alcohol should be taken in excess. When the dehydration is carried out above 140°C , it leads to elimination forming an alkene.



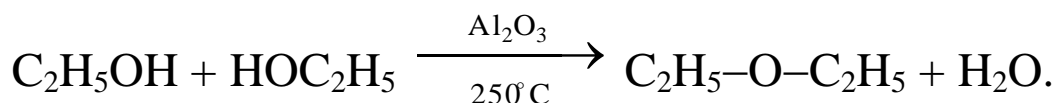
Dehydration of alcohols to ether is useful for the preparation of symmetrical ethers only. If we try to prepare unsymmetrical ether using a combination of two alcohols (ROH & $\text{R}'\text{OH}$), it leads to the formation of a mixture of three ethers ($\text{R}-\text{O}-\text{R}$, $\text{R}-\text{O}-\text{R}'$ and $\text{R}'-\text{O}-\text{R}$).

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Dehydration of alcohols to ether is an example of nucleophilic substitution. A protonated alcohol molecule acts as substrate and the second alcohol molecule act as nucleophile. The reaction can proceed by S_N1 or S_N2 process. Primary alcohols react by S_N2 process and secondary & tertiary alcohols undergo reaction by S_N1 process.

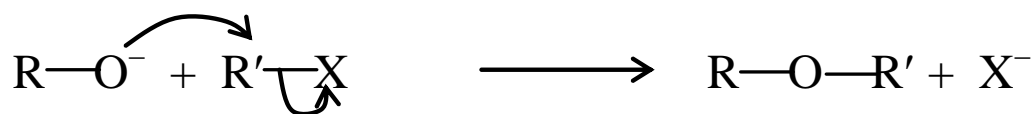


Dehydration of alcohols can also be achieved by passing vapours of ethyl alcohol over heated Al_2O_3 at 250°C .



Williamson's Etherification Method

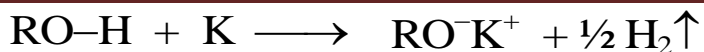
When an alkoxide is treated with an alkyl halide, ether is produced. The method was developed by Williamson and is useful for the preparation of symmetrical as well as unsymmetrical ethers.



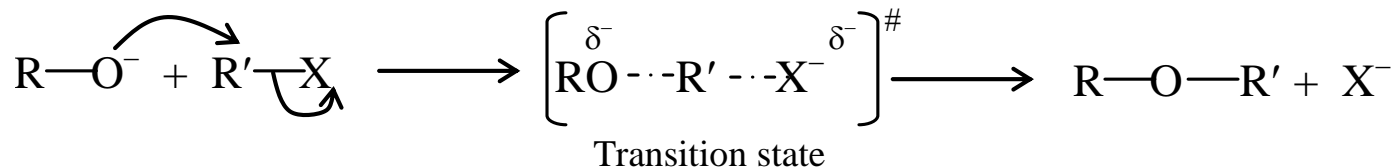
where R' can be same as or different from R .

The alkoxide can be prepared by the action of alcohols with sodium or potassium.

ALCOLHOLS, PHENOLS AND ETHERS



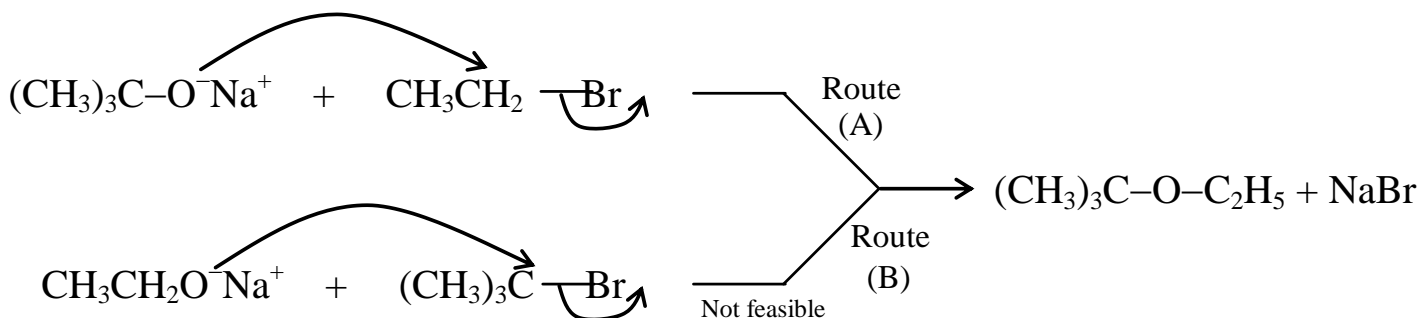
This reaction involves $\text{S}_{\text{N}}2$ mechanism, with alkoxide ion acting as nucleophile and alkyl halide as the substrate. The complete mechanism follows as



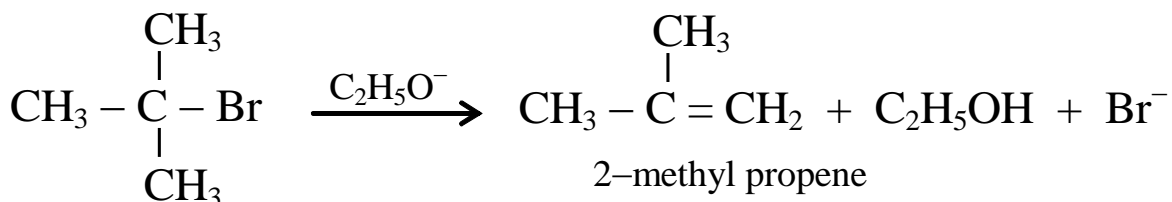
For ether to be obtained as major product, reaction should follow substitution and minimize elimination reaction. This can be achieved by taking only methyl halides or 1° halides with lesser branching near the reaction site.

But if we take 2° and 3° alkyl halides, which have more tendency to undergo elimination, will give very less yield of ethers.

Suppose, we want to prepare ethyl *tert*-butyl ether. There are two possible routes to prepare it.



Route (A) is more suitable to prepare given ether as the alkyl halide involved in this route is a primary one while in route (B), the halide being a 3° , it will lead to elimination reaction forming an alkene, 2-methyl propene.



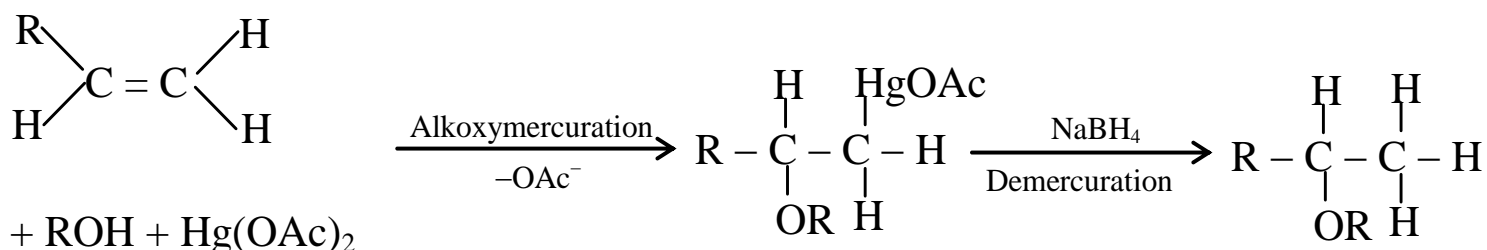
Alkoxymercuration–Demercuration

In overall alkoxymercuration–demercuration reaction, ROH is added to the double bond. The reaction does not involve any carbocation as intermediate, so it

ALCOLHOLS, PHENOLS AND ETHERS

is free from rearrangement and also involves syn addition, which is in accordance to Markownikoff's rule.

Alkenes react with mercuric acetate in the presence of alcohol to give alkoxymercurial compound, which on demercuration by NaBH_4 gives ethers.

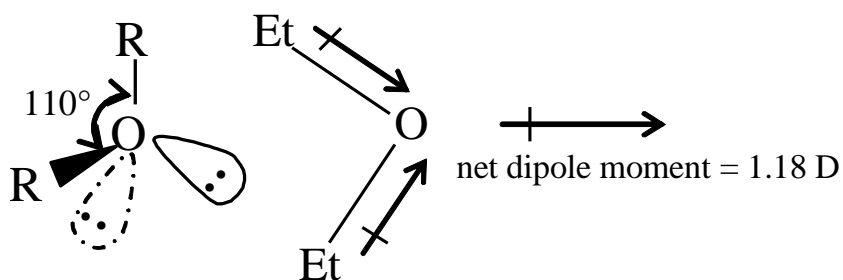


General Physical Properties Of Ethers

Diethyl ether is a highly volatile liquid, used as a solvent, as an anesthetic and in the preparation of Grignard reagents.

Boiling point of ethers is less than that of the corresponding alcohols (of similar molar mass) due to absence of hydrogen bonding. The solubility of ethers in water is comparable to that of the alcohols as both are able to form hydrogen bond with water. The hybridization of oxygen atom in ether is sp^3 , so the shape of an ether molecule is angular or bent with bond angle of 110° . The bond angle is greater than the normal bond angle in a tetrahedron with lone pairs, as repulsion between the bulkier alkyl groups is dominant over the lone pair repulsion.

Ether molecules are polar and they have a small net dipole moment. The net dipole moment of diethyl ether is 1.18 D.

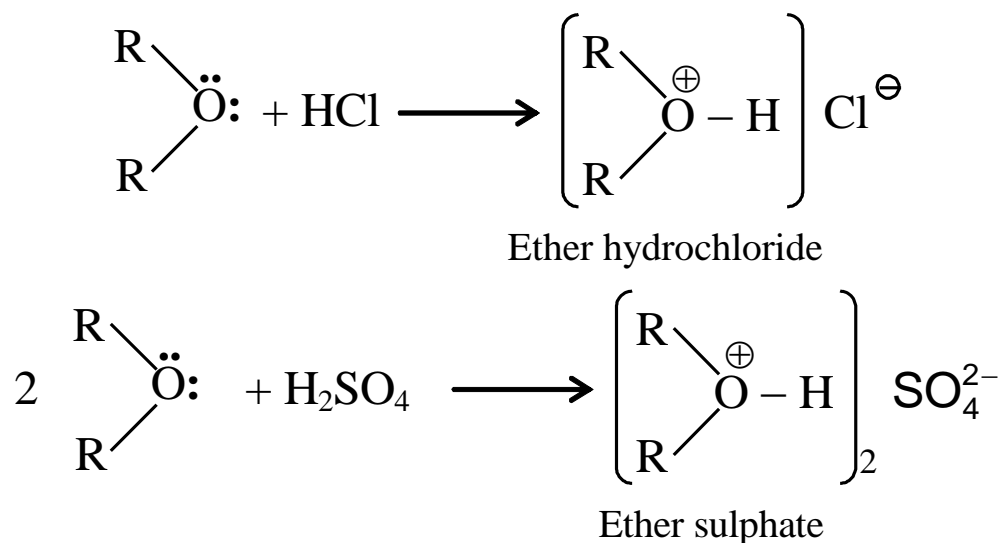


General Chemical Reactions Of Ethers

Ethers are quite unreactive compounds as ether linkage is very stable towards bases, oxidising agents and reducing agents. Ethers can be easily cleaved in the presence of acids. Few of the common reactions of ether are as follows:

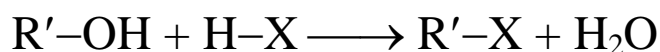
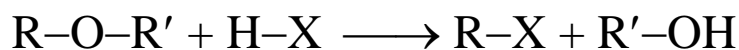
Oxonium Salt Formation

When ethers are treated with cold concentrated inorganic acids, these form oxonium salts. The reaction between ether and acid is a Lewis acid–base type interaction.



Cleavage By Heating With Acids

Ethers on reaction with acids (HX) in presence of heat undergoes cleavage to form an alkyl halide and an alcohol. Alcohol on further reaction with HX gives second molecule of alkyl halide.



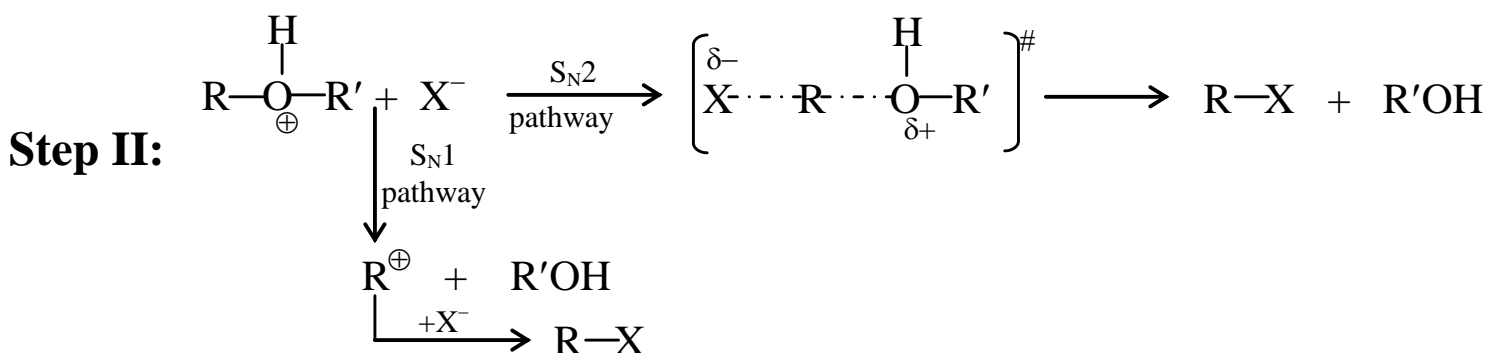
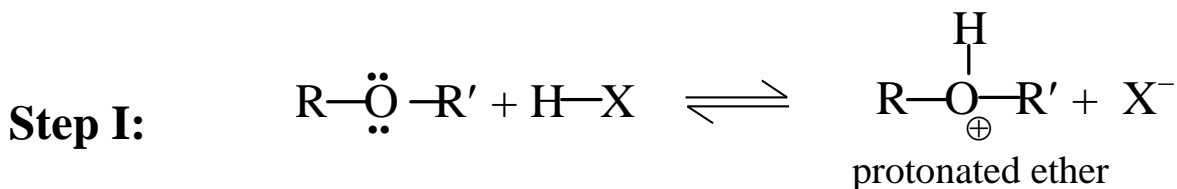
HI is more reactive towards ether than HBr and HBr is more reactive than HCl.

The cleavage of ethers takes place in vigorous conditions i.e. concentrated acids (HI and HBr) and at elevated temperatures.

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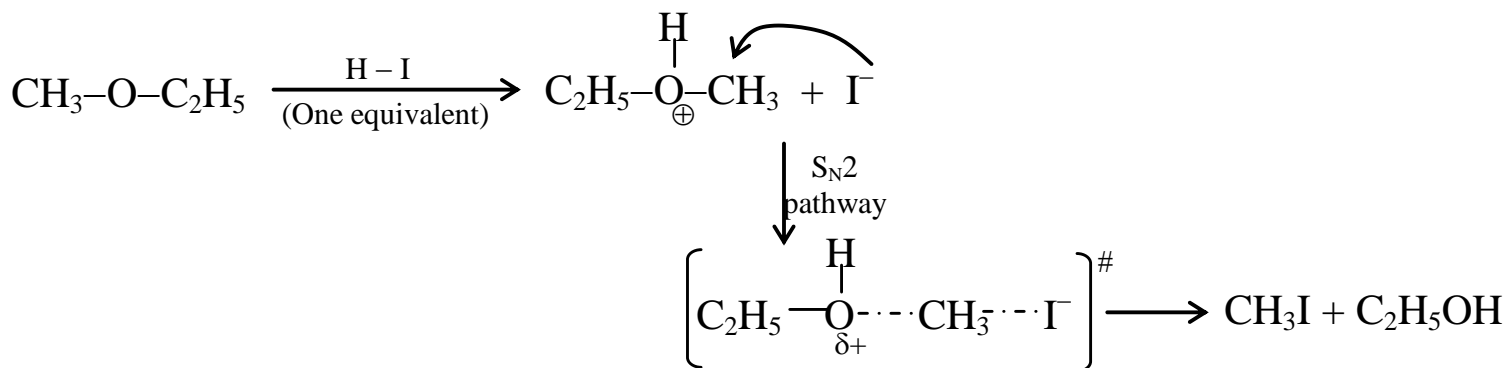
Mechanism:

In the first step, ether is protonated by HX to give protonated ether. In the second step, halide ion acts as nucleophile and attacks protonated ether to undergo cleavage. This step is favoured because the leaving group (alcohol) is weakly basic.



Reaction in second step can take the direction of S_N1 or S_N2 pathway, depending upon the conditions employed and the structure of ether. When both the alkyl groups are methyl or 1°, it will follow S_N2 reaction and when at least one of the alkyl group is 3°, the reaction follows S_N1 pathway. For all other cases, it can undergo S_N1 or S_N2 pathway, depending upon the reaction conditions.

For example,



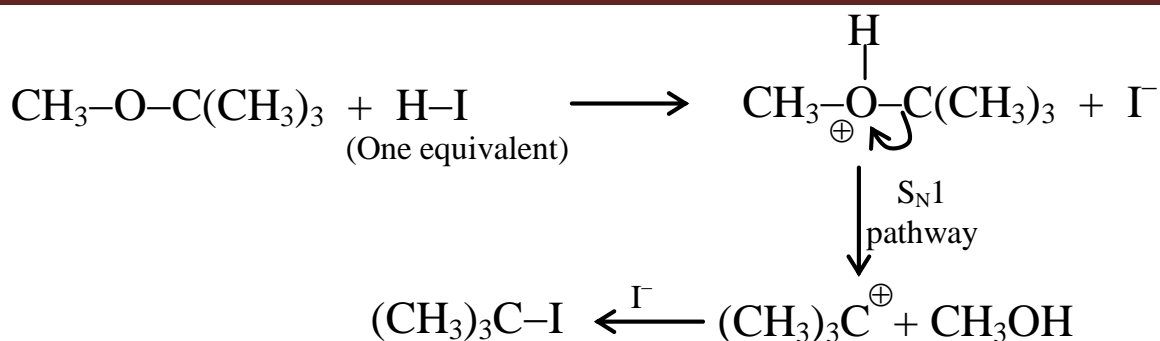
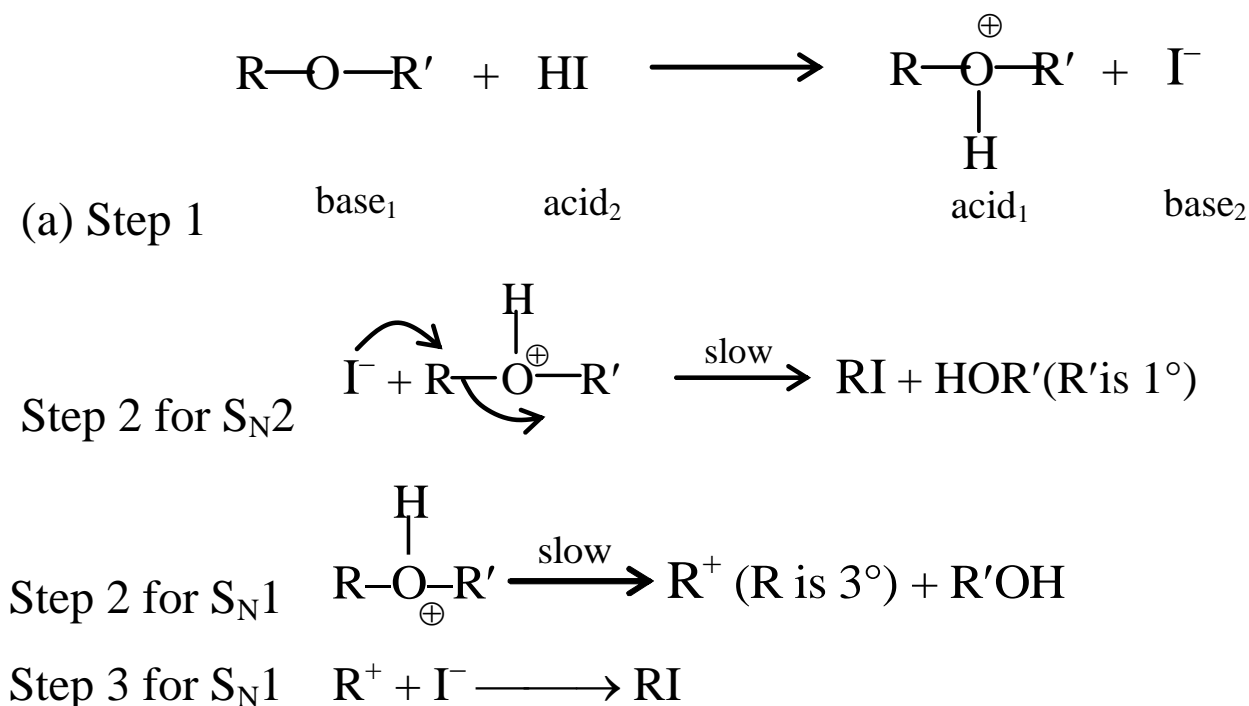


Illustration 4.

- (a) Give S_N2 and S_N1 mechanisms for the cleavage of ethers with HI.
- (b) Why does S_N2 cleavage occur at a faster rate with HI than with HCl?

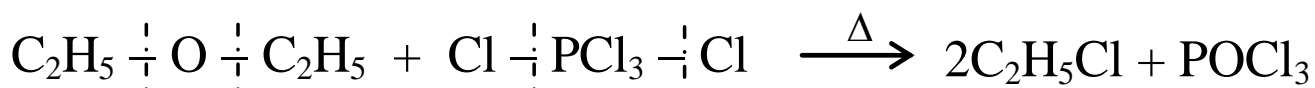
Solution:



- (b) The transfer of H⁺ to ROR' in step 1 is greater with HI, which is a stronger acid, than with HCl. Furthermore, in step 2, I[−], being a better nucleophile than Cl[−], reacts at a faster rate.

Action Of PCl₅ Or SOCl₂

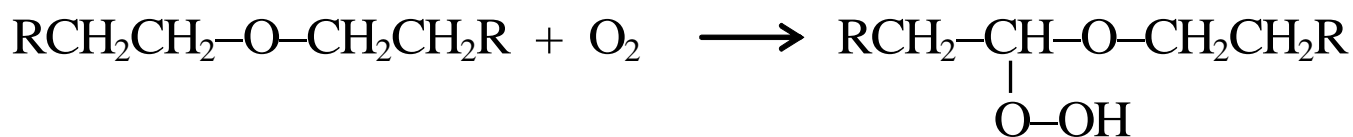
Ethers on heating with PCl₅ or SOCl₂ undergoes cleavage to form alkyl chlorides.



The cleavage by PCl_5 or SOCl_2 is used to distinguish metameric ethers as their cleavage products would be different.

Oxidation Of Ether By Air Or Ozone

When ethers are exposed to atmospheric oxygen for a long time, they are oxidised to ether hydroperoxides. Ether hydroperoxides are solids, which explodes on slightest heating or on rubbing. So ether samples, which are exposed to air should not be used for solvent extraction, as during distillation, explosion may occur. Thus, from such ether samples, hydroperoxides are to be removed before using it for solvent extraction.

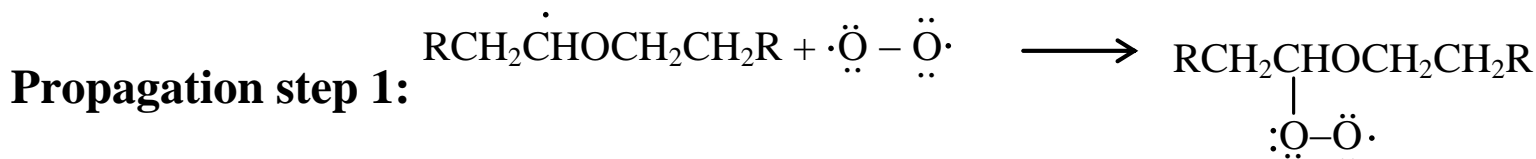
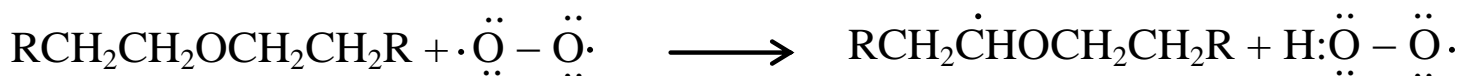


Ethers are purified by extraction with excess of FeSO_4 solution, which reduces the $-\text{OOH}$ group to the non-explosive, innocuous $-\text{OH}$ group.

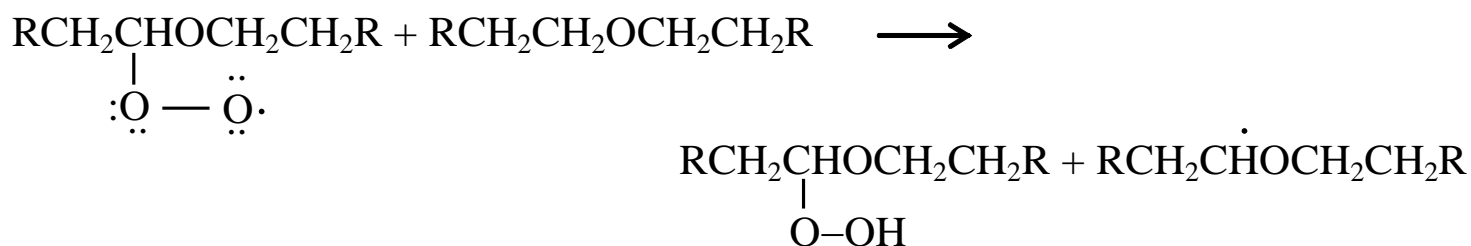
This reaction has a radical mechanism in which oxygen (a diradical) is the radical initiator.

Mechanism:

Initiation step:



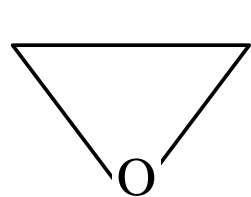
Propagation step 2:



Step 1 and 2 of the propagation step are repeated to continue the chain mechanism. The chain may finally terminate by the collision between any two free radicals.

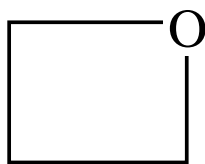
Cyclic Ethers

If oxygen atom is a part of carbon skeleton in the ring, then such ethers are called cyclic ethers. Their general formula is $(\text{CH}_2)_n\text{O}$ where $n = 2, 3, 4, 5$ and 6 .



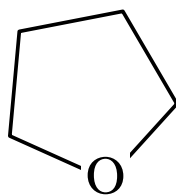
(n = 2)

Oxirane



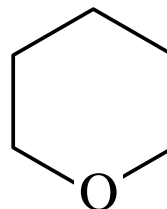
(n = 3)

Oxetane



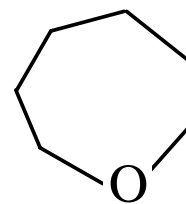
(n = 4)

Oxolane



(n = 5)

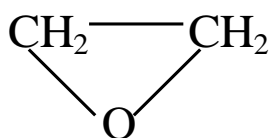
Oxane



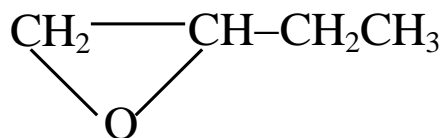
(n = 6)

Oxepane

Three membered cyclic ethers can also be considered as oxides of the parent alkene. Thus, they are named as alkene oxides or epoxides.

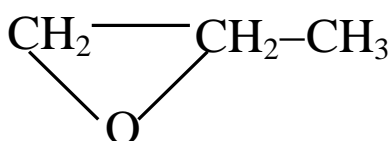


ethylene oxide
(epoxy ethane)

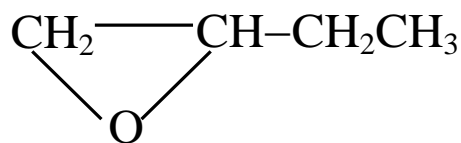


1, 2-butene oxide
(1, 2-epoxy butane)

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propylene oxide/ 2-methyl oxirane
(1, 2-epoxy propane)

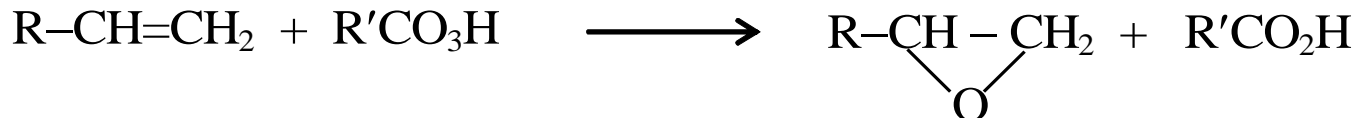


2, 3-butene oxide
2, 3-dimethylcoxirane
(2, 3-epoxy butane)

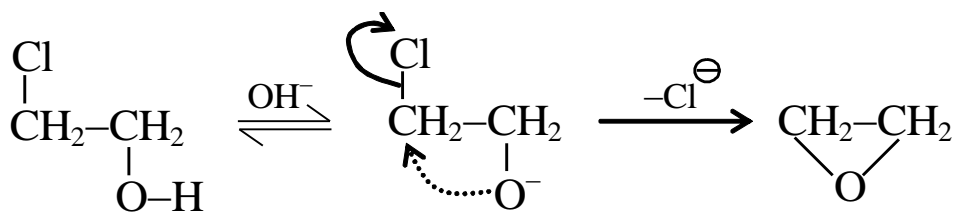
There are two IUPAC approved ways to name epoxides. According to one method, the three-membered oxygen containing ring is called “oxirane”, with oxygen atom occupying 1-position. Thus, propylene oxide is called 2-methyl oxirane. Alternatively, an epoxide can also be named as an alkane, with “epoxy” substituent and the numbers of the carbons to which the oxygen is attached immediately preceding the alkane name.

Preparation Of Epoxides

Epoxide can be prepared by the oxidation of alkene using peroxy acids.



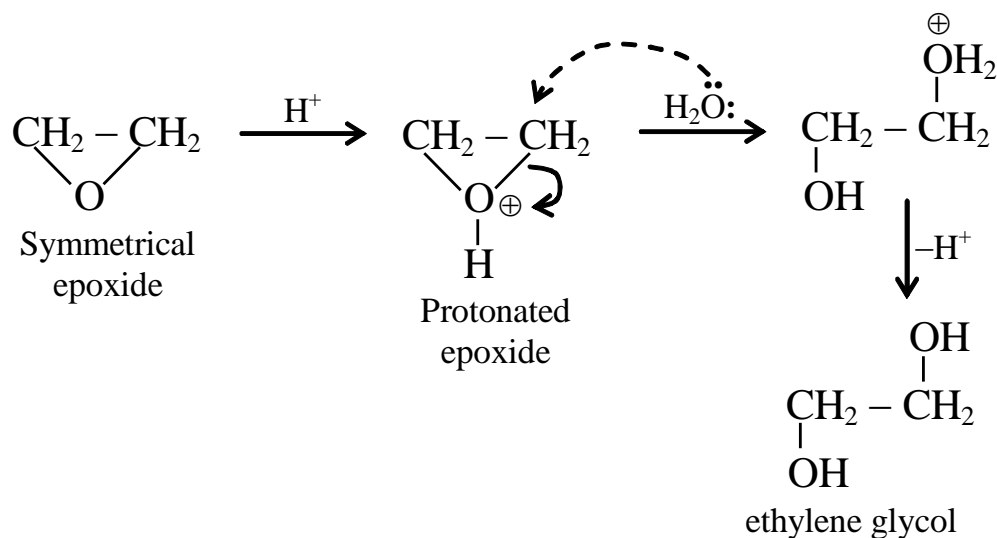
The reaction is referred as epoxidation and we have already discussed its mechanism in the lesson alkenes. Three membered cyclic ethers can also be prepared by internal $\text{S}_{\text{N}}2$ reaction of a chlorohydrin.



Reactions Of Epoxides

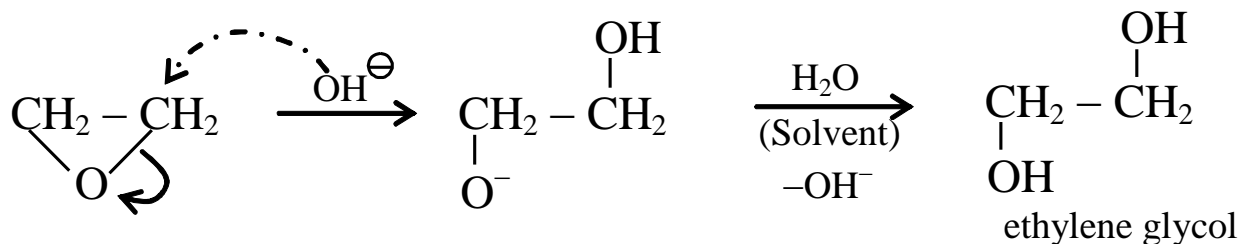
As three membered epoxide ring is highly strained, so they are highly susceptible to ring cleavage in order to get relieve from the strain. Thus, epoxides can be cleaved by acids as well as by bases.

Acid-Catalysed Cleavage Of Epoxides



In the first step, protonation takes place to give protonated epoxide. This is then attacked by H_2O (a poor nucleophile) to undergo ring opening at room temperature, which finally loses H^+ to give ethylene glycol.

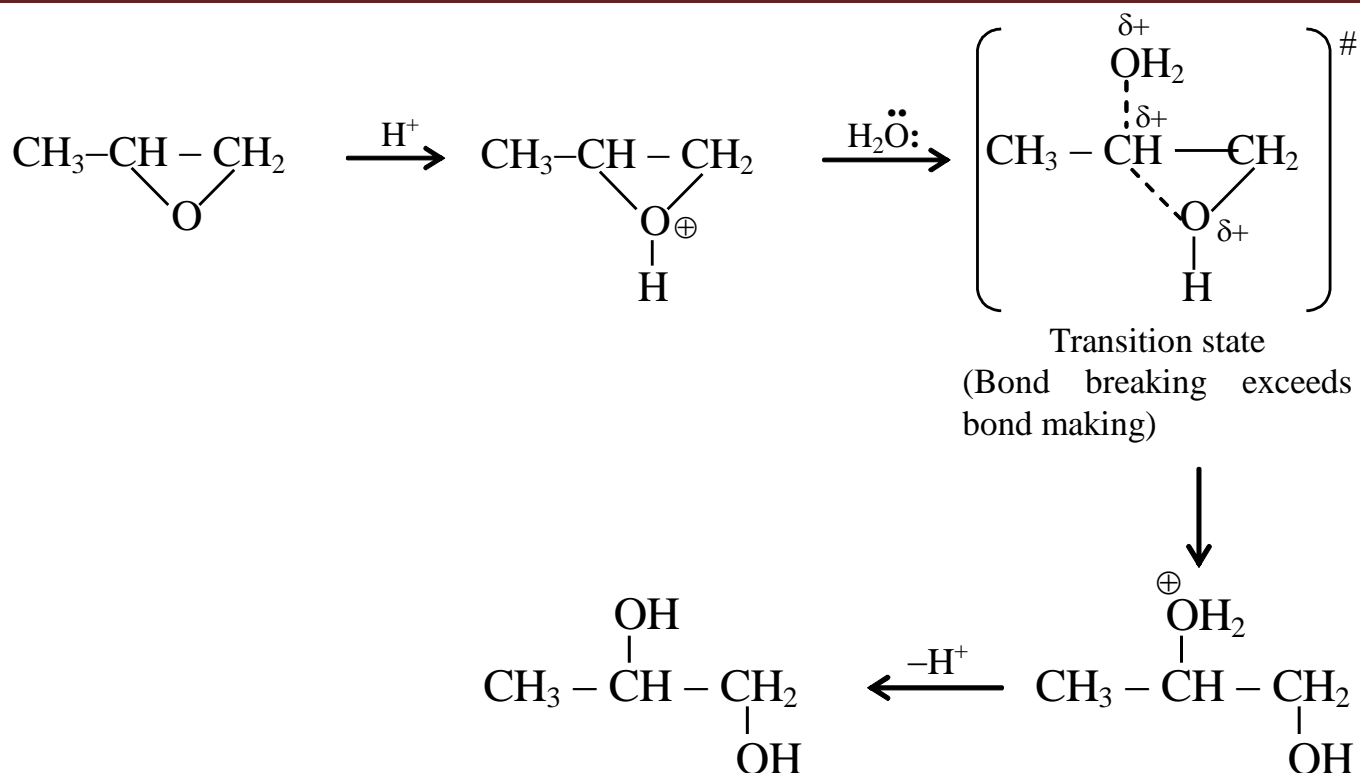
Base-Catalysed Cleavage Of Epoxides



Here, the nucleophile attacks epoxide ring and cleave it, which then abstracts a proton from the solvent (or from the acid added after the reaction is over) to give ethylene glycol. When a nucleophile attacks an unprotonated epoxide, the reaction is a pure $\text{S}_{\text{N}}2$ and thus nucleophile attacks the less hindered carbon.

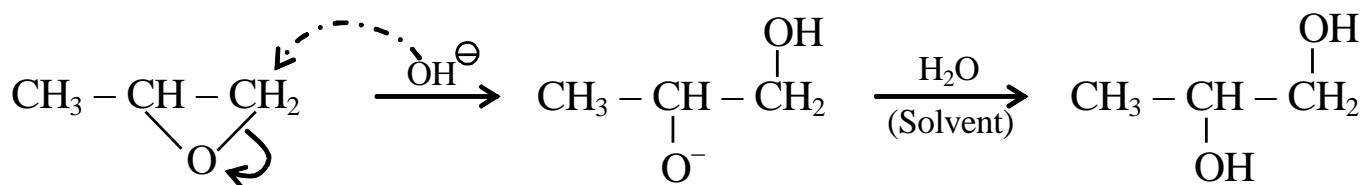
In case of unsymmetrical epoxides, for instance, propylene oxide, the acid-catalysed cleavage proceeds as follows:

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In this case, after the protonation step, nucleophile attacks at the more substituted carbon because the leaving group (alcohol) is better one and the nucleophile (H_2O) is poor one. Thus, leaving group starts leaving before the nucleophile attacks or in other words, bond breaking is more than bond making in the transition state. As the carbon–oxygen bond breaks faster, a partial positive charge develops on the carbon that is losing its share of the oxygen's electrons and protonated epoxide breaks preferentially in the direction that puts the partial positive charge on the more substituted carbon because the positive charge is more stable here due to +I effect of methyl group. Thus, we can say that the reaction proceeds by $\text{S}_{\text{N}}2$ pathway with considerable $\text{S}_{\text{N}}1$ characteristics in it. The reaction is neither pure $\text{S}_{\text{N}}1$ (because a carbocation is not fully formed) nor pure $\text{S}_{\text{N}}2$ (because leaving group begins to depart before the compound is attacked by the nucleophile).

In propylene oxide, base–catalysed cleavage proceed as follows:



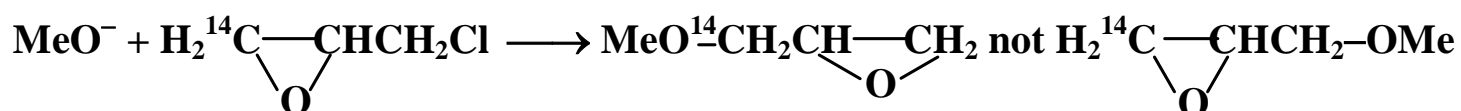
ALCOLHOLS, PHENOLS AND ETHERS

Since, this reaction is a pure S_N2 reaction, so nucleophile attacks at the less substituted carbon to undergo ring opening. The alcohol-alkoxide ion then takes up a proton from the solvent to give final product.

The product of acid-catalysed cleavage and base-catalysed cleavage of propylene oxide are different because they are enantiomers having similar values of optical rotation but with different sign.

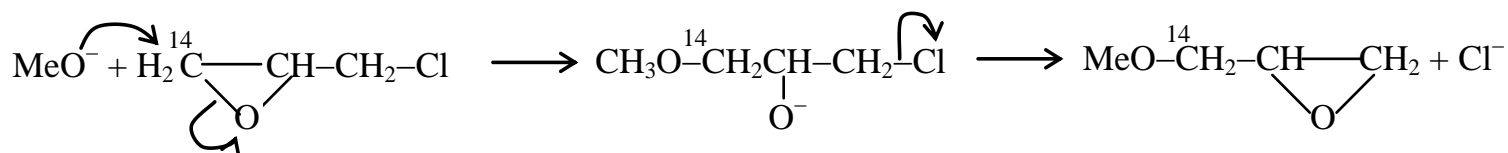
Illustration 5.

Account for the ^{14}C -labeled product from the following reaction,



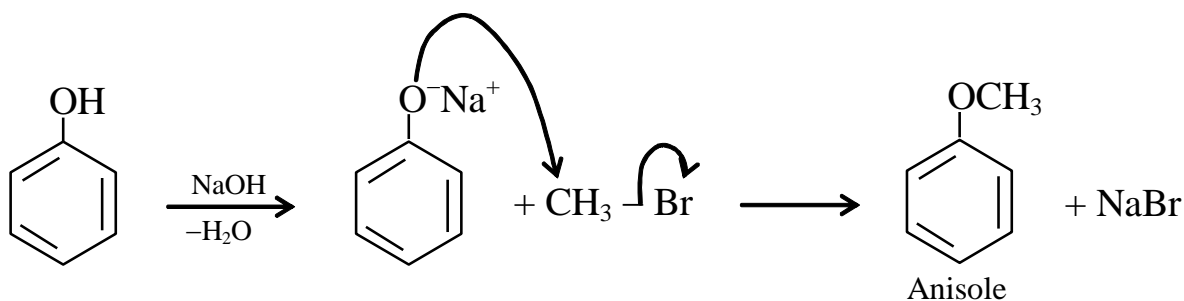
Solution:

This is not a direct Williamson reaction. Instead the reaction is initiated by an S_N2 displacement by CH_3O^- on the less substituted ^{14}C of the epoxide, giving an intermediate alkoxide ion. The O^- then acts as a nucleophile (neighboring group participation) to displace Cl^- by a second S_N2 reaction, forming the product.

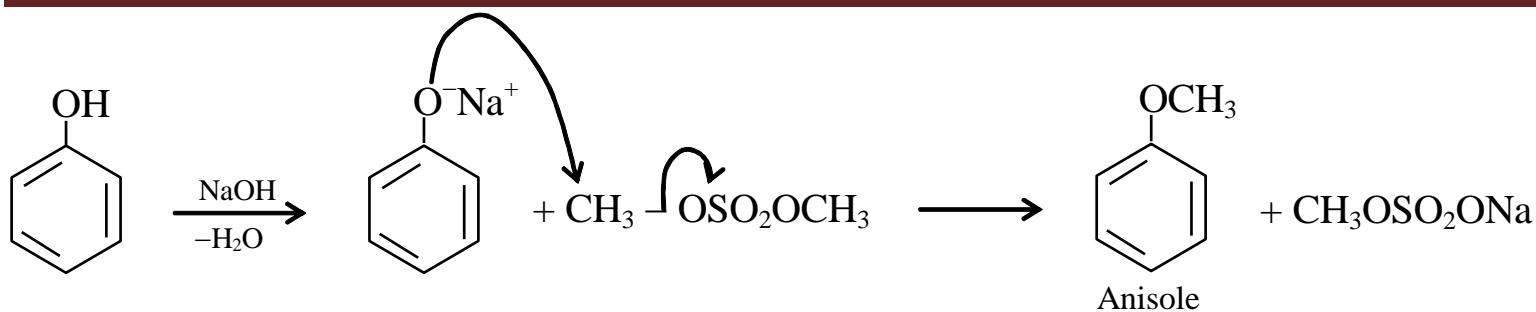


Aryl Ethers

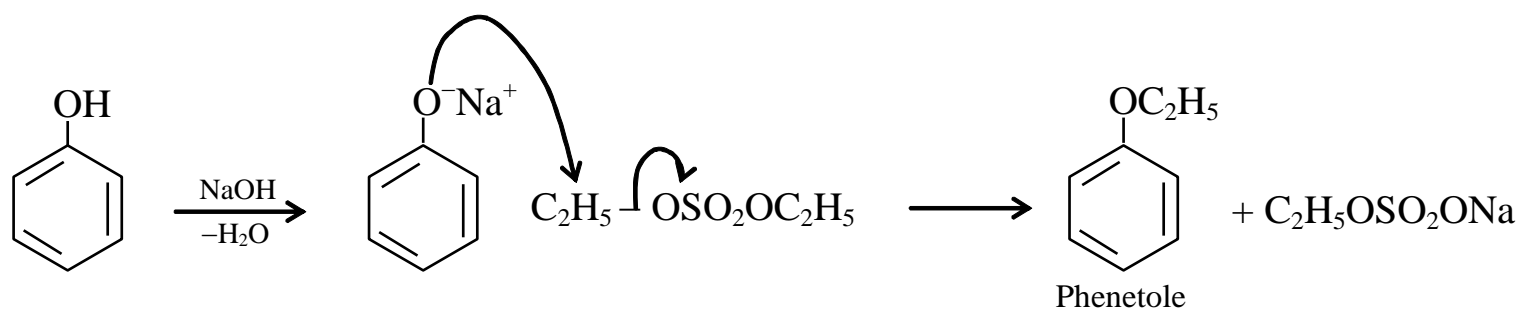
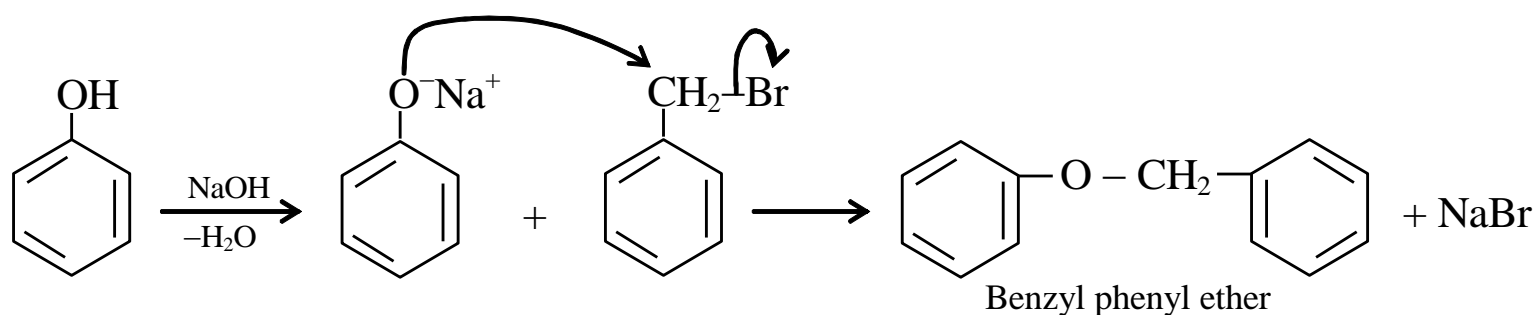
Phenols are converted into alkyl aryl ethers by reaction in alkaline solution with alkyl halides. For the preparation of aryl methyl ethers, dimethyl sulfate, $(\text{CH}_3)_2\text{SO}_4$ is frequently used instead of more expensive methyl halides. For example,



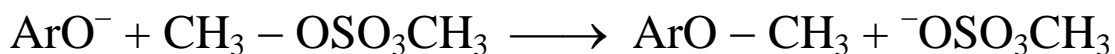
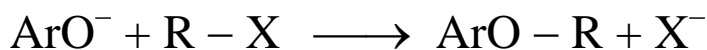
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The second method is a better method to prepare anisole because methyl sulphonates (mesylates) are better leaving group than Br, which causes faster substitutions. Secondly, with respect to CH₃Br, dimethyl sulphate is less expensive, so economically, (CH₃)₂SO₄ is better to cause methylation of phenol.



The mechanism of the above reaction can be outlined as follows. In alkaline solutions, phenol exist as phenoxide ion which acts as nucleophile and attacks the alkyl halide (or the dialkyl sulfate) and displaces halide ion (or sulfate ion).

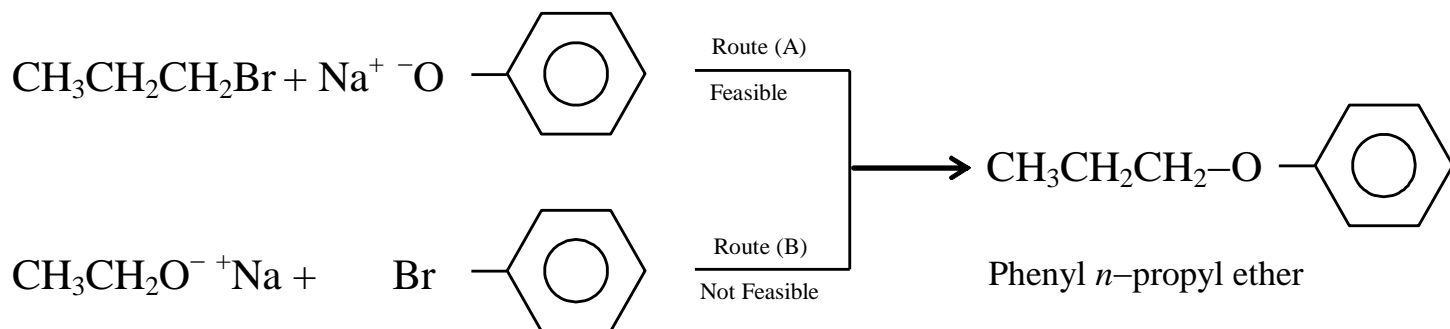


The above reaction is familiar *Williamson's synthesis*, which can even be used for the preparation of unsymmetrical ethers like alkyl aryl ethers.

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Since phenoxides are prepared from phenols and since alkyl halides are conveniently prepared from alcohols, alkyl aryl ethers (like dialkyl ethers) are ultimately synthesized from two hydroxy compounds.

Aryl halides cannot be used in the *Williamson's synthesis* because of their low reactivity towards nucleophilic substitution. For the preparation of any alkyl aryl ether, there can be two combinations of reactants, but one combination can usually be ruled out. For example,



Fundamental Solved Examples

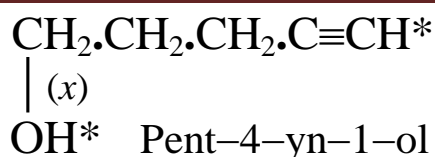
Example 1.

Compound (X) ($\text{C}_5\text{H}_8\text{O}$) does not react appreciably with Lucas reagent at room temperature but gives a precipitate with ammoniacal silver nitrate. With excess of MeMgBr , 0.42 g of (X) gives 224 ml CH_4 at STP. Treatment of (X) with H_2 in presence of Pt catalyst followed by boiling with excess HI gives *n*-pentane. Suggest structure for (X) and write the equations involved.

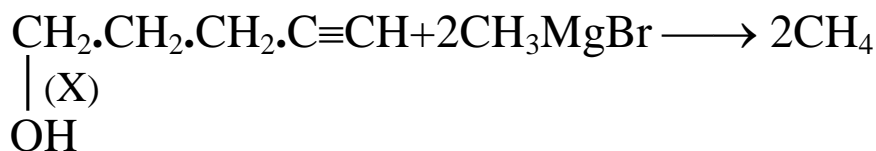
Solution:

- (1) (X), ($\text{C}_5\text{H}_8\text{O}$) does not react with Lucas reagent appreciably at room temperature but gives precipitate with ammoniacal AgNO_3 and thus, (X) has terminal alkyne linkage as well as primary alcoholic group.
- (2) (X) on hydrogenation and then reacting with HI gives pentane and thus, (X) is straight chain compound.
- (3) Keeping in view of the above facts (X) may be

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(4) Its reaction with MeMgBr gives CH_4 . (It has two acidic or active H^* atoms) and thus, 1 mole of (X) will give two mole of CH_4 .



84 g (X) gives 2×22.4 litre CH_4

$$0.42 \text{ g (X) will give } \frac{2 \times 22.4 \times 0.42}{84} = 224 \text{ ml CH}_4$$

Given fact is confirmed.

Example 2.

10 g of a mixture of hexane and ethanol are reacted with sodium to give 200 ml hydrogen at 27°C and 760 mm pressure. What is the percentage of ethanol into the mixture?

Solution:

Given, Hexene + ethanol = 10 g



$$\text{Now, Mole of H}_2 \text{ formed} = \frac{PV}{RT} = \frac{760 \times 200}{760 \times 100 \times 0.0821 \times 300} = 8.13 \times 10^{-3} \text{ mole}$$

(\because 200 ml H_2 is formed at 27°C and 760 mm pressure)

Now, $\frac{1}{2}$ mole H_2 is formed by = 46 g $\text{C}_2\text{H}_5\text{OH}$

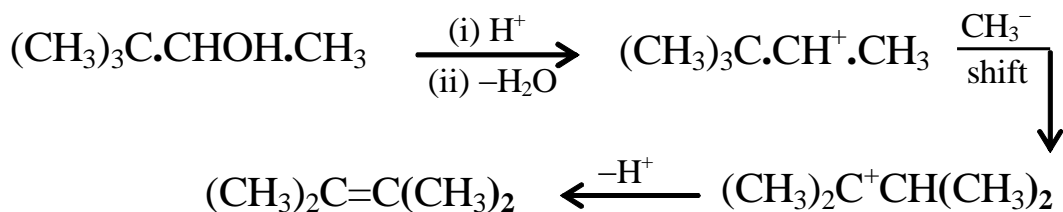
$$8.13 \times 10^{-3} \text{ is formed by} = 46 \times 8.13 \times 10^{-3} \times 2 \text{ g C}_2\text{H}_5\text{OH} = 0.748 \text{ g}$$

$$\therefore \% \text{ of ethanol in mixture} = \frac{0.748 \times 100}{10} = 7.48\%$$

Example 3.

3, 3-Dimethyl-butan-2-ol loses a molecule of water in the presence of concentrated sulphuric acid to give tetramethylethylene as a major product. Suggest a suitable mechanism.

Solution:



Example 4.

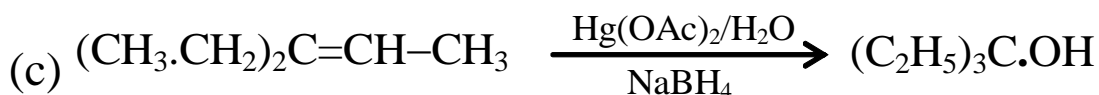
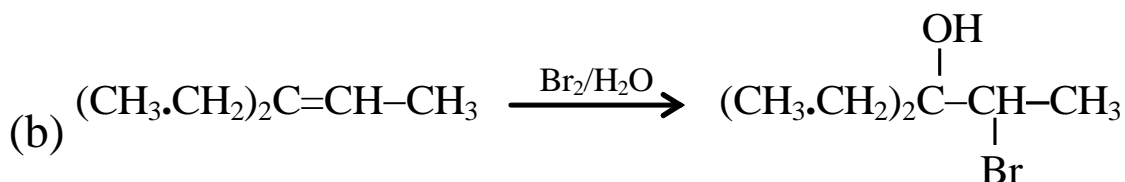
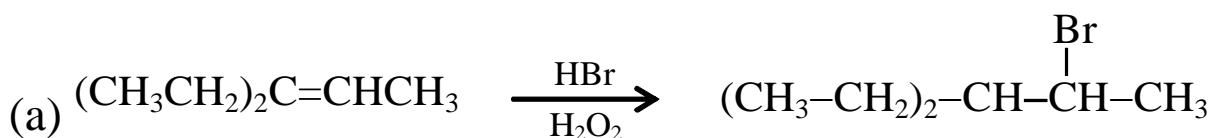
Give the structure of the major organic products formed 3-ethyl-2-pentene under each of the following reaction conditions.

(a) HBr in the presence of peroxide

(b) Br₂ / H₂O

(c) Hg(OAc)₂ /H₂O; NaBH₄.

Solution:



Example 5.

Identify the ethers that are cleaved with excess conc. HI to yield (a) (CH₃)₃Cl and CH₃CH₂CH₂I, (b) cyclohexyl and methyl iodides and (c) I(CH₂)₅I.

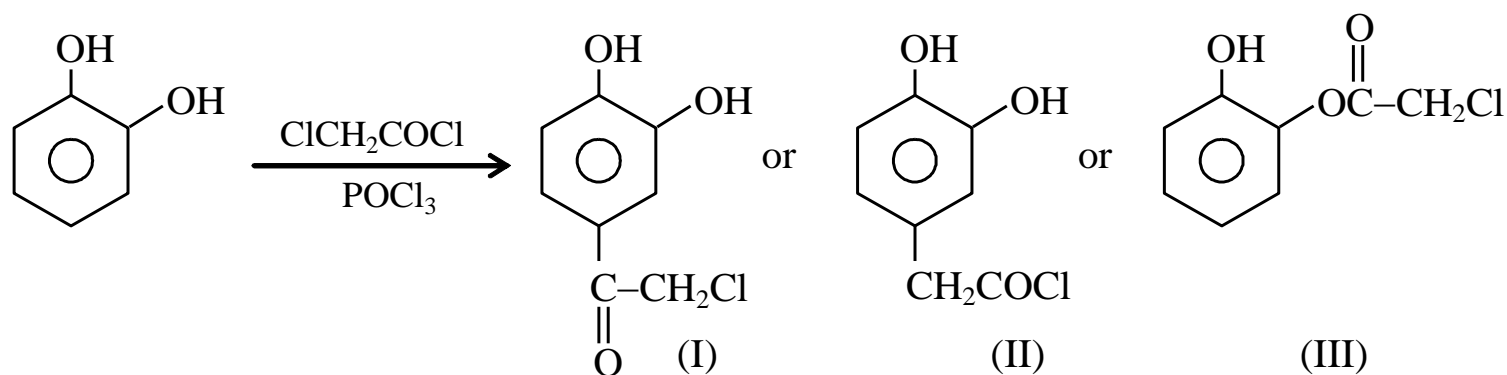
Solution:

Place an O atom between the C's bonded to I's. (a) $(\text{CH}_3)_3\text{COCH}_3\text{CH}_2\text{CH}_3$ (b) cyclohexyl and methyl iodides and (c) The presence of two I's in the same product indicates a cyclic ether, i.e., tetrahydropyran.

Example 6.

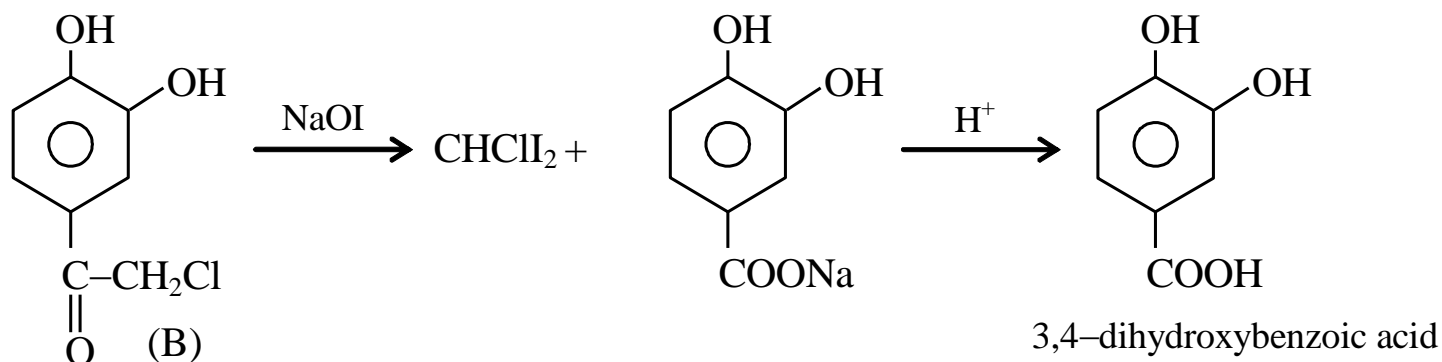
Compound (A), $\text{C}_9\text{H}_{13}\text{O}_3\text{N}$ shows optical isomerism when 1,2-dihydroxybenzene is treated with chloroethanoyl chloride in the presence of POCl_3 , compound (B), $\text{C}_8\text{H}_7\text{O}_3\text{Cl}$, is obtained which upon treatment with methyl amine gives compound (C), $\text{C}_9\text{H}_{11}\text{O}_3\text{N}$. Reduction of (C) with Pd/H_2 yields (A). Compound (B) when heated with NaOI and subsequent treatment of the product formed with dilute acid solution yields 3,4-dihydroxybenzoic acid. Deduce the structure of (A).

Solution:

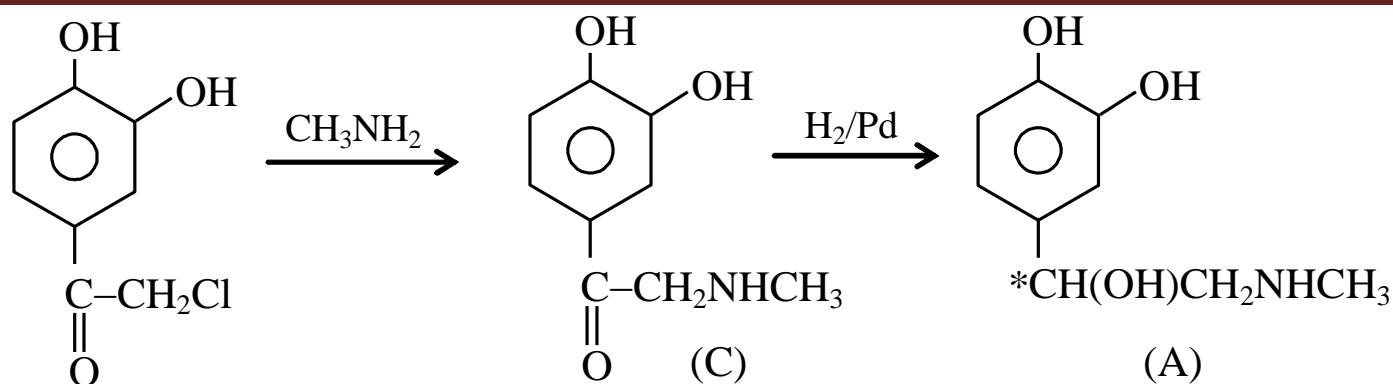


1,2-dihydroxybenzene may undergo ring acylation or ring alkylation or esterification to form compound (B).

Since (B) gives haloform test, the only possibility is (I).



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Example 7.

- (a) Isomers (G) and (H), $\text{C}_{10}\text{H}_{12}\text{O}$, are isolated from the oil of bay leaf. They are insoluble in aq. NaOH and decolorize Br_2/CCl_4 and KMnO_4/H^+ . Each is vigorously oxidized to p-anisic acid, p- $\text{MeOC}_6\text{H}_4\text{COOH}$. Ozonolysis of (G) and (H) give the same products. (a) Identify (G) and (H).
- (b) Give the structure of a third isomer (I) that is also oxidized to p-anisic acid and that give the same product on hydrogenation as does (G) and (H). (d) Suggest a chemical reaction that can distinguish it from (G) and (H).

Solution:

- (a) Both (G) and (H) have 5° of unsaturation, four owing to a benzene ring and one to a $\text{C}=\text{C}$ bond as evidenced by positive tests with Br_2 and KMnO_4/H^+ for unsaturation. They are not phenolic since they are not acidic. Isolation of p- $\text{MeOC}_6\text{H}_4\text{COOH}$ shows that (G) and (H) are methyl ethers with a para substituted alkenyl side chain. They do not differ in the position of $\text{C}=\text{C}$ but rather are cis-trans isomers because they give the same ozonolysis products. Since seven C's are accounted for by the ring and the C of OCH_3 , the alkenyl side chain has three C's. In order to exhibit stereoisomerism, the side chain is $-\text{CH}=\text{CHCH}_3$. (G) and (H) are cis- and trans-p- $\text{MeOC}_6\text{H}_4\text{CH}=\text{CHCH}_3$ (anethole).
- (b) The structural isomer (I) is p- $\text{MeOC}_6\text{H}_4\text{CH}_2\text{CH}=\text{CH}_2$ which also gives anisic acid on oxidation and is reduced to p- $\text{MeOC}_6\text{H}_4\text{CH}_2\text{CH}_2\text{CH}_3$, as are (G) and (H). (d) Reductive ozonolysis of (G) and (H) gives CH_3CHO which

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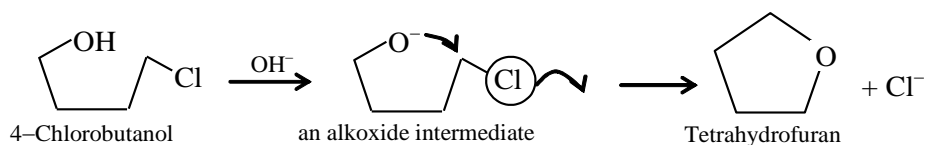
gives a positive test with NaOI. (I) is reductively ozonized to $\text{H}_2\text{C} = \text{O}$, which gives a negative test with NaOI.

Example 8.

(a) Synthesize tetrahydrofuran using the Williamson synthesis. (b) Through which conformation does the substrate react? (c) What by-product might one expect in this synthesis? (d) Why is very little of this byproduct formed?

Solution:

(a) The $\text{S}_{\text{N}}2$ reaction to prepare cyclic ethers must be intramolecular. The number of C's separating X and OH in the chain is the number in the ring. In this case enough alkoxide ion can be formed by adding NaOH to the alcohol.



The alkoxide intermediate may not be completely formed. The incipient anion can begin to displace Cl^- as it forms, a one step reaction.

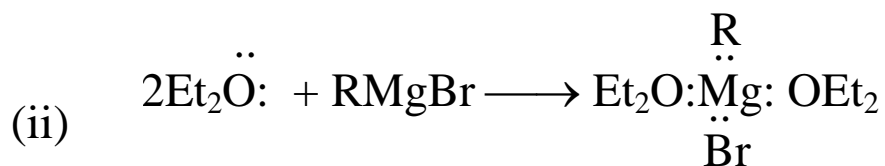
- (b) As shown in the equation in (a), the substrate must be in the highest energy-eclipsed conformation
- (c) $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$.
- (d) Formation of the diol is a bimolecular displacement, which is slower than the intramolecular ring closure.

Example 9.

- (a) Why are ethers such as Et_2O used as solvents for (i) BF_3 and (ii) RMgBr ?
- (b) Compare the Lewis basicities of tetrahydrofuran, diethyl ether and di-isopropyl ether and give your reasoning.

Solution:

- (a) Because of their unshared e^- 's, ethers are also Lewis bases capable of reacting with Lewis acids such as BF_3 and RMgBr to form coordinate covalent bonds.



Note that two molecules of ether coordinate tetrahedrally with one Mg^{2+} .

- (b) In addition to the amount of electron density on the nucleophilic site, steric affects also influence basicities. The greater the steric hindrance encountered in the formation of the coordinate bond, the weaker is the Lewis basicity. In tetrahydrofuran, the R groups (the sides of the ring) are “tied back” leaving a very exposed O atom free to serve as a basic site. The 2° R groups in di-isopropyl ether furnish more steric hindrance than do the 1° ethyl groups in ethyl ether. The order of decreasing Lewis basicity is thus

tetrahydrofuran > ethyl ether > i-propyl ether.