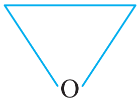
ETHERS Section - 3

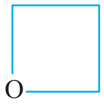
In ethers, the oxygen atom is bonded to two carbon atoms. The hydrocarbon group may be alkyl (1°, 2°and 3°), allylic, vinyl, alkynyl or aryl. Consider some examples :

CH_3-O-CH_3 Dimethyl ether	$C_2H_5-O-CH_3$ Ethyl methyl ether	$CH_2=CH-O-CH_3$ Methyl vinyl ether
$CH_2=CH-O-CH=CH_2$ Divinyl ether	$CH_2=CHCH_2-O-CH_3$ Allyl methyl ether	$CH_3-O-C_6H_5$ Methyl phenyl ether (Anisole)

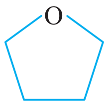
There are various types of cyclic ethers. Cyclic ethers consisting of two carbons in a three member ether are called oxiranes or epoxides. Cyclic ethers consisting of three carbons in a four member ether are called oxetanes. Cyclic ethers consisting of four carbons in a five member ether are called tetrahydrofurans.



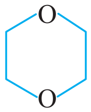
Oxirane
(Epoxide)



Oxetane
(Oxacyclobutane)



Tetrahydrofuran
(Oxacyclopentane)



1, 4 - Dioxane
(1, 4 - Dioxacyclohexane)

Preparations of Ethers

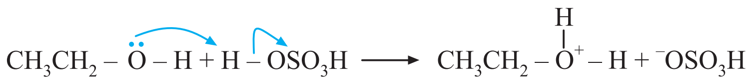
1. **From alcohols :** Dehydration of alcohols by H_2SO_4 at 170°C gives alkenes, whereas at 140°C gives ethers. The dehydration of alcohols to ether is helped by distilling the ether as it is formed.

$$CH_3CH_2OH \xrightarrow[170°C]{H_2SO_4} CH_2 = CH_2 \qquad \text{(Alkene)}$$

$$CH_3CH_2OH \xrightarrow[140°C]{H_2SO_4} CH_3CH_2 - O - CH_2CH_3 \qquad \text{(Ether)}$$

The formation of ethers occurs by S_N2 mechanism with one molecule of alcohols acting as the nucleophile and another protonated molecules of the alcohols acting as the substrate. The mechanism of the reaction is given below.

Step : 1 The alcohol accepts a proton from the acid to give a protonated alcohol.

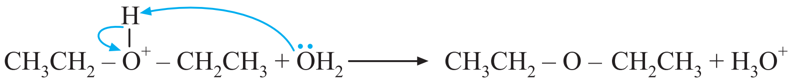


$$CH_3CH_2-\ddot{O}-H + H-OSO_3H \longrightarrow CH_3CH_2-\overset{H}{\overset{|}{O^+}}-H + {}^-OSO_3H$$

Step : 2 The other molecule of alcohol acts as a nucleophile and attacks the protonated alcohol in an S_N2 reaction to give a protonated ether.

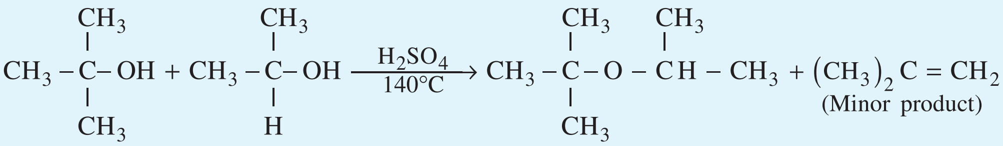
$$CH_3CH_2-\ddot{O}-H + CH_3CH_2-\overset{H}{\overset{|}{O^+}}-H \longrightarrow CH_3CH_2-\overset{H}{\overset{|}{O^+}}-CH_2CH_3 + H_2O$$

Step : 3 The protonated ether transfers the proton to water molecule to give ether.



$$CH_3CH_2-\overset{\displaystyle H}{\overset{|}{O^+}}-CH_2CH_3+\ddot{O}H_2\longrightarrow CH_3CH_2-O-CH_2CH_3+H_3O^+$$

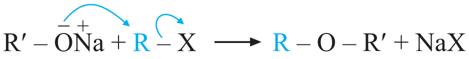
Note : (i) In case, when alkyl groups are 3°, S_N1 type path is followed. 3° alkyl alcohol forms a carbocation (stable) and second alcohol acting as a nucleophile adds to it (solvolysis). An elimination product is also formed as a minor product.



$$CH_3-\underset{CH_3}{\overset{CH_3}{C}}-OH+CH_3-\underset{H}{\overset{CH_3}{C}}-OH\xrightarrow[140^\circ C]{H_2SO_4}CH_3-\underset{CH_3}{\overset{CH_3}{C}}-O-\overset{CH_3}{CH}-CH_3+\underset{\text{(Minor product)}}{(CH_3)_2C=CH_2}$$

(ii) This method is generally limited to the preparation of symmetrical ethers, because a combination of two alcohols usually yields a mixture of three ethers.

2. Williamson's Synthesis : This is the most important method of formation of ethers (nucleophillic substitution reaction), also known as Williamson's synthesis. It consists of S_N2 attack by alkoxide ion on an alkyl halide, alkyl sulphate or alkyl sulphonate.



$$R'-\overset{-\,+}{ONa}+R-X\longrightarrow R-O-R'+NaX$$

The alkoxide ion reacts with substrate in an S_N2 reaction to give an ether. The substrate must have a good leaving group. Important leaving groups are : halides (X^-), sulphates ($-OSO_2OR$) and sulphonates ($-OSO_2R$). The substrate must have a primary alkyl group for good yield. In case of tertiary substrate, elimination occurs. The other factor which contributes to substitution is low temperature.

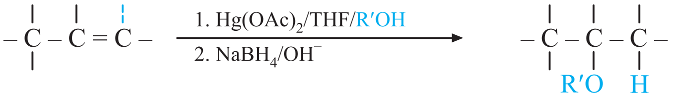
Note : The aromatic ethers are formed when phenoxides react with alkyl sulphates in an S_N2 reaction.

$$\underset{\text{Sodium phenoxide}}{C_6H_5ONa}+\underset{\text{Dimethyl sulphate}}{CH_3-OSO_2O-CH_3}\longrightarrow\underset{\text{Methyl phenyl ether}}{C_6H_5OCH_3}+NaOSO_2OCH_3$$

3. Gas phase reaction :

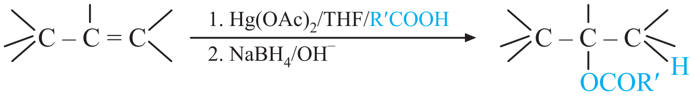
$$\underset{\text{vapours}}{2ROH(g)}\xrightarrow[260^\circ-280^\circ C]{Al_2O_3}R-O-R+H_2O$$

4. Oxymercuration - Demercuration :



$$-\underset{|}{\overset{|}{C}}-\overset{|}{C}=\overset{|}{C}-\xrightarrow[2.\ NaBH_4/OH^-]{1.\ Hg(OAc)_2/THF/R'OH}-\underset{|}{\overset{|}{C}}-\underset{R'O}{\overset{|}{C}}-\underset{H}{\overset{|}{C}}-$$

(Ether)



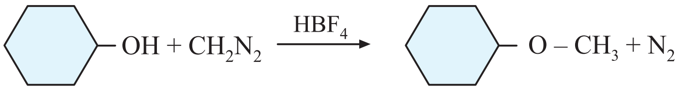
$${>}C-\overset{|}{C}=C{<}\xrightarrow[2.\ NaBH_4/OH^-]{1.\ Hg(OAc)_2/THF/R'COOH}{>}C-\underset{OCOR'}{\overset{|}{C}}-C{<}_{H}$$

(Ester)

Note : If water is used instead of alcohols and acid, an alcohol is formed as per Markovnikov's addition.

5. **By the action of Diazomethane :** Methyl ethers can also be prepared by the action of diazomethane (CH_2N_2) on alcohols in presence of HBF_4 as catalyst.

$$CH_3CH_2OH + CH_2N_2 \xrightarrow{HBF_4} CH_3CH_2-O-CH_3 + N_2$$



6. **From Grignard Reagents :** Higher ethers can be prepared by treating α-halo ethers with suitable Grignard reagents. For example,

$$CH_3-O-CH_2Cl + CH_3MgI \xrightarrow[\text{ether}]{\text{Dry}} CH_3-O-CH_2CH_3 + Mg(I)Cl$$

7. **By treating Alkyl halide with dry Silver oxide :**

$$2(CH_3)_2CHCl + Ag_2O \longrightarrow (CH_3)_2CH-O-CH(CH_3)_2 + 2AgCl$$

Physical properties of Ethers :

(i) Dimethyl ether and ethyl methyl ether are gases. All others are colourless liquids with pleasant odours.

(ii) They are lighter than water. Lower ethers are highly volatile and very inflammable.

(iii) They are sparingly soluble in water but readily soluble in organic solvents. Solubility of ethers in water in presence of small amount of alcohols perhaps due to hydrogen bonding between ether and water molecules $(R_2\overset{\delta-}{O}\cdots\overset{\delta+}{H}-OH)$. Ethers themselves are very good solvents.

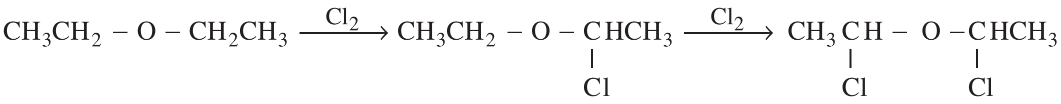
(iv) Boiling points of ethers show a gradual increase with increase in molecular mass. Ethers have low boiling points than isomeric alcohols as there is no association between the molecules as in alcohols due to hydrogen bonding. The boiling points of ethers are close to the boiling points of alkanes.

(v) On account of $R-O-R'$ bond angle being $100°$, two dipoles do not cancel each other and molecules have small net dipole moment making the ethers somewhat polar.

Reactions of Ethers

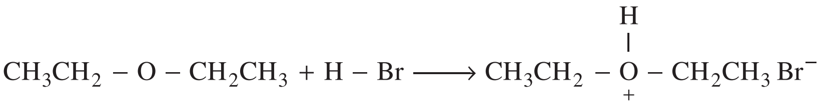
Ethers in general are less reactive and react only with acids. The reactive sites in ethers are : $C-H$ bonds (as in alkanes) and – O – group of ether bond. Ethers resist the attack of nucleophiles and bases. However ethers are very good solvents in many organic reactions due to their ability to solvate cations by donating the electron pair from oxygen atom.

1. **Halogenation of ethers :** Ethers like alkanes undergo halogenation in dark to give halogenated ethers. The hydrogen atom attached to the carbon atom directly linked to oxygen atom is replaced by halogens.



$$CH_3CH_2-O-CH_2CH_3 \xrightarrow{Cl_2} CH_3CH_2-O-\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3 \xrightarrow{Cl_2} CH_3\underset{\displaystyle Cl}{\underset{|}{C}}H-O-\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3$$

2. **Ethers as Base :** The oxygen atom of ethers makes them basic. They react with a proton donor to give oxonium salts.



$$CH_3CH_2-O-CH_2CH_3 + H-Br \longrightarrow CH_3CH_2-\underset{+}{\overset{\overset{\displaystyle H}{|}}{O}}-CH_2CH_3\,Br^-$$

3. Reaction with acids :

Ethers undergo cleavage under quite vigorous conditions, such as concentrated acids (usually HI and HBr) and high temperatures.

$$R-O-R'+HX \xrightarrow{\Delta} RX + R'OH$$

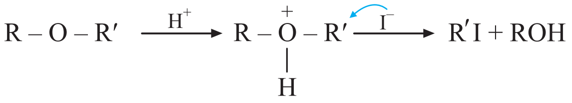
If the acid is present in excess, then the alcohol formed, further reacts with HX to give a halide (Nucleophilic substitution).

- A di-alkyl ether (symmetric ether) yields two alkyl halide molecules, if HX is present in excess, under hot conc. conditions.

$$R-O-R+HX \longrightarrow ROH + RX \quad ; \quad ROH + HX \longrightarrow RX + H_2O$$

$$R-O-R \xrightarrow[\substack{\text{excess} \\ \text{(hot. conc.)}}]{HX} 2RX$$

- **For Mixed Ethers**

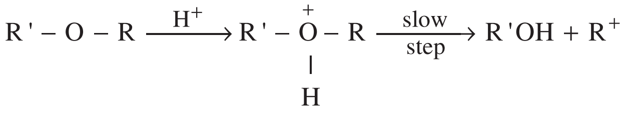


$$R-O-R' \xrightarrow{H^+} R-\underset{\substack{| \\ H}}{\overset{+}{O}}-R' \xrightarrow{I^-} R'I + ROH$$

(i) In case when both alkyl groups are 1° or 2° (i.e. R or $R' \neq 3°$), then S_N2 path occurs.

I^- as a nucleophile attacks the smaller of the two alkyl groups to give an alkyl iodide. As I^- makes an S_N2 attack, consider steric factors. So, the smaller of the alkyl groups goes with the iodide ion and the larger group forms alcohols.

(ii) If any one of R or R′ is 3°, then we have different products via different mechanism. Here S_N1 type of path is followed. Let R be 3°.

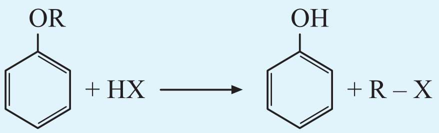


$$R'-O-R \xrightarrow{H^+} R'-\underset{\substack{| \\ H}}{\overset{+}{O}}-R \xrightarrow[\text{step}]{\text{slow}} R'OH + R^+ \qquad \text{(3° carbocation, highly stable)}$$

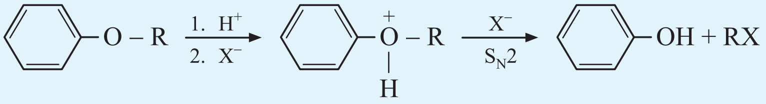
$$R^+ + I^- \longrightarrow R-I \qquad \text{(Hence 3°R forms iodide)}$$

Note :

- Excess of HX gives a mixture of alkyl halides.
- Reactivity of halogen acids : HI > HBr > HCl
- Alkyl aryl ethers are cleaved at the alkyl – oxygen bond due to the more stable aryl-oxygen bond. The reaction yields phenol and alkyl halide.



Phenols do not react further to give halide (Nucleophillic substitution does not take place in aromatic compounds).

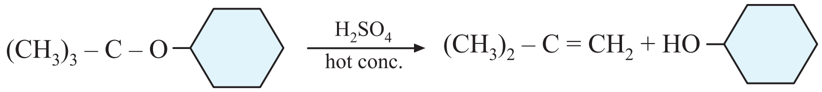


Important :

Since it is S_N2 path, X^- should be a strong nucleophile. Hence in cleavage of aromatic ether, only HI (I^- being strong nucleophile) can be used.

- **With hot concentrated H_2SO_4 :** Secondary and tertiary ethers react with hot conc. H_2SO_4 to give a mixture of alcohols and alkenes.

$$(CH_3)_3 - C - O - CH_3 \xrightarrow[\text{hot conc.}]{H_2SO_4} (CH_3)_2 - C = CH_2 + CH_3OH$$



Cyclohexyl tert. butyl ether

Isobutene

Cyclohexanol

Note : Ease of formation of alkene follows : 3° > 2° > 1° (*with respect to alkyl group*).

4. **With Phosphorus pentachloride :** Phosphorus pentachloride also brings about the cleavage of C – O bond of ethers leading to the formation of alkyl halides.

$$CH_3CH_2 - O - CH_2CH_3 + PCl_5 \longrightarrow 2CH_3CH_2 - Cl + POCl_3$$

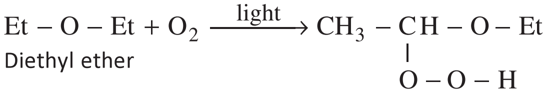
5. **Reaction with Acid chloride and Anhydrides :** Acid chlorides and anhydrides react with ethers when heated in the presence of anhydrous. $ZnCl_2$ or $AlCl_3$ to form alkyl halides and esters.

$$\underset{\text{Diethyl ether}}{Et - O - Et} + \underset{\text{Acetyl chloride}}{CH_3COCl} \xrightarrow[\Delta]{\text{anhyd. } ZnCl_2} \underset{\text{Ethyl chloride}}{C_2H_5Cl} + \underset{\text{Ethyl acetate}}{CH_3COOEt}$$

However with anhydrides only esters are formed.

$$\underset{\text{Diethyl ether}}{(C_2H_5)_2O} + \underset{\text{Acetic anhydride}}{(CH_3CO)_2O} \xrightarrow[\Delta]{\text{anhyd. } AlCl_3} \underset{\text{Ethyl acetate}}{2CH_3COOC_2H_5}$$

6. **Action of Air and Light : (Formation of Peroxides) :** When exposed to air and light for a long time, ethers are oxidised to form hydro-peroxides or simply peroxides.



$$\underset{\text{Diethyl ether}}{Et - O - Et} + O_2 \xrightarrow{\text{light}} CH_3 - \underset{\substack{|\\ O-O-H}}{CH} - O - Et$$

1 - Ethoxyethyl hydroperoxide

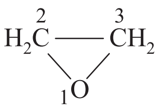
Therefore, serious explosions may occur during distillation of old samples of ethers if peroxides are not removed. Presence of peroxides in old samples of ethers may be detected by shaking them with a freshly prepared solution of $FeSO_4$ followed by addition of KCNS. Appearance of a red colour indicates the presence of peroxides. A simple method to remove peroxides is to shake an old sample of ether with aqueous solution of KI or ferrous salt.

7. **Hydrolysis of Ethers :** Ethers when treated with dilute aqueous acids give alcohols.

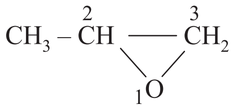
$$R - O - R \xrightarrow{H_3O^+ / H_2O} 2\ ROH$$

Oxirane (Epoxide)

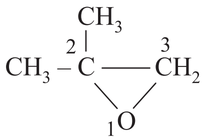
Epoxides are cyclic ethers with three membered rings. In IUPAC system, epoxides are called as Oxiranes.
The most common epoxide is ethylene oxide.



Oxirane
(Epoxy ethane)



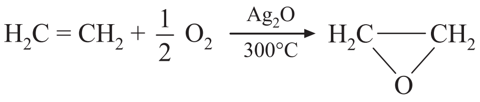
2-Methyl oxirane
(1, 2-Epoxy propane)



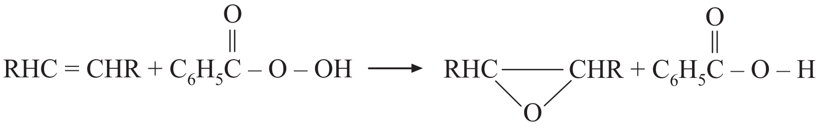
2, 2-Dimethyl oxirane
(1, 2-Epoxy-2-methylpropane)

Preparation of Oxiranes

1. **Oxidation of Ethylene :** Epoxide or ethylene oxide is prepared by partial oxidation of ethylene in presence of Ag_2O.



2. **Epoxidation :** The most important method of formation of epoxides is the reaction of an alkene with an organic peroxy acid or peracid, such as perbenzoic acid ($C_6H_5CO-O-OH$) or peracetic acid ($CH_3CO-O-OH$) or *mCPBA* (m-chloroperoxobenzoic acid) This process is known as epoxidation.

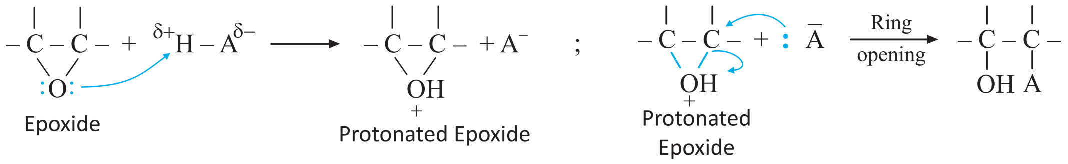


> ***Note :*** The above reaction is a stereo specific reaction i.e., it involves *cis*-addition of an electrophillic oxygen atom. It means *cis*-alkene will give only *cis*-epoxide and a *trans*-alkene will give only *trans*-epoxide.

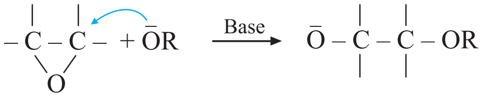
Reactions of Oxiranes

Due to the strain in the ring, epoxides are highly reactive towards nucleophillic substitution reaction (unlike ethers). They undergo ring opening reactions so as to release the strain. Epoxides undergo *acid catalysed* and *base catalysed* opening of the ring.

1. **Acid Catalysed Opening :** The acid reacts with epoxides to produce a protonated epoxide. The protonated epoxide undergoes ring opening by attack of nucleophile (A^-) on sterically hindered carbon atom, because acid catalysed ring opening is S_N1 type reaction



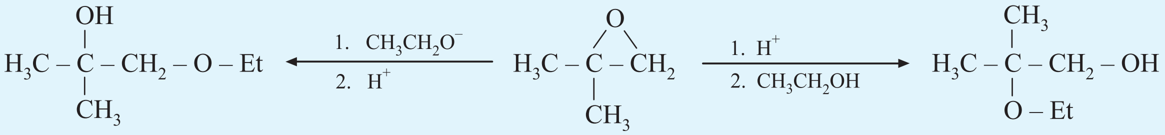
2. **Base Catalysed Opening :** Epoxides can also undergo base-catalysed ring opening provided the attacking nucleophile is also a strong base such as an alkoxide or hydroxide ion. A strong nucleophile (alkoxide, RO^-) is able to open the ring by a backside attack (as observed in a S_N2 reaction)



Epoxide

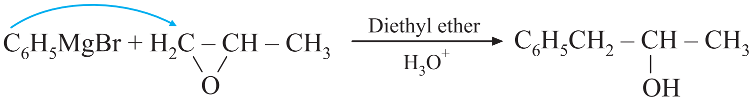
Note :

- Under acidic conditions, ring opening in protonated epoxide occurs by cleavage of C – O bond that can produce a more stable (3°) carbonium ion.
- Under basic conditions, the alkoxide simply attacks the *less hindered carbon atom* in an S_N2 type displacement.
- Symmetrically substituted epoxides give the same product in both the acid-catalysed and base-catalysed ring openings. An unsymmetrical epoxide gives different products under acid-catalysed and base-catalysed conditions,

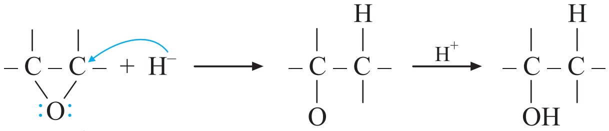


2, 2-Dimethyl oxirane

3. **Cleavage of Oxiranes by Grignard Reagent and $LiAlH_4$:** In case of Grignard reagent, the Nu end, i.e., R attacks on the carbon atom of the epoxide. Here nucleophile attacks at less substituted ring carbon in the base catalysed ring opening (As explained above).



Epoxides are reduced to alcohols on treatment with $LiAlH_4$; hydride ion (as Nu^-) is transferred to the less crowded carbon.

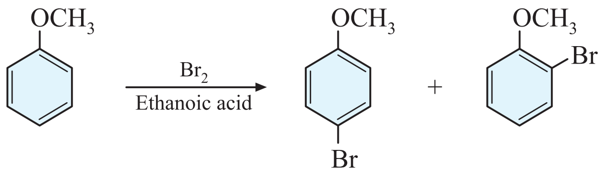


Epoxide

Electrophilic substitution reaction in Aromatic Ethers

The alkoxy group is an Activating and ortho and para directing, just like – OH group in phenol. The following S_E reactions are observed.

(i)



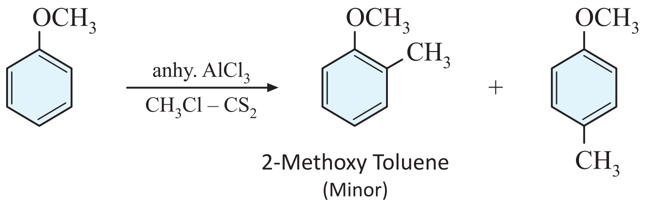
o-Bromoanisol (Minor)

Anisole

p-Bromoanisol (Major)

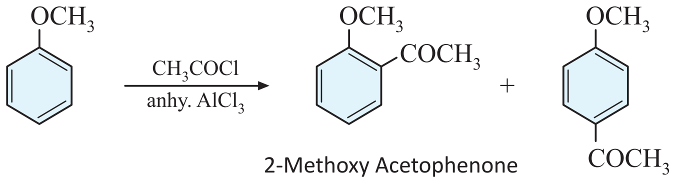
Anisole undergoes bromination with Br_2 in ethanoic acid, even in the absence of Iron (III) bromide catalyst.

(ii) Friedel - Crafts Reactions :



2-Methoxy Toluene (Minor)

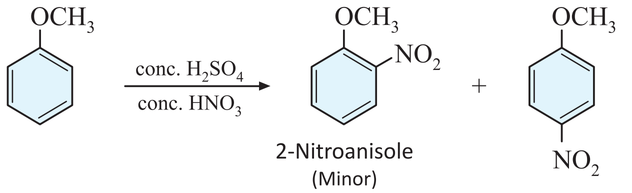
4-Methoxy Toluene (Major)



2-Methoxy Acetophenone (Minor)

4-Methoxy Acetophenone (Major)

(iii) Nitration :

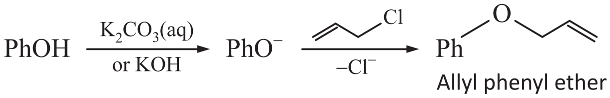


2-Nitroanisole (Minor)

4-Nitroanisole (Major)

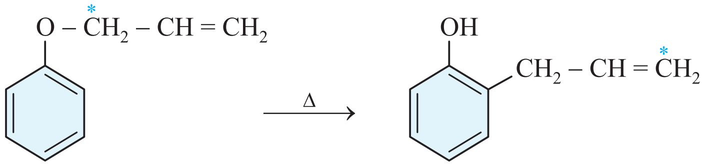
Claisen Rearrangement of Allyl phenyl ether :

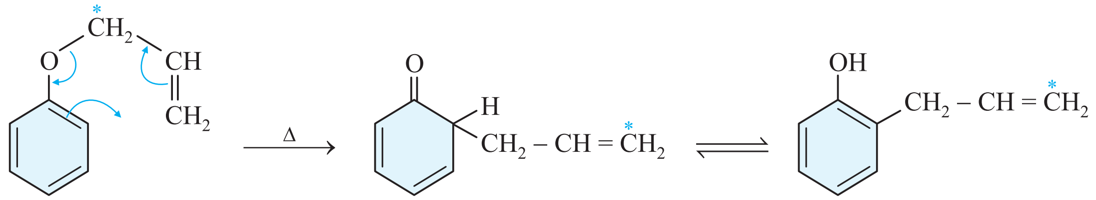
Allyl phenyl ether can be prepared by following reaction.



Allyl phenyl ether

- Claisen rearrangement is a concerted reaction with an intramolecular process.





Keto-form

enol-form

IN-CHAPTER EXERCISE - C

Choose the correct alternative. Only One Choice is Correct. Question marked with '*' may have More than One Correct option.

1. $Ph - OCH_3 + HI \longrightarrow A + B$. *A and B are* :

(A) $Ph - I, CH_3OH$ **(B)** $Ph - OH, CH_3I$ **(C)** P_6H_6, CH_3I **(D)** $Ph - I, CH_4$

2. *Epoxides react with Grignard reagent to form*

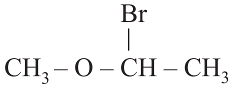
(A) 1° alcohol **(B)** 2° alcohols **(C)** 3° alcohols **(D)** *Any of the three*

3. *Which of the following is the best procedure to make isopropylmethylether using the Williamson method ?*

(A) $CH_3OH + (CH_3)_2CHOH + H_2SO_4$ **(B)** $CH_3OH + (CH_3)_2CHCH_2OH + H_2SO_4$

(C) $CH_3ONa + (CH_3)_2CHBr$ **(D)** $CH_3I + (CH_3)_2CHONa$

4. *The final product obtained in the following reaction is* : $CH_3 - O - CH = CH_2 \xrightarrow[\text{Anhydrous}]{\text{HBr}}$

(A) CH_3OH and $CH_3 - CH_2Br$ **(B)**  $CH_3 - O - \overset{\overset{\displaystyle Br}{|}}{C}H - CH_3$

(C) $CH_3Br + CH_3CHO$ **(D)** $CH_3OH + CH_2 = CH - Br$

5. *The C–O–C angle in ether is* :

(A) 180° **(B)** $109^\circ 28'$ **(C)** 110° **(D)** 104°

6. *When diethyl ether is heated with an excess of* PCl_5, *it yields* :

(A) *ethyl choride* **(B)** *diethyl ether peroxide*

(C) *ethanoyl chloride* **(D)** *perchlorodiethyl ether*

7. *Diethyl ether on heating with hot conc. HI gives two moles of* :

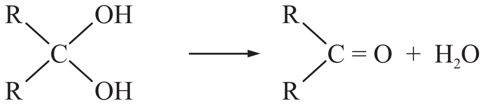
(A) *ethanol* **(B)** *iodoform* **(C)** *ethyl iodide* **(D)** *methyl iodide*

DIHYDRIC ALCOHOLS Section - 4

Dihydric alcohols are called as diols. There are two types of diols :

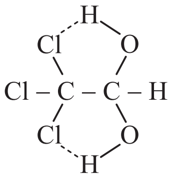
(i) Geminal diol **(ii)** Vicinal diol

Geminal diols are unstable because of steric reason. These are hydrates of carbonyl compounds.

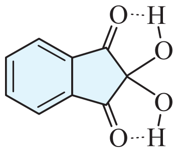


Geminal diol

Some geminal diols are stable due to intramolecular H-bonding.



Chloral hydrate



Ninhydrin