1. **A brief guide to alcohol, ether and epoxy-alkane structure-naming-nomenclature**
2. **The names and structures of aliphatic alcohols $C_nH_{2n+1}OH$ (and isomeric ethers)**
3. **Alcohol Reactions**
   - **Electrophilic Substitution at Oxygen**
   - **Hydroxyl Group Substitution**

TEST - Alcohols and ethers

- Give the names
- Write the structural formula
- Write all isomeric compounds
- Alcohols Reactions

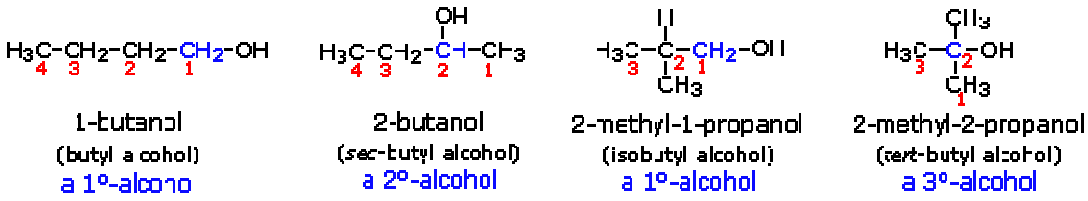
A brief guide to alcohol, ether and epoxy-alkane structure-naming-nomenclature

- *How do we systematically name alcohols? molecules that contain the hydroxy/hydroxyl group -OH*
- *How do we systematically name ethers? molecules that contain the carbon-oxygen-carbon C-O-C link*

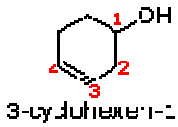
Alcohols are usually named by the first procedure and are designated by an **ol** suffix, as in ethanol, CH_3CH_2OH (note that a locator number is not needed on a two-carbon chain). On longer chains the location of the hydroxyl group determines chain numbering. For example: $(CH_3)_2C{=}CHCH(OH)CH_3$ is 4-methyl-3-penten-2-ol. Other examples of IUPAC nomenclature are shown below, together with the common names often used for some of the simpler compounds. For the mono-functional alcohols, this common system consists of naming the **alkyl group** followed by the word **alcohol**. Alcohols may also be classified as primary, **1º**, secondary, **2º** & tertiary, **3º**, in the same manner as alkyl halides.

- Primary alcohols ('prim') have the structure R-CH2-OH, R = H, alkyl, aryl etc. i.e. apart from methanol they have one alkyl/aryl group attached to the C of the C-OH group and 2 (3 in case of methanol only) H's attached to the C of the C-OH functional group.
- Secondary alcohols ('sec') have the structure R2CH-OH, R = alkyl or aryl etc. i.e. they have two alkyl/aryl groups attached to the C of the C-OH group and 1 H attached to the C of the C-OH functional group.
- Tertiary alcohols ('tert') have the structure R3C-OH, R = alkyl or aryl etc. i.e. they have three alkyl/aryl groups attached to the C of the C-OH group and no H attached to the C of the C-OH functional group.

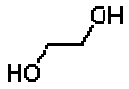
This terminology refers to alkyl substitution of the carbon atom bearing the hydroxyl group (colored blue in the illustration).



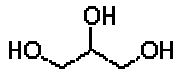
2-propen-1-ol
(allyl alcohol)



3-cyclohexen-1-ol



1,2-ethanediol
(ethylene glycol)

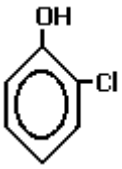


1,2,3-propanetriol
(glycerol)

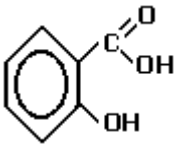
Alcohols have the hydroxy group OH attached to at least one of the carbon atoms in the chain. If the OH group is directly attached to a benzene ring , it is classified as a **phenol.**

1. **phenols**:

phenol,

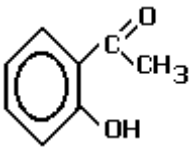


2-chloro**phenol**,

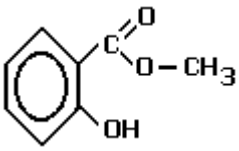


2-hydroxybenzoic acid,

2. **phenols:**



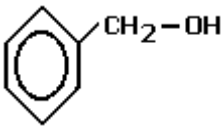
2-hydoxyphenylethanone,



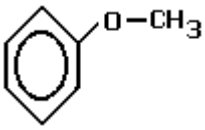
methyl 2-hydoxybenzoate,

- all have an **OH group attached directly to a benzene ring**.

3. **aliphatic alcohol:**

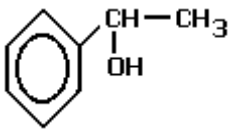


phenylmethanol (benzyl alcohol), which is isomeric with the **ether**,

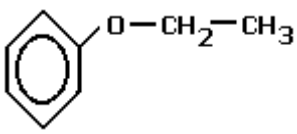


methoxybenzene (anisole)

4. **aliphatic alcohol:**



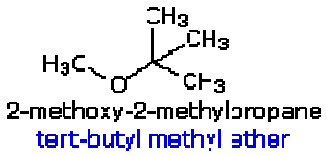
1-phenylethanol, which is isomeric with the **ether**,

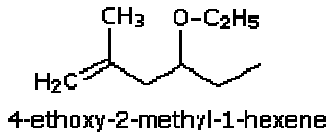


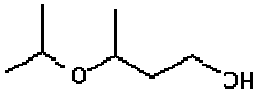
ethoxybenzene (phenetole)

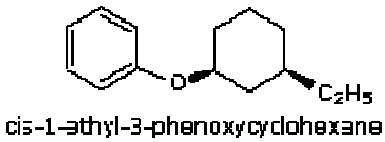
Ethers are named on the basis of the longest carbon chain with the O-R or alkoxy group, e.g. methoxy CH_3O- or ethoxy CH_3CH_2O- etc. treated as a substituent group.

Ethers are compounds having two alkyl or aryl groups bonded to an oxygen atom, as in the formula $R^1–O–R^2$. **The ether functional group does not have a characteristic IUPAC nomenclature suffix**, so it is necessary to designate it as a substituent. To do so the common alkoxy substituents are given names derived from their alkyl component, as shown in the table. Simple ethers are given common names in which the alkyl groups bonded to the oxygen are named in alphabetical order followed by the word "ether". The top left example shows the common name in blue under the IUPAC name. Many simple ethers are symmetrical, in that the two alkyl substituents are the same. These are named as "dialkyl ethers". Examples are: $CH_3CH_2OCH_2CH_3$, diethyl ether (sometimes referred to as ether), and $CH_3OCH_2CH_2OCH_3$, ethylene glycol dimethyl ether (glyme).



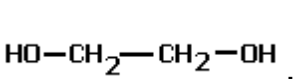
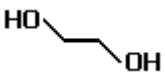
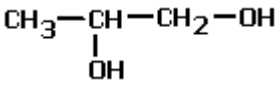
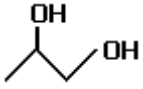
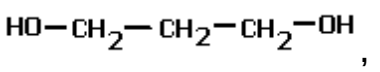
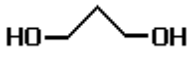
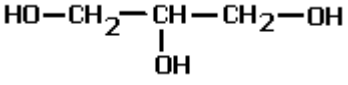
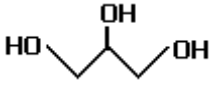
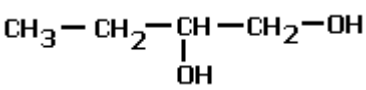
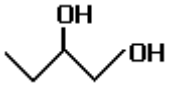






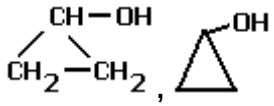
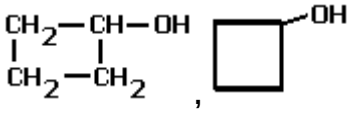
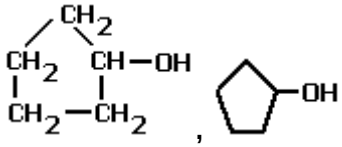
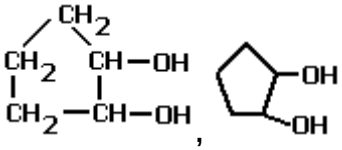
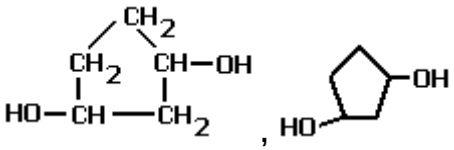
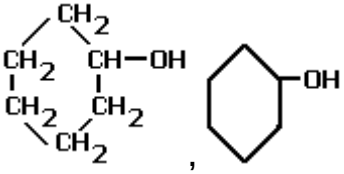
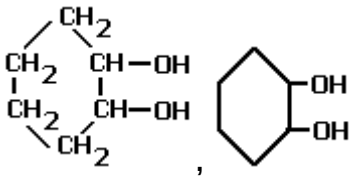
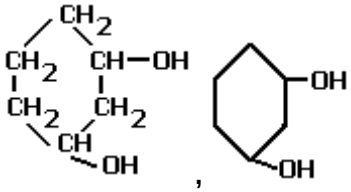
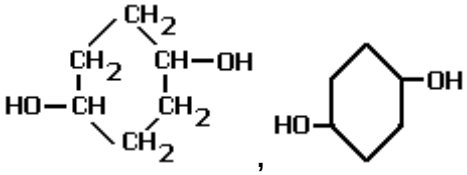
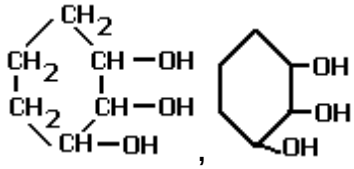
Alkyl Group	Name	Alkoxy Group	Name
$CH_3–$	Methyl	$CH_3O–$	Methoxy
$CH_3CH_2–$	Ethyl	$CH_3CH_2O–$	Ethoxy
$(CH_3)_2CH–$	Isopropyl	$(CH_3)_2CHO–$	Isopropoxy
$(CH_3)_3C–$	tert-Butyl	$(CH_3)_3CO–$	tert-Butoxy
$C_6H_5–$	Phenyl	$C_6H_5O–$	Phenoxy

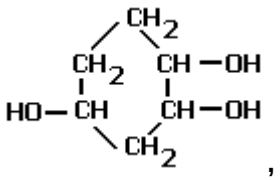
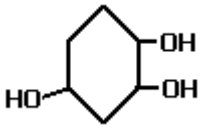
Diol and **triol** structures are named on the basis of the longest carbon chain and the suffix 'ol'. Diol and triol means two or three hydroxy groups in the molecule. The positions of the OH groups is denoted with the lowest possible numbers. The prefix uses the full parent alkane name e.g. butane…. **Examples of diols and triols**

1. **Ethane-1,2-diol** (*ethylene glycol*, *glycol*), **$C_2H_6O_2$**,  , 
2. **Propane-1,2-diol, $C_3H_8O_2$,**  , 
3. **Propane-1,3-diol** ,  , 
4. **Propane-1,2,3-triol** (*glycerol*),  , 
5. **Butane-1,2-diol, $C_4H_{10}O_2$,**  , 

Cycloalcohols (cycloalkanols) are named on the basis of the number of carbon atoms in the ring (minimum 3) and the prefix 'cyclo' and the suffix **'ol'** The prefix alkane name e.g. 'prop' has an 'a' added but leaves out the end 'ne' if more than one OH group (note in mono-hydroxy alcohols its propan… and in diols/triols etc. it is propane…)

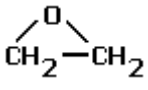
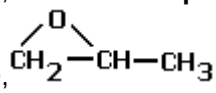
Examples of cyclic alcohols

1. **Cyclopropanol** (*cyclopropyl alcohol*), **C_3H_6O,** 
2. **Cyclobutanol** (*cyclobutyl alcohol*), **C_4H_8O**, 
3. **Cyclopentanol** (*cyclopentyl alcohol*), **$C_5H_{10}O$**, 
4. **Cyclopentane-1,2-diol, $C_5H_{10}O_2$,** 
5. **Cyclopentane-1,3-diol, $C_5H_{10}O_2$,** 
6. **Cyclohexanol** (*cyclopropyl alcohol*), **$C_6H_{12}O$**, 
7. **Cyclohexa-1,2-diol, $C_6H_{12}O_2$,** 
8. **Cyclohexane-1,3-diol ,** 
9. **Cyclohexane-1,4-diol ,** 
10. **Cyclohexane-1,2,3-triol ,** 

11. **Cyclohexane-1,2,4-triol, $C_6H_{12}O_3$,**  , 

Epoxy compounds have a -C-C-O- triangle (epoxide/oxirane ring) in their structure which is equivalent to the simplest cyclic ether.

Examples of epoxy compounds

- C_2H_4O,  **epoxyethane** (ethylene oxide)
- C_3H_6O,  **epoxypropane** (propylene oxide)

The names and structures of aliphatic alcohols $C_nH_{2n+1}OH$ (and isomeric ethers)

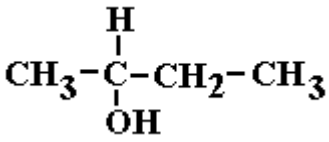
Here are four structural isomers of $C_4H_{10}O$ which are alcohols:

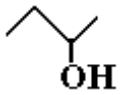
1. **Butan-1-ol** (prim) (1-butanol, n-butanol, *n-butyl alcohol*):

(a) $CH_3CH_2CH_2CH_2OH$ or (b) $CH_3-CH_2-CH_2-CH_2-OH$

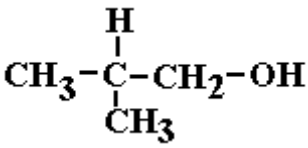
and the skeletal formula is (c) 

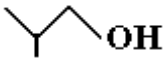
2. **Butan-2-ol** (sec) (2-butanol, *sec-butyl alcohol*, shortened structural formulae

(a) $CH_3CH(OH)CH_2CH_3$ or (b)  and the skeletal formula is

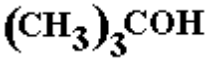
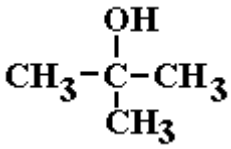
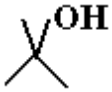
(c) 

3. **2-methylpropan-1-ol** (sec) (2-methyl-1-propanol, *isobutyl alcohol*, i*sobutanol*), shortened structural formulae

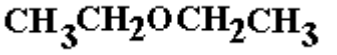
(a) $(CH_3)_2CHCH_2OH$ or (b)  and the skeletal formula is

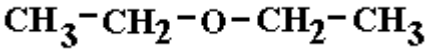
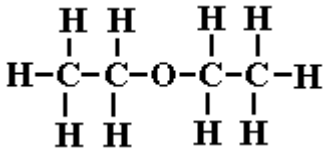
(c) 

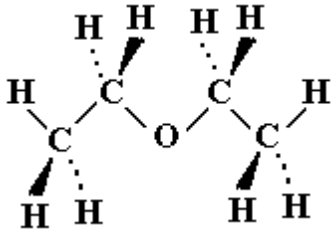
4. **2-methylpropan-2-ol** (tert) (2-methyl-2-propanol, *tert-butyl alcohol*), shortened structural formulae

(a)  or (b)  and the skeletal formula is (c) 

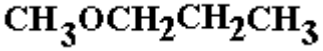
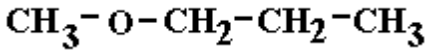
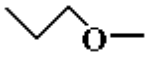
There are three isomeric ethers, isomeric with the alcohols of molecular formula  :

5. **ethoxyethane** (*diethyl ether*, '*ether*'), structural formulae (a)  ,

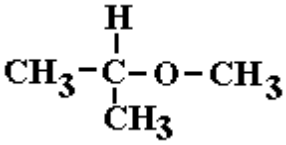
(b)  , (c)  or



(d) and the skeletal formula is (e) 

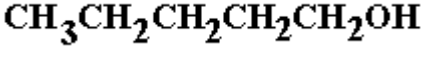
6. **1-methoxypropane** (*methyl propyl ether*), use of prefix number now required, shortened structural formulae (a)  or (b)  and the skeletal formula is (c) 

7. **2-methoxypropane**, shortened structural formula (a)  or

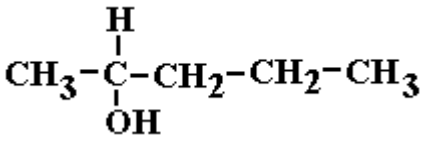
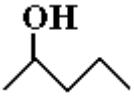


(b) and the skeletal formula is (c) 

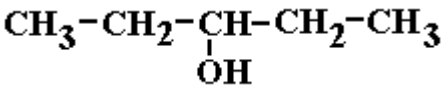
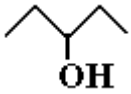
There are 8 isomeric alcohols derived from the molecular formula :

1. **pentan-1-ol** (1-pentanol, n-pentanol, *n-pentyl alcohol*, *n-amyl alcohol*), , shortened structural formula (a)  or (b) and the skeletal formula is (c) 

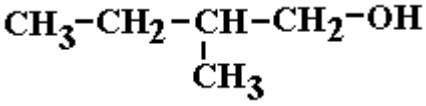
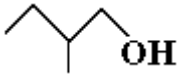
2. **pentan-2-ol** (2-pentanol), shortened structural formula (a)  or

(b)  and the skeletal formula is (c) 

3. **pentan-3-ol** (3-pentanol), shortened structural formula (a)  or

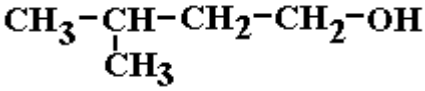
(b)  and the skeletal formula is (c) 

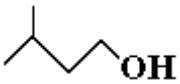
4. **2-methylbutan-1-ol** (2-methyl-1-butanol*, 'active' amyl alcohol*), shortened structural formula

(a)  or (b)  and the skeletal formula is (c) 

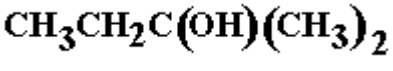
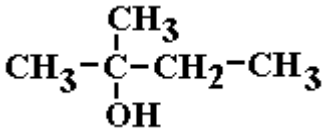
NOTE from now on you will notice that the lowest number is for the 'highest ranking' substituent in the main carbon chain i.e. 'ol' ranks higher than 'methyl' and uses the lowest available number first.

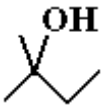
5. **3-methylbutan-1-ol** (3-methyl-1-butanol*, isopentanol, isoamyl alcohol*), shortened structural formula

(a)  or (b)  and the skeletal formula is

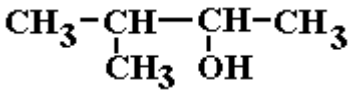
(c) 

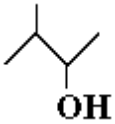
6. **2-methylbutan-2-ol** (2-methyl-2-butanol, t-amyl alcohol, t-pentanol), shortened structural formula

(a)  or (b)  and the skeletal formula is

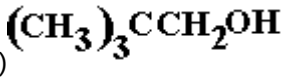
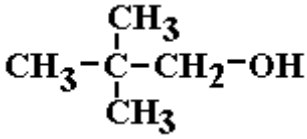
(c) 

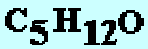
7. **3-methylbutan-2-ol** (3-methyl-2-butanol, shortened structural formula

(a)  or (b)  and the skeletal formula is

(c) 

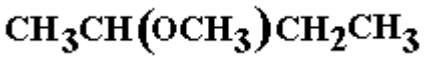
8. **2,2-dimethylpropan-1-ol** (2,2-dimethyl-1-propanol, *neopentyl alcohol*), shortened structural formula

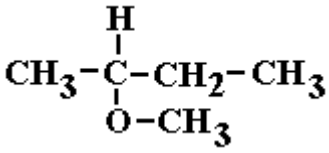
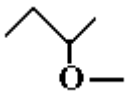
(a)  or (b)  and the skeletal formula is (c) 

There are 6 isomeric ethers, also isomeric with the above 8 alcohols derived from the molecular formula 

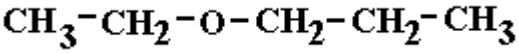
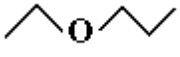
9. **1-methoxybutane**, shortened structural formula (a)  or

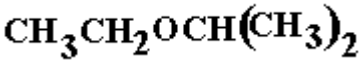
(b) and the skeletal formula is (c) 

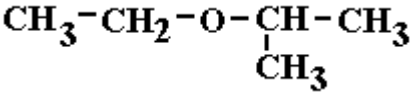
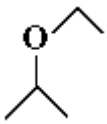
10. **2-methoxybutane**, shortened structural formula (a)  or

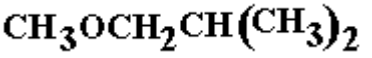
(b)  and the skeletal formula is (c) 

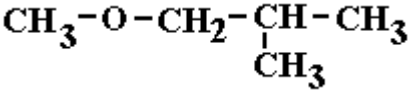
11. **1-ethoxypropane**, shortened structural formula (a)  or

(b)  and the skeletal formula is (c) 

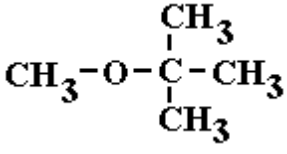
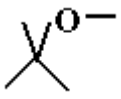
12. **2-ethoxypropane**, shortened structural formula (a)  or

(b)  and the skeletal formula is (c) 

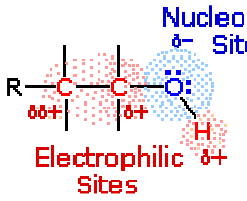
13. **1-methoxy-2-methylpropane**, shortened structural formula (a)  or

(b)  and the skeletal formula is (c) 

14. **2-methoxy-2-methylpropane**, shortened structural formula (a)  or

(b)  and the skeletal formula is (c) 

Alcohol Reactions



The functional group of the alcohols is the hydroxyl group, –OH. Unlike the alkyl halides, this group has two reactive covalent bonds, the C–O bond and the O–H bond. The electronegativity of oxygen is substantially greater than that of carbon and hydrogen. Consequently, the covalent bonds of this functional group are polarized so that oxygen is electron rich and both carbon and hydrogen are electrophilic, as shown in the drawing on the right. Indeed, the dipolar nature of the O–H bond is such that alcohols are much stronger acids than alkanes (by roughly 1030 times), and nearly that much stronger than ethers (oxygen substituted alkanes that do not have an O–H group). The most reactive site in an alcohol molecule is the hydroxyl group, despite the fact that the O–H bond strength is significantly greater than that of the C–C, C–H and C–O bonds, demonstrating again the difference between thermodynamic and chemical stability.

Electrophilic Substitution at Oxygen

1. Substitution of the Hydroxyl Hydrogen

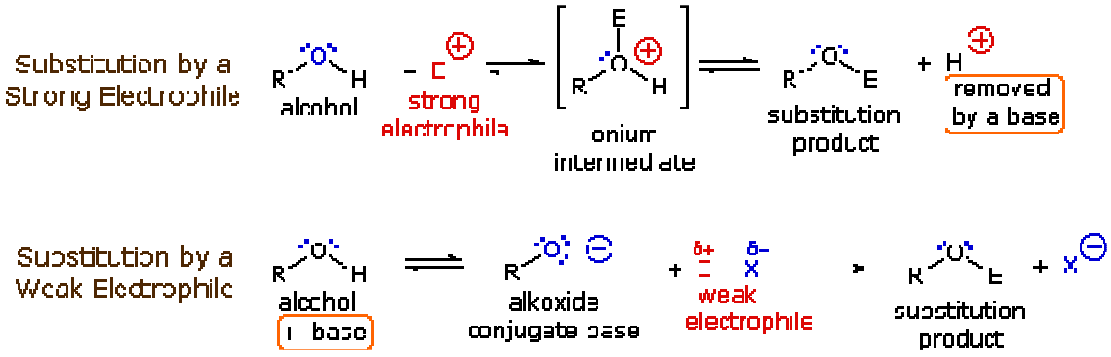
Because of its enhanced acidity, the hydrogen atom on the hydroxyl group is rather easily replaced by other substituents. A simple example is the facile reaction of simple alcohols with sodium (and sodium hydride), as described in the first equation below. Another such substitution reaction is the isotopic exchange that occurs on mixing an alcohol with deuterium oxide (heavy water). This exchange, which is catalyzed by acid or base, is very fast under normal conditions, since it is difficult to avoid traces of such catalysts in most experimental systems.

$$2\ R\text{–}O\text{–}H + 2\ Na \longrightarrow 2\ R\text{–}O^{(-)}Na^{(+)} + H_2$$

$$R\text{–}O\text{–}H + D_2O \rightleftharpoons R\text{–}O\text{–}D + D\text{–}O\text{–}H$$

$$R\text{–}O\text{–}H + NaOH \longrightarrow \text{no reaction}$$

The mechanism by which many substitution reactions of this kind take place is straightforward. The oxygen atom of an alcohol is nucleophilic and is therefore prone to attack by electrophiles. The resulting "onium" intermediate then loses a proton to a base, giving the substitution product. If a strong electrophile is not present, the nucleophilicity of the oxygen may be enhanced by conversion to its conjugate base (an alkoxide). This powerful nucleophile then attacks the weak electrophile. These two variations of the substitution mechanism are illustrated in the following diagram.

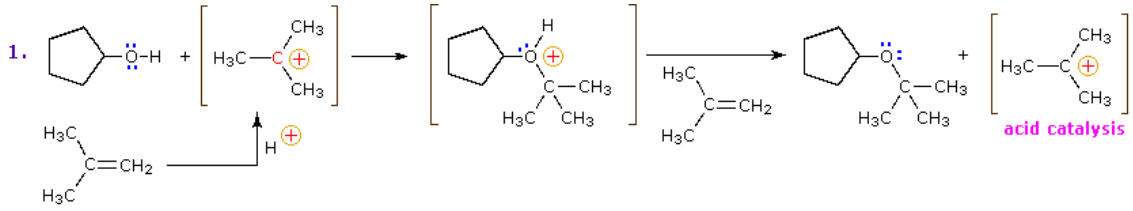


The preparation of tert-butyl hypochlorite from tert-butyl alcohol is an example of electrophilic halogenation of oxygen, but this reaction is restricted to 3º-alcohols because 1º and 2º-

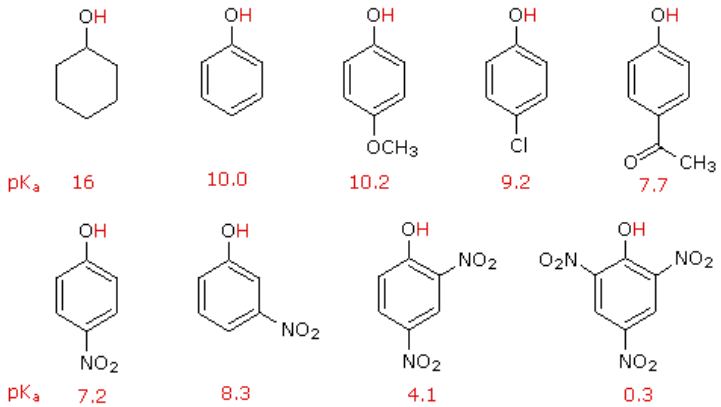
hypochlorites lose HCl to give aldehydes and ketones. In the following equation the electrophile may be regarded as $Cl^{(+)}$.

$$(CH_3)_3C–O–H \;+\; Cl_2 \;+\; NaOH \longrightarrow (CH_3)_3C–O–Cl \;+\; NaCl \;+\; H_2O$$

Alkyl substitution of the hydroxyl group leads to ethers. This reaction provides examples of both strong electrophilic substitution (first equation below), and weak electrophilic substitution (second equation). The latter S_N2 reaction is known as the **Williamson Ether Synthesis**, and is generally used only with 1º-alkyl halide reactants because the strong alkoxide base leads to E2 elimination of 2º and 3º-alkyl halides.



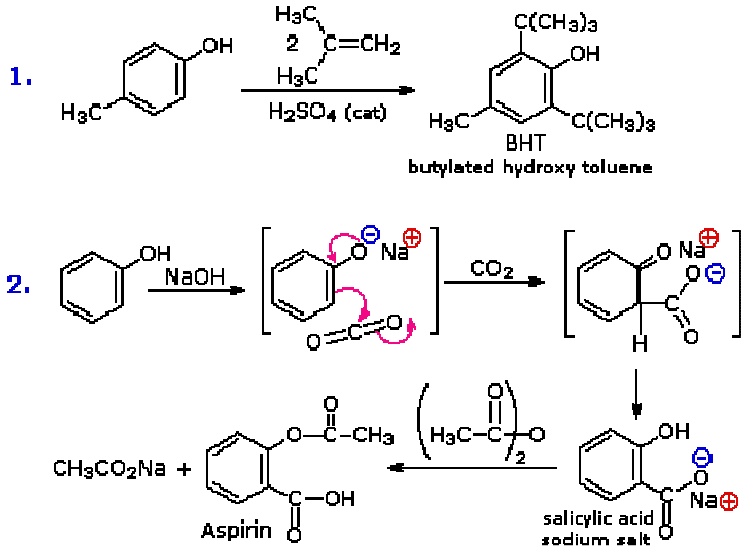
On the other hand, substitution of the hydroxyl hydrogen atom is even more facile with phenols, which are roughly a million times more acidic than equivalent alcohols. This phenolic acidity is further enhanced by electron-withdrawing substituents ortho and para to the hydroxyl group. The alcohol cyclohexanol is shown for reference at the top left. It is noteworthy that the influence of a nitro substituent is over ten times stronger in the para-location than it is meta, despite the fact that the latter position is closer to the hydroxyl group. Furthermore additional nitro groups have an additive influence if they are positioned in ortho or para locations. The trinitro compound shown at the lower right is a very strong acid called picric acid.



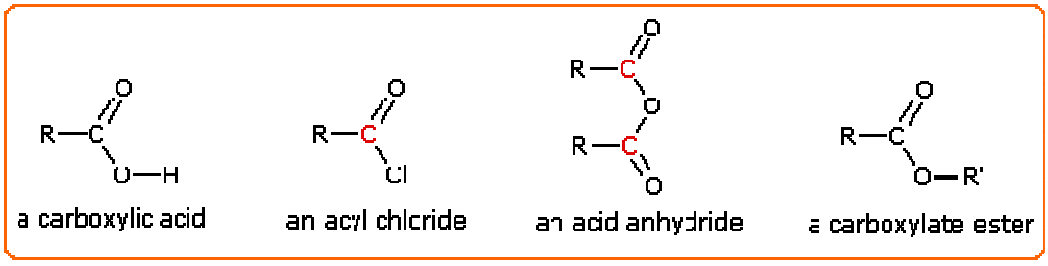
As with the alcohols, the phenolic hydroxyl hydrogen is rather easily replaced by other substituents. For example, phenol reacts easily with acetic anhydride to give phenyl acetate. Likewise, the phenolate anion is an effective nucleophile in S_N2 reactions, as in the second example below.

$$C_6H_5–OH \;+\; (CH_3CO)_2O \longrightarrow C_6H_5–O–COCH_3 \;+\; CH_3CO_2H$$
$$2\ C_6H_5–OH \;+\; 2\ Na \longrightarrow 2C_6H_5–O^{(–)}\ Na^{(+)} + H_2$$
$$C_6H_5–OH \;+\; NaOH \longrightarrow C_6H_5–O^{(–)}\ Na^{(+)} + H_2O$$

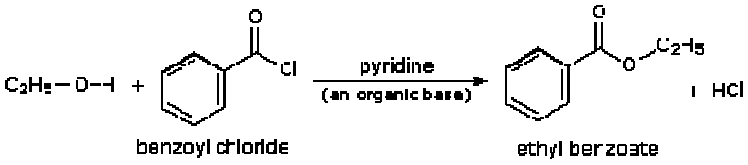
The facility with which the aromatic ring of phenols and phenol ethers undergoes electrophilic substitution has been noted. Two examples are shown in the following diagram. The first shows the Friedel-Crafts synthesis of the food preservative BHT from para-cresol. The second reaction is interesting in that it further demonstrates the delocalization of charge that occurs in the phenolate anion. Carbon dioxide is a weak electrophile and normally does not react with aromatic compounds; however, the negative charge concentration on the phenolate ring enables the carboxylation reaction shown in the second step. The sodium salt of salicylic acid is the major product, and the preference for ortho substitution may reflect the influence of the sodium cation. This is called the **Kolbe-Schmidt reaction**, and it has served in the preparation of aspirin, as the last step illustrates.



One of the most important substitution reactions at oxygen is **ESTER FORMATION** resulting from the reaction of alcohols with electrophilic derivatives of carboxylic and sulfonic acids. The following illustration displays the general formulas of these reagents and their ester products, in which the R'–O– group represents the alcohol moiety. The electrophilic atom in the acid chlorides and anhydrides is colored red. Examples of specific esterification reactions:

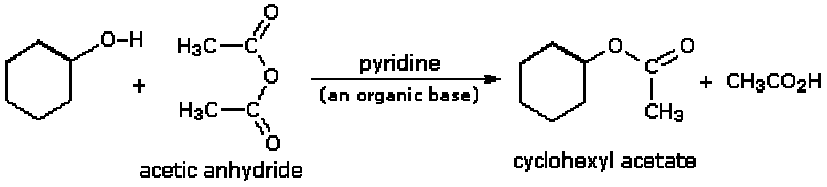


Acyl chloride Estarification



The pyridine combines with the HCl produced in this reaction.

Anhydride Estarification



The pyridine combines with the acetic acid produced in this reaction.

Hydroxyl Group Substitution

Using the chemical behavior of alkyl halides as a reference, we are encouraged to look for analogous substitution and elimination reactions of alcohols. The chief difference, of course, is a change in the leaving anion from halide to hydroxide. Since oxygen is slightly more electronegative than chlorine (3.5 vs. 2.8 on the Pauling scale), we expect the C-O bond to be more polar than a C-Cl bond. Furthermore, an independent measure of the electrophilic character of carbon atoms from their nmr chemical shifts (both ^{13}C & alpha protons), indicates that oxygen and chlorine substituents exert a similar electron-withdrawing influence when bonded to sp^3 hybridized carbon atoms. Despite this promising background evidence, alcohols do not undergo the same S_N2 reactions commonly observed with alkyl halides. For example, the rapid S_N2 reaction of 1-bromobutane with sodium cyanide, shown below, has no parallel when 1-butanol is treated with sodium cyanide. In fact ethyl alcohol is often used as a solvent for alkyl halide substitution reactions such as this.

$$CH_3CH_2CH_2CH_2{-}Br + Na^{(+)}\,CN^{(-)} \longrightarrow CH_3CH_2CH_2CH_2{-}CN + Na^{(+)}\,Br^{(-)}$$

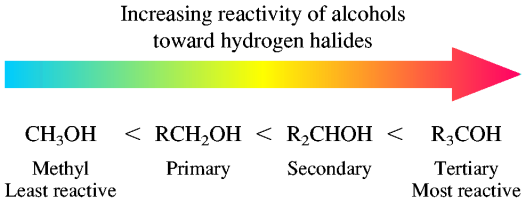
$$CH_3CH_2CH_2CH_2{-}OH + Na^{(+)}\,CN^{(-)} \longrightarrow \text{No Reaction}$$

The key factor here is the stability of the leaving anion (bromide vs. hydroxide). We know that HBr is a much stronger acid than water (by more than 18 powers of ten), and this difference will be reflected in reactions that generate their conjugate bases. The weaker base, bromide anion, is more stable and its release in a substitution or elimination reaction will be much more favorable than that of hydroxide ion, a stronger and less stable base. Clearly, an obvious step toward improving the reactivity of alcohols in S_N2 reactions would be to modify the –OH functional group in a way that improves its stability as a leaving anion. One such modification is to conduct the substitution reaction in strong acid so that –OH is converted to $–OH_2^{(+)}$. Since the hydronium ion ($H_3O^{(+)}$) is a much stronger acid than water, its conjugate base (H_2O) is a better leaving group than hydroxide ion. The only problem with this strategy is that many nucleophiles, including cyanide, are deactivated by protonation in strong acid, effectively removing the nucleophilic co-reactant needed for the substitution. The strong acids HCl, HBr and HI are not subject to this difficulty because their conjugate bases are good nucleophiles and are even weaker bases than alcohols. The following equations illustrate some substitution reactions of alcohols that may be effected by these acids. As was true for alkyl halides, nucleophilic substitution of 1º-alcohols proceeds by an S_N2 mechanism, whereas 3º-alcohols react by an S_N1 mechanism. Reactions of 2º-alcohols may occur by both mechanisms and often produce some rearranged products. The numbers in parentheses next to the mineral acid formulas represent the weight percentage of a concentrated aqueous solution, the form in which these acids are normally used.

$$CH_3CH_2CH_2CH_2{-}OH + HBr\ (48\%) = CH_3CH_2CH_2CH_2{-}OH_2^{(+)}\,Br^{(-)} = CH_3CH_2CH_2CH_2{-}Br + H_2O$$

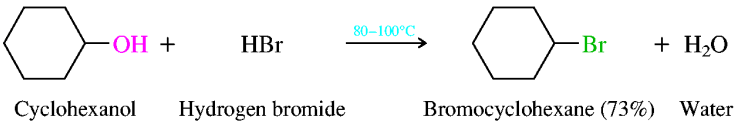
$$(CH_3)_3C{-}OH + HCl\ (37\%) = (CH_3)_3C{-}OH_2^{(+)}\,Cl^{(-)} = (CH_3)_3C^{(+)}\,Cl^{(-)} + H_2O = (CH_3)_3C{-}Cl + H_2O$$

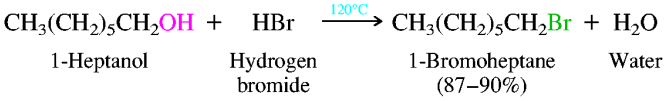
The order of reactivity of the hydrogen halides parallels their acidity: HI > HBr > HC1 > > HF. Hydrogen iodide is used infrequently, however, and the reaction of alcohols with hydrogen fluoride is not a useful method for the preparation of alkyl fluorides. Among the various classes of alcohols, tertiary alcohols are observed to be the most reactive and primary alcohols the least reactive.



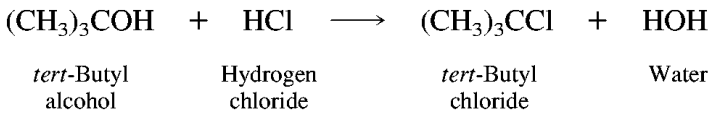
Tertiary alcohols are converted to alkyl chlorides in high yield within minutes on reaction with hydrogen chloride at room temperature.

Secondary and primary alcohols do not react with HC1 at rates fast enough to make the preparation of the corresponding alkyl chlorides a method of practical value. Therefore, the more reactive hydrogen halide HBr is used; even then, elevated temperatures are required to increase the rate of reaction.

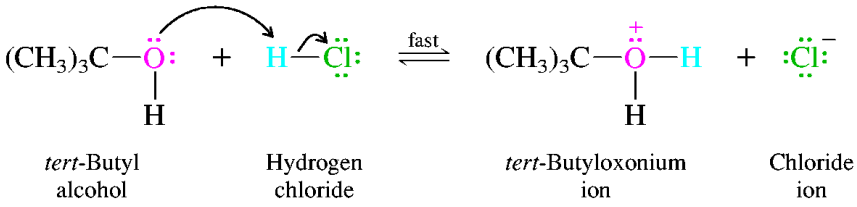




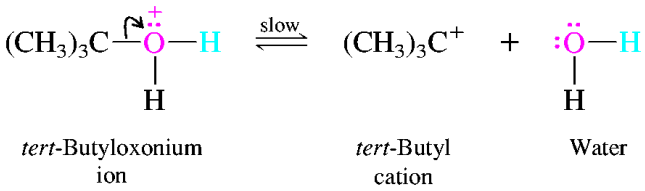
Overall Reaction:



Step 1: Protonation of *tert*-butyl alcohol to give an alkyloxonium ion:



Step 2: Dissociation of *tert*-butyloxonium ion to give a carbocation:



Step 3: Capture of *tert*-butyl cation by chloride ion: