

3.Organic Compounds Containing Carbon, Hydrogen and Oxygen: Alcohols and Ethers

❖ Learning objectives:

- To give an overview of some relevant compounds of C, H and O and particularly the alcohols.
- To prepare the ground for understanding the chemistry of later compounds containing alcohol and ether groups.



Diagnostic test

Read the following questions .And try solve them

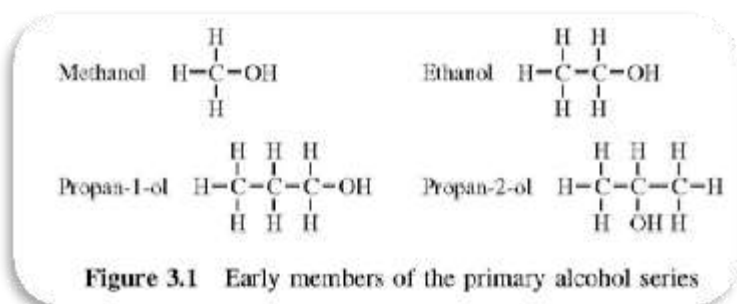
1. What is the chemical name of the alcohol used in alcoholic drinks?
2. The alcohols are members of the monohydric alcohol series with the general formula $C_nH_{2n+1}OH$.
Give the formula and names for the alcohols when $n=1$ and 3
3. In what structural way does methanol resemble water?
4. C_6H_5OH has an OH group joined to a six-membered ring. What is the compound called?
5. Glycerine is a trihydric alcohol, $CH_2OH.CHOH.CH_2OH$. What is the chemical name?
6. C_2H_6O is the general formula for an alcohol and also dimethyl ether. Give the formula for each isomer.

Ethanol, C_2H_5OH , is commonly called alcohol. Some desperate people drink meths, containing methanol, CH_3OH , as a means of getting drunk but it sends them blind and eventually insane, hence the expression 'blind drunk'.

Antifreeze, $C_2H_4(OH)_2$, and glycerine, $C_3H_5(OH)_3$, are members of different alcohol series and behave differently.

3.1 Alcohols, $C_nH_{2n+1}OH$

The compounds commonly known as 'the alcohols' are molecules containing only one OH group; they have the general formula $C_nH_{2n+1}OH$ and should more correctly be called the 'monohydric alcohols', i.e. only one OH group per molecule.



The occurrence of different isomers in the alcohol series is due to the OH group being located at different positions on the carbon chain. There are no alcohol isomers of the first two members of the series. In C_3H_7OH there are

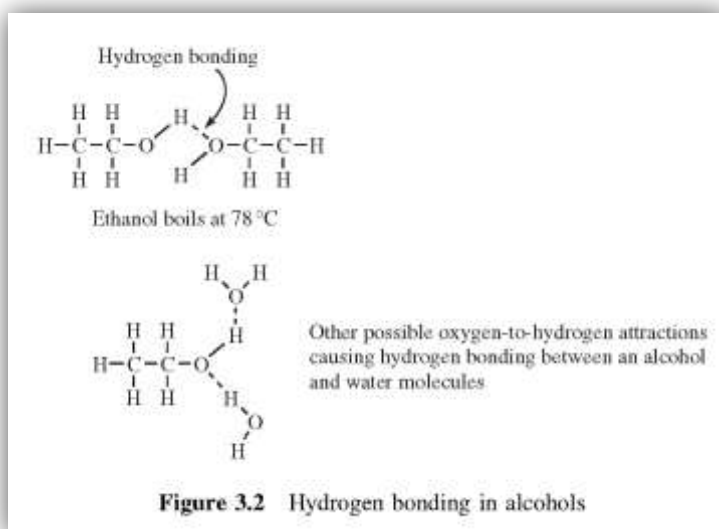
two possible positions of the OH, e.g. $CH_3.CH_2.CH_2.OH$ and $CH_3.CH(OH).CH_3$. The alcohols are named using a system that clearly locates the position of the OH (or ol) group on the carbon chain. $n=4$ C_4H_9OH is butanol. You can try your hand at drawing and naming the four alcohol isomers. They will all have the same overall chemical formula but different structures.

3.1.1. Properties of alcohols:

Some of the properties of alcohols resemble those of water, particularly their solvent properties and the chemical reactions of the OH group. ***They differ most in their toxicity.***

Only ethanol is non-poisonous in small quantities and low concentrations. Also, the members of the alcohols with lower molecular weights exhibit 'hydrogen bonding. This hydrogen bonding makes the boiling points higher than expected because

of the extra forces holding the alcohol molecules together and its hydrogen bonding with water if in solution. For example, ethanol boils at 78 C whereas its molecular weight might lead you to expect it to boil at about 40°C. **Figure 3.2.**



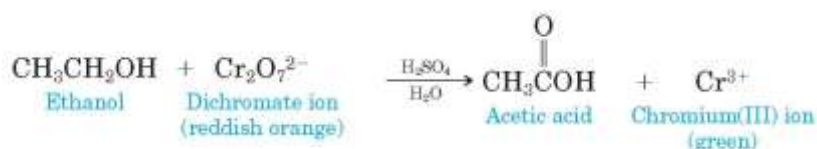
Pure ethanol, C_2H_5OH , is called 'absolute ethanol' and is used in medicine as a solvent, specimen storage liquid and cleansing agent. It mixes well with water and can be easily diluted. This property is unusual for covalent organic compounds as they are usually insoluble and immiscible in water. The solubility here is because of the similarity between the OH in the water structure, $H.OH$, and the alcohol C_2H_5OH . Medicinal solutions in alcohol are called '**tinctures**'.

Ethanol, we know, is made when fruit sugars ferment. Ethanol (and methanol) can become an addictive material. **Prolonged intake can damage tissues, particularly the liver.** It has been found that people with alcohol dependency can be treated using a drug called ‘**antabuse**’ or **disulfiran**, which has no effect unless the person consumes alcohol. They then feel sick and nauseous, which is hoped will turn the person off alcohol. The drug acts by inhibiting the normal breakdown, within the body, of one of the oxidation products of alcohol, called ethanal. This builds up in the system, causing the nausea. The mechanism for its action follows the pathway: alcohol, $C_2H_5OH \rightarrow$ by oxidation to ethanal, CH_3CHO further oxidation normally to $CO_2 + H_2O$. In the case of antabuse, this last stage is prevented or delayed.

Some applications

Breath-Alcohol Screening:

Potassium dichromate oxidation of ethanol to acetic acid is the basis for the original breath-alcohol screening test used by law enforcement agencies to determine a person’s blood alcohol content (BAC). The test is based on the difference in color between the dichromate ion (reddish orange) in the reagent and the chromium (III) ion (green) in the product.



In its simplest form, breath-alcohol screening uses a sealed glass tube that contains a potassium dichromate– sulfuric acid reagent impregnated on silica gel as shown in the figure 3.3.

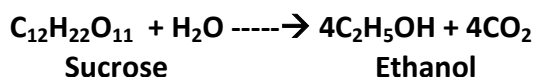


Figure 3.3

As breath containing ethanol vapor passes through the tube, reddish orange dichromate ion is reduced to green chromium(III) ion. To estimate the concentration of ethanol in the breath, one measures how far the green color extends along the length of the tube. When it reaches beyond the halfway point, the person is judged as having a *sufficiently high blood alcohol content(BAC) to warrant further, more precise testing.*

3.2.1 .Fermentation:

Everyone knows that fermentation of sugar solutions aided by the enzymes in yeast produces ethanol. This process by the action of fungi breaks down the large sugar molecules in fruits into ethanol



The bubbles in champagne are the CO₂ given off in this reaction. Some sugars also give side reactions to produce other compounds. These can be slightly toxic and 'head splitting' in their after-effects. Home brewed wines and beers often contain these unwanted compounds. These unwanted side products are removed by professional wine makers by prolonged storage in wooden barrels, which absorbs the more toxic materials.

Methanol, CH₃OH, is water soluble. 'Meths' is an industrial solvent mixture of ethanol and methanol. It often contains a purple dye and an additive to make it unpalatable to drink. Methanol is poisonous (**one spoonful of neat methanol can kill**). It can produce similar physiological symptoms to ethanol if consumed in very small quantities in diluted form. It has the additional hazard that it sends people **blind and insane and can become addictive**.

The alcohols as a group or homologous series of compounds are widely used industrially as a starting point for making other compounds, including drugs, detergents, dyes, plastics etc. The higher alcohols, with three or more carbon atoms, are certainly not consumable. They have unpleasant smells, tastes and are toxic. They are used as industrial solvents for paints and dyes etc. The higher members of the alcohols are waxy materials. Only the first few alcohols are water soluble; the rest are insoluble in water.

3.3. Other alcohols: di- and tri-hydric alcohols

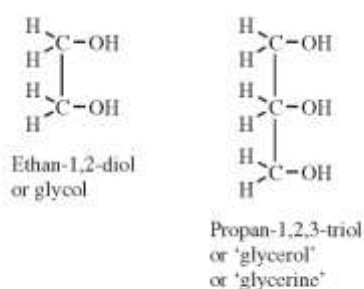


Figure 3.3 Di-hydric and tri-hydric alcohols

Alcohols that have one OH in a molecule are termed **mono-hydric alcohols**. Those with two OH groups are called **di-hydric alcohols**. The compound we use **as 'antifreeze'** for cooling systems in car engines is such a compound, **ethan-1,2-diol** (the older name is ethylene glycol; **Figure 3.3**). Simple **trihydric alcohols** contain three OH groups per molecule and an example is **propan-1,2,3-triol or glycerol or 'glycerine'** (**Figure 3.3**). Its derivatives and compounds figure greatly in the

structures of fats (lipids chapter).

A common African tree gives hope for AIDS cure', The compound, containing OH groups (**Figure 3.4**), has potent antifungal properties stronger than any drug currently on the market. It is being extracted and purified to be used in treating immuno-compromised patients such as those suffering from AIDS. These and other extracts are undergoing clinical trials. Because it takes six trees to make just 50 g of the active compound.

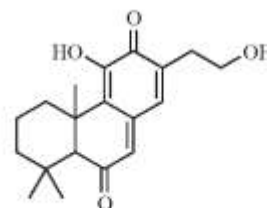


Figure 3.4 A molecule to help in AIDS research

3.4 Aromatic OH compounds: phenol Aromatic compounds have ring structures with alternate single and double bonds. Benzene has a molecular formula of C₆H₆. The carbon atoms are joined together in a hexagonal ring and have alternate single and double bonds.

If one of the hydrogen's is substituted by an 'OH' group (hydroxyl group), you get C_6H_5OH . This compound is called 'phenol'. In phenol a single OH group is joined directly onto the ring. A few of the molecules of phenol can release a hydrogen atom when they dissolve in water to form hydrogen ions. This makes the phenol weakly acidic and a strong antiseptic (although not used now on humans). The hydrogens directly attached to the rings cannot be ionized off (Figure 3.5). It is possible to form

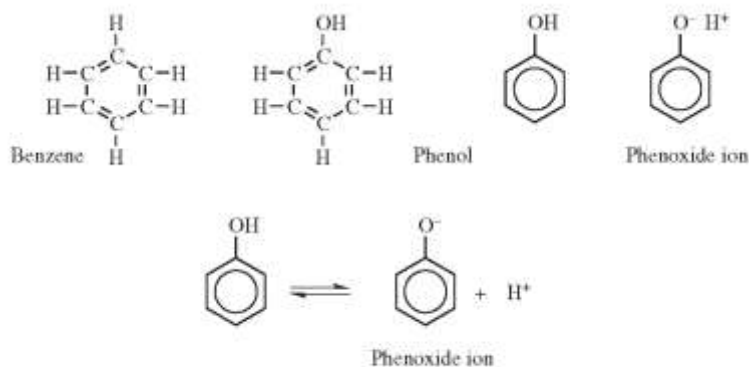


Figure 3.5 Phenol

3.5 Ethers are isomers of alcohols

Ethanol, C_2H_6O , is normally written showing it as C_2H_5OH , but there is another common material that has the same molecular formula but a

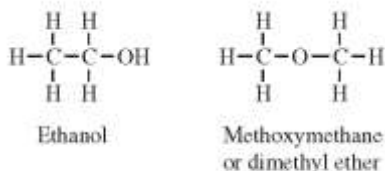


Figure 3.7 Isomers of C_2H_6O

-O- for the ethers.

The ethers are also an homologous series. We will only use the common compound simply called 'ether' as a further example. It is really diethyl ether or ethoxy ethane, $C_2H_5.O.C_2H_5$. 'Ether' was one of the earliest inhaled anesthetics and it has a sweet sickly smell. Diethyl ether has a low boiling point (no hydrogen bonding unlike ethanol) and is easily evaporated at room temperatures. If you leave the bottle open it will soon evaporate into a heavy vapour which is extremely flammable. Never use ether near flames or sparks because fire and explosions are possible.

Home Work: What are the alcohol structures and functional group isomers of diethyl ether, $C_4H_{10}O$ or $C_2H_5.O.C_2H_5$?

compounds with more than one OH joined onto the aromatic ring. These are also antiseptics.

3.4. Cyclic alcohols:

Cyclic compounds are ring compounds that have no double bonds. Cyclic alcohols have at least one OH attached to the ring. The OH here is not acidic and can behave like a usual OH alcohol (Figure 3.6).

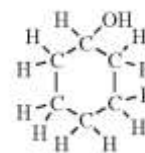


Figure 3.6 Cyclohexanol

different arrangement of the atoms in the molecule (Figure 3.7). This is dimethyl ether or methoxymethane, $CH_3.O.CH_3$. Alcohols and ethers with the same molecular formula are called 'functional group isomers', since they differ in their functional groups, i.e. OH for the alcohols and

A rock climber became trapped by his arm in a rock fall. To save his life he amputated his own arm with a Swiss army knife without anaesthetic.

It was William Morton, in 1846, who first noted that ether could be used as an anaesthetic for dentistry and surgery. Before that all surgery was conducted on conscious patients. Chloroform, CHCl_3 , was developed later and Queen Victoria gave the process of anaesthesia credence when she gave birth to a child in 1853 and suffered little or no pain. More recent inhaled anaesthetics include 'isoflurane', $\text{CF}_3 \cdot \text{CH}(\text{Cl}) \cdot \text{O} \cdot \text{CHF}_2$. Draw its structure (hint: it is also an ether).

Answers to the diagnostic test

1. Ethanol (1)
2. $n = 1$, CH_3OH , methanol; $n = 3$, propanol, $\text{C}_3\text{H}_7\text{OH}$ (4)
3. Both have an 'OH' in their formula (1)
4. Phenol (1)
5. Propan-1,2,3-triol or 1,2,3-trihydroxy propane (1)
6. $\text{CH}_3\text{CH}_2\text{OH}$, ethanol and dimethyl ether, CH_3OCH_3 (2)

Further questions;

1. Explain the two different types of isomerism shown by (i) ethanol and dimethyl ether and (ii) butanol and its four isomers (hint – do not forget the optical isomers of one of them).
2. In what ways are the following compounds similar and in what ways are they different: water, methanol, ethanol.
3. You might expect the boiling points of compounds with roughly the same molecular mass to be roughly the same. They are not. Ethanol $\text{C}_2\text{H}_5\text{OH}$ (molecular mass 46) boils at 78 °C. Propane C_3H_8 (molecular mass 44) boils at -42 °C. Can you suggest why?
4. Which is the first member of the alcohol series $\text{C}_n\text{H}_{2n+1}\text{OH}$ to show:
(i) optical isomerism;
(ii) functional group isomerism with an ether;
(iii) chain or structural isomerism with another alcohol.
5. It is unfortunate that some alcoholics fall to the level of drinking 'meths'. What is 'meths' and how does it affect their health?
6. Give examples and uses of one each of the following:
(i) monohydric alcohol; (ii) dihydric alcohol; (iii) a trihydric alcohol;
(iv) an aromatic compound containing an OH group; (v) a cyclic alcohol; (vi) an ether.

References : Chemistry, An Introduction for Medical and Health Sciences, Alan Jones , John Wiley & Sons Ltd . 2013.