## X.6. FUNCTIONAL GROUPS

***Definition:*** A **FUNCTIONAL GROUP** is a specific group of atoms which exists in a molecule and gives a molecule an ability to react in a specific manner or gives it special properties.

Hydrocarbons have a limited range of properties and uses. Functional groups allow the addition of specific properties to a molecule. For example, by carefully choosing the functional groups present in a molecule, a chemist can

- make a molecule act as a base, an acid, or both;
- give the molecule a particular solubility;
- give a molecule a pleasant or unpleasant smell;
- make a molecule react with specific chemicals;
- make a molecule explosive.

The previous sections have already introduced some functional groups: halides, carbon–carbon double bonds (in alkenes) and carbon–carbon triple bonds (in alkynes). This section examines some other important functional groups and how their presence changes the properties of the parent hydrocarbon.

### A. ALCOHOLS

***Definition:*** An **ALCOHOL** is an organic compound containing an OH group.

> **RULE:** When naming an **ALCOHOL**
> - number the hydrocarbon chain to give the LOWEST possible number to the OH group.
> - place the number immediately before the name of the parent hydrocarbon, separated by a dash. Alkyl groups (and their numbers) are placed in front of the number for the OH.
> - indicate the presence of an OH group by changing the "e" ending of the hydrocarbon chain to "ol". ( The ending "ol" comes from "alcoh***ol***".)

***EXAMPLES:***

$CH_3-OH$ = methanol (commercial name = methyl hydrate)

$CH_3-CH_2-OH$ = ethanol ("beverage alcohol")

$CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_3$ = 2–butanol

$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_3$ = 5–methyl–3–hexanol

### PROPERTIES OF ALCOHOLS

- There are two opposing solubility tendencies which exist in all alcohols.
  – the OH group tends to make alcohols soluble in water
  – the non–polar hydrocarbon chain tends to make alcohols insoluble in water

  Methanol, ethanol and propanol are highly soluble in water ("miscible") because the hydrocarbon chain is small and the hydrogen–bonding of the OH group to water molecules "wins out".

  Butanol is moderately soluble in water as a result of a "tie" between the tendency of the OH group to promote solubility and the tendency of the longer hydrocarbon chain to resist dissolving.

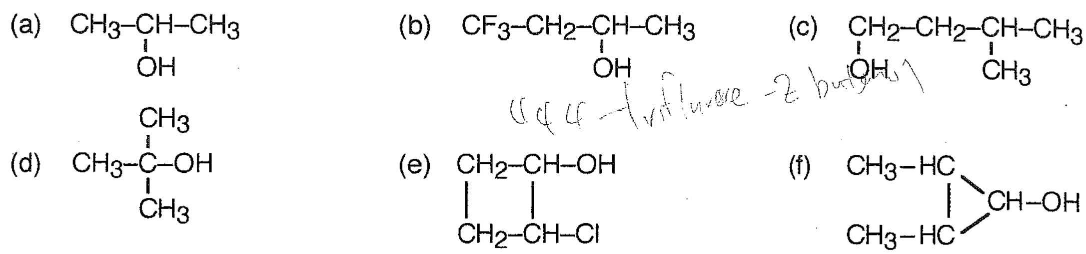
  Pentanol and higher alcohols are effectively insoluble in water as a result of the increasing dominance of the hydrocarbon chain.

- All alcohols are poisonous; ethanol is no exception – it is simply less poisonous than other alcohols.

***EXERCISES:***

32. Draw the following compounds.
    (a) 1–butanol
    (b) 2–methyl–1–cyclopentanol
    (c) 2,2–dichloro–3–methyl–4–nonanol
    (d) 2,5–diethyl–1–cyclohexanol
    (e) 3–methyl–1–pentanol
    (f) 1,1,1–trifluoro–2–propanol

33. Name the following compounds.




## B. OTHER FUNCTIONAL GROUPS

In addition to alcohols there are several other functional groups which can change the properties of a hydrocarbon chain. You are not required to know how to name compounds containing the functional groups listed below. It is sufficient that you can recognize and name the groups present in a given compound. (The names of the compounds in the examples are given for your interest only.)

In section C, you will be shown how to name an additional functional group called an "ester".

### ALDEHYDES

An ***aldehyde*** is an organic compound containing a C=O group at the end of a hydrocarbon chain.

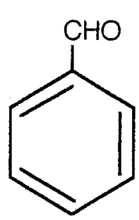
The aldehyde group actually looks like $-\overset{\overset{\displaystyle O}{\|}}{C}-H$ or simply –CHO.

***EXAMPLES:*** Some typical aldehydes are shown below.

$H-\overset{\overset{\displaystyle O}{\|}}{C}-H$ or HCHO (name = methanal; common name = formaldehyde)

$CH_3-CHO$ (name = ethanal)

$CH_3-CH_2-CH_2-\underset{\underset{\displaystyle CH_3}{|}}{CH}-CHO$ (name = 2–methylpentanal)




(name = benzaldehyde)

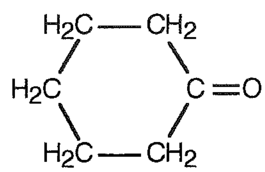
## KETONES

A ***ketone*** is an organic compound containing a C=O group at a position OTHER THAN AT THE END OF A HYDROCARBON CHAIN.

***EXAMPLES:*** Some typical ketones are shown below.

$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3$ or $CH_3COCH_3$ (name = propanone; common name = acetone)

$CH_3CH_2COCH_2CH_2CH_3$ (name = 3–hexanone)



(name = cyclohexanone)

## ETHERS

An ***ether*** is a compound in which an oxygen joins two hydrocarbon groups.

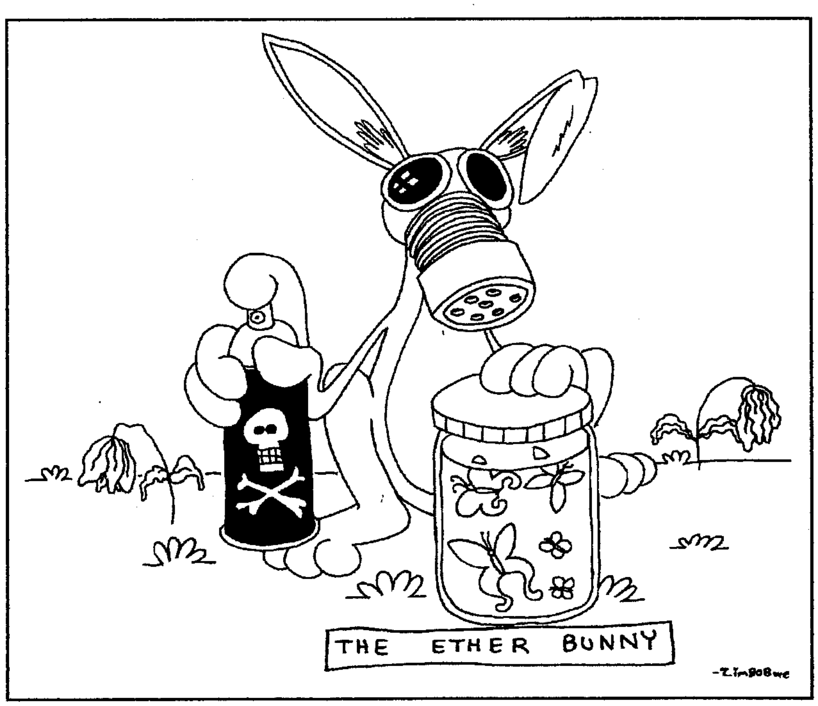
Several ethers have anaesthetic properties: ethoxyethane was formerly used in hospitals and is still used by biologists to "quiet" or anaesthetize insects.

***EXAMPLES:*** Some typical ethers are shown below.

$CH_3CH_2-O-CH_2CH_3$ (name = ethoxyethane; common name is "hospital ether")

$CH_3-O-CH_2CH_2CH_3$ (name = 1–methoxypropane; an anaesthetic)

$CH_3-\underset{\underset{\displaystyle CH_3}{|}}{\overset{\overset{\displaystyle CH_3}{|}}{C}}-CH_2-CH_2-O-CH_3$ (name = 1–methoxy–3,3–dimethylbutane)



## AMINES

An ***amine*** is an organic compound containing an $NH_2$ group. Amines are organic bases and react with acids. Typically, amines have a "fish–like" odour.

***EXAMPLES:*** Some typical amines are shown below.

$CH_3-CH_2-NH_2$ (name = aminoethane)

$H_2N-CH_2-CH_2-CH_2-CH_2-NH_2$ (name = 1,4–diaminobutane; common name is putrescine, produced by decomposing meat)

$CH_3-\underset{\underset{\displaystyle NH_2}{|}}{CH}-CH_2-CH_2-CH_3$ (name = 2–aminopentane)

## AMIDES

An ***amide*** is an organic compound containing a $CONH_2$ group. The $CONH_2$ group is also some–times shown as

$$-\overset{\overset{\displaystyle O}{\|}}{C}-NH_2\ .$$

***EXAMPLES:*** Some typical amides are shown below.

$CH_3-CONH_2$ (name = ethanamide)

$CH_3-CH_2-CH_2-CH_2-CH_2-CONH_2$ (name = hexanamide)

$CH_3-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}-CH_2-CONH_2$ (name = 3,3–dimethylbutanamide)

## CARBOXYLIC ACIDS

A ***carboxylic acid*** is an organic compound which contains a COOH group. The COOH group is also sometimes shown as

$$-\overset{\overset{\displaystyle O}{\|}}{C}-O-H\ .$$

Carboxylic acids are commonly referred to as "organic acids".

***EXAMPLES:*** Some typical carboxylic acids are shown below.

$CH_3COOH$ (name = ethanoic acid; commonly called acetic acid)

HCOOH (name = methanoic acid; common name = formic acid, found in red ant venom)

$CH_3-CH_2-CH_2-COOH$ (name = butanoic acid; common name = butyric acid, responsible for the odour of "smelly feet")

## A Digression on Amino Acids

An ***amino acid*** is a carboxylic acid with an amine group at the 2–position. Although there are numerous amino acids, only 20 different amino acids are essential biological "building blocks".

***EXAMPLE:*** $CH_3\text{–}\underset{\displaystyle NH_2}{\underset{|}{CH}}\text{–}COOH$ = 2–aminopropanoic acid (common name = alanine)

Amino acids can react with both acids and bases.

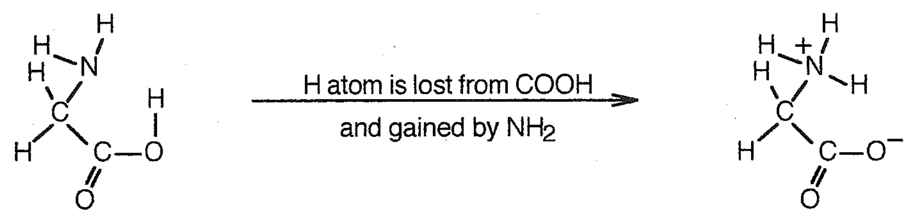
***EXAMPLE:*** Reaction with acids – $CH_3\text{–}\underset{\displaystyle NH_2}{\underset{|}{CH}}\text{–}COOH + H^+ \longrightarrow CH_3\text{–}\underset{\displaystyle {}^+NH_3}{\underset{|}{CH}}\text{–}COOH$

Reaction with bases – $CH_3\text{–}\underset{\displaystyle NH_2}{\underset{|}{CH}}\text{–}COOH + OH^- \longrightarrow CH_3\text{–}\underset{\displaystyle NH_2}{\underset{|}{CH}}\text{–}COO^- + H_2O$

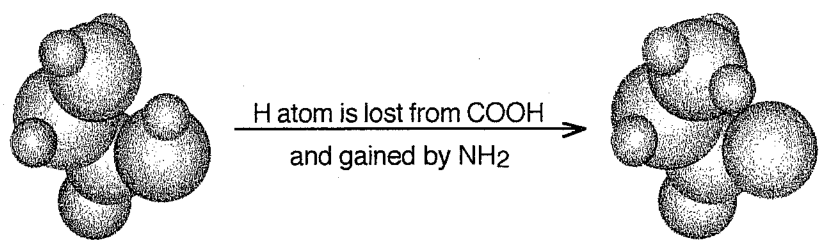
After reacting with either an acid or base the amino acid is ionic and remains soluble in water.

There are two properties of amino acids which are especially important.

a) **Amino acids are highly soluble in water** because amino acids have both acid and base groups arranged such that the acid and base groups can "neutralize" each other.

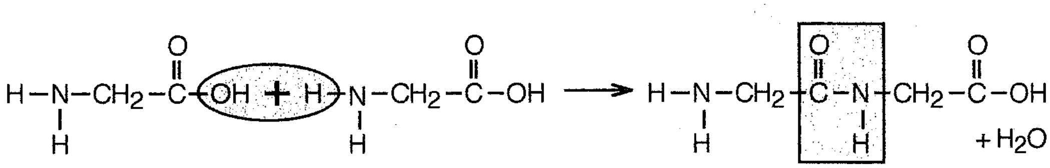



or, using space–filling models



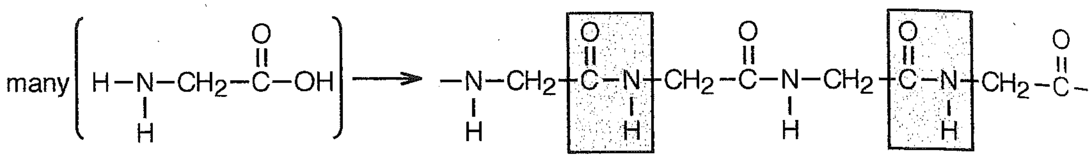

The resulting ionic compound is highly soluble in water.

b) **Amino acids link with each other to form "dipeptides" and "polypeptides".**




a "dipeptide"

The shaded oval, above, shows how water is removed from two molecules and allows the molecules to link together. The box indicates that the molecules are now joined together by an "amide linkage" (or "peptide bond" or "peptide linkage")



a "polypeptide"

As seen above, a series of amino acid molecules can be joined by a series of amide linkages to form a polypeptide.

## C. ESTERS

An ***ester*** is a compound in which a COO group ( $-C\begin{matrix} /\!\!/O \\ \backslash O \end{matrix}$ ) joins two hydrocarbon chains.

> **RULE:** To name an **ESTER**
> - the hydrocarbon chain attached directly to the carbon side of the COO group has its "e" ending changed to "oate". The C in the COO group is considered to be part of the parent hydrocarbon chain.
> - the hydrocarbon chain attached to the oxygen side of the COO group is named as an alkyl group; the name of the alkyl group is used as a separate, initial word.

***EXAMPLES:*** Some typical esters are shown below.

$CH_3\text{–}CH_2\text{–}CH_2\text{–}COO\text{–}CH_3$ = methyl butanoate

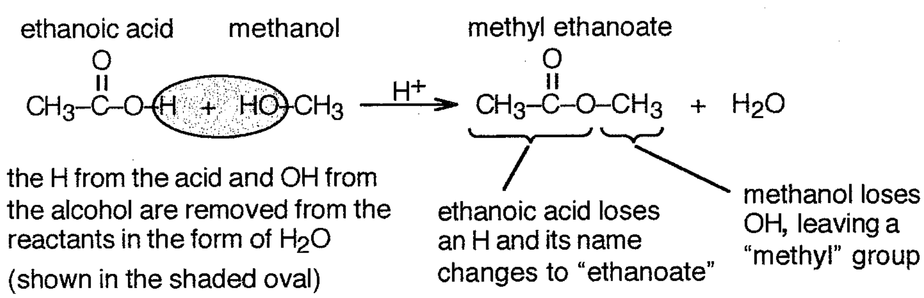
$HCOO\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_3$ = butyl methanoate

$CH_3\text{–}CH_2\text{–}COO\text{–}CH_2\text{–}CH_3$ = ethyl propanoate

$CH_3\text{–}COO\text{–}CH_2\text{–}CH_2\text{–}CH_3$ = propyl ethanoate

### Preparation and Properties of Esters

Esters are prepared by reacting an organic acid and an alcohol in the presence of an inorganic acid such as HCl or $H_2SO_4$. In the example below, ethanoic acid reacts with methanol (written backwards); the "$H^+$" over the reaction arrow indicates that $H^+$ is used as a catalyst.




The actual experimental procedure for producing small amounts of impure esters is quite simple.

Mix a few millilitres of the desired carboxylic acid and a few millilitres of the desired alcohol in a test tube. Add a few drops of concentrated sulphuric acid and heat over a bunsen burner for a minute or so. Be sure not to overheat the liquid and cause it to spurt out the end of the tube. [The distinctive presence of the ester is detected by cautiously smelling the contents of the tube.]

Organic acids have a "sharp, pungent and biting" odour which is often quite unpleasant. (Butanoic acid has the odour of "rancid sneakers", only FAR MORE CONCENTRATED!) Alcohols also have a "sharp" odour, although generally less so than that of acids having a similar number of carbon atoms. Methanol and ethanol have very little odour but their smell tends to "catch" in the nasal passage. Propanol and higher alcohols have more intense and often unpleasant odours which also tend to "catch" in the nasal passage.

The odour of esters, on the other hand, is generally very pleasant. In small amounts, esters form the basis of many fragrant fruit and flower smells.

***EXAMPLE:***

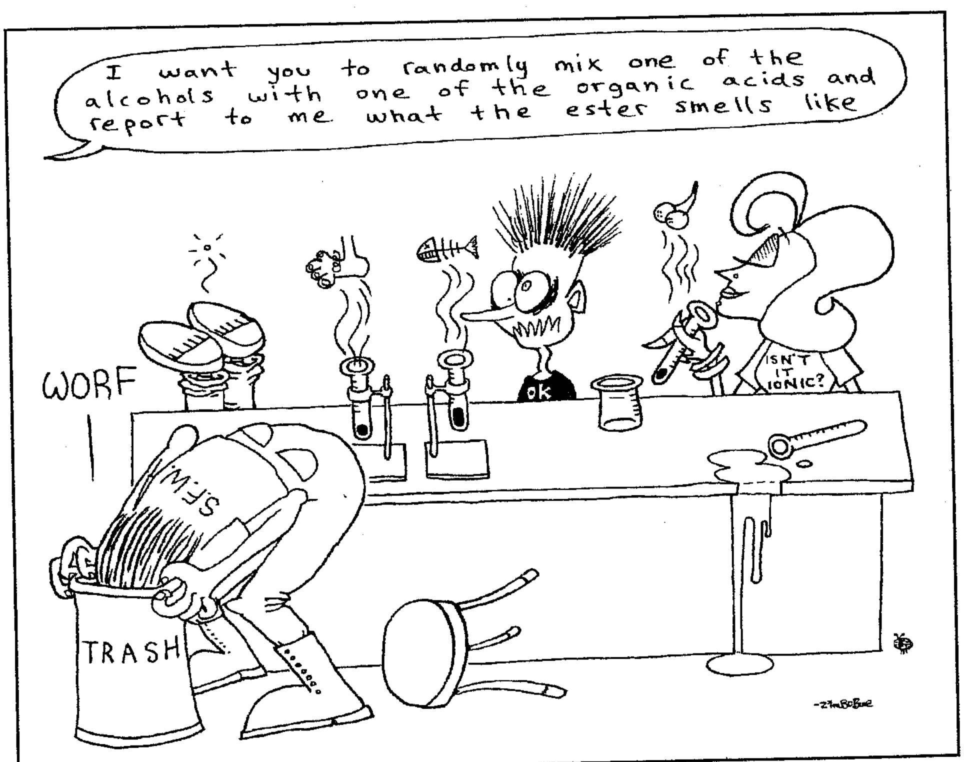
| Ester | Odour | Ester | Odour |
|---|---|---|---|
| methyl butanoate | pineapples | pentyl propanoate | apricots |
| pentyl ethanoate | bananas | ethyl methanoate | rum |
| octyl ethanoate | orange rind | | |

***EXERCISES:***

34. Name the following molecules.
    (a) $CH_3-CH_2-COO-CH_3$
    (b) $HCOO-CH_2-CH_2-CH_3$
    (c) $CH_3-CH_2-CH_2-COO-CH_2-CH_3$
    (d) $CH_3-COO-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$
    (e) $CH_3-CH_2-CH_2-CH_2-COO-CH_2-CH_2-CH_2-CH_3$

35. Draw the following molecules.
    (a) propyl pentanoate
    (b) methyl hexanoate
    (c) ethyl propanoate
    (d) butyl butanoate
    (e) hexyl methanoate

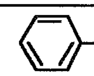
36. Draw the carboxylic acid molecule and alcohol molecule which are used to make each ester in exercise 34.




**The new Chemistry 11 teacher is about to find that not all esters have a pleasant smell.**

## D. A SUMMARY OF THE FUNCTIONAL GROUPS

The functional groups which have been introduced in this unit are shown in the table below. The exercise which follows is designed to help you learn to recognize the presence of specific functional groups in a given molecule.

| Name | Functional Group | Name | Functional Group |
|---|---|---|---|
| alkene | C=C | ether | –O– |
| alkyne | C≡C | amine | $-NH_2$ |
| halide | –F, –Cl, –Br or –I | amide | $-CONH_2$ |
| alcohol | –OH | carboxylic acid | –COOH |
| aldehyde | –CHO | ester | –COO– |
| ketone | –CO– | aromatic ring |  |

***EXERCISE:***

37. Circle the functional groups which exist in each of the following molecules and label each group as one of:

| | | | |
|---|---|---|---|
| DOU = double bond , | TRI = triple bond , | ARO = aromatic ring , | HAL = halide , |
| ALC = alcohol , | ALD = aldehyde , | KET = ketone , | ETH = ether , |
| AMN = amine , | AMD = amide , | CAR = carboxylic acid , | EST = ester. |

(a) $Br{-}CH_2CH_2CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3$

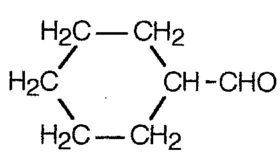
(b) $HC{\equiv}CCH_2C{\equiv}CH$

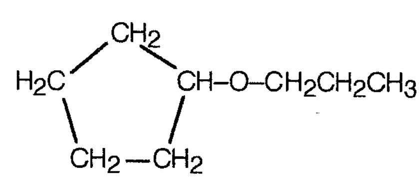
(c) $HOCH_2\overset{\displaystyle OH}{\overset{|}{C}}H\underset{\displaystyle OH}{\underset{|}{C}}HCH_2OH$

(d) $CH_3CH_2CH{=}CH\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3$

(e) $CH_3{-}\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}{-}CO{-}CH_3$

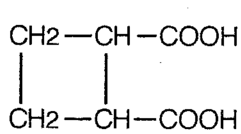
(f) $CH_3{-}\overset{\displaystyle CH_2OH}{\overset{|}{\underset{\displaystyle CH_2OH}{\underset{|}{C}}}}{-}NH_2$

(g) 

(h) 

(i) $CH_3{-}CO{-}\underset{\displaystyle COOCH_3}{\underset{|}{C}}HCH_2CH_2\underset{\displaystyle COOCH_3}{\underset{|}{C}}H{-}CO{-}CH_3$

(j) $CH_2{=}CH\underset{\displaystyle CH_3}{\underset{|}{C}}HC{\equiv}CH$

(k) 

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