FAMILIES OF ORGANIC COMPOUNDS

Year 11 Chemistry

2023

Arabic *
MERGEFOR

Key Knowledge

- **The grouping of hydrocarbon compounds into families (alkanes, haloalkanes, alkenes, alcohols, carboxylic acids) based upon similarities in their physical and chemical properties, including general formulas and general uses based on their properties**
- **Representations of organic compounds (structural formulas, semi-structural formulas)**
- **Naming according to the International Union of Pure and Applied Chemistry (IUPAC) systematic nomenclature (limited to non-cyclic compounds up to C8, and structural isomers up to C5)**
- **The grouping of hydrocarbon compounds into families (alkanes, haloalkanes, alkenes, alcohols, carboxylic acids) based upon similarities in their physical and chemical properties, including general formulas and general uses based on their properties**
- **Representations of organic compounds (structural formulas, semi-structural formulas) and naming according to the International Union of Pure and Applied Chemistry (IUPAC) systematic nomenclature (limited to non-cyclic compounds up to C8, and structural isomers up to C5)**
- **Plant-based biomass as an alternative renewable source of organic chemicals (for example, solvents, pharmaceuticals, adhesives, dyes and paints) traditionally derived from fossil fuels**

What is Organic Chemistry?

Organic Chemistry is the study of compounds of carbon (excluding inorganic compounds containing carbon such as carbonates, carbides and cyanides).

There are a huge number of organic compounds and carbon compounds are over 90% of all known chemicals. Carbon forms strong bonds with carbon. Carbon forms four covalent bonds. Carbon can form single, double or triple bonds and can form long chains or rings.

Hydrocarbons contain only the elements carbon and hydrogen. Organic compounds may contain other elements eg oxygen or nitrogen. Some of the families we will become familiar with include alkanes, alkenes, and alkynes.

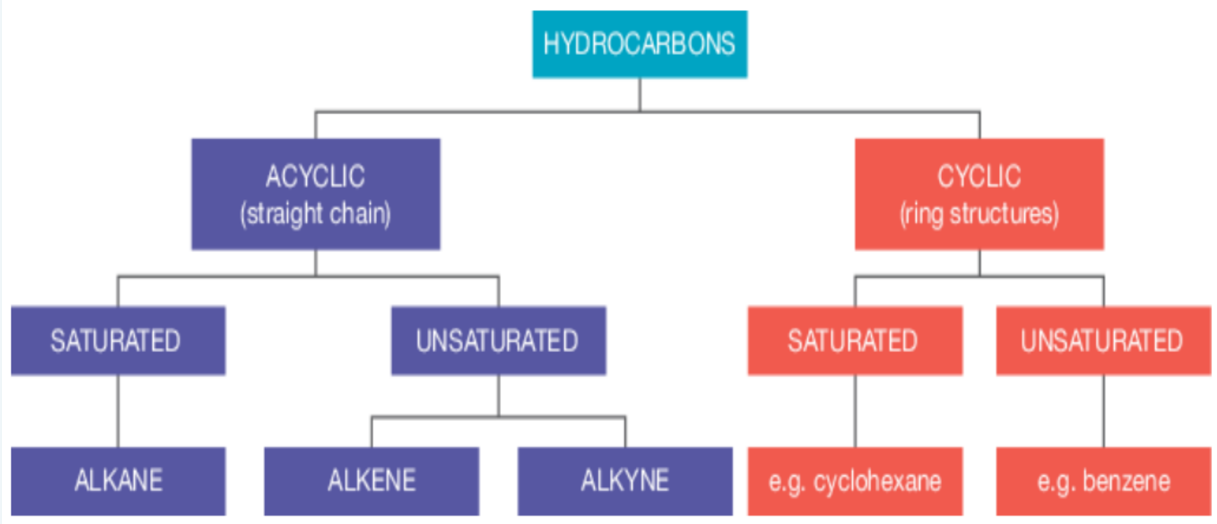


FIGURE 7.4 The classes of hydrocarbons

Hydrocarbons

Hydrocarbons are molecules made of only carbon and hydrogen. Hydrocarbons are found in crude oil.

Acyclic hydrocarbons have carbons arranged in a straight chain (including branched molecules. They include:

- Alkanes (only single carbon-carbon bonds)
- Alkenes (have at least one double carbon-carbon bond)
- Alkynes (have one carbon-carbon triple bond)

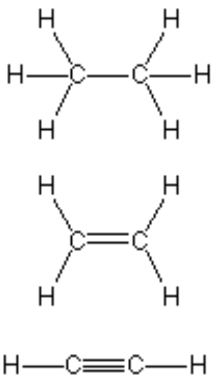
Alkanes are saturated hydrocarbons (have the maximum number of hydrogen/ no double or triple bonds between carbons) and alkenes and alkynes are unsaturated hydrocarbons (have a double bond or triple bond respectively).

Acyclic hydrocarbons

alkane

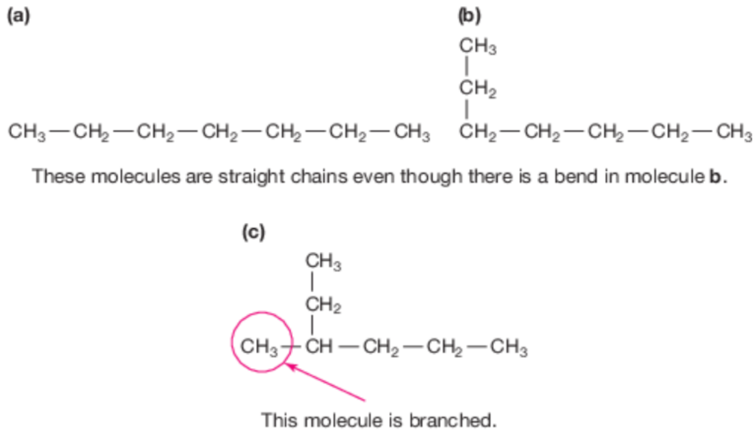
alkene

alkyne



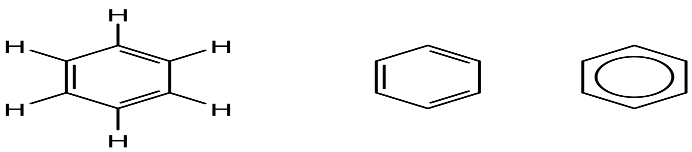
aliphatic hydrocarbons

FIGURE 7.5 Acyclic molecules can be straight chain or branched.



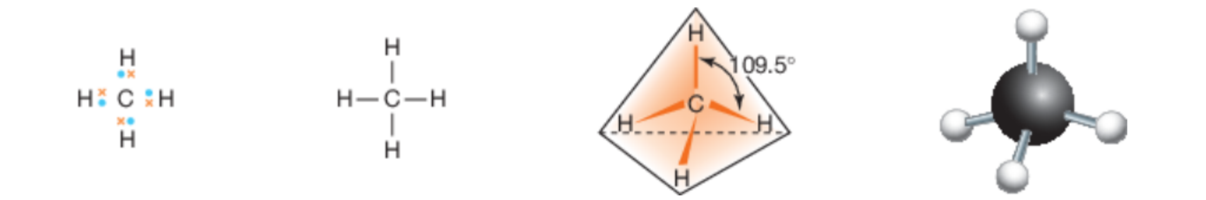
Cyclic hydrocarbons

Cyclic hydrocarbons have the carbon atoms in a ring eg cyclohexane, benzene



Different ways to represent organic molecules

FIGURE 7.6 Electron dot structure, structural formula, molecular shape, and ball-and-stick model of methane



General properties of hydrocarbons

The electronegativities of carbon and hydrogen are similar and therefore the C-H bond is considered non-polar. Hydrocarbon molecules are non-polar. The covalent bond is an intramolecular bond. The forces between hydrocarbon molecules are dispersion forces.

- Small hydrocarbons have low mp and bp because of weak dispersion forces
- Branched molecules have lower mp and bp than straight chain molecules of similar length because the branches prevent molecules coming close (and therefore weaker dispersion forces)
- Hydrocarbons are insoluble in water because water has hydrogen bonds between water molecules and they are more attracted to each other. Hydrocarbons are soluble in non-polar solvents (‘like dissolves like’)

Uses of hydrocarbons

Hydrocarbons are used for transport fuels (alkanes), as precursors for other chemicals, raw materials for plastic manufacture and, in the case of alkynes, ethyne is used for welding. There are issues related to the source of hydrocarbons as crude oil is finite (ie will run out) and combustion of fuels releases carbon dioxide to the atmosphere adding to the enhanced Greenhouse Effect.

Arabic * MERGEFOR

TABLE 7.1 Common straight-chain alkanes

Formula	Name	Phase	Boiling point	Typical use
CH_4	Methane	Gas	−161.5 °C	Natural gas
C_2H_6	Ethane	Gas	−89 °C	Refrigerant
C_3H_8	Propane	Gas	−42 °C	Liquid petroleum gas
C_4H_{10}	Butane	Gas	−1 °C	Manufacture of synthetic rubber
C_5H_{12}	Pentane	Liquid	36.1 °C	Solvent
C_6H_{14}	Hexane	Liquid	68 °C	Filling for thermometers
C_7H_{16}	Heptane	Liquid	98 °C	Testing engine knocking
C_8H_{18}	Octane	Liquid	125.6 °C	Automobile petroleum
C_9H_{20}	Nonane	Liquid	151 °C	Gasoline
$C_{16}H_{34}$	Hexadecane	Liquid	286.8 °C	Lubricating oil
$C_{20}H_{42}$	Icosane	Solid	343.1 °C	Wax candles
$C_{28}H_{58}$	Octacosane	Solid	440 °C	Tar

Alkanes

Alkanes have only single bonds between the carbons. All of the alkanes have the same ending *-ane* and the prefix indicates how many carbons are present.

1C - meth (methane) 6C - hex (hexane)
2C - eth (ethane) 7C - hept (heptane)
3C - prop (propane) 8C - oct (octane)
4C - but (butane) 9C - non (nonane)
5C - pent (pentane) 10C - dec (decane)

Draw the structures of the first five alkanes (show all bonds)

Homologous series

The alkanes (and the alkenes and the alkynes) are a homologous series.
A homologous series is a series of organic compounds in which each successive member differs by a $-CH_2$ from the previous compound.
Alkanes have the general formula of C_nH_{2n+2} (where n is the number of carbon atoms)

Questions:

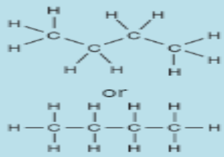
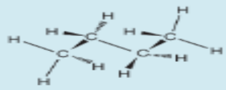
1) Determine the number of hydrogen atoms present if the number of carbons is 18

2) Write the formula for an alkane that has 30 hydrogen atoms

Representing organic molecules

There are many ways to represent organic molecules including structural formulas, molecular formulas, empirical formulas, semi-structural formulas, skeletal or 3D diagrams.
Structural formulas - shows the way the atoms in a molecule are connected (ie shows all covalent bonds). They may be drawn to show the shape of the backbone or at right angles to make it easier to see individual bonds. You must show all bonds.
Semi-structural formulas - Also known as a condensed formula and is an abbreviation of the structural formula on a single line. Go C by C.
Brackets are used to indicate side chains and are after the carbon to which they are attached. $CH_3CH_2CH_2CH(CH_3)\ CH_2CH_3$.
Brackets are also used if there are successive, repeating CH_2 groups eg $CH_3(CH_2)_{16}CH_3$

TABLE 7.3 Different ways of representing butane molecules

Formula	Example	Notes
Molecular	C_4H_{10}	This shows the actual number and kinds of atoms in a molecule.
Empirical	C_2H_5	This shows the simplest whole number ratio of atoms in a molecule.
Structural		This shows the actual arrangement of atoms in a molecule. As molecules become longer, the second example of a structural formula tends to be used.
Semi-structural or condensed	$CH_3CH_2CH_2CH_3$ or $CH_3(CH_2)_2CH_3$	These can be written on a single line, with each carbon atom being followed by the atoms that are joined to it. Repeated CH_2 groups can be collected together in brackets with a subscript as shown.
Skeletal		These use lines and vertices to simplify a structural formula. It is assumed that a carbon atom (and enough hydrogens to satisfy carbon's valency) is present at each vertex and at the ends. Double bonds and other different types of atoms are specifically shown. This representation is usually used for more complex molecules and will be encountered in Units 3 and 4.
3D structural or shape diagram		This shows the 3D arrangement of atoms, with the bonds represented as follows: • The continuous line is in the plane of the paper. • The dashed line extends to the back of the paper. • The solid wedge comes out of the plane of the paper.

Reactions of alkanes

Alkanes can undergo combustion reactions and substitution reactions.

Combustion reactions - This is a redox reaction in which the alkane reacts with oxygen to form carbon dioxide and water. Note that if oxygen is limited, the products may include carbon monoxide which is a toxic gas. Balance the C, H and then O last

Eg Write a balanced equation to show the combustion of propane

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

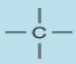
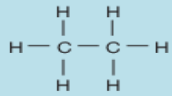
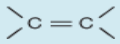
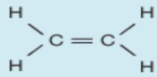
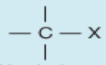
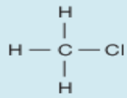
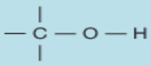
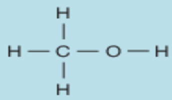
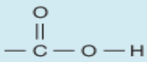
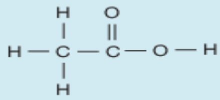
Substitution reactions - reactions with either chlorine or fluorine in which one (or more) of the chlorine (or fluorine) take the place of a hydrogen atom.

Haloalkanes and functional groups

Haloalkanes are not hydrocarbons. The halogen is known as a functional group. A functional group is an atom (or group of atoms) that confers certain properties. A functional group is responsible for characteristic chemical reactions for that homologous series (see Table 7.4 for various functional groups)

Haloalkanes have higher mp and bp because the molecules are polar
Melting points (and boiling points) increase with increasing size of the haloalkane
Haloalkanes are only slightly soluble in water but are more soluble in organic solvents. They can be used as organic solvents (except fluoroalkanes). They can be used as flame retardants in fire extinguishers, refrigerants, spray propellants, solvents and pharmaceuticals but can be toxic to the environment.

TABLE 7.4 Functional groups

Functional group	Type of compound	Suffix or prefix	Example	Systematic name
	Alkane	*-ane*		Ethane
	Alkene	*-ene*		Ethene
—C≡C—	Alkyne	*-yne*	H—C≡C—H	Ethyne
 (X = halogen)	Haloalkane	*halo-*		Chloromethane
	Alcohol	*-ol*		Methanol
	Carboxylic acid	*-oic acid*		Ethanoic acid

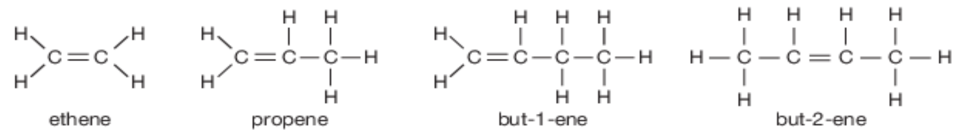
Alkenes

Alkenes contain a double bond between two carbon atoms. They have the general formula CnH2n. The names end in -ene and the prefix indicates how many carbons are present.

Write the formula for the alkene that has 7 carbon atoms

Arabic * MERGEFOR

FIGURE 7.14 Structural formulas of the first three alkenes



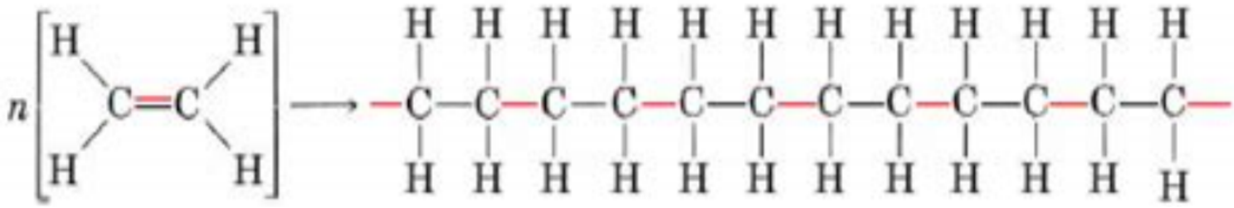
Reactions of alkenes

Alkenes can undergo **combustion** and **addition reactions**

Addition reactions - small molecules may react with the alkene across the double bond. No atoms are lost and only one product is formed.

$C_2H_4 + H_2 \rightarrow C_2H_6$

Alkenes can undergo **addition polymerisation** to form **polymers**.



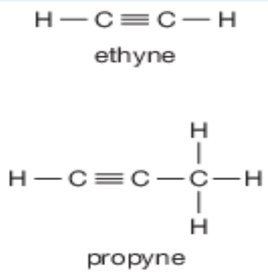
Alkynes

Alkynes are hydrocarbons that contain a **triple bond** between two carbon atoms

The general formula for an alkyne is **CnH2n-2**

The alkynes end in **-yne** and the prefix indicates the number of carbon atoms

FIGURE 7.17 Structural formulas of two alkynes



Alkynes can undergo **combustion reactions** and **addition reactions**

$$2C_2H_2\,(g) + 5O_2\,(g) \rightarrow 4\,CO_2\,(g) + 2H_2O\,(g).$$

Arabic * MERGEFOR

NAMING HYDROCARBONS

Rules for naming hydrocarbons

- Rule 1: Determine the longest chain of carbon atoms. This will form the basis of the name.
- Rule 2: Determine which end is nearest to a branch, a double bond or a triple bond. (A double or triple bond takes precedence over a branch if they are equidistant from either end of the chain.)
- Rule 3: Number the carbon atoms from the end chosen.
- Rule 4: Name any branches first with the ending *-yl* (for example, methane becomes *methyl* and ethane becomes *ethyl*), then the longest chain, and then any single or double bond.
- Rule 5: When two or more branches occur on the same carbon atom, the number of the carbon atom is indicated for each branch, with the names given in alphabetical order (ignoring the prefixes described in rule 6). Place a comma between numbers and a dash between a number and a word.
- Rule 6: When two or more identical branches occur on the carbon chain, the prefixes *di-*, *tri-* and *tetra-* are used.

TIP: Avoid the following common errors when naming hydrocarbons:

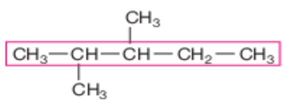
- not identifying the longest chain possible
- not listing the side branches in alphabetical order
- omitting the prefixes *di-*, *tri-* and *tetra-* when they are required.

SAMPLE PROBLEM 3

Naming organic compounds with single bonds

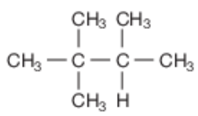
click to expand

Use the rules for naming organic compounds to systematically name the following compound.



PRACTICE PROBLEM 3

Use the rules for naming organic compounds to systematically name the following compound.



SAMPLE PROBLEM 4

Drawing organic compounds with double bonds

click to expand

Draw the structure for 2-methylhex-1-ene.

PRACTICE PROBLEM 4

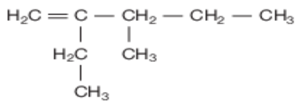
Draw the structure for a molecule of 3-methylpent-1-ene.

SAMPLE PROBLEM 5

Naming organic compounds with double bonds and multiple branches

click to expand

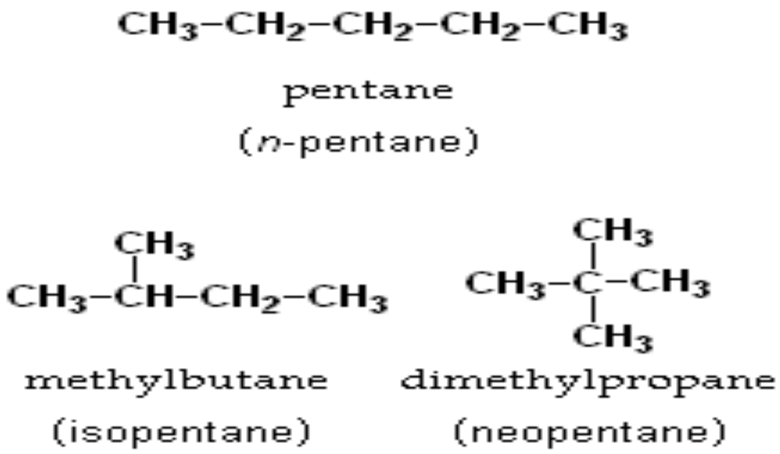
Name the following compound.



ISOMERS

Structural Isomers have the same molecular formula but different structural formula. Structural isomers have different physical properties and names because the molecules have different shapes. The only intermolecular forces are dispersion forces but some isomers can not get as close together and will have lower mp.

Arabic * MERGEFOR



SAMPLE PROBLEM 6

Drawing isomers for alkanes

click to expand

Draw three possible isomers for pentane, C_5H_{12}.

PRACTICE PROBLEM 6

Draw three possible isomers for hexane, C_6H_{14}.

ALCOHOLS

Alcohols are carbon chains containing one or more -OH groups (hydroxyl functional group) and the name ends with -ol.

The general formula for an alcohol is $C_nH_{2n+1}OH$

Alcohols have higher boiling points than the corresponding alkane or alkene as there is hydrogen bonding. The boiling points of alcohols increase with increasing molecular size as the non-polar section of the molecule increases, the strength of the dispersion forces increase. Alcohols are soluble in water because hydrogen bonds can form between alcohol molecules and water molecules. Solubility decreases as the non-polar portion increases (ie with increasing size)

FIGURE 7.25 The first four alcohols shown as their structural formula and their semi-structural formula. Common uses are also listed.

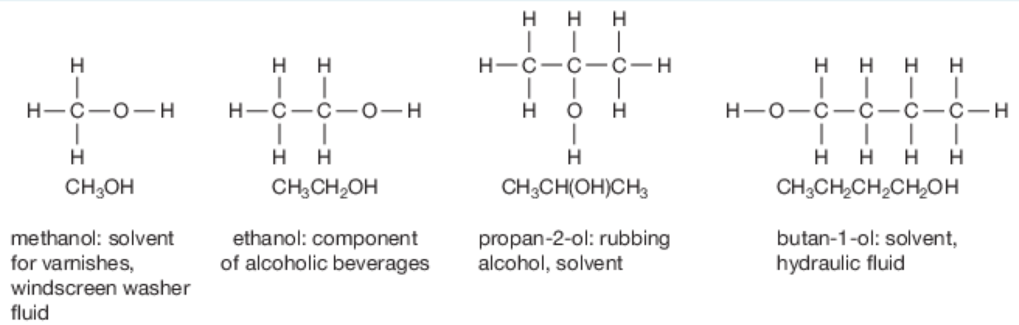
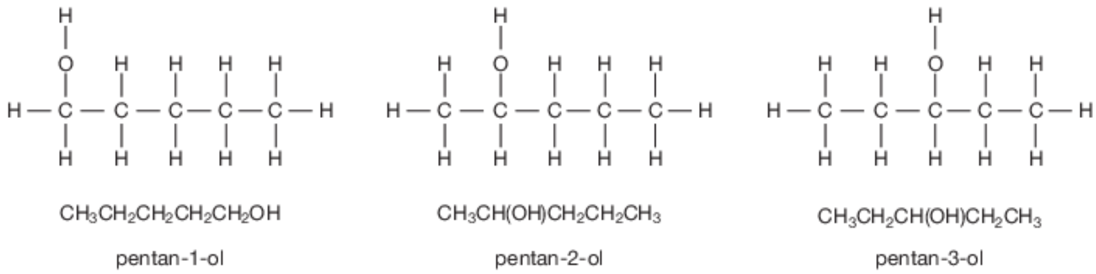


FIGURE 7.26 The structural and semi-structural formulas of the isomers of pentanol, $C_5H_{12}O$



REACTIONS AND USES OF ALCOHOLS

Alcohols undergo combustion with oxygen to form carbon dioxide and water. Smaller alcohols like methanol and ethanol can be used as fuels (or in blends such as E10). Ethanol can be used as a solvent and is in many products such as perfumes or cosmetics. Methanol can be used to make other chemicals. Isopropanol can be used as a skin disinfectant (rubbing alcohol) because of its rapid evaporation rate or to dissolve oil.
Alcohols can react with carboxylic acids to produce esters.

Arabic * MERGEFOR

SAMPLE PROBLEM 7
Determining the properties of various alcohols

click to expand

Consider the following alcohols: ethanol, butan-1-ol and decan-1-ol.

a. Which would have the highest boiling point?
b. Which would be the most soluble in water?

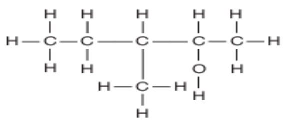
PRACTICE PROBLEM 7
Consider the following alcohols: propan-1-ol, octan-1-ol and pentan-1-ol.

a. Which would have the highest boiling point?
b. Which would be the most soluble in water?

SAMPLE PROBLEM 8
Naming alcohols

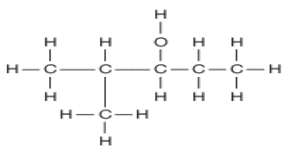
click to expand

a. Name the following molecule.



b. Write the semi-structural formula for this molecule.

PRACTICE PROBLEM 8
a. Name the following molecule.



CARBOXYLIC ACIDS
Carboxylic acids contain the carboxy group (-COOH)

They have the general formula $C_nH_{2n+1}COOH$

Arabic * MERGEFOR

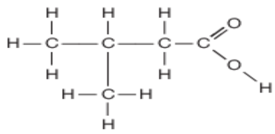
The trends for carboxylic acids are similar to that for alcohols. Carboxylic acids are soluble in water although solubility decreases with size. They have relatively high boiling points due to hydrogen bonding. They are weak acids and many are found in foods.
Carboxylic acids react with bases to form a salt and water. Carboxylic acids react with reactive metals (eg magnesium) to produce a salt and hydrogen gas. Carboxylic acids react with carbonates to form a salt, water and carbon dioxide. Carboxylic acids react with alcohols to form esters (and water).

SAMPLE PROBLEM 9

Naming carboxylic acids

click to expand

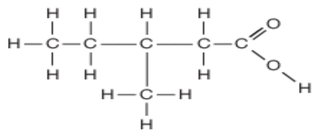
a. Name the following carboxylic acid.



b. Write the semi-structural formula for this compound.

PRACTICE PROBLEM 9

a. Name the following carboxylic acid.



b. Write the semi-structural formula for this compound.

ESTERS

Esters are formed when a carboxylic acid reacts with an alcohol. Esters are organic compound.
Esters can give fruity smells to fruits and synthetic esters can provide suitable smells in commercial products.
The reaction to form an ester is called **esterification** and is a **condensation reaction**.
The functional group for an ester is -COO-

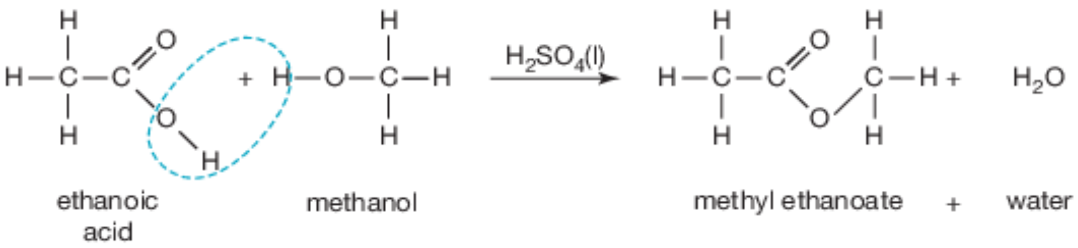
The alcohol provides the first part of the name and the carboxylic acid provides the second part eg ethanol and methanoic acid would form the ester ethyl methanoate.

FORMATION OF AN ESTER

$$\text{carboxylic acid} + \text{alcohol} \xrightarrow{H_2SO_4} \text{ester} + \text{water}$$

$$CH_3COOH(l) + CH_3OH(l) \xrightarrow{H_2SO_4} CH_3COOCH_3(l) + H_2O(l)$$

$$\text{ethanoic acid} + \text{methanol} \xrightarrow{H_2SO_4} \text{methyl ethanoate} + \text{water}$$



SAMPLE PROBLEM 10

Naming esters produced from alcohols and carboxlyic acids

click to expand

Name the esters produced from the following alcohols and carboxylic acids and write their molecular formula.

a. Propanoic acid and ethanol
b. Methanoic acid and ethanol
c. Ethanoic acid and methanol
d. Which two esters from those listed are isomers?

PRACTICE PROBLEM 10

Name the esters produced from the following alcohols and carboxylic acids and write their molecular formula.

a. Propanoic acid and methanol
b. Methanoic acid and propan-1-ol
c. Ethanoic acid and ethanol
d. Which esters from those listed are isomers?

PROPERTIES AND USES OF ESTERS

Esters have low boiling points because the intermolecular force is dipole-dipole and dispersion forces. Esters can form hydrogen bonds with water and smaller esters may be soluble. They become less soluble with size.
Esters can form the original reagents by heating the ester with a dilute acid (sulfuric acid) or dilute base (sodium hydroxide) in a type of reaction called hydrolysis.
Lipids are esters and are important biomolecules in living things.
Biodiesel is a methyl ester which can be used as a fuel.

TABLE 7.7 The trend in ester solubility with increasing molecular size

Name	Formula	Solubility in water (g/100 g)
Ethyl methanoate	$HCOOCH_2CH_3$	10.5
Ethyl ethanoate	$CH_3COOCH_2CH_3$	8.8
Ethyl propanoate	$CH_3CH_2COOCH_2CH_3$	1.7

TABLE 7.8 Some esters and their uses

Name	Common name	Uses
Methyl salicylate		Liniment (treatment for sprains and bruises)
Ethyl ethanoate	Ethyl acetate	Nail polish remover, glue
Ethyl butanoate	Ethyl butyrate	Banana flavouring
Propyl ethanoate	Propyl acetate	Pear flavouring
Ethyl hexanoate		Pineapple flavouring
Acetylsalicylic acid	Aspirin	Pain relief, blood thinner

FOSSIL FUELS AS SOURCES OF HYDROCARBONS

Fossil fuels provide fuels and many of the chemicals that we currently use. Fossil fuels are non-renewable and combustion of fuels produces carbon dioxide. Many of the products from fossil fuels cannot be recycled and the production is an example of a **linear economy**.
Plastics are polymers which are made of monomers.

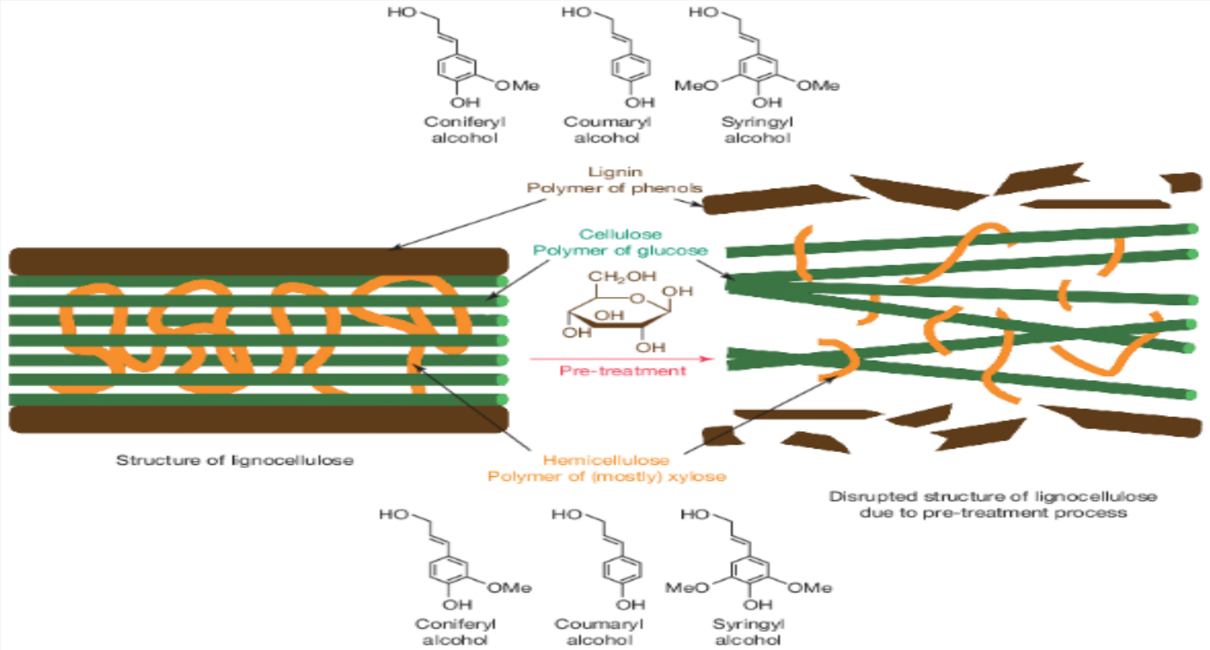
An alternative would be to used **biomass**.

PLANT BIOMASS

One way to reduce the dependency on fossil fuels is to use biomass to produce feedstock chemicals. It may mean that more land is used for these purposes and contribute to deforestation. An alternative is to use non-edible parts of plants or waste material to make it a sustainable process. The use of renewable feedstocks is a core principle of green chemistry and recycling can lead to a circular economy.

Lignocellulose is a common biomass used as an industrial feedstock. Cellulose, hemicellulose and lignin are polymers from trees, shrubs, vegetables and grasses. They don't dissolve in water to it is difficult to break them down. Scientists are working on a number of strategies including the use of ionic liquids, catalysts or lignin degrading bacteria. Biotechnology may result in a wider range of products (eg use of fermentation)

FIGURE 7.36 Lignocellulose must be broken down before it can be used as a feedstock.



USE OF CHEMICALS FROM PLANTS

Lignin - can be converted into renewable compounds for the flavouring industry and plastics, adhesives, surfactants and lubricants

Cellulose - a long unbranched polymer made of glucose monomers that can be made into paper, textiles, pharmaceuticals, cosmetics, emulsifiers, detergents and explosives.
Hemicellulose from wood biomass - small branched polymer cf cellulose and has many monomers than can be used to make furans to make lycra, takeaway cups and ethanol.

MATERIALS AND PRODUCTS FROM ORGANIC COMPOUNDS

Look at the extensive table 7.9 pages 298 - 299 on materials made from organic compounds (7.5.3).
Is there a use of organic compounds that you were not aware of?

REVIEW

Complete the review questions from the Question Guide
Make sure you understand the flowchart
Read through the summary (including the glossary)