Organic Chemistry

Definitions

Homologous series: A homologous series is a family of organic compounds which conform to the same general formula and each member differs from the next by a $-CH_2$ group. Compounds in the same homologous series contain the same functional group and have similar chemical properties.

Funtional group: A functional group is an atom or a group of atoms that gives a molecule its characteristic properties.

Alkanes: Alkanes are compounds which conform to the general formula of C_nH_{2n+2}. Each member of the alkane homologous series differs from the next by a $-CH_2$ unit.

Alkenes: Alkenes are compounds which conform to the general formula of C_nH_{2n}. Each member of the alkene homologous series differs from the next by a $-CH_2$ unit.

Alcohols: Alcohols are compounds which conform to the general formula of $C_nH_{2n+1}OH$. Each member of the alcohol homologous series differs from the next by a $-CH_2$ unit.

Carboxylic acids: Carboxylic acids are compounds which conform to the general formula of $C_nH_{2n+1}COOH$. Each member of the alkane homologous series differs from the next by a $-CH_2$ unit.

Structural isomers: Structural isomers are compounds which have the same molecular formulae but different structural formulae.

Unsaturated: A unsaturated compound contains C=C bonds (carbon-carbon double bond).

Polyunsaturated: A substance is said to be polyunsaturated if it contains multiple carbon-carbon double bond.

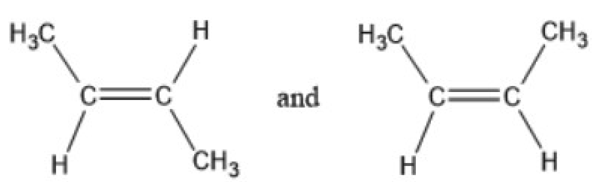
Macromolecule: A macromolecule is a long-chain / large molecule that is formed by linking together many small repeating units known as monomers. Different macromolecules have different units and/or different linkages.

Polymerisation: The process of joining together a large number of small molecules (monomers) to form macromolecules.

Addition polymerisation: Addition polymerization is the process whereby a large number of small repeating units join together without losing any molecules or atoms to form a polymer.

Condensation polymerisation: Condensation polymerisation is the process whereby a large number of small repeating units join together with the elimination of small molecules such as H_2O, HCl etc to form a polymer.

Geometric isomers example



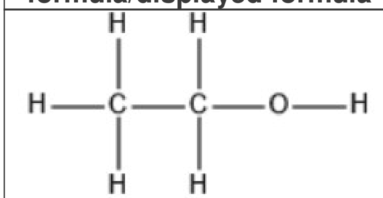
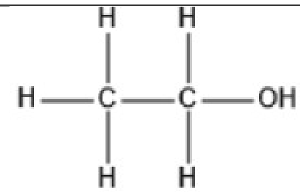
Naming of organic compounds

The names of organic compounds consist of a prefix, suffix, and occasionally a number to denote the position of the functional group.

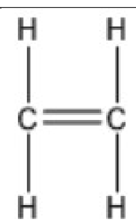
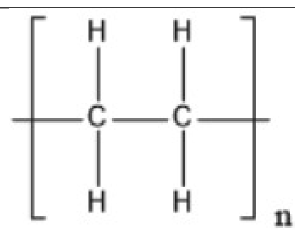
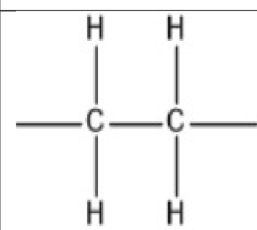
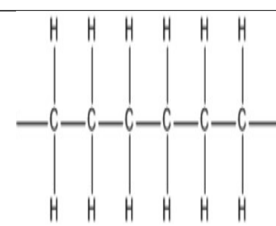
No of C atoms	Prefix
1	meth–
2	eth–
3	prop–
4	but–
5	pent–
6	hex–
7	hept–
8	oct–
9	non–
10	dec–

Functional group	Suffix
alkane	–ane
alkene	–ene
alcohol	–ol
carboxylic acid	–oic
ester	–oate

Different types of formula/structures

Full structural formula/displayed formula	Structural formula	Condensed formula
		CH_3CH_2OH
Formula	**Molecular formula**	**Empirical formula**
C_2H_5OH	C_2H_6O	C_2H_6O

Different types of structures for macromolecules

Monomer	Formula	1 repeating unit	3 repeating units/part of the structure
			

Physical properties

Physical property	Properties for different functional groups	Trend
Melting point/Boiling point	Alkanes and alkenes with 4C or less are gases Alcohols and carboxylic acids are liquids or solids	↑ as no of C ↑ Vdw forces becomes stronger as Mr increases, requiring more energy to overcome
Viscoscity		↑ as no of C ↑ Vdw forces becomes stronger as Mr increases, therefore it is harder for the liquid to flow
Solubility in water	Alkanes and alkenes are insoluble Alcohols and carboxylic acids are soluble	↓ as no of C ↑
Density	Generally less dense than water	↑ as no of C ↑
Flammability		Flammability ↓ as no of C ↑, as the number of bonds to be broken ↑, which ↑ Ea

Summary of organic chemistry reactions

Combustion

Examples:

Complete combustion

CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (*l*)

Incomplete combustion

$3CH_4$ (g) + $5O_2$ (g) → CO_2 (g) + 2CO (g) + $6H_2O$ (*l*)

$2CH_4$ (g) + $3O_2$ (g) → CO_2 (g) + C (s) + $4H_2O$ (*l*)

Reactants: oxygen

Conditions: –

Note: Substances with higher % by mass of C (eg alkenes vs alkanes) have higher tendency to undergo incomplete combustion.

Substitution reaction of alkane

Examples:

$CH_4 + Cl_2$ → CH_3Cl + HCl

$CH_4 + Br_2$ → CH_3Br + HBr

Reactants: Cl_2 (g) or Br_2 (*l*)

Conditions: uv light

Note: Multiple substitutions can occur to produce CH_2Cl_2, $CHCl_3$ and CCl_4

Catalytic cracking of long chain hydrocarbons

Examples:

$C_{12}H_{26} \rightarrow C_4H_{10} + C_8H_{16}$

$C_{18}H_{38} \rightarrow C_8H_{16} + C_{10}H_{20} + H_2$

Reactants: –

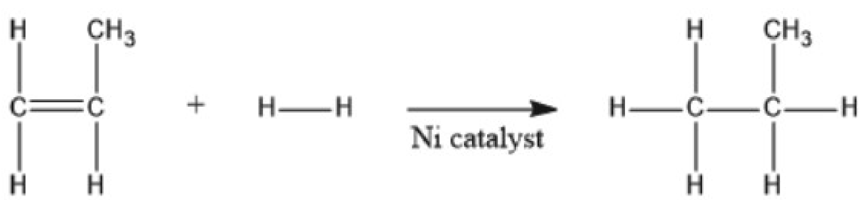
Conditions: Al_2O_3 or SiO_2 as catalyst, high temperature

Note:

- Used to produce short chain alkanes to meet the demand for these alkanes, especially petrol
- Used to produce short chain alkenes as raw material to manufacture ethanol and plastics like poly(ethene).
- Used to produce hydrogen, which is an important raw material for the manufacture of ammonia in the Haber Process and the manufacture of margarine, and also as fuel for rockets and hydrogen-oxygen fuel cells.

Addition of hydrogen (hydrogenation)

Example:



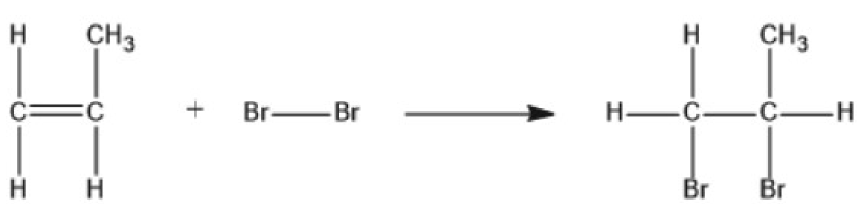
Reactants: H_2 (g)

Conditions: Ni as catalyst, heat

Note: Used to manufacture margarine (solid at rtp) from vegetable oil (liquid at rtp)

Addition of bromine (bromination)

Example:



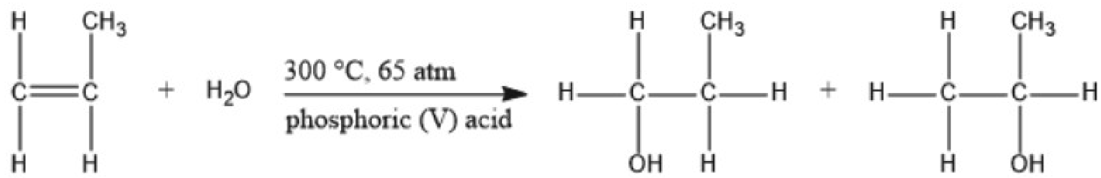
Reactants: Br_2 (*l*) or Br_2 in CCl_4

Conditions: absence of uv light

Note: Can be used as distinguishing test for alkenes.

Addition of steam (hydration)

Example:



Reactants: steam

Conditions: 300 ℃, 65 atm, phosphoric (V) acid as catalyst

Note: The hydrogen atom and hydroxyl group can add to either side of the C=C, forming 2 possible products if an unsymmetrical alkene is reacted.

Fermentation

Example:

$C_6H_{12}O_6$ (aq) → $2CO_2$ (g) + $2C_2H_5OH$ (aq)

Reactants: yeast, water

Conditions: 37 ℃, no light, anaerobic condition

Note:

- Kept at 37 ℃ because yeast's enzymes will be denatured above this temperature.
- Fermentation of sugars produces only a dilute solution of ethanol (up to about 15 %) because enzymes will also be denatured if percentage of ethanol goes beyond 15%. Ethanol can then be obtained from this liquid mixture by fractional distillation.
- Anaerobic condition is used because yeast will adopt aerobic respiration when oxygen is present, resulting in formation of water and carbon dioxide instead of ethanol and carbon dioxide. The ethanol produced may also be oxidised by oxygen to produce ethanoic acid (turns sour).

Ethanol made from fermentation is a carbon-neutral fuel because:

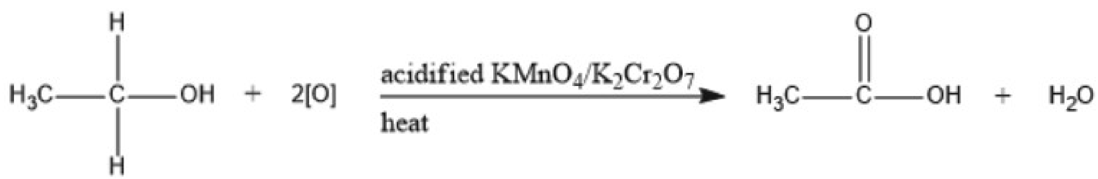
1) Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
2) Fermentation: $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$
3) Combustion: $2C_2H_5OH + 6O_2 \rightarrow 6H_2O + 4CO_2$

Comparison between hydration and fermentation

	Addition of steam	**Fermentation**
Time	Takes shorter time	Takes longer time
% yield	100%	15% ethanol solution
Types of alcohol produced	Different alcohols can be obtained	Only ethanol
Cost	Higher	lower
Renewability	Renewable because ethene comes from petroleum	Renewable because glucose comes from sugar cane

Oxidation of alcohols with acidified $KMnO_4/K_2Cr_2O_7$

Oxidation of primary alcohol example 1:



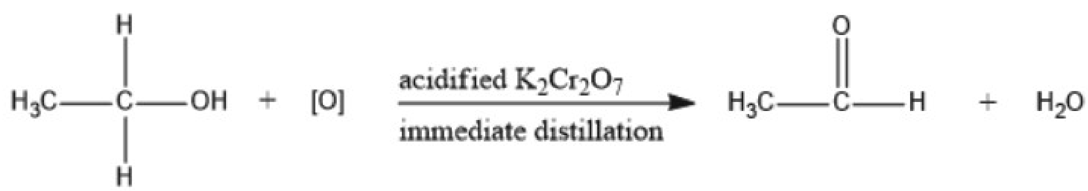
[O] represents oxygen from oxidising agent

Reactants: acidified $KMnO_4/K_2Cr_2O_7$

Conditions: heat under reflux

Note: Can be used as distinguishing test

Oxidation of primary alcohol example 2:

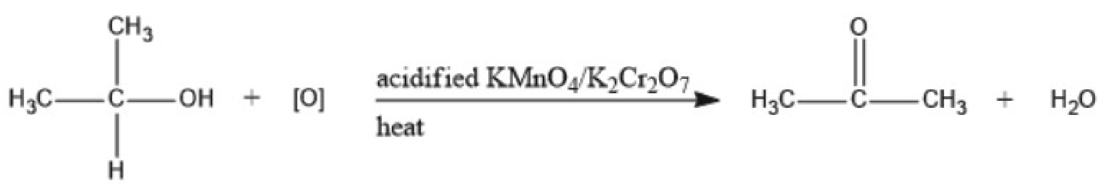


Reactants: acidified $K_2Cr_2O_7$

Conditions: immediate distillation

Note: Can be used as distinguishing test

Oxidation of secondary alcohol example:

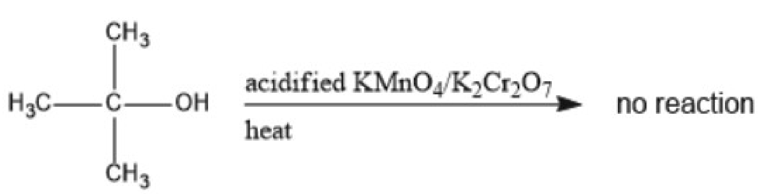


Reactants: acidified $KMnO_4/K_2Cr_2O_7$

Conditions: heat under reflux

Note: Can be used as distinguishing test

Oxidation of tertiary alcohol example:



Oxidation of alcohol by oxygen in the air with bacteria

Example:

C_2H_5OH (aq) + 2[O] → CH_3COOH (aq) + H_2O (*l*)

[O] represents oxygen from oxidising agent

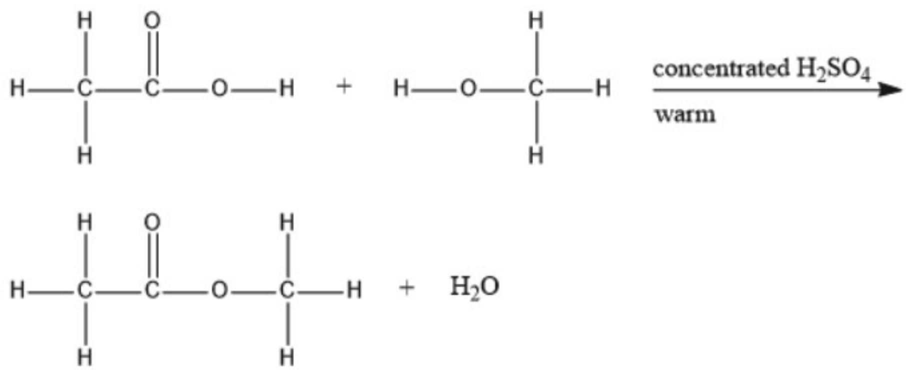
Reactants: oxygen in the air

Conditions: action by bacteria in the air

Note: This causes alcoholic drinks to turn sour if exposed to the air for some time due to oxidation of ethanol to ethanoic acid.

Esterification

Example:



Reactants: carboxylic acid with alcohol

Conditions: concentrated H_2SO_4 as catalyst, warm

Note: When naming the ester, the alcohol should be named before the acid. For example, the ester formed above is methyl ethanoate.

Reaction of carboxylic acid with reactive metal

Example:

$2CH_3COOH + Mg$ → $(CH_3COO)_2Mg + H_2$

Reactants: reactive metal

Conditions: –

Note: Can be used as distinguishing test for carboxylic acid. Very reactive metals like sodium should not be used.

Reaction of carboxylic acid with carbonate

Example:

$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$

Reactants: any carbonate

Conditions: –

Note: Can be used as distinguishing test for carboxylic acid

Reaction of carboxylic acid with base

Example:

$2CH_3COOH + MgO \rightarrow (CH_3COO)_2Mg + H_2O$

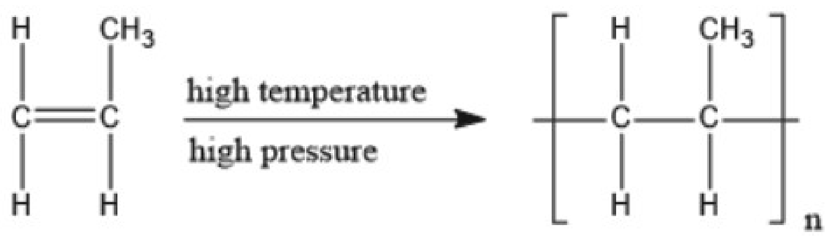
Reactants: any base

Conditions: –

Note: –

Addition polymerisation

Example:



Reactants: alkene monomer

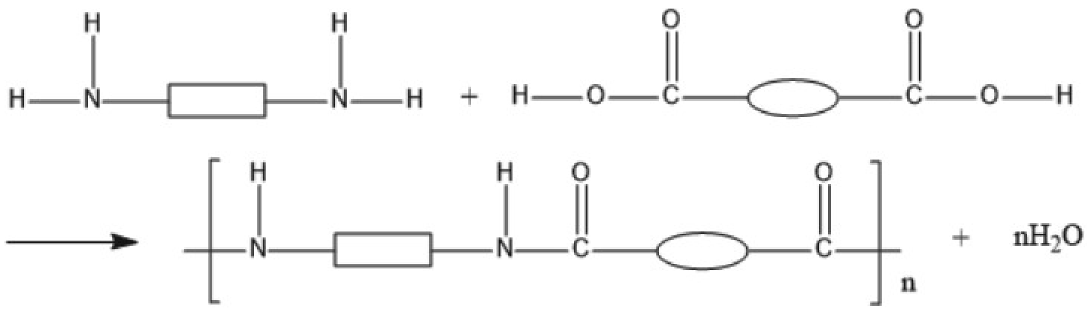
Conditions: high temperature and pressure

Note: The polymers formed will be a mixture of polymers with different chain lengths, so there will be a range of melting points.

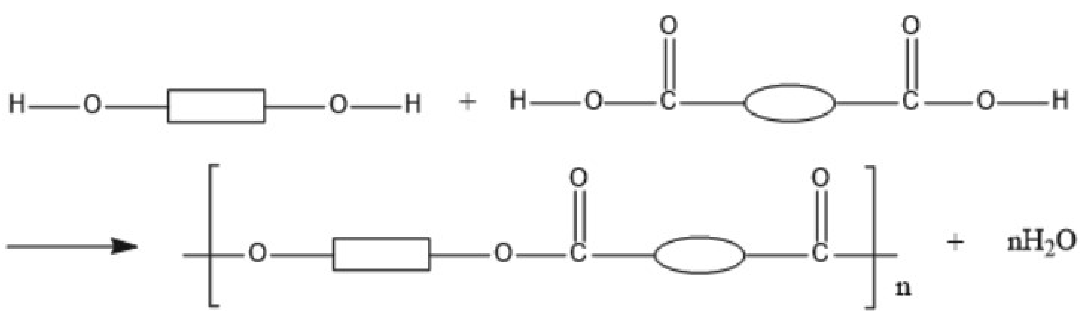
Condensation polymerisation

Examples:

Formation of Nylon (polyamide)



Formation of Terylene (polyester)



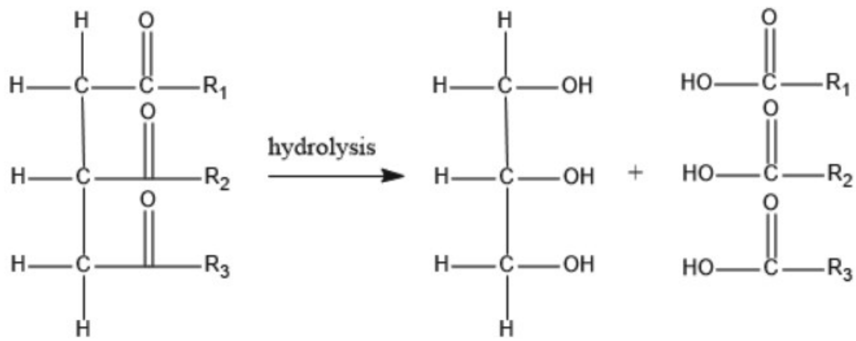
Reactants: diamine + dicarboxylic acid, diol + dicarboxylic acid, monomer with 1 alcohol and 1 carboxylic acid group, etc

Conditions: –

Note: The polymers formed will be a mixture of polymers with different chain lengths, so there will be a range of melting points.

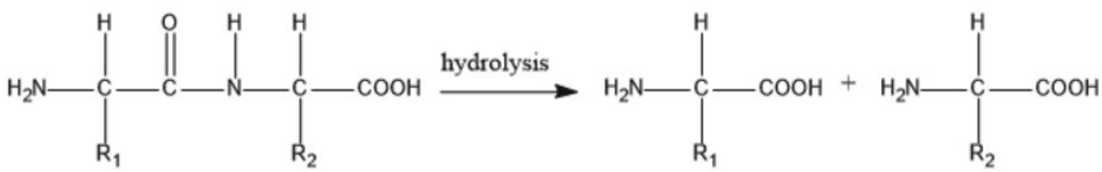
Hydrolysis of fats and proteins

Hydrolysis of fats example:



Note: R_1, R_2 and R_3 are H or any carbon chain

Hydrolysis of polypeptide example:



Summary of distinguishing tests

Functional Group	Distinguishing test
Alkane	NA
Alkene	Reddish brown bromine will turn colourless spontaneously if alkene is present.
Alcohol	Purple acidified potassium manganate(VII) solution will turn colourless OR orange acidified potassium dichromate(VI) solution will turn green if primary or secondary alcohol is present.
Carboxylic acid	If carboxylic acid is present, when sodium carbonate is added, there will be effervescence of a colourless odourless gas that forms a white precipitate in limewater.
Ester	If ester is present, there will be a sweet smell.

Explanation of how petroleum fractions are separated

1. Petroleum is heated in a furnace and vapourised. The hot vapour will flow up the fractionating column and start to cool down.
2. Each fraction condenses at a different temperature and comes out of the column at different height depending on their boiling points.
3. The hydrocarbons with the lower boiling point range will distill over at the top of the column, where the temperature is lower, while the ones with the higher boiling point range will distil over at the bottom where the temperature is higher.

Different petroleum fractions and their uses

Fraction	No. of carbon atoms (n)	Boiling Point Range (ºC)	Uses
Petroleum gas	1 – 4	< 40	Fuel for cooking
Petrol (Gasoline)	5 – 10	40 – 75	Fuel for car engines
Naphtha	7 – 14	75 – 150	Feedstock (raw material) for petrochemicals (E.g. plastics, detergents, alcohol, drugs)
Kerosene (Paraffin)	11 – 16	160 – 250	Fuel for jet engines; cooking and heating
Diesel	16 – 20	250 – 300	Fuel for diesel engines of buses, taxis and lorries
Lubricating oil	20 – 35	300 – 350	Lubricants for machines; making of waxes and polishes
Bitumen	>70	> 350	Make road surfaces

Issues related to fossil fuels

- Petroleum is a finite non-renewable resource and the world's petroleum reserves are depleting.
- The supply of petroleum is being depleted very rapidly, and there is a need for its conservation.
- Petroleum, besides being used as fuel, has other important uses like being used as a raw material for the manufacture of essential chemical compounds like medicine and plastics.
- Combustion of petroleum also contributes to pollution (due to the production of CO and C) and global warming (due to the production of CO_2).

Alternative fuels

Possible sources of alternative fuels:

- Palm oil and ethanol (from sugarcane) from plants can be used as fuels for vehicles.
- Methane produced when organic matter (waste material from plants and animals) is allowed to decay in the absence of air.
- Hydrogen which can be obtained from photolysis of water (renewable) or from catalytic cracking of long chain hydrocarbon (non-renewable).

Advantages of using hydrogen as an alternative fuel:

1. Clean fuel, producing only water.
2. Renewable, can be manufactured. (Note that this only applies if hydrogen is obtained from water instead of petroleum)
3. Produces more energy per unit mass (reaction is more exothermic).

Disadvantages of using hydrogen as an alternative fuel:

1. Hydrogen needs to be liquefied for both transport and storage, which increases costs.

Uses of ethanol

- In alcoholic drinks
- As a fuel for motor vehicles
- As a solvent in pains, varnishes, deodorants and perfumes

Uses of esters

- Used as solvent for cosmetics and glue.
- Used in preparation of perfumes and artificial food flavouring because they are sweet smelling.

Uses of macromolecules

Macromolecule	Uses + related propeties
Poly(ethane)	Used to make plastic bottles, plastic bags and clingfilm
Nylon	It is used for making strong ropes, fishing lines, zippers, tents, parachutes and rain coats Nylon is light yet strong; can be stretched without breaking; waterproof.
Terylene	It is made into fibre and woven into cloth, used for making clothes and curtains. Terylene is shrink-proof and crease-proof, which makes it easy to wash and dry.

Advantages and disadvantages of macromolecules

Advantages	Disadvantages
Light, tough and waterproof	Burn easily; a fire risk in buildings and vehicles
Resistant to decay, corrosion and chemical attack	Causes air pollution: When plastics are disposed of by burning, poisonous gases like CO may be produced when there is insufficient oxygen. Plastics like PVC also produce very acidic gases like hydrogen chloride (HCl).
Can be easily moulded into various shapes	Causes land pollution: Plastics are non-biodegradable (cannot be decomposed by bacteria in the soil). They will not rot when buried underground. Accumulation of plastic waste takes up space and causes land pollution.