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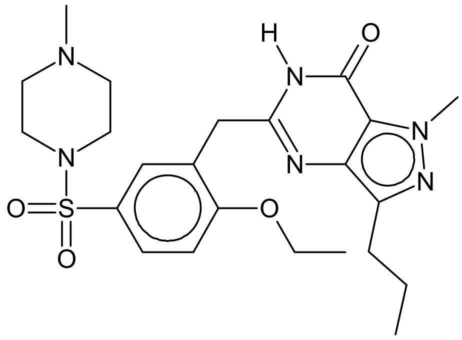
Chem Lectures

19. EVERYTHING ABOUT ORGANIC CHEMISTRY

1. Fuels and Crude Oil
2. Alkanes and Alkenes
3. Alcohols, Carboxylic Acids and Esters
4. Macromolecules

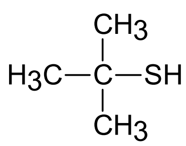
Let's take a look at the molecule below:



The molecule above is Viagra®, and its purpose, to treat erectile dysfunction in men! Current statistics show that 1 in 10 men in the World have erectile dysfunction, and when translated to Singapore with a population of 4.5 million, this means that 450000 men have this problem!

The Viagra® molecules looks pretty complicated at first sight, but it is actually a very simple molecule. Not to mention, it has helped Pfizer, the company which synthesized the molecule, earn millions of dollars every year!

Something closer to us, have you ever wondered why cooking gas smells like "cooking gas"? Actually, the gas itself is odourless, but very small amounts of an organic compound such as *tert*-butylthiol is added to give it a characteristic odour.



tert-butylthiol

The smell of this organic compound is so pungent that only 1 part in 5×10^{10} parts is required for humans to detect the smell!

Yes, organic chemistry is rich (and sometimes aromatic) science! Rich in that it is a vast pool of knowledge waiting to be exploited. Rich in that it encompasses many aspects of importance in the biological world. Rich in that it is a field of science which can potentially earn millions or billions of dollars for both companies and economies!

Learning Outcomes

1. Name natural gas and petroleum as sources of energy.
2. Describe petroleum as a mixture of substances and its separation into useful fractions by fractional distillation.
3. Name the fractions from the fractional distillation of petroleum and state their uses.
4. Discuss issues relating to the competing uses of oil as an energy source and as a chemical feedstock.
5. Describe a homologous series and its general characteristics.
6. Describe the alkanes and alkenes as homologous series in terms of their general formulae, similar chemical properties and gradation in physical properties.
7. Draw the structures of the C_1 to C_4 alkanes and C_2 to C_4 alkenes and name the unbranched structures.
8. Describe the properties of alkane and alkenes.
9. Describe the differences between saturated and unsaturated hydrocarbons from the structures and use of aqueous bromine.
10. Define isomerism and identify isomers.
11. State the meaning of polyunsaturated when applied to food products.
12. Describe the manufacture of margarine.
13. Describe the manufacture of alkenes and hydrogen by cracking hydrocarbons.
14. Describe the alcohols and organic acids as homologous series containing the –OH and –COOH groups respectively.
15. Draw the structures of the first four members of each homologous series and name the unbranched structures.
16. Describe some properties and reactions of alcohols and organic acids.
17. Describe the formation of ethanol and ethanoic acid and state some of their uses.
18. Describe the formation of esters and state some of their commercial uses.
19. Describe the term macromolecule.
20. Describe the formation of polyethene as an example of addition polymerisation.
21. State some uses of polyethene as a typical plastic.
22. Deduce the structure of a polymer from a given monomer and vice versa.
23. Describe nylon and terylene as condensation polymers.
24. State some typical uses of man-made fibres such as nylon and terylene.
25. Describe pollution problems caused by the disposal of non-biodegradable plastics.

Fuels and Crude Oil – Pre-Reading Segment

1. What are Fuels?

- A fuel is a substance that is burnt to produce heat energy.

- **Petroleum** (also called crude oil) is a thick black liquid which contains **a mixture of hydrocarbons**. It can be separated into useful fractions by **fractional distillation**. Large amounts of petroleum are produced in the Middle East, the USA and Russia.

Hydrocarbons = compounds made up of only C and H

- **Natural gas** is a colourless gas which contains mainly **methane**, CH_4. Natural gas is usually found together with the petroleum in the Earth.

- **Complete combustion** of petroleum or natural gas in sufficient oxygen gives rise to carbon dioxide and water, e.g.,

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

- **Incomplete combustion** of petroleum or natural gas gives rise to carbon monoxide and carbon (also known as soot), together with water and carbon dioxide, e.g.,

$$2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(g)$$
$$CH_4(g) + O_2(g) \rightarrow C(s) + 2H_2O(g)$$

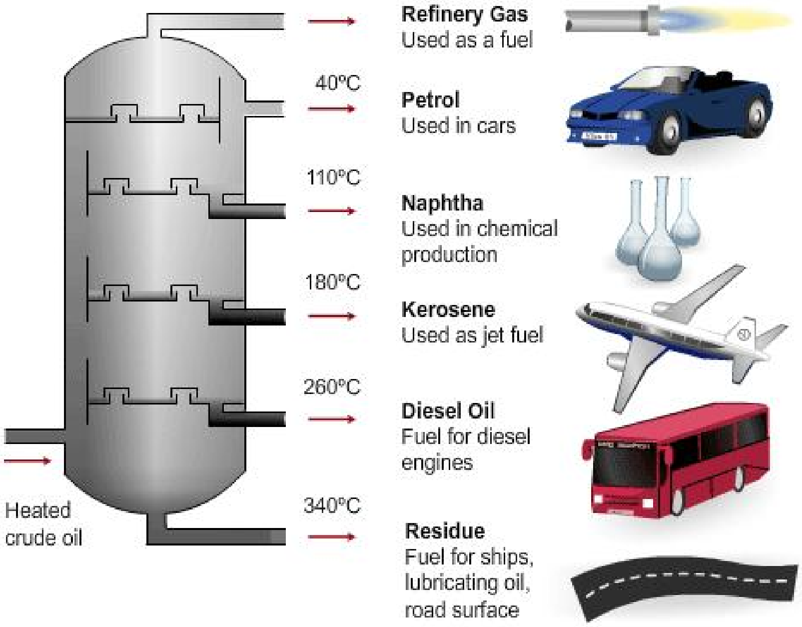
- Petroleum and natural gas are called fossil fuels because they are formed from the remains of animals which died hundreds of millions of years ago. They are found between layers of non-porous rocks. And oil rig is used to drill a hole through the rock layers to extract the petroleum and natural gas.

2. Fractional Distillation of Petroleum

- The hydrocarbons in the petroleum can be separated into useful fractions by **fractional distillation**.

- This is carried out in a **fractionating column** where separation of a mixture of hydrocarbons is based on different boiling points of the hydrocarbons in a mixture.

- The petroleum is first heated in a furnace. The **oil vaporises** and **passes up the fractionating column**. The fractions condense out of the column at different heights **depending on their boiling points**.



- **Heavy fractions** (contains molecules with higher molecular masses) have **higher boiling points** and condense on the bubble caps. They come out as fractions nearer the bottom of the column.

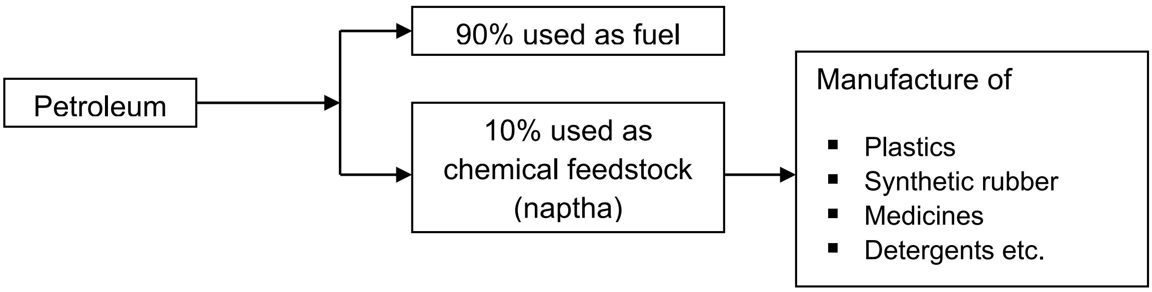
- **Lighter fractions** (contains molecules with lower molecular masses) have **lower boiling points** and their vapours are able to carry on up the column. They come out as fractions nearer the top of the column.

- The properties of the fractions vary with increasing number of carbon atoms per molecule:
  (a) Boiling point range increases
  (b) More viscous
  (c) Less flammable
  (d) Burn with a more smoky flame

Fraction	Boiling point/ °C	Size of molecules	Uses
Petroleum gas	below room temperature	Up to 4 C atoms	• Bottled gas for cooking and heating
Petrol (gasoline)	35-75	5-10 C atoms	• As fuel for car engines
Naphtha	70-170	7-14 C atoms	• Used as chemical feedstock for chemical industry (e.g., petrochemical industry – manufacture of plastics, detergents, etc)

Fraction	Boiling point/ °C	Size of molecules	Uses
			• As fuel to provide energy
Paraffin (Kerosene)	170-250	10-16 C atoms	• Used as a fuel for aircraft engines • Use as a fuel for heating and cooking
Diesel oil	250-340	14-25 C atoms	• Used as a fuel for diesel engines
Lubricating oil	350-500	20-35 C atoms	• Used as lubricants for machines and as a sources of polishes and waxes
Bitumen	Above 450	More than 50 C atoms	• For making road surfaces

3. Main Uses of Petroleum



- Petroleum is non-renewable resource and the world's petroleum reserves are finite. With the supply of petroleum decreasing rapidly, there is a growing need for its conservation.

- About 90% of the petroleum is burnt as fuel. However, petroleum is also important as a chemical feedstock for the manufacture of chemical compounds which are essential for our comfort and health such as medicines etc. Therefore it is a waste to just burn petroleum away.

- The burning of petroleum can cause pollution and global warming.

Fuels and Crude Oil – End of Pre-Reading Segment

Alkanes

4.1 Classification of Organic Compounds

- Organic compounds are classified into different families. Compounds in the same family have the same functional group.

- A functional group is an atom or group of atoms that gives a compound its characteristic chemical properties.
  - Alkenes: C=C
  - Alcohols: –OH
  - Carboxylic: –COOH

- A homologous series is a group of compounds with a **general formula**, **similar chemical properties** and **showing a gradation in physical properties** as a result of increase in the size and mass of the molecules, e.g. melting and boiling points, viscosity, flammability.

  (a) Members have the same general formula; each member differs from the next by a – CH_2– group of atoms.

  (b) Have chemical properties which are very similar for each member (since they have the same functional group)

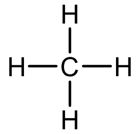
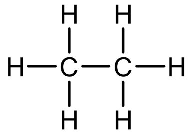
  (c) Have physical properties which show a steady gradation on going down the series.

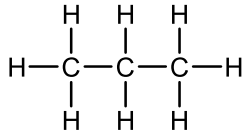
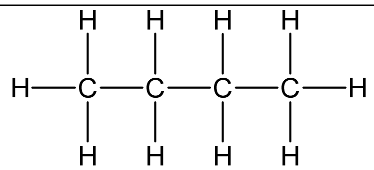
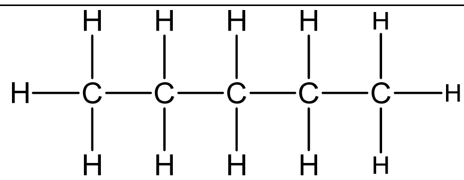
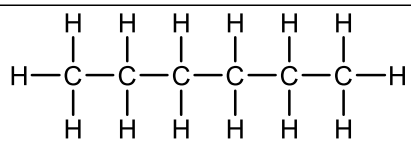
  (d) Can be made by similar methods.

4.2 What are Alkanes

- **Alkanes** form a homologous series consists of **saturated hydrocarbons** with the general formula $\mathbf{C_nH_{2n+2}}$. Each subsequent alkene varies by a -CH_2- group. Alkanes are compounds contain only carbon-carbon single covalent bonds (C–C) and carbon-hydrogen single covalent bonds (C–H).

- Each carbon atom is bonded to 4 other atoms with single covalent bonds.
  Note: Saturated hydrocarbons contain only single covalent carbon-carbon bonds

Alkane	Molecular formula	Displayed Structural formula **(shows how all the atoms in a molecule are bonded together)**	Relative molecular mass	Boiling point/ °C	State (at r.t.p)
methane	CH_4		16.0	-161	gas
ethane	C_2H_6		30.0	-89	gas

Alkane	Molecular formula	Displayed Structural formula **(shows how all the atoms in a molecule are bonded together)**	Relative molecular mass	Boiling point/ °C	State (at r.t.p)
propane	C_3H_8		44.0	-42	gas
butane	C_4H_{10}		58.0	-1	gas
pentane	C_5H_{12}		72.0	36	liquid
hexane	C_6H_{14}		86.0	69	liquid

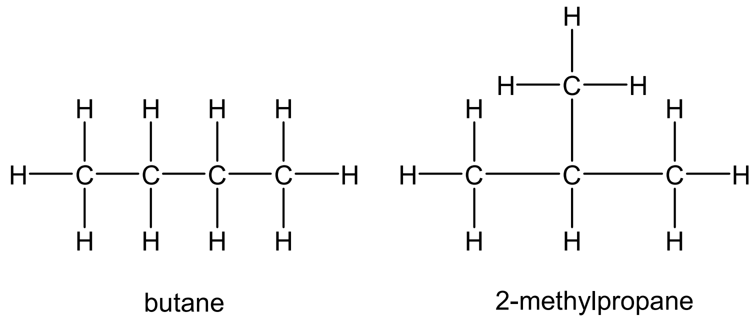
Checkpoint 1

1. Ethane is an alkane with 2 carbon atoms.
   (a) Draw the structural formula of ethane.

   (b) Draw a 'dot-and-cross' diagram to show the bonding in ethane. Show only the outermost electrons.

4.3 Isomerism in Alkanes

- Isomers are compounds with the **same molecular formula** but different structural formula.



Name	Butane	2-methylpropane
Molecular formula	C_4H_{10}	C_4H_{10}
Density	0.58 g dm^{-3}	0.56 g dm^{-3}
Melting point	-138 ^oC	-138 ^oC
Boiling point	-0.5 ^oC	-11.7 ^oC

- The smallest alkane member to exhibit isomerism has 4 carbon atoms i.e., the molecular formula is C_4H_{10}. The molecular formulae C_4H_{10} could represent butane (an unbranched alkane) or 2-methylpropane (a branched alkane).

- These isomers have similar functional groups hence similar chemical properties, but they differ in physical properties.

4.4 Physical Properties of Alkanes

Name	Molecular formula	M.p. (^oC)	B.p. (^oC)	State at r.t.p.*	Density (g/cm^3)
methane ethane propane butane	CH_4 C_2H_6 C_3H_8 C_4H_{10}	–182 –172 –187 –138	–162 –89 –42 –0.5	gas	0.000 68 0.001 27 0.001 86 0.002 45
pentane hexane • • • heptadecane	C_5H_{12} C_6H_{14} • • • $C_{17}H_{36}$	–130 –95 • • • 22	36 69 • • • 292	liquid	0.63 0.66 • • • 0.77
octadecane nonadecane	$C_{18}H_{38}$ $C_{19}H_{40}$	28 32	308 320	solid	0.78 0.78

* room temperature and pressure

(1) Melting and boiling point

The **melting point and boiling point of the alkanes increases as the relative molecular mass increases**. More energy is required to overcome the stronger van der Waals forces of attraction between the alkane molecules.

(2) Solubility

Alkanes are compound with simple molecular structure. They are **insoluble in water but soluble in organic solvents** such as benzene and tetrachloromethane.

(3) Density

The densities of the alkanes **increase as their relative molecular mass increase**. In general, the liquid alkanes are less dense than water.

(4) Viscosity

The alkanes **become more viscous, i.e., more difficult to flow as their relative molecular mass increase**. The stronger van der Waals forces between the alkane molecules require more energy to be broken. The longer molecules also results in more 'entanglement'.

(5) Flammability

As the **relative molecular mass of alkane molecules increases**, the percentage of carbon in the alkane molecules also *increases*. They are **more difficult to burn**, and when burnt, produce a smokier flame. The smoky flame is caused by the incomplete combustion of alkane molecules.

4.5 Chemical Properties of Alkanes

- Alkanes are generally unreactive due to the strong C–C and C–H bonds.

(1) Combustion

- Complete combustion occurs when alkanes are burnt in sufficient oxygen to produce carbon dioxide and water only.

  $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

- Incomplete combustion occurs when alkanes are burnt in insufficient oxygen. Carbon monoxide, soot and water are formed.

  $2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(g)$
  $CH_4(g) + O_2(g) \rightarrow C\ (s) + 2H_2O(g)$

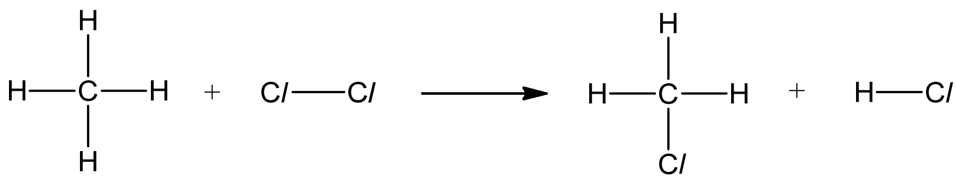
- Combustion is an exothermic reaction.

(2) Substitution – reaction with halogens

- A substitution reaction involves the replacement of the hydrogen atoms in the alkane molecules with another atom(s) (in this case, halogen atoms).

- Alkanes can react with chlorine in the presence of UV light, e.g., methane with chlorine.

$$CH_4(g) + Cl_2(g) \longrightarrow \underset{\textit{chloromethane}}{CH_3Cl(g)} + HCl(g)$$



Enrichment

Substitution of methane by chlorine in the presence of UV light can proceed until all the hydrogen atoms have been substituted.

$$CH_4(g) + Cl_2(g) \longrightarrow \underset{\textit{chloromethane}}{CH_3Cl(g)} + HCl(g)$$

$$CH_3Cl(g) + Cl_2(g) \longrightarrow \underset{\textit{dichloromethane}}{CH_2Cl_2(g)} + HCl(g)$$

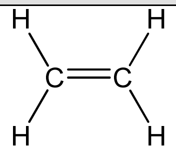
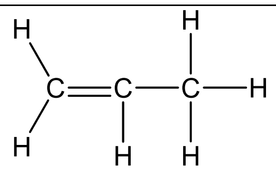
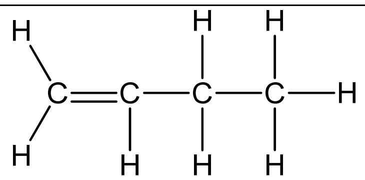
$$CH_2Cl_2(g) + Cl_2(g) \longrightarrow \underset{\substack{\textit{trichloromethane} \\ \textit{(chloroform)}}}{CHCl_3(l)} + HCl(g)$$

$$CHCl_3(l) + Cl_2(g) \longrightarrow \underset{\textit{tetrachloromethane}}{CCl_4(l)} + HCl(g)$$

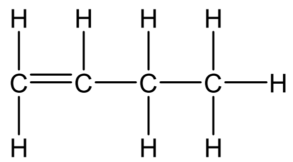
Alkenes

4.6. What are Alkenes

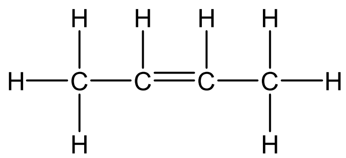
- **Alkenes** form a homologous series consists of **unsaturated hydrocarbons** with the general formula $\mathbf{C_nH_{2n}}$. Each subsequent alkene varies by a $-CH_2-$ group. Alkenes are compounds containing carbon-carbon double covalent bond (C=C) and carbon-hydrogen single covalent bond (C–H).

Name	Molecular formula	Displayed Structural formula	Melting Point / °C	Boiling point /°C	Density / g cm^{-3}	Physical State (at r.t.p)
ethene	C_2H_4		-169	-104	-	gas
propene	C_3H_6		-185	- 47	-	gas
butene	C_4H_8		-185	- 6	-	gas
pentene	C_5H_{10}	-	-135	30	0.63	liquid
hexene	C_6H_{12}	-	-140	64	0.67	liquid
heptene	C_7H_{14}	-	-119	93	0.70	liquid
octene	C_8H_{16}	-	-104	122	0.72	liquid

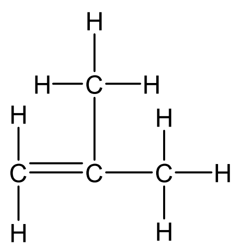
- The smallest alkene member to exhibit structural isomerism has 4 carbon atoms, i.e., the molecular formula is C_4H_8.



1-butene
(but-1-ene)



2-butene
(but-2-ene)



2-methylpropene

4.7 Physical Properties of Alkenes

- Similar to alkanes, the melting points, boiling points, densities and viscosities increases as relative molecular mass increases; the flammability decreases.

4.8 Chemical Properties of Alkenes

- Alkenes are more reactive than alkanes because they contain carbon-carbon double covalent bond.

(1) Combustion

- Alkenes have a higher percentage of carbon compared to alkanes, and burn with sootier flames compared to alkanes with similar number of carbon atoms, to give carbon dioxide and water.

$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$ Complete combustion
$C_2H_4(g) + 2O_2\,(g) \rightarrow 2CO(g) + 2H_2O(g)$ Incomplete combustion

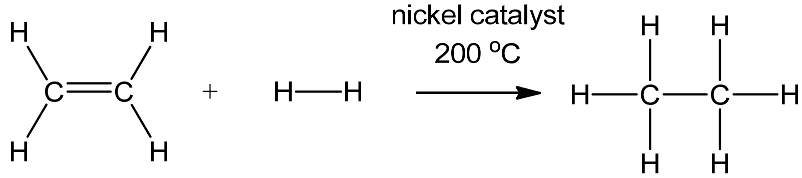
(2) Addition reactions – with (A) hydrogen, (B) halogens, (C) steam, (D) alkene molecules

- The C=C group in alkenes reacts with chemicals in addition reactions. An addition reaction is one in which two or more molecules react to form a single product.

- **Addition of hydrogen**

  - Also known as hydrogenation.
  - Requires a nickel catalyst.
  - Used in the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product.

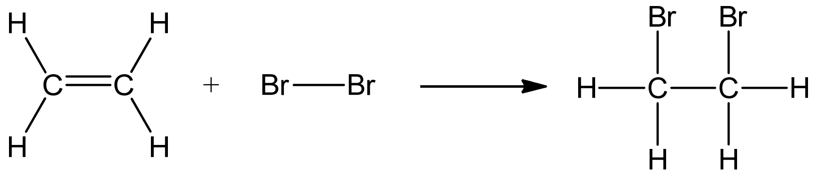
$$C_2H_4(g) + H_2(g) \xrightarrow[200\ ^{o}C]{\text{nickel catalyst}} C_2H_6(g)$$



- **Addition of bromine**

  - Also known as bromination.
  - Reddish-brown liquid bromine changes to colourless when it reacts with ethene.
  - Useful identification test for unsaturated hydrocarbons – it decolourises reddish-brown bromine water.

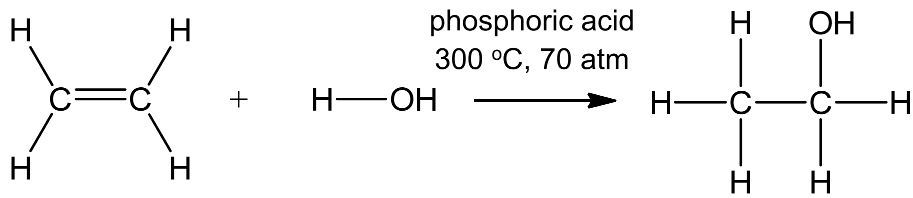
$$C_2H_4(g) + Br_2(l) \rightarrow CH_2BrCH_2Br(l)$$



- **Addition of steam**

  - Also known as hydration.
  - Alkenes react with steam to form alcohols.

$$C_2H_4(g) + H_2O(g) \xrightarrow[]{\text{phosphoric acid, } 300\ ^{o}C,\ 70\ atm} C_2H_5OH(l)$$

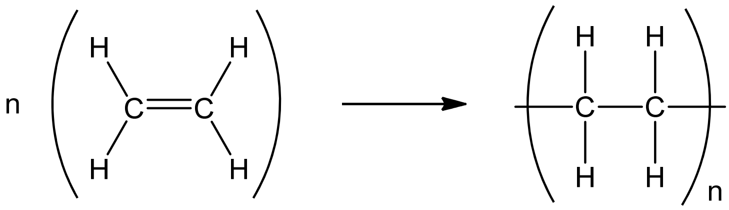


- **Addition of alkenes**

  - Also known as addition polymerisation
  - In the presence of a catalyst, many alkene molecules can join together to make one big molecule known as a polymer.

$$\text{ethene} \xrightarrow[\text{catalyst}]{\text{high temperature and pressure}} \text{ethane}$$

$$n(CH_2{=}CH_2) \xrightarrow[\text{catalyst}]{\text{high temperature and pressure}} -(CH_2CH_2)_n-$$



4.9 Production of Alkenes

- Alkenes are manufactured by the cracking of hydrocarbons. Long-chain hydrocarbons are broken down into short-chain hydrocarbons.

$$\text{hexane} \rightarrow \text{butane} + \text{ethane}$$
$$C_6H_{14} \rightarrow C_4H_{10} + C_2H_4$$

- A catalyst and high temperatures can be used to speed up the cracking process, i.e., catalytic cracking.

  Catalyst: aluminium oxide (Al_2O_3) and silicon dioxide (SiO_2)
  Temperature: 600 °C

  long-chain alkane → (mixture of short-chain alkenes) + (mixture of short-chain alkanes or H_2)

- Importance of cracking:

  (1) To produce short-chain alkenes, which are useful starting materials for ethanol and plastics

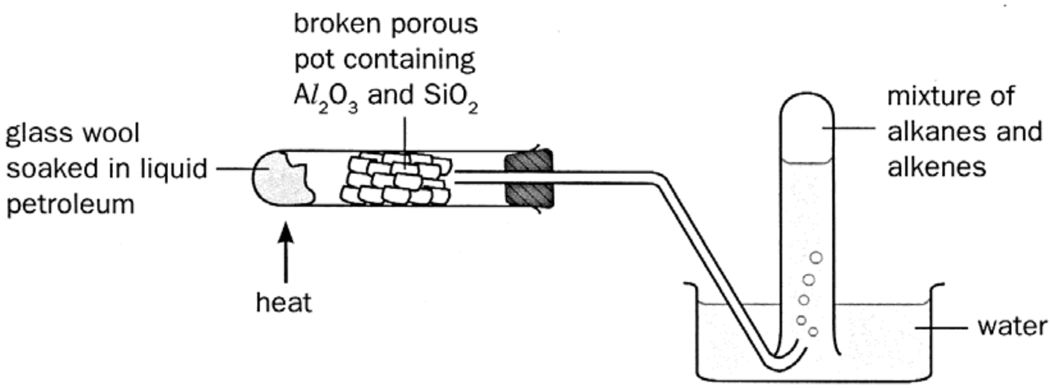
  $C_{18}H_{38} \rightarrow C_6H_{14} + 6C_2H_4$

  (2) To produce hydrogen

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

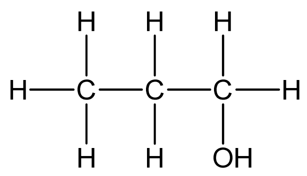
  (3) To produce petrol

- Cracking in the laboratory on a small scale:



Checkpoint 2

1. The structural formula of compound **X** is as shown below. Deduce
   (a) the structure of the original hydrocarbon
   (b) the compound which reacted with it, and
   (c) the name of the chemical reaction which produced compound **X**.



compound **X**

2. Compounds **W** and **Y** were bubbled into two separate test tubes containing bromine water. Only compound **W** decolourised bromine water. The general chemical formula for **W** and **Y** are C_2H_a, where a represents the number of hydrogen atoms. Draw the structural formulae of compounds **W** and **Y**, and state the hydrocarbon family they belong to.

3. Which one of the following is the formula of an alkene?

A	CH_4	**C**	C_4H_8
B	C_2H_6	**D**	C_4H_{10}

4. Which one of the following is an isomer of butane?

A

C

B

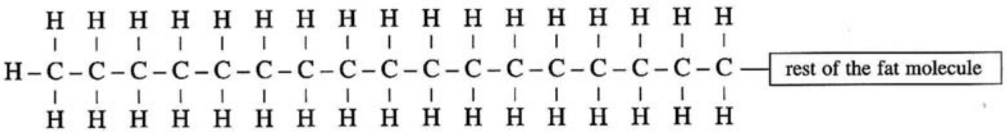
D

4.10 Polyunsaturated Fats and Oils

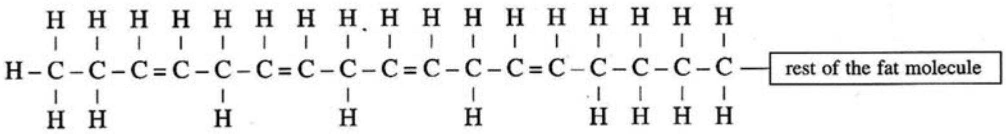
- Solid animal fats, such as butter and lard, and vegetables oils like palm oil and corn oil are different in appearance although both are organic compounds with similar molecular structures.

- Oils and fats are made up of **fatty acids**, which are long-chain carboxylic acids.

- There are two types of fats: **saturated** fats and **unsaturated** fats.



A



B

- Molecule A represents **saturated fat** because it consists only of **carbon-carbon single covalent bonds** between them.

- Molecule B represents **unsaturated fat** because **carbon-carbon double covalent bonds** exist between the carbon atoms.

- Fats contain mainly saturated fatty acids while oils contain a larger proportion of unsaturated fatty acids. Due to their structure, oils have lower melting points than fats and are liquids at room temperature.

- In both fats and oils, the **hydrocarbon chains** usually **contain more than one carbon-carbon double covalent bonds**. Hence, they are called **polyunsaturated** fats and oils.

- Our body requires a certain amount of fats to produce energy. Fats stored in the body also help to keep us warm. However, too much fat is harmful. Dieticians now recommend that saturated fats in diet be replaced by polyunsaturated vegetable oils.

4.11 A Summary: Alkanes vs Alkenes

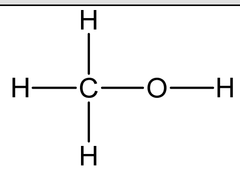
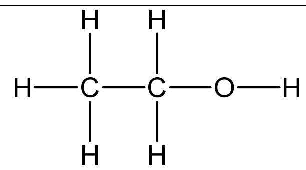
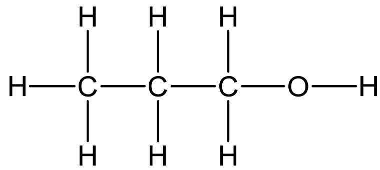
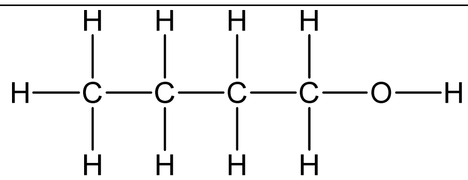
	Alkanes	**Alkenes**
Similarities	1. Contains carbon and hydrogen only 2. Flammable 3. Complete combustion produces carbon dioxide and water only	
Differences	• Only single covalent bonds between carbon atoms	• At least one double covalent bond between carbon atoms
	• Generally unreactive • Undergoes substitution reaction	• More reactive than alkanes • Undergoes addition reaction
	• Does not decolourise reddish-brown bromine water	• Decolourises reddish-brown bromine water.
	• Small-chain alkanes burn cleanly	• Alkenes of similar length of carbon chain burns with a smokier flame

Alcohols

5.1 What are Alcohols

- **Alcohols** form a homologous series containing the –OH functional group or hydroxyl group, with the general formula $\mathbf{C_nH_{2n+1}OH}$.

> **NOTE:** Do not confuse hydroxyl group (–OH) with the hydroxide ion (OH^-).

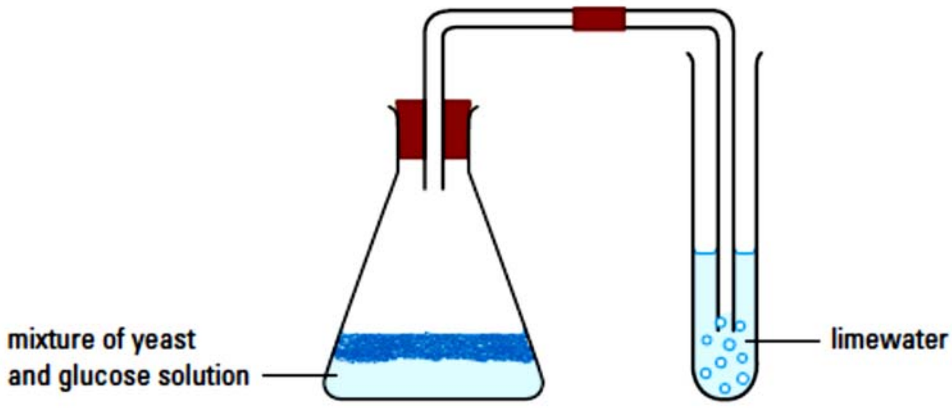
Number of carbon atoms	Chemical name	Structural formula **(use this way of expressing to show the –OH group)**	Molecular formula	Displayed Structural formula
1	methanol	CH_3**OH**	CH_4O	
2	ethanol	C_2H_5**OH** (CH_3CH_2**OH**)	C_2H_6O	
3	propanol	C_3H_7**OH** ($CH_3CH_2CH_2$**OH**)	C_3H_8O	
4	butanol	C_4H_9**OH** ($CH_3CH_2CH_2CH_2$**OH**)	$C_4H_{10}O$	

5.2 Manufacture of Ethanol (An Alcohol)

- There are two main ways of preparing ethanol:
  1. Fermenting sugar or starch with yeast
     - o Fermentation is a chemical reaction in which sugars are broken down into smaller molecules such as ethanol by micro-organisms such as yeast, e.g., fermentation of glucose to form ethanol.

$$C_6H_{12}O_6(aq) \xrightarrow{\text{yeast, 37 °C}} 2CH_3CH_2OH(aq) + CO_2(g)$$

$$\text{glucose} \xrightarrow{\text{yeast, 37 °C}} \text{ethanol + carbon dioxide}$$



(i) The mixture of yeast and glucose is kept at 37 °C as this is the optimum temperature for enzymes in yeast to function. To high a temperature and the enzymes in yeast will be denatured and cannot function as catalysts.

(ii) Carbon dioxide is released during fermentation. Hence frothing is observed in the flask. A while precipitate also forms in limewater.

(iii) Fermentation is carried out in the absence of oxygen. When there is oxygen present, little to no ethanol is produced. Oxygen can also oxidise ethanol into ethanoic acid.

$$CH_3CH_2OH(aq) + O_2(g) \rightarrow CH_3COOH(aq) + H_2O(l)$$

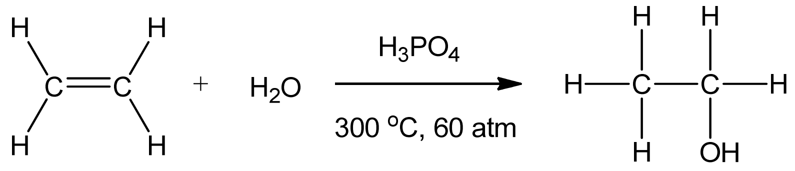
(iv) A dilute solution of ethanol is formed. It is only about 15% concentrated. Above this concentration, the yeast dies and fermentation stops. Ethanol is separated from the mixture by fractional distillation.

2. Reacting ethene with steam (steam addition/ hydration)

   o Main industrial method of producing ethanol.

$$C_2H_4(g) + H_2O(g) \xrightarrow[\text{300 °C, 60 atm}]{\text{phosphoric(V) acid } (H_3PO_4)} CH_3CH_2OH(aq)$$

$$\text{ethene + steam} \xrightarrow[\text{300 °C, 60 atm}]{\text{phosphoric(V) acid } (H_3PO_4)} \text{ethanol}$$

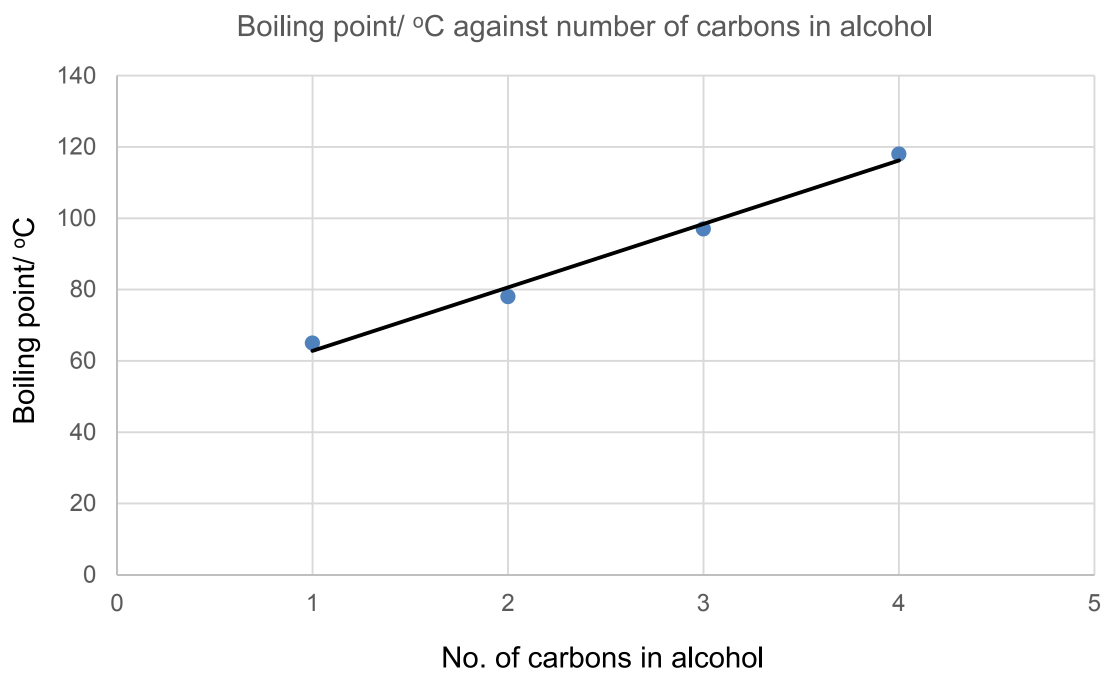


5.3 Physical Properties of Alcohols

(1) Boiling point

- Alcohols are volatile liquids at r.t.p.

- Their boiling points increase steadily as their relative molecular mass increases. More energy is required to overcome the stronger intermolecular forces of attraction between the alcohol molecules.



- They have higher boiling points compared to alkanes or alkenes with similar number of carbon atoms due to the presence of the hydroxyl group.

(2) Solubility

- The short chain alcohols (methanol, ethanol, propanol) are soluble in water, but solubility decreases as the relative molecular mass increases.

5.4 Chemical Properties of Alcohols

(1) Combustion

- Ethanol burns cleanly with a pale blue flame.
- Complete combustion of ethanol produces carbon dioxide and water only at r.tp.

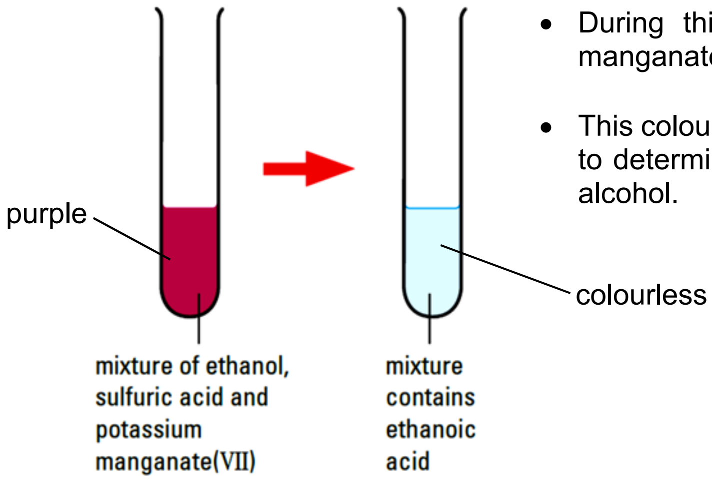
$$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

- The reaction is exothermic.

(2) Oxidation

- Alcohols can be oxidised into carboxylic acids by warming them with suitable oxidising agents such as acidified potassium manganate(VII), e.g., ethanol to ethanoic acid.

$$CH_3CH_2OH(aq) + 2[O] \xrightarrow[\text{heat}]{\text{KMnO}_4\text{, dil. }H_2SO_4} CH_3COOH(aq) + H_2O(l)$$



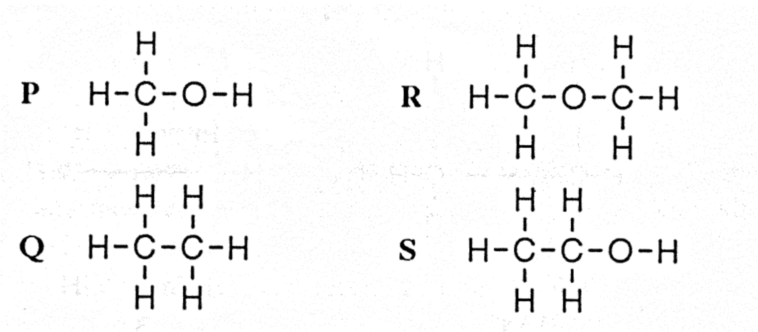
- During this reaction, purple acidified potassium manganate(VII) is decolourised.
- This colour change was once used in breathalysers to determine if a person has consumed excessive alcohol.

(3) Reaction with organic acids

- Alcohols can react with organic acids to form esters (**see Section 6.3**).

Checkpoint 3

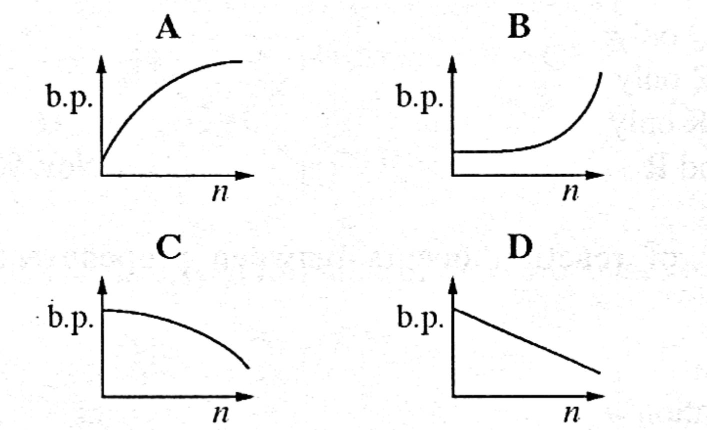
1. The diagrams show the structures of four organic molecules.



Which two are members of the same homologous series?

2. In the alkane series of hydrocarbons C_nH_{2n+2}, the boiling point (b.p.) of the compound increases as *n* increases.

Which graph correctly represents this effect?



3. The following tests were done on two colourless liquids.

	Shake with bromine water	**Heat with acidified potassium manganate(VII)**
Liquid **X**	decolourises	remains purple
Liquid **Y**	remains reddish-brown	decolourises

Which of the following could be liquids **X** and **Y**?

	Liquid **X**	Liquid **Y**
A	C_5H_{12}	C_4H_8
B	C_2H_4	CH_3CH_2OH
C	C_3H_8	CH_3CH_2OH
D	C_2H_4	C_3H_8

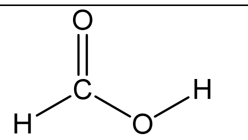
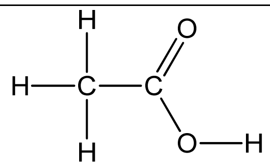
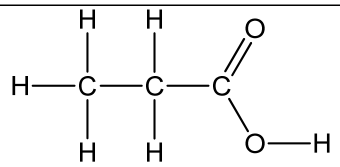
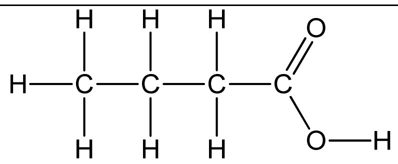
4. Which compound has an addition reaction with chlorine?

A C_2H_4
B C_2H_6
C C_2H_5OH
D CH_3COOH

Carboxylic Acids

6.1 What are Carboxylic Acids

- **Carboxylic acids** form a homologous series containing the –COOH (called carboxyl group) functional group with the general formula $\mathbf{C_nH_{2n+1}COOH}$.

Number of carbon atoms	Chemical name	Molecular formula	Structural formula	Displayed Structural formula
1	methanoic acid	CH_2O_2	H**COOH**	
2	ethanoic acid	$C_2H_4O_2$	CH_3**COOH**	
3	propanoic acid	$C_3H_6O_2$	CH_3CH_2**COOH**	
4	butanoic acid	$C_4H_8O_2$	$CH_3CH_2CH_2COOH$	

6.2 Physical Properties of Carboxylic Acids

(1) Boiling point

- Gradual increase in boiling point as the relative molecular mass increases. More energy is required to overcome the strong intermolecular forces between the carboxylic acid molecules.

(2) Solubility

- Only the first few members of the homologous series are soluble in water. The rest are insoluble.

6.3 Chemical Properties of Carboxylic Acids

(1) Acidic properties

- Carboxylic acids behave like weak acids as they can dissociate partially in water to release hydrogen ions. The will turn blue litmus paper red (pH < 7).

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$$

$$\text{ethanoic acid} \rightleftharpoons \text{ethanoate ion + hydrogen ion}$$

- Reaction with relatively reactive metals – hydrogen gas is evolved

$$Mg(s) + 2CH_3COOH(aq) \rightarrow \underbrace{(CH_3COO)_2Mg(aq)}_{\textit{magnesium ethanoate}} + H_2(g)$$

- Reaction with carbonates – carbon dioxide gas is evolved

$$Na_2CO_3(s) + 2CH_3COOH(aq) \rightarrow \underbrace{2CH_3COONa(aq)}_{\textit{sodium ethanoate}} + H_2O(l) + CO_2(g)$$

- Reaction with bases – neutralisation reaction (forms salt and water)

$$NaOH(aq) + CH_3COOH(aq) \rightarrow \underbrace{CH_3COONa(aq)}_{\textit{sodium ethanoate}} + H_2O(l)$$

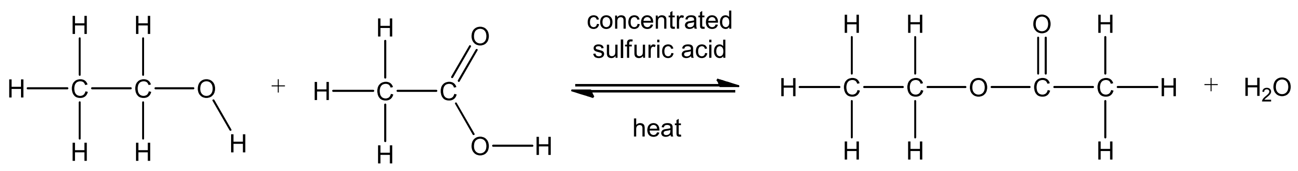
(2) Reacts with alcohols to form esters – esterification

- Esters are sweet-smelling colourless liquids which are insoluble in water.

- Warming ethanol with ethanoic acid in the presence of a little concentrated sulfuric acid as catalyst will produce an ester, ethyl ethanoate.

name from the alcohol portion

name from the acid portion

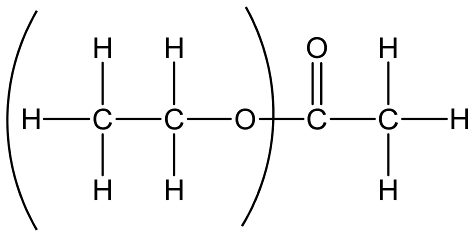


ethanol + ethanoic acid ⇌ ethyl ethanoate + water

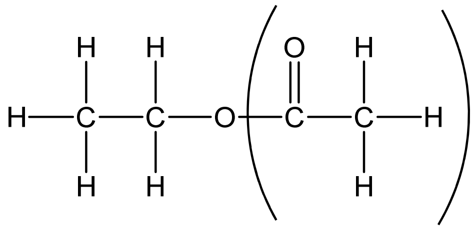
More About Esters

Naming

- The naming of esters follow this convention: (name from alcohol)(name of carboxylic acid)



ethyl (from ethanol)



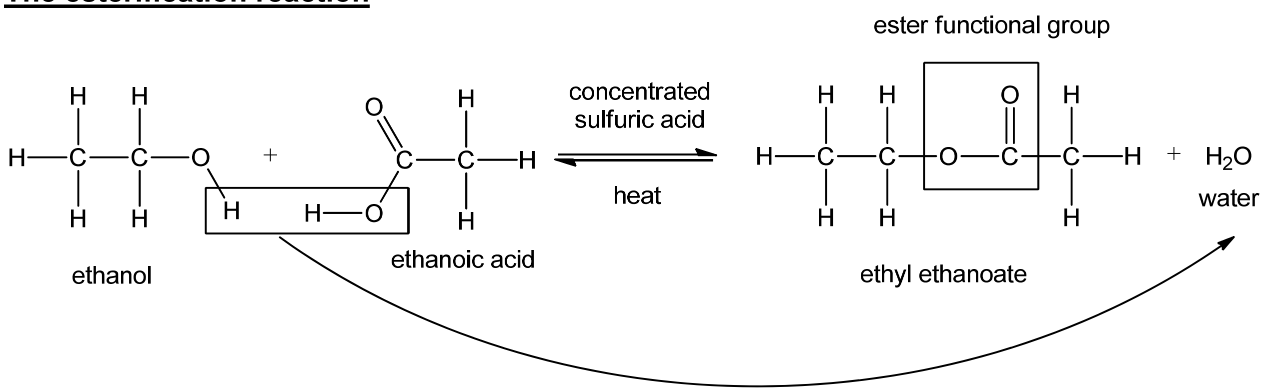
ethanoate (from ethanoic acid)

Structural formula

- Ethyl ethanoate is written as $CH_3CH_2OOCCH_3$ or $CH_3\underline{\mathbf{C}}OOCH_2CH_3$

This C belongs to the carboxyl group of the acid. If the formula was written this way: $\underline{CH_3CH_2CO}OCH_3$, this compound is actually methyl propanoate (the underlined portion is the acid now)

The esterification reaction



Uses of esters

- In perfumes, in food flavourings

Checkpoint 4

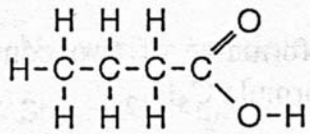
1. Name the following esters, and state the formula of the ester formed.

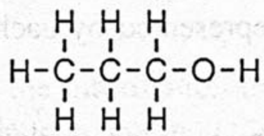
Alcohol	Acid	Name of ester	Formula of ester
ethanol	methanoic acid		
ethanol	ethanoic acid		
ethanol	propanoic acid		

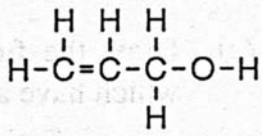
2. The results of tests on compound **X** are shown.

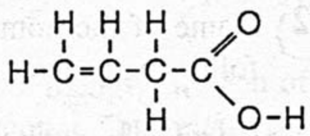
test	*result*
add bromine water	turns colourless
add aqueous sodium carbonate	carbon dioxide formed

What is compound X?

A 

B 

C 

D 

3. A 10 cm^3 sample of gaseous hydrocarbon was completely burnt in oxygen. The total volume of products was 70 cm^3. Which equation represents the combustion of the hydrocarbon?

A $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

B $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$

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

D $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

6.3 Production of Ethanoic Acid

- There are two ways for producing ethanoic acid:

  (1) Oxidation of ethanol by acidified potassium manganate(VII) with heating

$$CH_3CH_2OH(aq) + 2[O] \xrightarrow[\text{heat}]{KMnO_4,\ \text{dil. } H_2SO_4} CH_3COOH(aq) + H_2O(l)$$

  (2) Oxidation of ethanol by oxygen in air

$$CH_3CH_2OH(aq) + O_2(g) \longrightarrow CH_3COOH(aq) + H_2O(l)$$

<u>Checkpoint 5</u>

1. Write a chemical equation for the reaction between dilute ethanoic acid and aqueous potassium carbonate.

2. Write a chemical equation for the reaction between dilute propanoic acid and sodium. Explain how we can test for the gas evolved.

Macromolecules

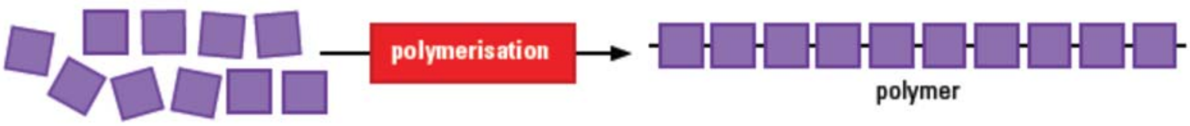
7.1 What are Macromolecules

- A macromolecule is a large molecule made by joining together many small molecules.

- **Polymers** (synthetic) are examples of macromolecules which are made up of large number of small molecules called **monomers** joined together. **Polymerisation** is the process of joining together these small molecules to form big molecules.

- Polymer molecules may be made up of 50 to 50,000 monomers. One chain may not have the same length as the other. Different polymers are made up of different monomers and have different linkages between monomers.

- The repeating unit is the smallest part of the polymer which when repeated many times, forms the whole polymer.



- **Polymers do not have sharp melting points**. They soften over a range of temperature.

- Naturally occurring macromolecules include starch, cellulose, latex, fats, and proteins.

- Synthetic macromolecules such as plastics include commonly used polyethene, polystyrene and polyvinylchloride (PVC).

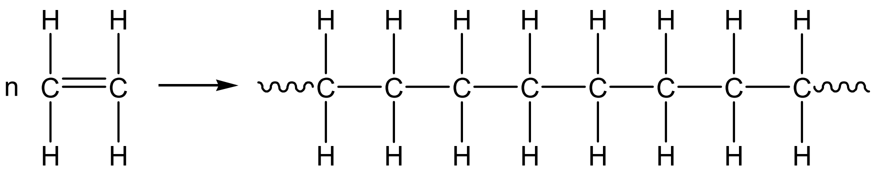
- Polymers are classified into two categories: (1) Addition polymers and (2) Condensation polymers.

7.2 Addition Polymerisation

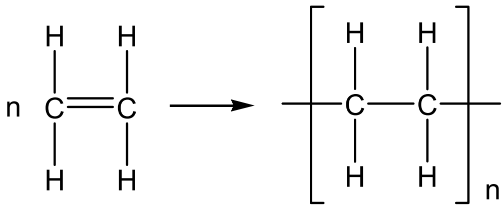
- Addition polymerisation is a reaction where **unsaturated monomers** join together to form one large molecule as the only product. No molecules or atoms are lost during the process. The polymer is known as an addition polymer, e.g.,

Polyethene

n (ethene) → polyethene   n = as many as 50,000

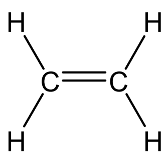
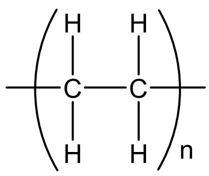
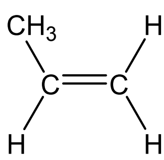
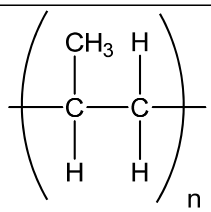
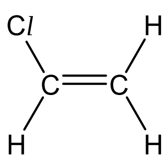
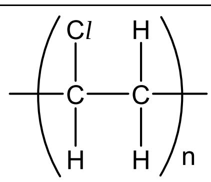


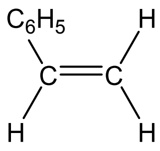
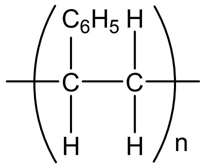
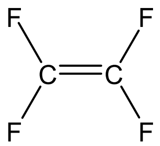
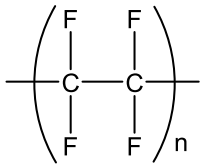
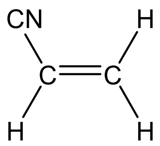
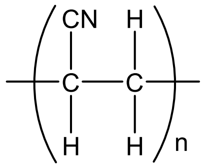
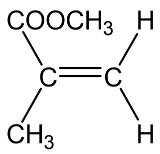
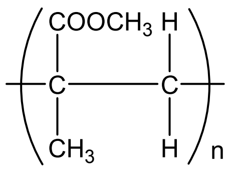
repeating unit



$n(CH_2{=}CH_2) \rightarrow –(CH_2CH_2)_n–$

In the presence of:
1. High temperature and pressure
2. Catalyst

monomer name	monomer formula	polymer name	polymer formula	uses
ethene		polyethene (polythene)		plastic bags, clingfilm etc
propene		polypropene		plastic bottles, containers etc
chloroethene (vinyl chloride)		polychloroethene (polyvinyl chloride, PVC)		Waterproof and insulating material, records

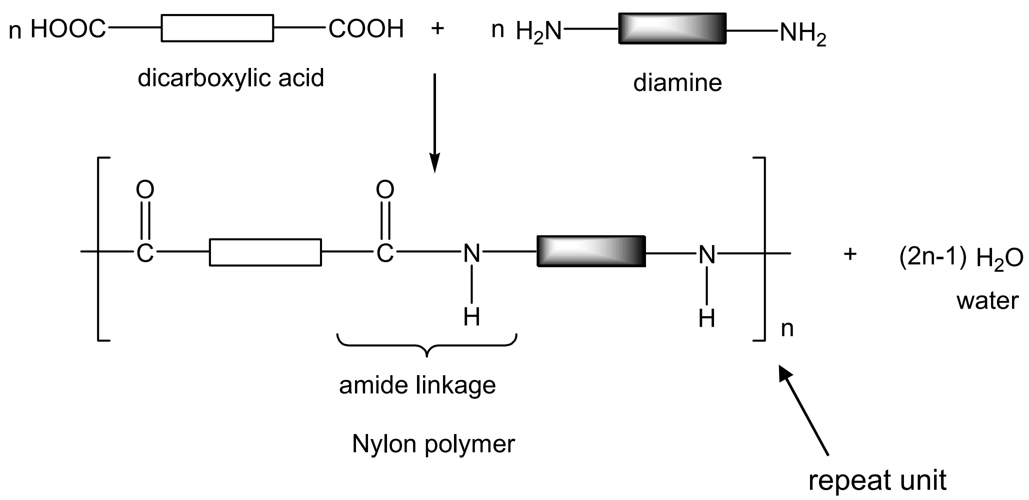
monomer name	monomer formula	polymer name	polymer formula	uses
phenylethene (styrene)		polyphenylethene (polystyrene)		packaging, ceiling tiles
tetrafluroethene		polytetrafluroethene (PTFE or Teflon)		non-stick saucepans, bridge bearings
propenonitrile (acrylonitrile)		polypropenonitrile (polyacrylonitrile, Acrilan, Orlon, Creslan)		synthetic fibre for carpet, clothes etc
methylmethacrylate		Polymethylmethacrylate (Perspex, Plexiglas)		Glass substitute

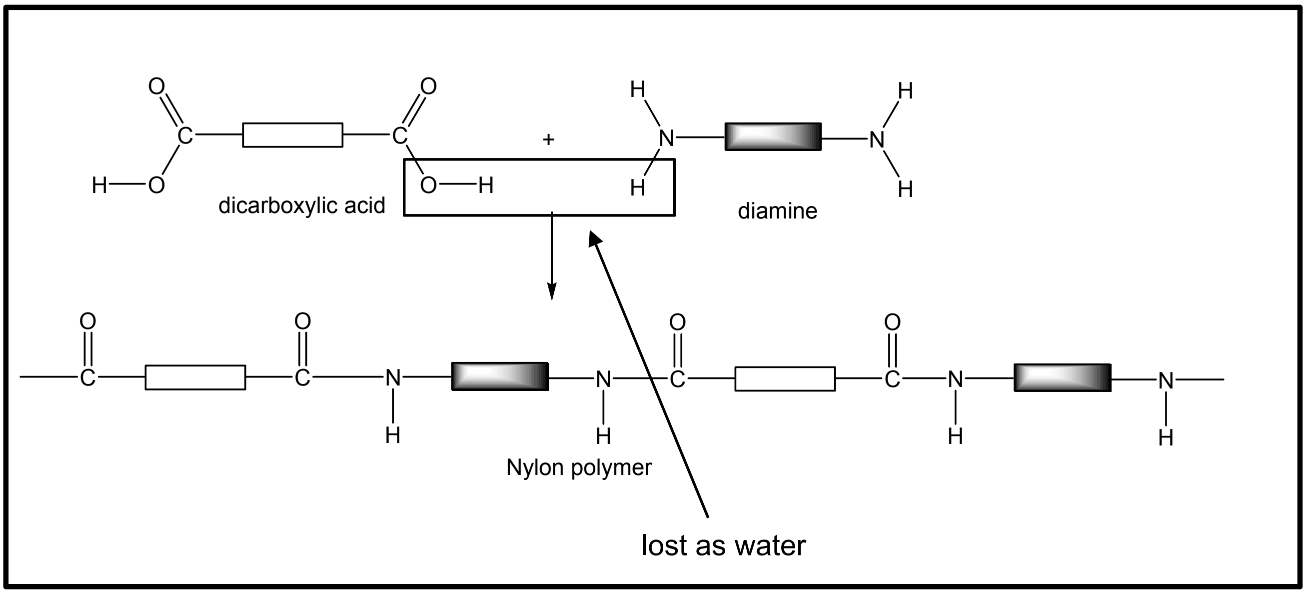
7.3 Condensation Polymerisation

- Condensation polymerisation occurs when monomers join together to form a polymer with the elimination of small molecules.

Nylon

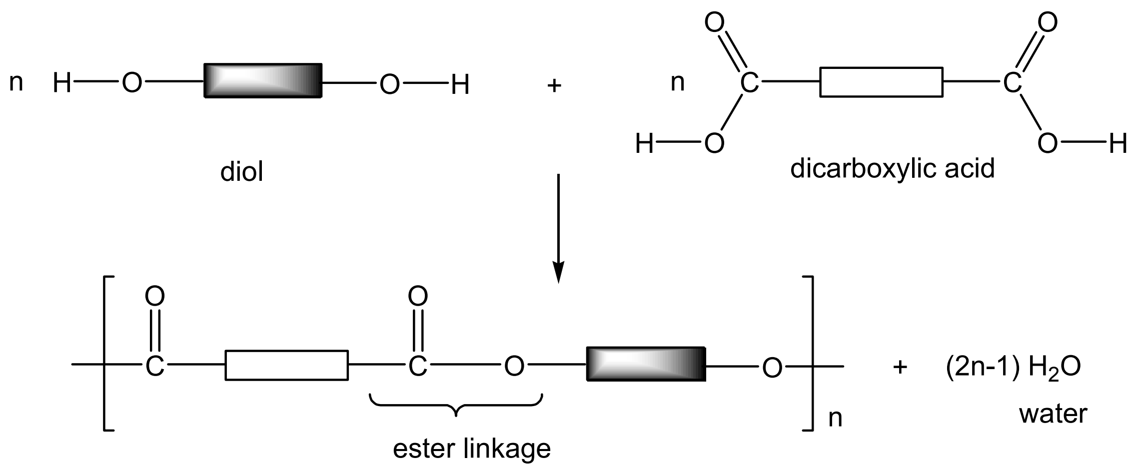
- Condensation polymer
- Synthetic fibre
- Strong and light, stretchable without breaking
- Made from two monomers
- Also known as polyamides because the monomers are joined together by amide linkages



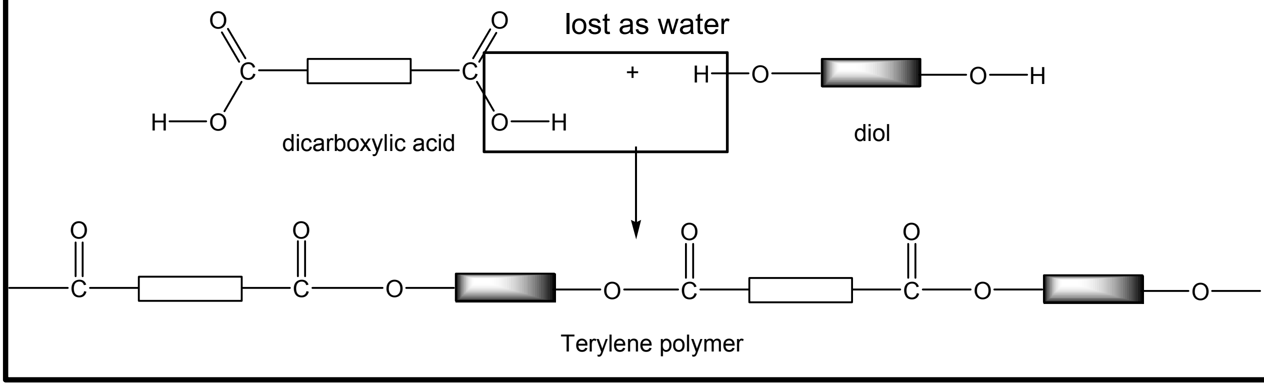


Terylene

- Condensation polymer
- Synthetic fibre
- Also known as polyester as the monomers are joined together by ester linkages



Terylene polymer



7.4 Why Plastics?

- All man-made polymers such as polyethene, nylon, Terylene are **plastics**. Plastics are used to replace natural materials such as wood, metals, cotton and leather because they are:

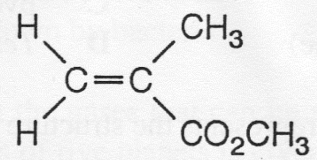
  (1) relatively cheaper and can be moulded easily into different shapes
  (2) lighter, tougher and waterproof
  (3) durable as they are resistant to decay, rusting and chemical attack

7.5 Disposal of Plastics

- Non-biodegradable – pollute the environment
- Burning releases toxic gases

<u>Checkpoint 6</u>

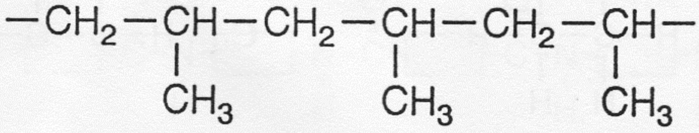
1. The structure of Perspex is shown.



Which description of *Perspex* is correct?

	type of polymer	*polymer formed by*
A	carbohydrate	condensation polymerisation
B	ester	addition polymerisation
C	hydrocarbon	addition polymerisation
D	polyester	condensation polymerisation

2. A polymer has the structure shown.

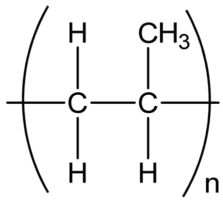


What is the molecular formula of the monomer?

A C_2H_4 **C** C_3H_6

B C_2H_6 **D** C_3H_8

3. The structure of a polymer is shown below.



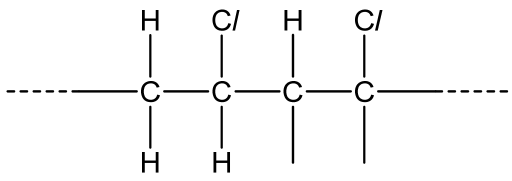
(a) What is meant by a polymer?

(b) Name the monomer from which this polymer is made.

(c) Give the empirical formula of this polymer.

(d) Calculate the percentage by mass of carbon in this polymer.

4. The diagram represents the structure of a common plastic.



(a) Draw the structure of the monomer from which it is made.

(b) This plastic is non-biodegradable. Explain the meaning of this term and describe the problems which this property causes.

(c) If this plastic is burned, a thick black smoke and a very acidic gas are produced.

(i) Suggest the identity of the black particles in the smoke.

(ii) Suggest the identity of the very acidic gas.

5. Propene can be polymerised.
   (a) Draw the structure of propene.

   (b) Name the polymer formed.

   (c) Name the type of polymerisation which takes place during this reaction, and draw the structure of the polymer which is formed.

Summary of Reactions