Topic 25 – Organic Chemistry

Subject content

Fuels and crude oil

- name natural gas, mainly methane, and petroleum as sources of energy
- describe petroleum as a mixture of hydrocarbons and its separation into useful fractions by fractional distillation (see also 1.2(a))
- name the following fractions and state their uses
  (i) petrol (gasoline) as a fuel in cars
  (ii) naphtha as the feedstock and main source of hydrocarbons used for the production of a wide range of organic compounds in the petrochemical industry (see also 11.1(d))
  (iii) paraffin (kerosene) as a fuel for heating and cooking and for aircraft engines
  (iv) diesel as a fuel for diesel engines
  (v) lubricating oils as lubricants and as a source of polishes and waxes
  (vi) bitumen for making road surfaces
- describe the issues relating to the competing uses of oil as an energy source and as a chemical feedstock (see also 11.1(c)(ii))

Alkanes

- describe a homologous series as 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
- describe the alkanes as a homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}
- draw the structures of branched and unbranched alkanes, C_1 to C_4, and name the unbranched alkanes methane to butane
- define isomerism and identify isomers
- describe the properties of alkanes (exemplified by methane) as being generally unreactive except in terms of combustion and substitution by chlorine

Alkenes

- describe the alkenes as a homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}
- draw the structures of branched and unbranched alkenes, C_2 to C_4, and name the unbranched alkenes ethene to butene
- describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the refinery process
- describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine
- describe the properties of alkenes (exemplified by ethene) in terms of combustion, polymerisation and the addition reactions with bromine, steam and hydrogen
- state the meaning of polyunsaturated when applied to food products
- describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product

Alcohols

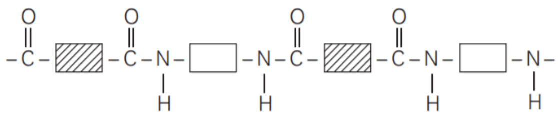
- describe the alcohols as a homologous series containing the –OH group
- draw the structures of alcohols, C_1 to C_4, and name the unbranched alcohols methanol to butanol
- describe the properties of alcohols in terms of combustion and oxidation to carboxylic acids
- describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose
- state some uses of ethanol, e.g. as a solvent; as a fuel; as a constituent of alcoholic beverages

Carboxylic acids

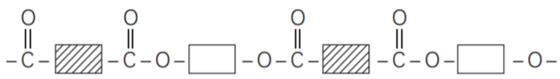
- describe the carboxylic acids as a homologous series containing the $–CO_2H$ group
- draw the structures of carboxylic acids, methanoic acid to butanoic acid, and name the unbranched acids, methanoic acid to butanoic acid
- describe the carboxylic acids as weak acids, reacting with carbonates, bases and some metals
- describe the formation of ethanoic acid by the oxidation of ethanol by atmospheric oxygen or acidified potassium manganate(VII)
- describe the reaction of a carboxylic acid with an alcohol to form an ester, e.g. ethyl ethanoate
- state some commercial uses of esters, e.g. perfumes; flavourings; solvents

Macromolecules

- describe macromolecules as large molecules built up from small units, different macromolecules having different units and/or different linkages
- describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer
- state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm
- deduce the structure of the polymer product from a given monomer and vice versa
- describe nylon, a polyamide, and Terylene, a polyester, as condensation polymers, the partial structure of nylon being represented as

  and the partial structure of Terylene as

  
- state some typical uses of man-made fibres such as nylon and Terylene, e.g. clothing; curtain materials; fishing line; parachutes; sleeping bags
- describe the pollution problems caused by the disposal of non-biodegradable plastics

Definition

Term	Definition
Homologous series	A family of organic compounds with similar <u>chemical properties</u> but diff <u>physical properties</u>, have same <u>general formula</u> + <u>functional group</u>

Functional group	An atom / group of atoms that give molecule its characteristic properties
Isomerism	Two or more compounds with the same molecular formula but different structural formula

25.1 Classification of Organic Compounds

Organic compound: compound that contain carbon (most also contain hydrogen)
Hydrocarbon: organic compounds that only contain carbon + hydrogen

Homologous series

Types of homologous series

1. **Alkanes**
2. **Alkenes**
3. **Alcohols**
4. **Carboxylic acids**

General characteristics:

- same general formula
- same functional group
- chemical formula differ by **$-CH_2-$** group
- physical properties show gradual change (no. of C atoms in mol increase)
- similar chemical properties

Naming

1. **Prefix** (no. of carbon atoms)

Prefix	**meth–**	**eth–**	**pro–**	**but–**	**pent–**	**hex–**
No. of carbon atoms	1	2	3	4	5	6

2. **Suffix** (homologous series)

Suffix	**–ane**	**–ene**	**–ol**	**–oic acid**
Homologous series	alkane	alkene	alcohol	carboxylic acid

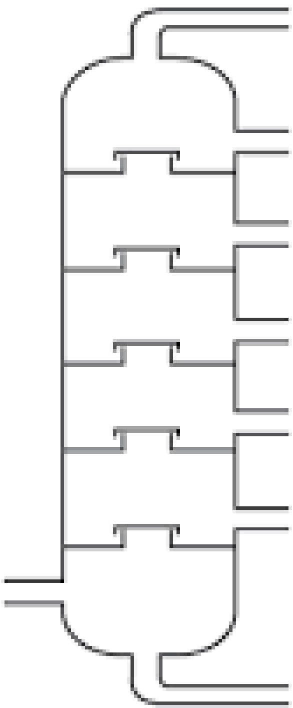
25.2 Fuels and Crude Oil

Fossil fuels

1. **Petroleum** / crude oil: naturally occurring mixture of hydrocarbons (mainly alkanes)
2. **Natural gas** (mostly methane + short-chain alkanes)

<u>Fractional distillation of petroleum</u>

<table>
<tr><th>Steps</th><th colspan="2">Fractions (<u>PPNKDLB</u>)</th><th>b.p. (°C)</th><th>C atoms</th><th>Uses</th></tr>
<tr><td rowspan="7">Furnace
• Heat petroleum → vapour
• Pass vapour into fractionating column

Fractionating column
• Rise up → cool + condense
• <u>Light</u> fraction: low bp → top (condense later)
• <u>Heavy</u> fraction: high bp → bottom (condense first)</td><td rowspan="7"></td><td>Petroleum gas
C_1 ~ C_4</td><td>< 40</td><td>1 ~ 4</td><td>Fuel: heating, cooking</td></tr>
<tr><td>Petrol
C_5 ~ C_{10}</td><td>40 ~ 75</td><td>5 ~ 10</td><td>Fuel: motorcars</td></tr>
<tr><td>Naphtha
C_7 ~ C_{14}</td><td>90 ~ 150</td><td>7 ~ 14</td><td>Feedstock: make petrochemicals</td></tr>
<tr><td>Kerosene
C_9 ~ C_{16}</td><td>150 ~ 240</td><td>9 ~ 16</td><td>Fuel: heating, cooking, aircraft engines</td></tr>
<tr><td>Diesel
C_{15} ~ C_{25}</td><td>220 ~ 250</td><td>15 ~ 25</td><td>Fuel: diesel engines</td></tr>
<tr><td>Lubricating oil
C_{20} ~ C_{35}</td><td>300 ~ 350</td><td>20 ~ 35</td><td>Lubricant
Source of waxes, polishes</td></tr>
<tr><td>Bitumen
> C_{70}</td><td>> 350</td><td>> 70</td><td>Pave road surface</td></tr>
</table>

Note:

- petroleum (mixture) ≠ petroleum gas (one of the fractions)
- more carbon atoms per molecule → high risk of incomplete combustion (not enough oxygen) → CO + soot (harmful pollutants)

<u>Competing uses of petroleum</u>

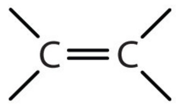
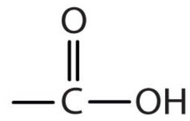
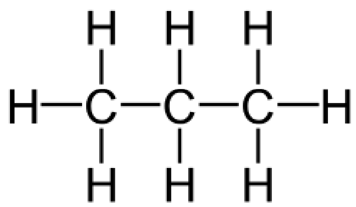
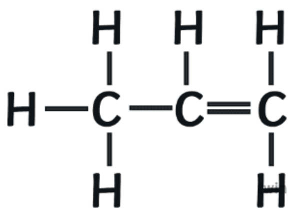
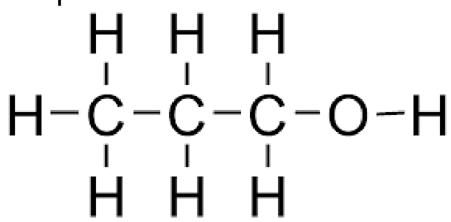
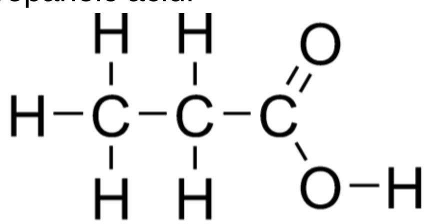
Uses of petroleum + limited supply

Fuel (90%)	**Petrochemical feedstock (10%)**
• Generate heat + electricity • Power motor vehicles + industrial activities	• Plastics, detergents, medicines, fertilisers, pesticides, synthetic rubber

Conserve petroleum

Method	Description
1. Reduce use of petroleum	• reduce no. of motor vehicles on road • drive smaller cars that consume less petrol • take public transport e.g. bus, MRT
2. Alternative energy sources	• alternative fuels • solar energy • nuclear energy
3. Improve design of power stations & vehicles	• use petroleum more efficiently

Summary

Organic compound	**Alkane**	**Alkene**	**Alcohol**	**Carboxylic acid**
General formula	$\mathbf{C_nH_{2n+2}}$ $n \geq 1$	$\mathbf{C_nH_{2n}}$ $n \geq 2$	$\mathbf{C_nH_{2n+1}OH}$ $n \geq 1$	$\mathbf{C_nH_{2n+1}COOH}$ $n \geq 0$
Functional group	–	 carbon-carbon double bond	– O–H hydroxyl group	 carboxyl group
Description	Saturated hydrocarbon (only contain C–C bonds)	Unsaturated hydrocarbon (contain C=C bonds)		Produced by oxidation of alcohol 1) in atmospheric oxygen 2) by acidified potassium manganate(VII)
Naming	n = 1: methane CH_4 n = 2: ethane C_2H_6 n = 3: propane C_3H_8 n = 4: butane C_4H_{10}	n = 2: ethane C_2H_4 n = 3: propene C_3H_6 n = 4: butene C_4H_8	n = 1: methanol CH_3OH n = 2: ethanol C_2H_5OH n = 3: propanol C_3H_7OH n = 4: butanol C_4H_9OH	n = 0: methanoic acid HCOOH n = 1: ethanoic acid CH_3COOH n = 2: propanoic acid C_2H_5COOH n = 3: butanoic acid C_3H_7COOH n = 4: pentanoic acid C_4H_9COOH
Structures	Propane: 	Propene: 	Propanol: 	Propanoic acid: 

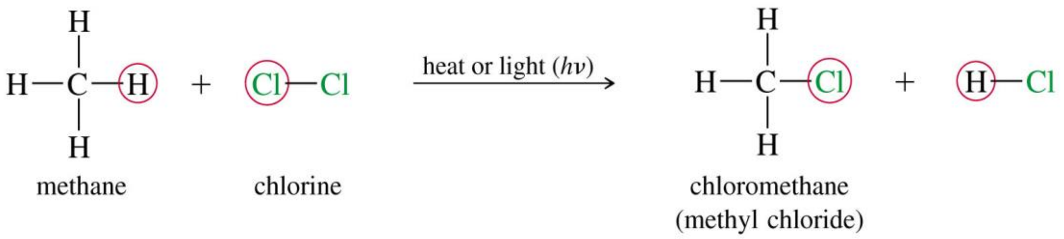
Organic compound	**Alkane**	**Alkene**	**Alcohol**	**Carboxylic acid**
Physical properties	1. Mp & bp ↑ 2. Viscosity ↑ 3. Flammability ↓ 4. All insoluble in water, soluble in organic solvent	1. Mp & bp ↑ 2. Viscosity ↑ 3. Flammability ↓ 4. All insoluble in water, some soluble in organic solvent	1. Mp & bp ↑ 2. Volatile colourless liquids 3. Flammable 4. Most are miscible in water	
Chemical properties	1. Combustion reaction (complete / incomplete) 2. Substitution reaction	1. Combustion reaction (complete / incomplete) 2. Addition reaction (break C=C bond, C atom bond with H / Br atom) 1) Hydrogenation 2) Bromination 3) Hydration 4) Polymerisation 3. Cracking of alkanes to obtain alkenes	1. Combustion reaction 2. Oxidation to form carboxylic acids 3. Dehydration 4. Esterification Ethanol production 1. Fermentation of glucose 2. Catalysed addition of steam to ethene	1. React with metal → salt + hydrogen 2. React with base → salt + water 3. React with carbonate → salt + water + carbon dioxide 4. React with alcohol → ester (esterification) Hydrolysis: ester → alcohol + carboxylic aci

25.3 Alkanes

Physical properties

Property	Trend	Explanation
1. **mp & bp**	increase	Molecular size increase, forces of attraction b/w molecules increase
2. **viscosity**	increase	Molecule larger, longer chain
3. **flammability**	decrease	More carbon atoms, more covalent bonds to break, larger energy to break all bonds + smokier flame

Chemical properties

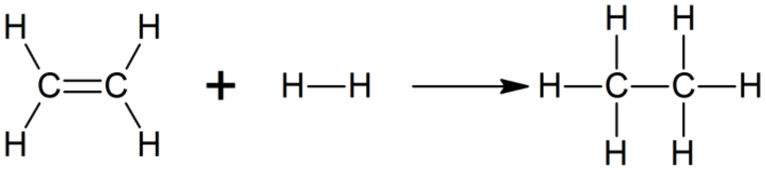
Property	Description
1. **Complete combustion**	Alkane + $O_2 \rightarrow CO_2 + H_2O$ (highly exothermic) Equation **Condition:** excess oxygen Methane: $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$ **Use:** fuels
2. **Incomplete combustion**	Alkane + $O_2 \rightarrow CO + H_2O$ (sooty flame) Equation **Condition:** insufficient oxygen Methane: $CH_4(g) + O_2(g) \rightarrow CO(g) + 2\ H_2O(g)$
3. **Substitution reaction**	React with halogen → one hydrogen atom replaced (*substituted*) by another atom Equation **Condition:** UV light Chloromethane:  Dichloromethane Trichloromethane Tetrachloromethane

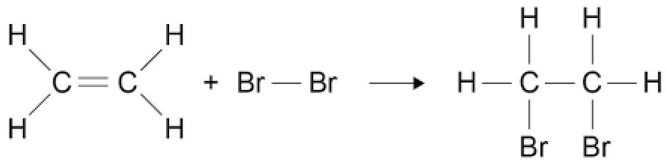
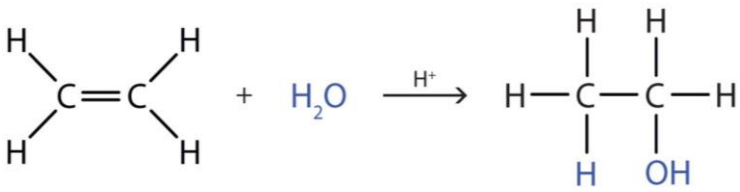
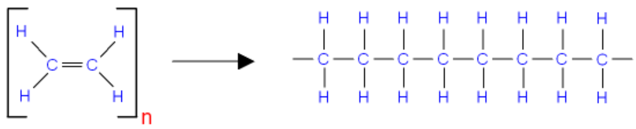
25.4 Alkenes

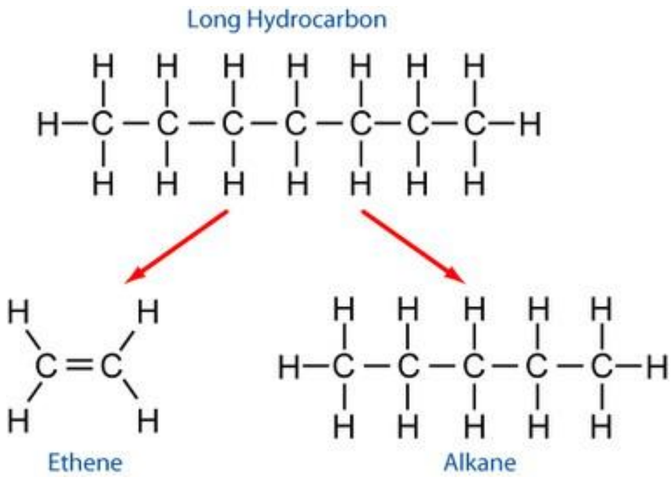
Physical properties

Property	Trend	Explanation
1. **mp & bp**	increase	Molecular size increase, forces of attraction b/w molecules increase
2. **viscosity**	increase	Molecule larger, longer chain
3. **flammability**	decrease	More carbon atoms, more covalent bonds to break, larger energy to break all bonds

Chemical properties

Property	Description
1. **Complete combustion**	Alkene + O_2 → CO_2 + H_2O (highly exothermic) Equation **Condition:** excess oxygen Ethene: $C_2H_4(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O(l)$
2. **Incomplete combustion**	Alkene + O_2 → CO + H_2O Equation **Condition:** insufficient oxygen Ethene: $C_2H_4(g) + 2\ O_2(g) \rightarrow 2\ CO(g) + 2\ H_2O(g)$
3. **Hydrogenation**	Alkene + H_2 → alkane Equation **Condition:** 200°C catalyst: nickel / palladium Ethene + hydrogen → ethane $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$  **Use:** produce margarine (saturated fats) from vegetable oil (unsaturated fats)
4. **Bromination**	Alkene + aqueous bromine

	Equation Ethene + bromine → 1,2-dibromoethane $C_2H_4(g) + Br_2(aq) \rightarrow CH_2BrCH_2Br(g)$  **Use:** test to distinguish alkene & alkane • Alkene: aq bromine decolourise **<u>rapidly</u>** (presence of C=C bond) • Alkane: aq bromine remain brown (absence of C=C bond)
5. **Hydration**	Alkene + steam → alcohol Equation **Condition:** 300°C 60 – 70 atm catalyst: phosphoric acid Ethene + steam → ethanol $C_2H_4(g) + H_2O(g) \rightarrow CH_3CH_2OH(g)$  **Use:** manufacture alcohol
6. **Polymerisation**	Simple alkenes (alkene monomers) join → macromolecules (polymer) Equation  Many ethene molecules Poly (ethene) **Use:** polyethene used to produce plastics
7. **Cracking of petroleum** (obtain alkene)	Long-chain alkanes → short-chain alkenes + short-chain alkanes / hydrogen gas (<u>useful</u> fractions) Equation **Condition:** 600°C catalyst: aluminium oxide + silicon dioxide (catalytic cracking) Heptane → ethene + pentane

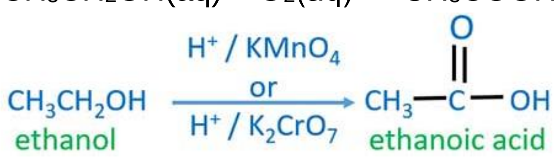
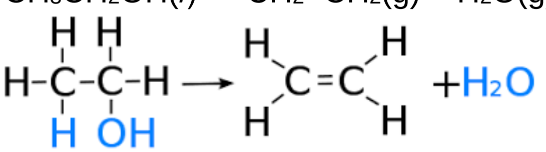
	 **Use:** 1) Produce short-chain alkenes • ethene, propene as starting materials to make ethanol, plastics 2) Produce hydrogen • Haber process to manufacture ammonia 3) Produce petrol • convert hydrocarbons of molecular mass → smaller molecules short in supply + high in demand • break down diesel / lubricating oil → petrol

25.5 Alcohol

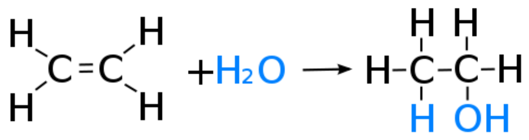
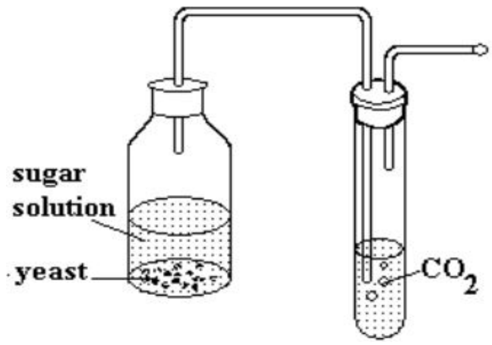
Physical properties

Property	Trend	Explanation
1. **mp & bp**	increase	Molecular size increase, forces of attraction b/w molecules increase
2. **solubility in water**	decrease	

Chemical properties

Property	Description
1. **Complete combustion**	Alcohol + $O_2 \rightarrow CO_2 + H_2O$ (highly exothermic) Equation **Condition:** excess oxygen Ethanol: $C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(l)$ **Use:** fuels
2. **Oxidation**	Alcohol + $O_2 \rightarrow$ carboxylic acid + H_2O • Alcohol mol lose 2 H atom + gain 1 O atom + maintain same no. of C atom Equation **Condition:** atmospheric oxygen in air OR heat with acidified potassium manganate(VII) or potassium dichromate(VI) (oxidising agent) Ethanol + oxygen → ethanoic acid + water $CH_3CH_2OH(aq) + O_2(aq) \rightarrow CH_3COOH(aq) + H_2O(l)$ 
3. **Dehydration**	Alcohol → alkene + water Equation **Condition:** heat catalyst: aluminium oxide Ethanol → ethene + water $CH_3CH_2OH(l) \rightarrow CH_2{=}CH_2(g) + H_2O(g)$ 

Ethanol – most widely used alcohol

Production	Condition
1. Addition of steam of ethene	Equation **Condition:** 300°C 60 – 70 atm catalyst: phosphoric acid Ethene + steam → ethanol $C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(l)$ 
2. Fermentation of glucose with yeast	Equation **Condition:** 37°C absence of oxygen catalyst: bacteria in yeast Glucose → ethanol + carbon dioxide $C_6H_{12}O_6(aq) \rightarrow 2\ C_2H_5OH(aq) + 2\ CO_2(g)$  ● Glucose solution mixed with yeast + temp kept at 37°C ● Fermentation: CO_2 produced → frothing (formation of foam) in flask + white ppt in limewater ● Dilute ethanol solution of 15% conc produced ○ alcohol content high → yeast dies → fermentation stop ○ obtain ethanol from liquid mixture via fractional distillation

Use:

1. Solvent for organic compounds that are insoluble in water
2. Alternative motor vehicle fuel (mixed with petrol)
3. Constituent of alcoholic beverages (wine, beer)

25.6 Carboxylic Acids

Physical properties

Property	Trend	Explanation
1. **mp & bp**	increase	Molecular size increase, forces of attraction b/w molecules increase

Chemical properties

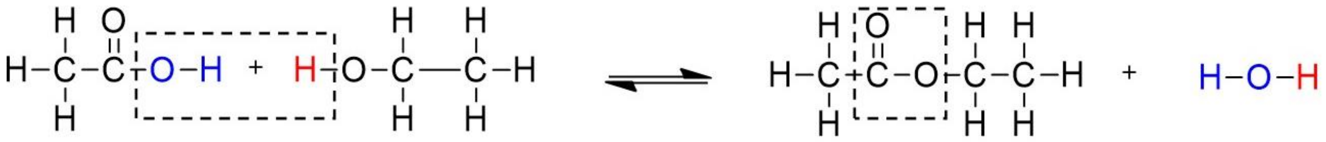
Acidic properties: weak acid (partial ionisation)

ethanoic acid ⇌ ethanoate ion + hydrogen ion $CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$

React with	Reaction
1. **Metal**	Carboxylic acid + metal → salt + hydrogen Equation Ethanoic acid + magnesium → magnesium ethanoate + hydrogen $2\ CH_3COOH(aq) + Mg(s) \rightarrow (CH_3COO)_2Mg(aq) + H_2(g)$
2. **Base**	Carboxylic acid + base → salt + water Equation Ethanoic acid + sodium hydroxide → sodium ethanoate + water $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$
3. **Carbonate**	Carboxylic acid + carbonate → salt + water + carbon dioxide Equation Ethanoic acid + sodium carbonate → sodium ethanoate + water + carbon dioxide $2\ CH_3COOH(aq) + Na_2CO_3(aq) \rightarrow 2\ CH_3COONa(aq) + H_2O(l) + CO_2(g)$
4. **Alcohol**	**Esterification:** Carboxylic acid + alcohol ⇌ ester + water (condensation rxn) Equation **Condition:** warm catalyst: conc sulfuric acid (dehydrating agent) Ethanoic acid + ethanol ⇌ ethyl ethanoate + water $CH_3COOH(aq) + C_2H_5OH(aq) \rightleftharpoons CH_3COOC_2H_5(aq) + H_2O(l)$
	Hydrolysis: Ester + water ⇌ carboxylic acid + alcohol Equation **Condition:** heat Ethyl ethanoate + water ⇌ ethanoic acid + ethanol

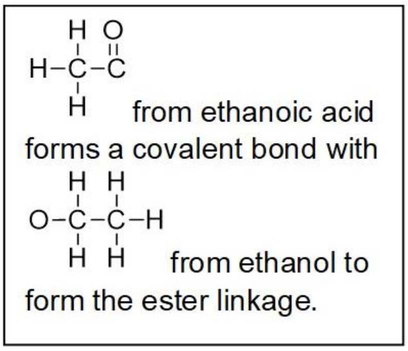
Ester

Esterification:



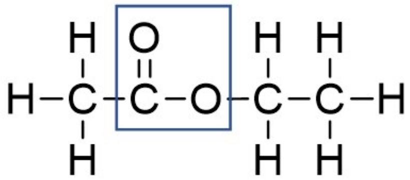
C-O bond in ethanoic acid is broken.

O-H bond in ethanol is broken.

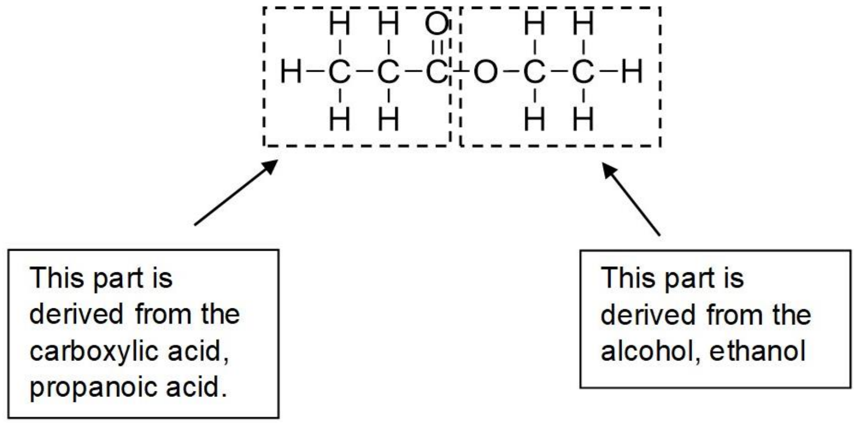


O-H from ethanoic acid forms a covalent bond with H from ethanol to form water

Functional group: **–COO–**



Naming: **(Alcohol)-yl (Acid)-oate**



Ester formed	Alcohol	Carboxylic acid
Ethyl butanoate **C_3H_7COO | C_2H_5**	Ethanol C_2H_5OH	Butanoic acid C_3H_7COOH
Ethyl methanoate **$HCOO$ | C_2H_5**	Ethanol C_2H_5OH	Methanoic acid $HCOOH$
Propyl propanoate **C_2H_5COO | C_3H_7**	Propanol C_3H_7OH	Propanoic acid C_2H_5COOH

Use:

1. Artificial food flavourings (sweet and fruity smell)
2. Solvents – cosmetics, perfumes, glue
3. Animal fats and vegetable oils (naturally occurring esters)

25.7 Macromolecules

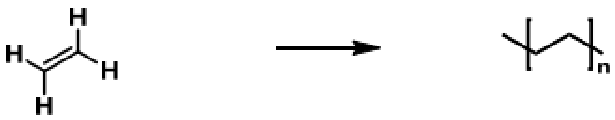
Terminology

Term	Definition
Macromolecule	Very large molecule made up of large number of atoms held together by strong covalent bonds
Monomer	Small molecule that can be joined together with other small molecules to form one large long-chain molecule
Polymer	Long-chain macromolecule formed by joining together many small molecules
Repeating unit	Smallest part of polymer that forms whole polymer when repeated
Polymerisation	Reaction where many monomers joined together to form polymer

Naming

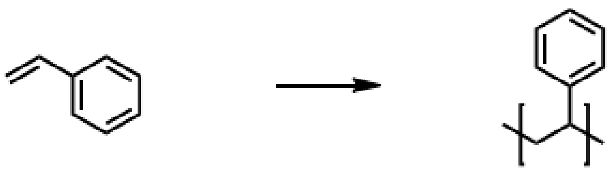
Name of polymer: derived from name of monomer

Ethylene



Poly(ethylene)

styrene



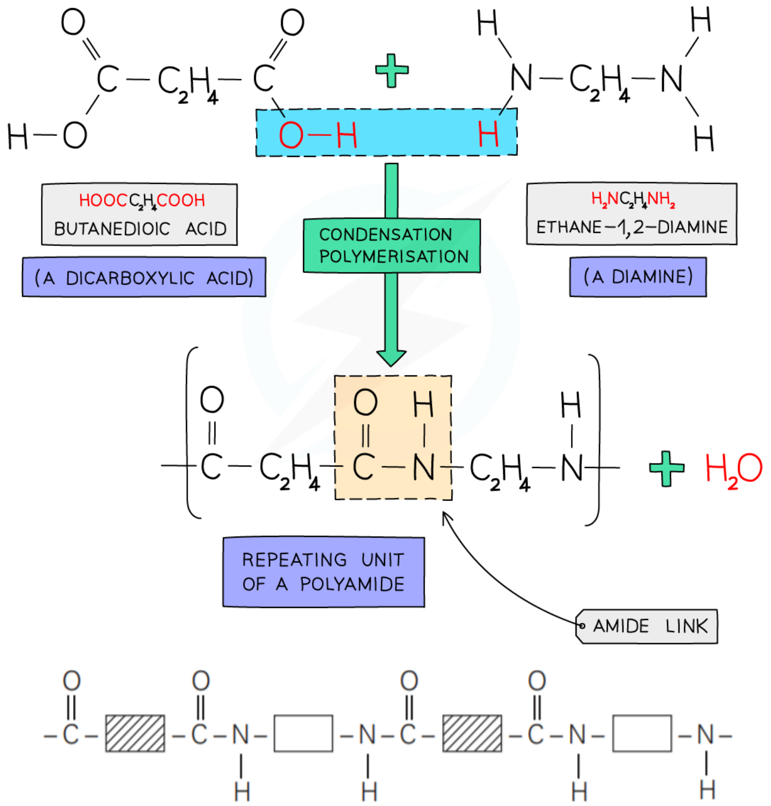
Poly(styrene)

Polymerisation

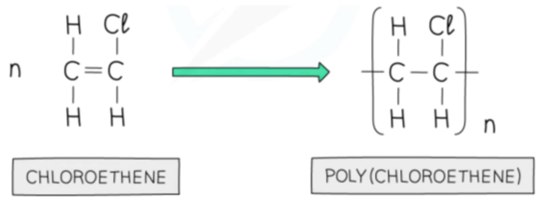
Addition polymerisation	Condensation polymerisation
Small unsaturated mol join together → 1 large long-chain mol (without losing any atom / mol)	Small mol join together → 1 large long-chain mol (elimination of a small mol)
Unsaturated monomer → addition polymer	Monomers with diff functional grp that react with one another → condensation polymer + small mol

Ethene → **poly(ethene)**

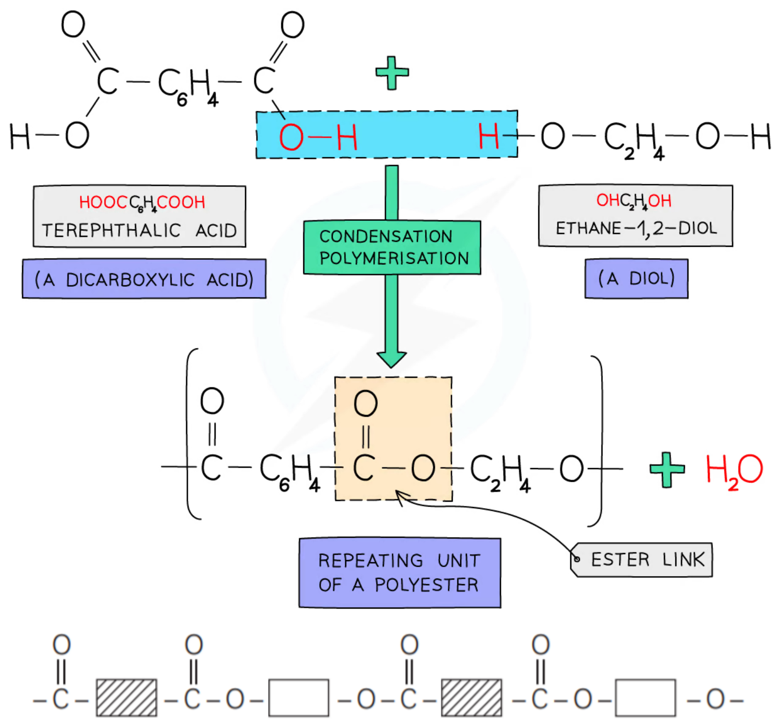
Diacid + diamine → **polyamide** (nylon)



Chloroethene → **poly(chloroethene)**



Diacid + diol → **polyester** (Terylene)



Uses of plastic & man-made fibres

1. Polyethene – plastic bags, clingfilm
2. Nylon (polyamide) – cloth, fishing lines, parachutes, rain coats
3. Terylene (polyester) – clothes, curtains

Plastics

Adv	Disadv
• Cheap to produce • Easily moulded into various shapes • Light, tough, waterproof • Durable	• Land pollution: not decomposed by bacteria in soil → waste build up • Air pollution: flammable, produce poisonous gases upon incineration • Water pollution: thrown into sea → marine animals mistaken for food → choke • Disease: clog up rivers & drains → breeding grounds for mosquitoes

Functional groups

Functional group	Found in
C=C (-ene)	• alkenes
– OH (-anol)	• alcohols • diols (to form polyesters)
– NH_2 (-amine)	• diamines (to form polyamides)
CONH	• polyamides
– COO – (*ALCOHOL*yl *ACID*oate)	• esters • polyesters
– COOH (-oic acid)	• carboxylic acids • diacids (to form polyamides/polyesters)

<u>Fuels and crude oil</u>

Multiple choice questions

1 Propene is used to make poly(propene).
Which fraction from petroleum is the main feedstock for the manufacture of propene?
(2021 P1 Q32)

A bitumen
B diesel
C <u>naphtha</u>
D paraffin

2 Petroleum can be separated into fractions using fractional distillation.
Which statements are correct?

1. Alkanes used in polishes and waxes have a higher boiling point than those used as diesel fuel.
2. Any of the fractions could be used as fuels because their enthalpy changes of combustion are negative.
3. The fraction used for petrol (gasoline) is extracted from higher up the fractionating column than the fraction used for paraffin (kerosene).
4. The fraction obtained at a particular point in the fractionating column always contains the same compounds in the same ratio.

(2019 P1 Q32)

A <u>1, 2 and 3</u>
B 1 and 4
C 2 only
D 3 and 4

3 Which two compounds are commonly used as fuels in engines? (2016 P1 Q32)

A <u>diesel and paraffin</u>
B methane and naphtha
C naphtha and bitumen
D paraffin and bitumen

4 Petroleum can be separated into fractions by fractional distillation.
Which statement about this process is not correct? (2015 P1 Q38)

A In a fractionating column, the bitumen fraction is obtained below the kerosene fraction.
B <u>The fraction obtained at the top of the fractionating column has the highest boiling point.</u>
C The lubricating oil fraction is a source of polishes and waxes.
D The relative molecular masses of the compounds obtained near the bottom of the fractionating column are higher than those of the compounds obtained near the top of the column.

Structured questions

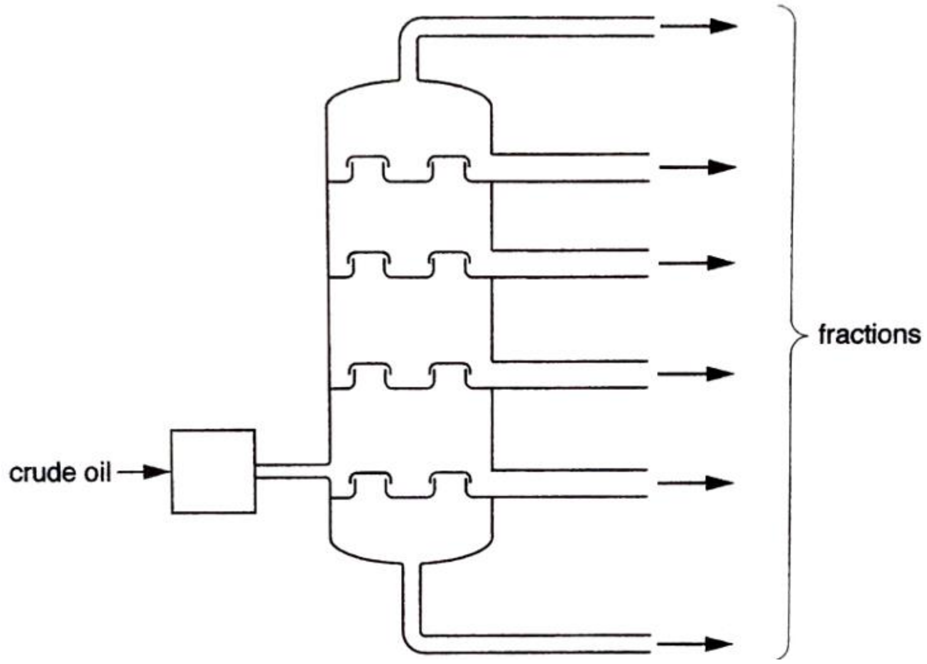
1 Naphtha is a fraction of crude oil. It is processed by cracking in an oil refinery.
Explain why cracking of naphtha is an important process in an oil refinery. [2]

(2014 P2 A6a)

Cracking of naphtha produces

- alkanes with fewer carbon atoms suitable for petrol
- alkenes, especially ethene, which is an important starting material for the making of plastics in the petrochemical industry.

2 Crude oil contains a mixture of hydrocarbons.
In a petrol refinery, fractional distillation is used to separate crude oil into fractions.



Within each fraction, the molecules are of a similar size.
Describe and explain how the process of fractional distillation separates crude oil into fractions. [5]

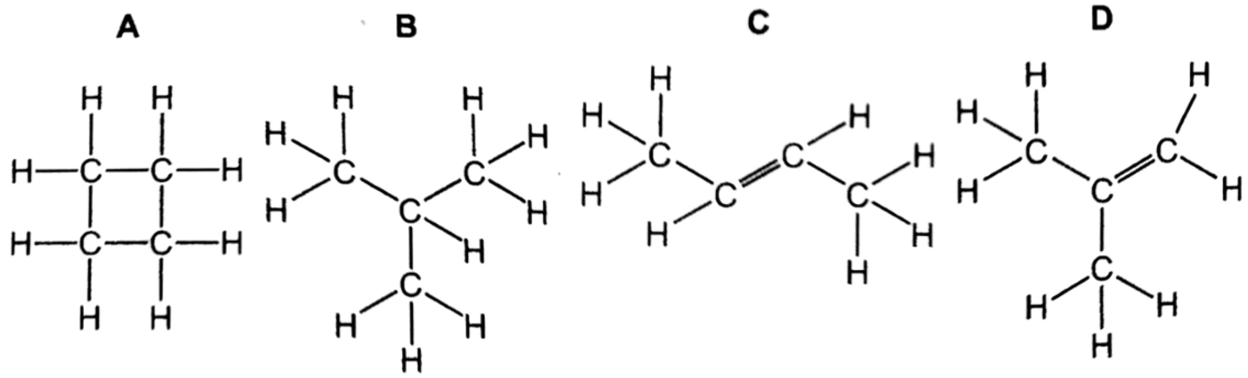
(2018 P2 B10 OR)

- Crude oil is first passed into a furnace which gets heated and turns into vapour.
- The vapour is passed into the fractionating column. As the hot vapour rises up the column, it cools and condenses.
- Each petroleum fraction is a mixture of hydrocarbons which boils over a certain temperature range.
- Lighter fractions consist of smaller hydrocarbons and have lower boiling points. They are collected at the top of the fractionating column as gases.
- Heavier fractions consist of bigger hydrocarbons and have higher boiling points. They are collected at the bottom of the fractionating column.

Homologous series

Multiple choice questions

1 Which structure is an isomer of butane? (2021 P1 Q35)



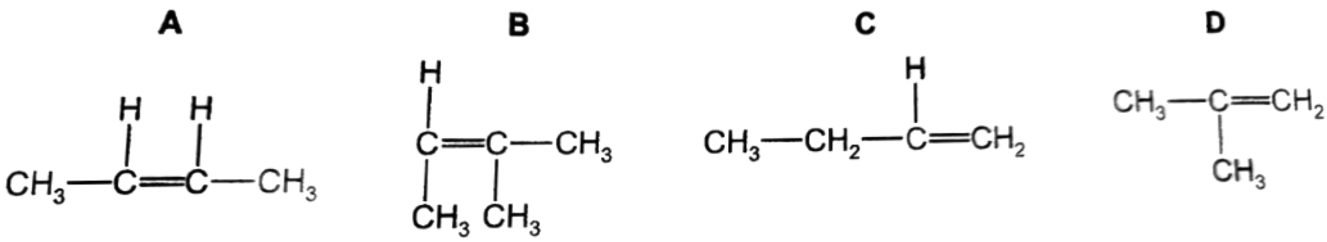
2 X reacts with steam to form Y. Y is oxidised to Z.

$$X \xrightarrow{\text{steam}} Y \xrightarrow{\text{oxidation}} Z$$

If Z is propanoic acid, what is the formula of X? (2021 P1 Q36)

A C_2H_4
B C_2H_6
C <u>C_3H_6</u>
D C_3H_8

3 Addition of hydrogen to an unknown alkene gives the alkane $(CH_3)_3CH$.
What is the unknown alkene? (2021 P1 Q37)



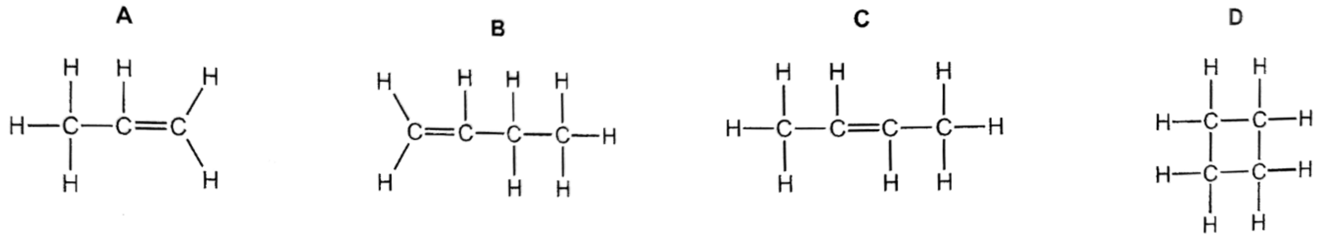
4 Q is a compound that forms a gas when added to aqueous sodium carbonate.
What is true about Q? (2021 P1 Q39)

A It could be formed by reducing ethanol
B It could form an easter with ethanoic acid
C <u>It could have the empirical formula C_2H_4O</u>
D It could have the molecular formula C_2H_4O

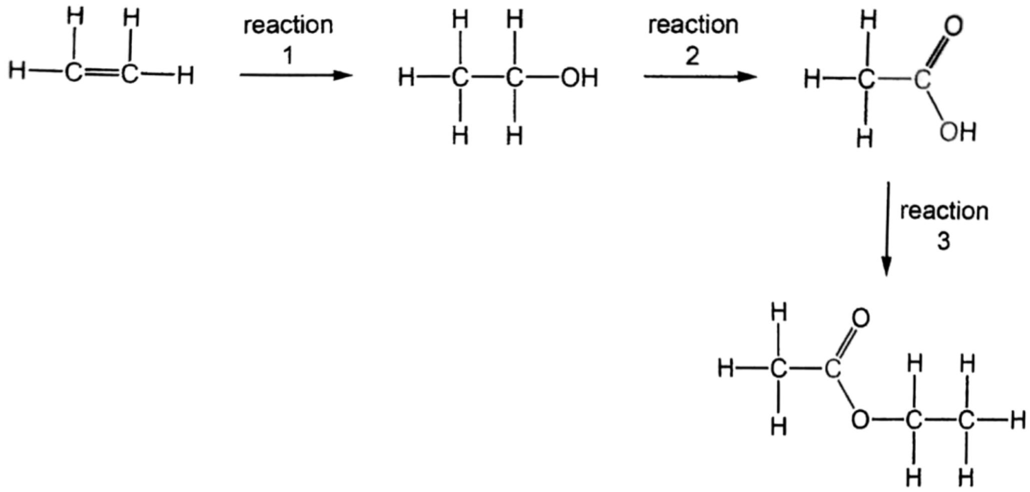
5 Compound Z

- has the empirical formula CH_2
- has an M_r of 56
- reacts with steam to form two alcohols that have different structural formulae

What is compound Z? (2020 P1 Q38 / 2016 P1 Q30)



6 The flow chart shows some of the reactions of organic compounds.



Which row describes the types of reactions involved? (2020 P1 Q39)

	reaction 1	reaction 2	reaction 3
A	addition	oxidation	esterification
B	reduction	oxidation	oxidation
C	oxidation	addition	esterification
D	addition	esterification	addition

7 Two of the isomers of butene, C_4H_8, are shown.

$CH_2=CHC_2H_5$ and $CH_3CH=CHCH_3$

How many of the statements about these two isomers are correct?

- Both decolourise aqueous bromine.
- Both produce the same molecule when reacted with bromine.
- Both produce the same molecule when reacted with hydrogen.
- When polymerised, the same polymer is produced.

(2019 P1 Q36)

A 1 **B** 2 **C** 3 **D** 4

8 Which statements about ethanol are correct?
Ethanol can be used:

1. as the source of energy in car engines
2. to dissolve the active ingredients in perfumes
3. to manufacture polyesters

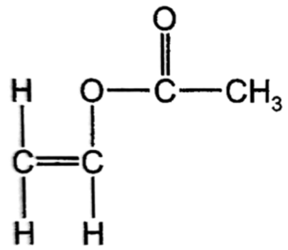
(2019 P1 Q37)

A 1 only
B <u>1 and 2</u>
C 2 only
D 2 and 3

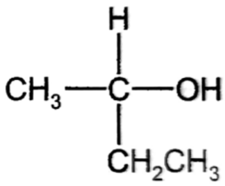
9 An alcohol and a carboyxlic acid are reacted together to form an ester. (2018 P1 Q39)
Which statement(s) is correct?

A The ester molecule has fewer oxygen atoms than the carboxylic acid molecule.
B The ester molecule has the same number of oxygen atoms as the alcohol molecule.
C <u>The ester molecule has more oxygen atoms than the alcohol molecule.</u>
D The ester molecule has more oxygen atoms than the carboxylic acid molecule.

10 The structures of two compounds, X and Y, are shown.



compound X



compound Y

Which statements are correct?

1. Both X and Y contain 4 carbon atoms per molecule.
2. Both X and Y contain a carbon atom that has 4 different groups attached to it.
3. X could form a polymer while Y could not.

(2018 P1 Q40)

A 1, 2 and 3
B 1 and 2 only
C <u>1 and 3 only</u>
D 2 and 3 only

11 Which alcohol cannot be oxidised to produce a carboxylic acid containing a CH_3 group?
(2017 P1 Q39)

A butanol
B ethanol
C methanol
D propanol

12 The reaction between a carboxylic acid C_xH_yCOOH and an alcohol $C_nH_{2n+1}OH$ produces an ester. How many hydrogen atoms does one molecule of the ester contain? (2017 P1 Q40)

A y + 2n
B y + 2n + 1
C y + 2n + 2
D y + 2n + 3

13 The boiling point of a covalent compound is determined by the strength of the intermolecular forces between its molecules.
Which covalent compound has the strongest forces of attraction between its molecules?
(2016 P1 Q38)

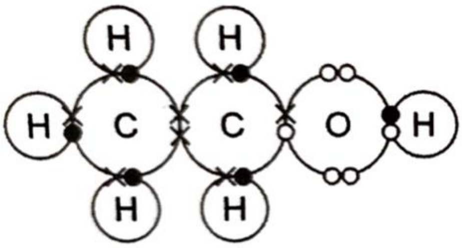
A butane
B ethane
C methane
D propane

14 Ethanol can be manufactured from ethene or from glucose. The table gives statements about the processes involved.
In which row are both statements incorrect? (2015 P1 Q33)

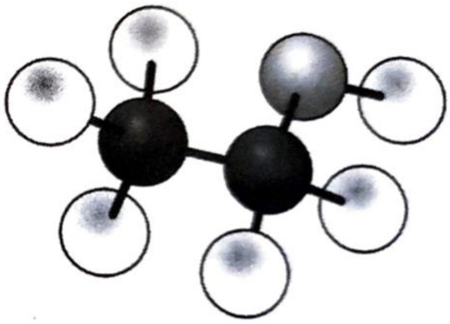
	process using ethene	process using glucose
A	conversion to ethanol needs temperatures greater than 100°C	conversion to ethanol produces carbon dioxide
B	conversion to ethanol uses yeast as catalyst	conversion to ethanol is carried out at 100°C
C	ethene is obtained by cracking	glucose is obtained from plants
D	the conversion reaction is carried out with the reagents as gases	the conversion reaction is carried out in aqueous solution

Structured questions

1 Several types of formulae, diagrams and models can be used to represent an ethanol molecule. Two representations are shown.



'dot-and-cross' diagram



ball and stick model

Tables 1 and 2 show some additional information about the length of the bonds in a molecule of ethanol and the atomic radius of each atom in ethanol.

Table 1

bond	length of bond / nm
C–H	0.109
C–C	0.154
C–O	0.143
O–H	0.096

Table 2

atom	atomic radius / nm
C	0.077
H	0.037
O	0.073

(1 000 000 000 nm = 1 m)

(2020 P2 B9 EITHER)

(a) Explain why **neither** the 'dot-and-cross' diagram nor the ball and stick model is an accurate representation of an ethanol molecule. [3]

Ball and stick model:

- Does not represent the size of carbon, hydrogen and oxygen atoms accurately. All atoms in the model have the same size which is incorrect. Carbon and oxygen atoms should be larger than hydrogen atoms.
- Does not represent bond length correctly. All bond lengths in the model are about the same, although the table shows that the bond lengths are different.

'Dot-and-cross' diagram:

- Bond length cannot be interpreted.

(b) The molecular and empirical formulae of ethanol are identical.

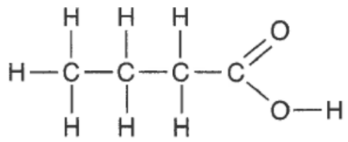
(i) Deduce the molecular formula of ethanol. [1]

C_2H_6O

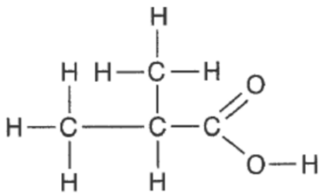
(ii) Explain why the molecular and empirical formulae of ethanol are identical. [1]

Ratio of carbon to hydrogen to oxygen atoms is in its simplest ratio.

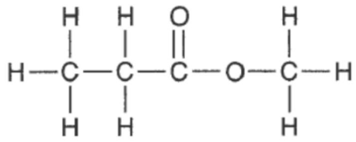
2 The diagrams show the structures of three isomers.



isomer 1



isomer 2



isomer 3

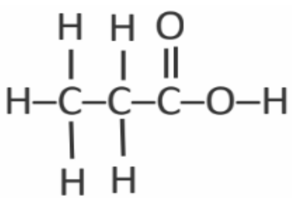
(2019 P2 B10 OR)

(a) The pH of each isomer is tested with Universal Indicator.
One of the isomers is neutral.
Describe and explain the results you would expect when the pH of each isomer is tested with Universal Indicator. [3]

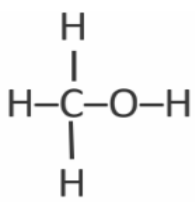
- Isomers 1 and 2 contain the carboxyl functional group (–COOH). Both isomers will ionise in water to produce H^+ ions that will cause the pH < 7. They will turn the green Universal Indicator orange / yellow.
- Isomer 3 contains the ester functional group (–COO–) which is neutral. Hence the pH = 7 and the green Universal Indicator remains unchanged.

(b) Isomer **3** can be made by reacting a carboxylic acid with an alcohol.
Draw the displayed formulae and give the names of the carboxylic acid and the alcohol that react to form isomer **3**. [3]

propanoic acid

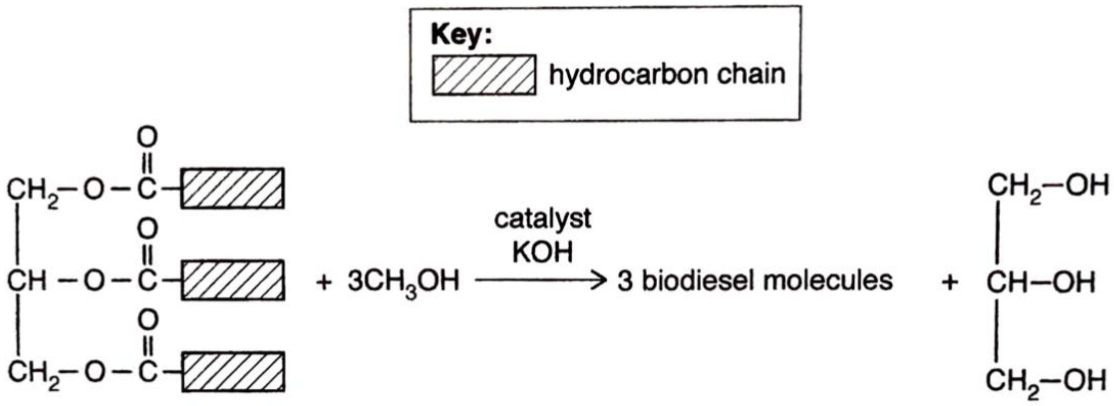


methanol



3 Vegetable oils that have been used for cooking can be reacted to make biodiesel for fuel.
Vegetable oils are tri-esters with long hydrocarbon chains.

Vegetable oils react with methanol.
The reaction uses a potassium hydroxide catalyst.



vegetable oil **methanol**

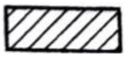
The diagram shows the structures of some of the molecules involved in the reaction.

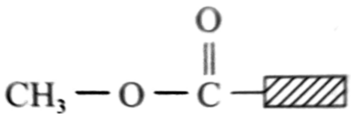
(2018 P2 B9)

(a) Suggest why vegetable oils are called *tri-esters*. [1]

Each molecule of the vegetable oil contains three ester linkages.

(b) 1 molecule of vegetable oil reacts to form 3 molecules of biodiesel. Biodiesel is an ester. Suggest the structure of one molecule of biodiesel.

Use  to represent the hydrocarbon chain. [2]

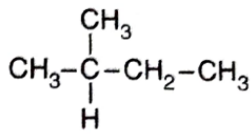
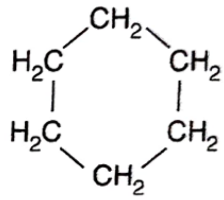
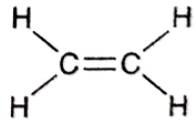


(c) Vegetable oils that have been used for cooking contain acids.
The oils must be treated to neutralise the acids before they can be used in the reaction to make biodiesel.
Using untreated oils affects the rate of the reaction.
Explain how and why using untreated oils affects the rate of the reaction. [2]

Acids in the vegetable oils react with potassium hydroxide catalyst which is added to increase rate of reaction by providing an alternative pathway with lower activation energy.

4 After fractional distillation, some molecules undergo further processes A, B and C in the refinery. Each process forms a range of different products.

The table shows some molecules used in each process with an example of a product formed.

process	molecule used in process	example of product formed in process
A	pentane $CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	
B	hexane $CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	
C	heptane $CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	

One of the processes is cracking.
Another process forms isomers of the molecules that are used in the process. This is called isomerisation. (2018 P2 B10 OR)

(a) Identify and explain which process in the table is cracking, which is isomerisation, and which process is neither.
Include references to molecular formulae, where relevant, in your answer. [4]

Process C is cracking.

Long-chain alkanes (heptane) are broken down to produce short-chain alkenes (ethene).

Process A is isomerisation.

The product formed has the same molecular formula C_5H_{12} as that of pentane but a different structural formula.

Process B is not cracking.

The hydrocarbon product has the same number of carbon atoms as hexane.

Process B is also not isomerisation.

The product has molecular formula C_6H_{12} which is different from hexane C_6H_{14}.

(b) Give a reason why cracking is important to the oil industry. [1]

Cracking converts long-chain hydrocarbons in the heavier petroleum fractions into smaller, more useful molecules such as those in petrol. The need for petrol is greater than that for diesel oil or lubricating oil.

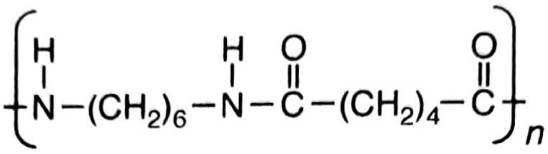
5 <u>The story of nylon</u>

Discovery, naming and properties

Wallace Carothers was an American research chemist in the 1930s. He researched new synthetic polymers to replace silk. At the time, silk was needed in very large quantities for parachutes. He is most famous for developing the first ‘nylon’.

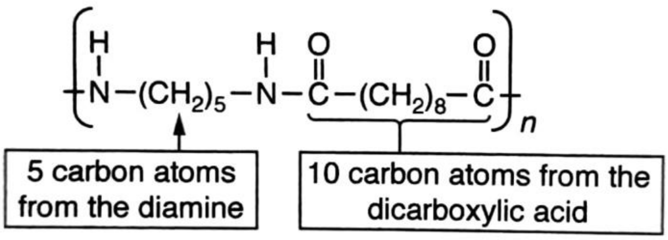
He reacted together a diamine and a dicarboxylic acid to make a type of polyamide that is called ‘nylon 6,6’.

nylon 6,6



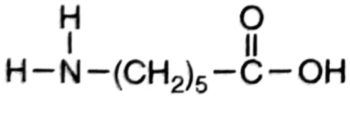
The numbers in the systematic names of each nylon refer to the number of carbon atoms from the diamine (the first number) and the dicarboxylic acid (the second number) which were used to make the nylon. For example, another type of nylon (nylon 5,10) was also made. Its structure is shown below.

nylon 5,10

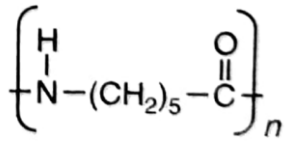


Later, nylon 6 was inverted. This can be made from a single monomer that has an amine group at one end and a carboxylic acid group at the other end.

monomer of nylon 6

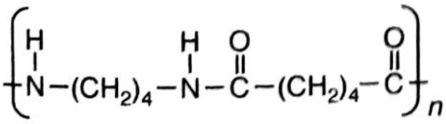


repeating unit of nylon 6

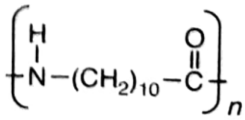


Other types of nylon were developed later.

repeating unit of nylon X



repeating unit of nylon Y



Different types of nylon are used for different purposes. One of the limits to their use is that they cannot be used in contact with solutions of strong acids because they react slowly with strong acids to form their original monomer molecules. Some uses of nylon are related to their melting points. For nylons made from two different monomers, the melting point is affected by the chain lengths of diamine and the dicarboxylic acid used to make the nylon.

name of nylon	melting point / °C
nylon 6,6	269
nylon 6,10	220
nylon 6	220
nylon 4,6	275
nylon 6,12	218
nylon 11	190

Using nylon

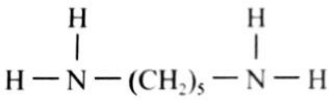
Nylons are useful because they are generally unreactive and can be made into very strong fibres. They are used to make clothing, fishing lines, ropes and machine parts. To be suitable for making fibres, the nylon chains must have a relative molecular mass of between 10000 and 20000. This length of molecule gives enough strength but is still flexible enough to be spun into fibres easily.

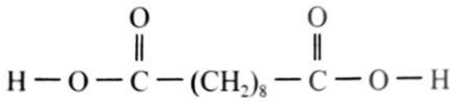
(2016 P2 B7)

(a) Name nylon X and nylon Y. [3]

nylon X: nylon 4,6
nylon Y: nylon 11

(b) Give the structural formulae of the two products that form when nylon 5,10 is left in contact with a strong acid. [2]





(c) A company wants to use nylon 6,6 to make fibres.

Calculate the minimum number of repeating units which must be present in one chain of the nylon 6,6. [2]

M_r of 1 repeating unit of nylon 6,6 ($C_{12}H_{22}N_2O_2$) = 226
For relative molecular mass of 10000,
no. of repeating units = 10000 / 226 = 44.2 (3 s.f.)
Hence, min no. of repeating units = 45

(d) The article says 'For nylons made from two different monomers, the melting point is affected by the chain lengths of the diamine and the dicarboxylic acid used to make the nylon'.
How is the melting point of the nylon affected by the chain lengths of the diamine and the dicarboxylic acid used? Explain your reasoning. [3]

diamine:

Comparing nylon 4,6 with nylon 6,6, the shorter the diamine chain length, the higher the melting point of the nylon.

dicarboxylic acid:

Comparing nylon 6,6 with nylon 6,10 and nylon 6,12, the longer the dicarboxylic chain length, the lower the melting point of the nylon.

6 A student collects some data about the fat content of some margerines.
The margerines tested are all mixtures of saturated fat A, unsaturated fat B, and water.
He also does an experiment to count how many drops of bromine water react with 10g of each type of margarine.

margarine	percentage by mass of saturated fat	percentage by mass of unsaturated fat	number of drops of bromine water per 10g
1	10	80	12
2	20	70	11
3	40	20	3

(2013 P2 B9 EITHER)

(a) What colour change happens when bromine reacts with a margarine? [1]

The reddish brown bromine solution turns colourless

(b) What is seen when the bromine is in excess? [1]

The mixture becomes reddish brown

(c) The margarines are sold in 500g packs. Which margarine contains most water per 500g? Explain your reasoning. [2]

Margarine 3

It contains the most water (40%) since the total percentage of saturated and unsaturated fats is 60% as compared to 90% in both Margarine 1 and 2.

(d) Another margarine contains 50g of saturated fat A and 20g of unsaturated fat B per 100g. Estimate the number of drops of bromine water that react with 10g of this margarine. [1]

3

(e) Some cooking oils contain a mixture of water with molecules of saturated and unsaturated fats. Iodine and bromine react in a similar way with fat molecules.
The mass of iodine that reacts with three different types of oil are shown in the table.

Oil	Mass of iodine that reacts with 100g of the oil / g
C	175
D	124
E	163

(i) A student says 'oil C contains a larger mass of fat than oil D'.
Do you agree with the student? Explain your reasoning. [2]

The student's deduction may not be entirely correct.

- Oil C contains larger mass of unsaturated fat than oil D based on the higher mass of iodine that has reacted.
- Since saturated fat has no reaction with iodine, its mass cannot be determined by reaction with iodine.

(ii) A pure fat has a molecular mass of 400. 100g of the fat reacts with 127g iodine. How many double bonds are there in each molecule of the fat? Show your working. [3]

No. of moles of iodine, I_2 = 127 / 2(127) = 0.500 mol

No. of moles of fat molecule = 100 / 400 = 0.250 mol

No. of moles of fat molecule : No. of moles of I_2 = 1:2

Each fat molecule will react with 2 molecules of I_2.

Hence, each fat molecule has 2 double bonds.

Macromolecules

Multiple choice questions

1 The table refers to the polymers nylon and poly(ethene).
Which row is correct? (2021 P1 Q40)

	polymer	type	use
A	nylon	addition	cling film
B	nylon	condensation	parachutes
C	poly(ethene)	addition	parachutes
D	poly(ethene)	condensation	cling film

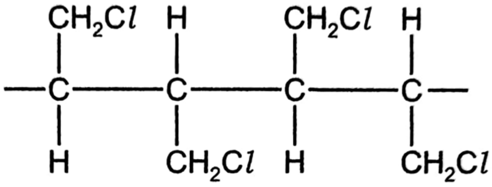
2 Two compounds, X and Y, react together to form the polymer nylon.

X	**Y**
$H_2N–(CH_2)_6–NH_2$	$HOOC–(CH_2)_4–COOH$

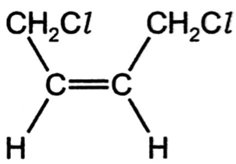
What is the formula of the partial structure which repeats within the polymer? (2020 P1 Q40)

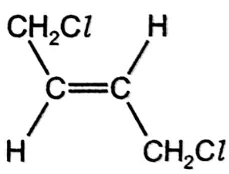
A $C_{10}H_{22}N_2O_2$
B $C_{12}H_{22}N_2O_2$
C $C_{10}H_{20}N_2O_4$
D $C_{12}H_{20}N_2O_4$

3 The diagram shows the partial structure of a polymer.



Which statement about this polymer is correct? (2019 P1 Q40)

A It could be made by addition polymerisation of 

B It could be made by condensation polymerisation of 

C Its monomer has the empirical formula $C_4H_6Cl_2$

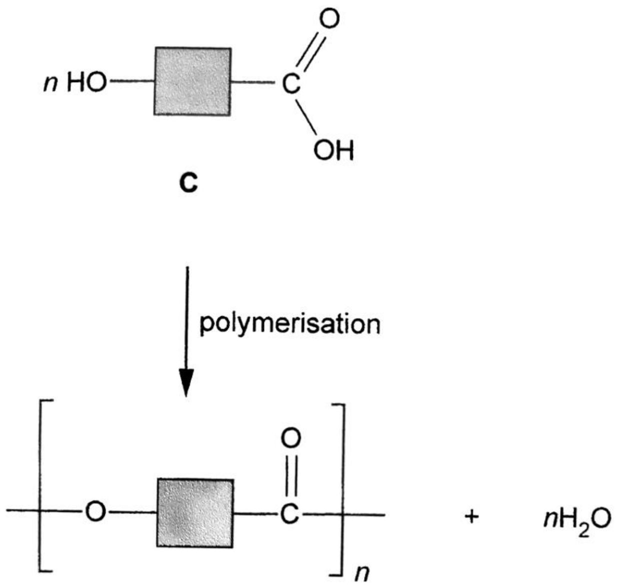
D Its monomer could be made by the reaction of an alkane with chlorine

4 Which compound, without the addition of any other reagent, polymerises to produce a polyamide similar to nylon? (2016 P1 Q37)

A C_2H_4COOH
B $C_2H_5NH_2$
C $H_2N(CH_2)_4NH_2$
D $H_2N(CH_2)_4COOH$

Structured questions

1 The figure below shows how molecule C polymerises to make another condensation polymer.



(2021 P2 B7b)

(a) The polymer formed from molecule C is a type of polyester.
Explain how the structure of the polymer shows that it is a polyester. [1]

Structure of the polymer shows the ester linkage. A polyester contains many ester linkages.

(b) The condensation polymerisation of molecule C can be compared with the addition polymerisation of ethene.
Outline one similarity and two differences between the condensation polymerisation of molecule C and the addition polymerisation of ethene. [3]

Condensation polymerisation of molecule C	**Addition polymerisation of ethene**
Involve only one type of monomer	
The polymer is formed with the removal of small molecules such as water	Ethene molecules join together without losing any molecules or atoms
Involves reaction between carboxyl functional groups and hydroxyl functional groups	Involves unsaturated monomers