Cambridge OL

Chemistry

CODE: (5070)

Chapter 12

Organic chemistry

A lot of the compounds that are present in living things have been found to be compounds containing carbon (Figure 12.1). These are known as **organic compounds**.

▲ **Figure 12.1** Living things contain organic compounds

12.1 Alkanes

Most of the hydrocarbons in petroleum belong to the family of compounds called **alkanes**.

The fully **displayed formulae** of some alkanes, containing carbon atoms covalently bonded to four other atoms by single bonds, are presented in Figure 12.2.

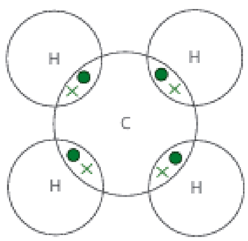
A **displayed formula** shows how the various atoms are bonded and shows all the bonds in the molecule as individual lines. Because these molecules possess only carbon–carbon single covalent bonds, they are said to be **saturated**, as no further atoms can be added.

Key definition

The **displayed formula** of a molecule is a diagram that shows how the various atoms are bonded and shows all the bonds in the molecule as individual lines.

A **saturated** compound has molecules in which all carbon–carbon bonds are single bonds.

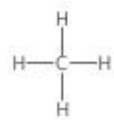
A family with these factors in common is called a **homologous series.**

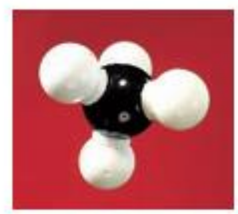


Methane molecule (CH_4)

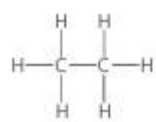
▲ **Figure 12.3** The covalent bonding scheme for methane

Methane

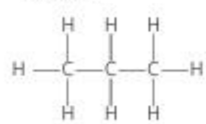




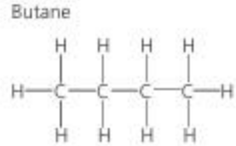
Ethane

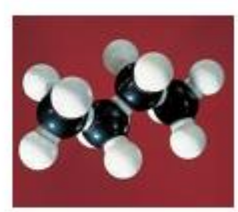


Propane



Butane





All the members of a homologous series can also be represented by a general formula. In the case of the alkanes, the general formula is:

C_nH_{2n+2}

As carbon atoms increase in a homologous series, their physical properties change. Alkanes' melting and boiling points increase due to increased intermolecular forces and the addition of a CH2 group. Compounds within a homologous series have similar chemical properties through their functional group, which is typically an atom or group present within the molecules. Alkanes, however, do not have a functional group.

Key definitions

A **homologous series** is a family of similar compounds with similar chemical properties due to the presence of the same functional group.

A **functional group** is an atom or group of atoms that determine the chemical properties of a homologous series.

Naming the alkanes

All the alkanes have names ending in -ane. The rest of the name tells you the number of carbon atoms present in the molecule.

Structural isomerism

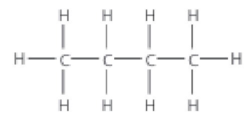
Displayed formulas can represent molecular formulas, illustrating atom-covalent bond connections. For instance, two compounds with C_4H_{10} have different structural formulae, names, and physical properties, as illustrated in Figure 12.4.

Compounds such as those in Figure 12.4 are known as **structural isomers**. **Isomers** are substances which have the same molecular formula but different **structural formulae** and displayed formulae.

> **Key definitions**
>
> **Structural isomers** are compounds with the same molecular formula, but different structural formulae.
>
> The **structural formula** of an organic compound is an unambiguous description of the way the atoms are arranged, including the functional group.

▼ **Table 12.1** Some alkanes and their physical properties

Alkane	Molecular formula	Melting point/°C	Boiling point/°C	Physical state at room temperature
Methane	CH_4	–182	–162	Gas
Ethane	C_2H_6	–183	–89	Gas
Propane	C_3H_8	–188	–42	Gas
Butane	C_4H_{10}	–138	0	Gas

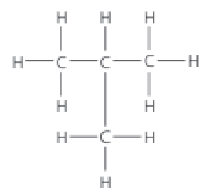


$CH_3CH_2CH_2CH_3$

Melting point −138°C

Boiling point 0°C

a Butane



$CH_3CH(CH_3)CH_3$

Melting point −159°C

Boiling point −12°C

b 2-Methylpropane

▲ **Figure 12.4** Displayed and structural formulae for the two isomers of C_4H_{10}

12.2 The chemical behaviour of alkanes

Alkanes are rather unreactive compounds. Gaseous alkanes, obtained through fractional distillation of petroleum, are useful fuels for cooking, heating, and heating. Natural gas, propane, and butane are used in cooking and heating, while butane is used in portable blowlamps and gas lighters. Alkanes are generally unreactive but undergo chemical reactions with halogens like chlorine, which react with methane in sunlight or ultraviolet light.

a This is burning methane

b Central heating systems can be run on propane

▲ **Figure 12.5**

We can see that one hydrogen atom of the methane molecule is substituted (replaced) by a chlorine atom to form chloromethane (see Figure 12.6). This type of reaction is known as a **substitution reaction.**

Other uses of alkanes

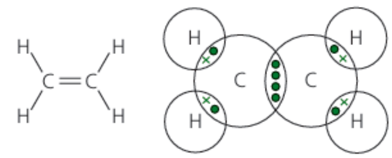
Heavy alkanes are used as fuels, waxes in candles, lubricating oils, and in the production of alkenes, a family of hydrocarbons.

Methane – another greenhouse gas

Methane, a natural greenhouse gas, is produced by cows and rice cultivation. It acts like a glasshouse, allowing heat in but not releasing it back out. The greenhouse effect may contribute to global warming, causing disastrous effects on life on Earth. Debates are ongoing on reducing methane emissions.

12.3 Alkenes

Alkenes, a homologous series of hydrocarbons, are more reactive than alkanes due to their double carbon-carbon covalent bond. **Unsaturated** molecules can be added by breaking one of the two bonds, forming their functional group and influencing their characteristic properties.



▲ **Figure 12.9** The bonding in ethene, the simplest alkene

Key definition

An **unsaturated** compound has molecules in which all carbon–carbon bonds are double bonds or triple bonds.

Naming the alkenes

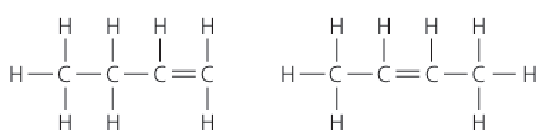
All alkenes have names ending in -ene. Alkenes, especially ethene, are very important industrial chemicals. They are used extensively in the plastics industry and in the production of alcohols such as ethanol and propanol. See Table 12.2 and Figure 12.10.

▼ **Table 12.2** The first three alkenes and their physical properties

Alkene	Molecular formula	Melting point/°C	Boiling point/°C	Physical state at room temperature
Ethene	C_2H_4	−169	−104	Gas
Propene	C_3H_6	−185	−47	Gas
Butene	C_4H_8	−184	−6	Gas

Structural isomerism in alkenes

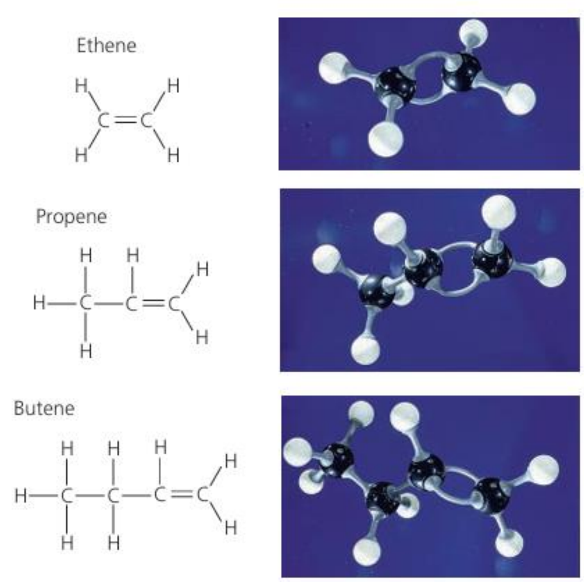
Structural isomers, which can represent molecular formulas, are sometimes used in alkanes. Butene and higher alkenes also exhibit structural isorism, with three compounds with the molecular formula C4H8. The structural formulas of but-1-ene and but-2-ene provide an unambiguous description of atom arrangement.



CH_3 CH_2 $CH=CH_2$ — But-1-ene

$CH_3CH=CHCH_3$ — But-2-ene

▲ **Figure 12.11** But-1-ene and but-2-ene: isomers of C_4H_8



▲ **Figure 12.10** Displayed formula and shape of the first three alkenes

Where do we get alkenes from?

Few alkenes exist in nature, with most used in the petrochemical industry through **catalytic cracking**, which breaks down larger, less useful alkane molecules from petroleum fractional distillation.

$$\text{dodecane} \longrightarrow \text{decane} + \text{ethene}$$

$$C_{12}H_{26}(g) \longrightarrow C_{10}H_{22}(g) + C_2H_4(g)$$

(found in kerosene) shorter alkane alkene

Another possibility is:

$$C_{12}H_{26}(g) \longrightarrow C_8H_{18}(g) + C_4H_8(g)$$

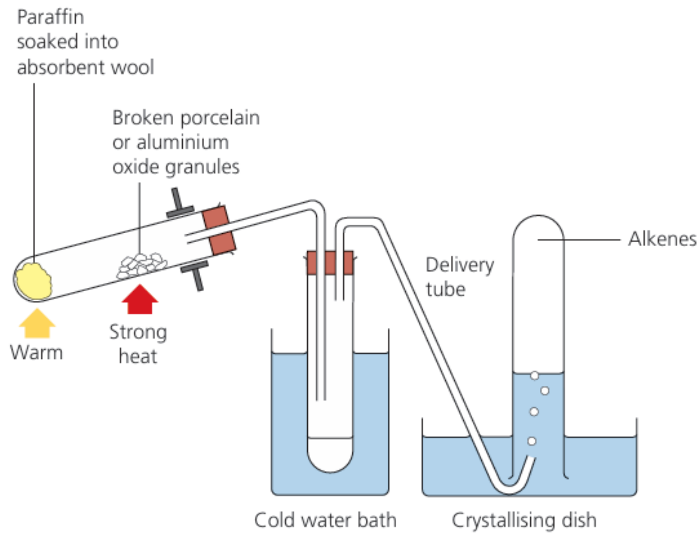
▼ **Table 12.3** Percentages of the fractions in petroleum and the demand for them

Fraction	Approx % in petroleum	Approx % demand
Refinery gas	2	5
Gasoline	21	28
Kerosene	13	8
Diesel oil	17	25
Fuel oil and bitumen	47	34

In these reactions, hydrogen may also be formed during cracking. The amount of hydrogen produced depends on the conditions used. Since smaller hydrocarbons are generally in greater demand than the larger ones, cracking is used to match demand (Table 12.3).

Oil companies don't have large surpluses of larger molecule fractions. Laboratory **thermal cracking** reactions can be carried out using broken pottery catalyst, but only as a teacher demonstration.

The double bond makes alkenes more reactive than alkanes in chemical reactions. For example, hydrogen adds across the double bond of ethene, under suitable conditions, forming ethane (Figure 12.13). This type of reaction is called an **addition reaction.**



▲ **Figure 12.12** The cracking of an alkane in the laboratory

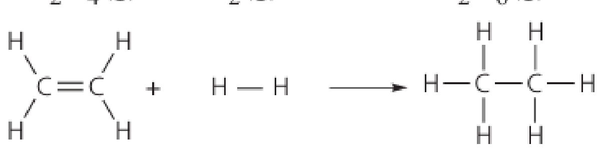
Addition reactions

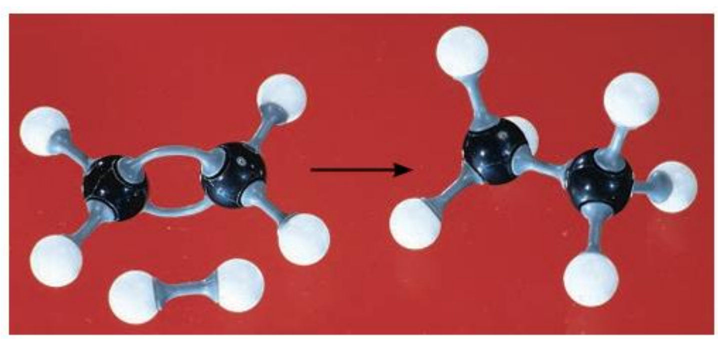
Hydrogenation

The reaction of hydrogenation in ethene involves the addition of hydrogen across the C=C double bond, requiring a temperature of 200°C and a nickel catalyst.

$$\text{ethene} + \text{hydrogen} \longrightarrow \text{ethane}$$

$$C_2H_4(g) + H_2(g) \longrightarrow C_2H_6(g)$$





▲ **Figure 12.13** The addition of hydrogen to ethene using molecular models

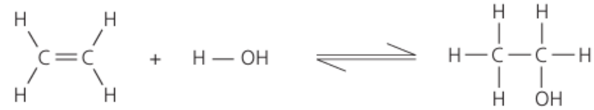
Hydration

The ethanol production process involves an addition reaction, where water is added to ethene, forming ethanol as a solvent and fuel. This reaction occurs at 300°C and 6000 kPa, using phosphoric acid catalysts.

The reaction of ethanol production involves a continuous process, where reactants are continuously fed into the reaction vessel or reactor as products are removed. The conditions are chosen to ensure the highest possible yield of ethanol, with a high percentage yield of approximately 96%.

$$\text{ethene} + \text{steam} \underset{\text{phosphoric(v) acid catalyst}}{\overset{300^\circ\text{C, 6000 kPa}}{\rightleftharpoons}} \text{ethanol}$$

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

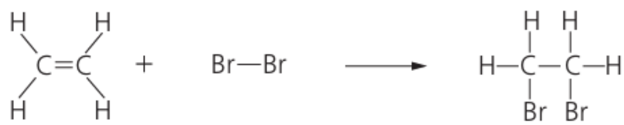


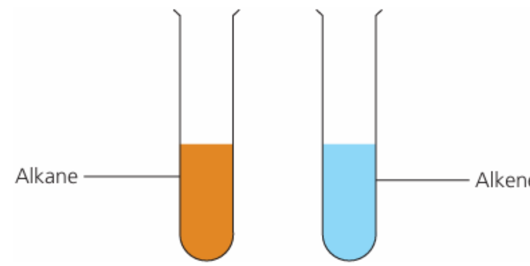
Halogenation – a test for unsaturated compounds

The reaction between bromine and alkenes is a chemical test for a double bond between two carbon atoms. When shaken with an alkene, the bromine solution loses its red/brown color, while an alkane, like hexane, does not show a color change.

$$\text{ethene} + \text{bromine} \longrightarrow \text{dibromoethane}$$

$$C_2H_4(g) + Br_2\text{ (in solution)} \longrightarrow C_2H_4Br_2\text{ (in solution)}$$

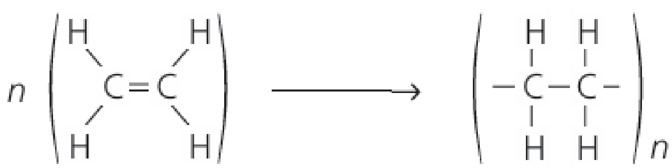




▲ **Figure 12.14** The alkane, has no effect on the bromine solution, but the alkene decolourises it

12.5 Polymers

The **plastics** industry, originating from the accidental discovery of polythene, is now produced in millions of tonnes worldwide annually. This material is produced by heating ethene to high temperatures and pressure, involving many monomer molecules.



When small molecules like ethene join to form long chains of atoms, called **polymers**, the process is called **polymerization**. The small molecules, like ethene, which join in this way are called **monomers**.

Key definitions

Polymers are large molecules built up from many small units called monomers.

Plastics are made from polymers.

Since in this polymerization process the monomer units add together to form only one product, the polymer, the process is called **addition polymerization**.

▲ **Figure 12.15** This model shows part of the poly(ethene) polymer chain

Environmental challenges of plastics

The alternatives to dumping plastic waste are certainly more economical and more satisfactory but also create their problems.

»Incineration schemes use waste heat for heating, but combustion issues lead to high temperatures, increasing energy costs due to potential toxic gas production.

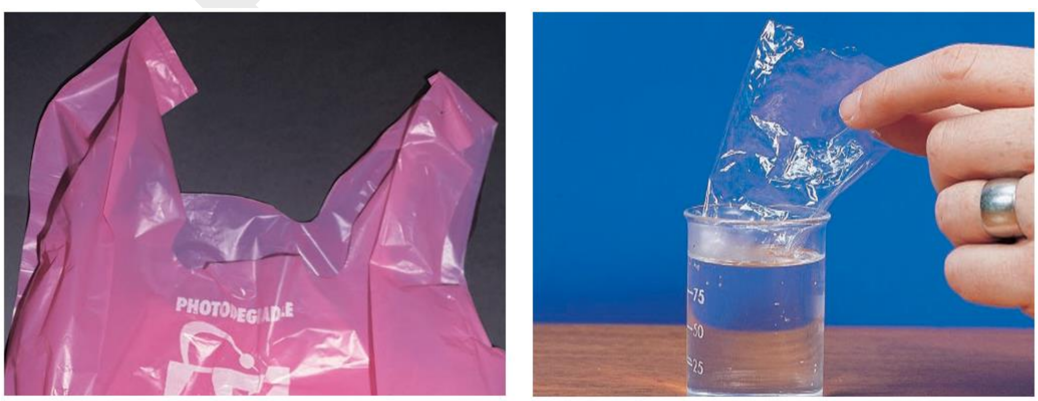
» Recycling generates large quantities of black plastic bags and sheeting for resale, but some plastics cannot be recycled due to their properties.

»**Biodegradable** plastics, as well as those polymers that degrade in sunlight (photodegradable, Figure 12.23a), have been developed.

Non-biodegradable plastics are causing extreme pollution in oceans, causing aquatic life to be decimated, prompting a rethinking of plastics' role in society.

▲ **Figure 12.22** Incineration plants can burn waste material to produce heat which can be used to provide warm water or can be converted into electricity

▲ **Figure 12.24** Non-biodegradable plastics accumulate in the oceans of the world



a This plastic bag is photodegradable

b This plastic dissolves in water

▲ **Figure 12.23**

Revision questions

12. Nov/2021/Paper_21/No.4

Alkenes are a homologous series of hydrocarbons.

(a) Alkenes are produced by cracking.

State the meaning of the term *cracking*.

....

.... [2]

(b) Margarine is manufactured from vegetable oils using a nickel catalyst.

(i) Name the other reactant used in this reaction.

.... [1]

(ii) State the type of chemical reaction which occurs when margarine is manufactured from vegetable oils.

.... [1]

(c) Ethanol is produced by the reaction of ethene with steam.

Construct the equation for this reaction.

(d) An organic compound contains 54.5% carbon, 9.10% hydrogen and 36.4% oxygen by mass.

Calculate the empirical formula of this compound.

14. Nov/2021/Paper_22/No.4

Alkanes are a homologous series of hydrocarbons. The boiling point, melting point and density of alkanes increase as the number of carbon atoms increases.

(a) (i) Give one **other** physical property of alkanes which increases as the number of carbon atoms increases.

.... [1]

(ii) Give two **other** characteristics of a homologous series.

1 ....

2 ....

[2]

(b) Two typical reactions of alkanes are combustion and cracking.

State the name of another typical chemical reaction of alkanes and the reactant needed to react with the alkanes.

type of reaction ....

reactant ....

[2]

(c) Alkenes are produced by cracking alkanes.

(i) State two conditions needed for cracking alkanes.

(ii) Tridecane, $C_{13}H_{28}$, can be cracked to produce an alkene with four carbon atoms and one other hydrocarbon only.

Construct an equation for this reaction.

35. Jun/2021/Paper_22/No.5

Petroleum (crude oil) provides the raw materials for making ethanol and ammonia.

(a) Describe how petroleum (crude oil) is separated to make fractions such as naphtha and petrol (gasoline).

....

....

.... [2]

(b) Compounds such as $C_{11}H_{24}$ in the naphtha fraction are cracked to make hydrogen, alkenes and smaller alkanes.

(i) Explain how the molecular formula $C_{11}H_{24}$ shows the compound is an alkane.

....

.... [1]

(ii) Construct an equation to show the cracking of $C_{11}H_{24}$ to make ethene and an alkane only.

.... [1]

(c) Describe how hydrogen is converted into ammonia in the Haber process.

Include the conditions used in the Haber process.

31. Jun/2021/Paper_21/No.3

Petroleum (crude oil) is a mixture of hydrocarbons.

(a) Petroleum (crude oil) is separated into fractions such as liquefied petroleum gas, petrol (gasoline) and naphtha.

(i) Name the process used to separate petroleum (crude oil) into fractions.

.... [1]

(ii) Name one **other** fraction separated from petroleum (crude oil).

Give a large-scale use for this fraction.

fraction ....

use ....
[1]

(iii) Petroleum (crude oil) does not contain enough of the fractions that contain smaller hydrocarbon molecules such as petrol (gasoline).

Petroleum contains a high proportion of larger hydrocarbon molecules such as naphtha.

Describe how the demand for smaller hydrocarbon molecules is satisfied.

16. Nov/2021/Paper_21/No.2c,d,e,f

(c) Ethyne is an unsaturated hydrocarbon.

State the meaning of the term *hydrocarbon*.

(d) Ethyne is a member of the alkyne homologous series.

The molecular formulae of the first four members of the alkyne homologous series are shown.

C_2H_2
C_3H_4
C_4H_6
C_5H_8

Predict the formula for the fifth member of the alkyne homologous series.

.... [1]

(e) Ethyne reacts with hydrogen in a similar way to ethene reacting with hydrogen.

The reaction between ethyne and hydrogen is exothermic.

(i) What type of chemical reaction occurs when ethyne reacts with hydrogen?

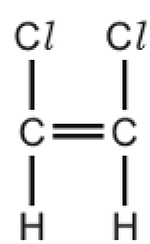
.... [1]

(ii) Predict the molecular formula of a product formed when ethyne reacts with hydrogen.

.... [1]

(f) 1,2-dichloroethene is produced when excess ethyne reacts with chlorine.

The structure of 1,2-dichloroethene is shown.



Deduce the partial structure of the polymer of 1,2-dichloroethene.

Show three repeat units.

20. Nov/2021/Paper_22/No.5

Alkenes are made in an oil refinery by cracking hydrocarbons.

(a) **(i)** Give one **other** reason why petroleum companies carry out cracking.

....

.... [1]

(ii) Complete the equation for the cracking of tridecane, $C_{13}H_{28}$, to form propene, C_3H_6, and one other hydrocarbon.

$$C_{13}H_{28} \rightarrow C_3H_6 + \text{..............}$$ [1]

(b) Propene is an alkene.

(i) Write the general formula for an alkene.

.... [1]

(ii) Propene reacts with steam by an addition reaction.

Predict the molecular formula of the product of this reaction.

.... [1]

(iii) When propene undergoes incomplete combustion, a small amount of carbon dioxide is formed.

Name two **other** substances formed when propene undergoes incomplete combustion.

.... and ....
[2]

39. Jun/2020/Paper_21/No.10

Fractional distillation and cracking are important processes in the conversion of petroleum (crude oil) into useful substances.

(a) Complete the sentence about petroleum (crude oil).

Choose from the list.

an alloy	**a compound**	**an element**
a mixture	**a polymer**	**a salt**

Petroleum (crude oil) is .... of hydrocarbons. [1]

(b) Fractional distillation separates petroleum (crude oil) into fractions such as paraffin (kerosene) and naphtha.

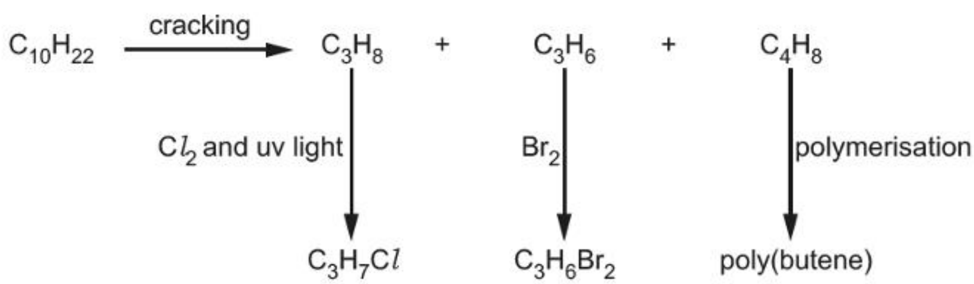
Give one use for the paraffin (kerosene) fraction.

.... [1]

(c) The naphtha fraction is used as a chemical feedstock.

One of the hydrocarbons in naphtha has the molecular formula $C_{10}H_{22}$.

The flow chart shows some compounds that can be made from $C_{10}H_{22}$.



(i) C_3H_8 is an alkane and C_3H_6 is an alkene.

Explain why, in terms of their general formulae, C_3H_8 is an alkane and C_3H_6 is an alkene.

(ii) In the presence of uv light chlorine reacts with C_3H_8.

Two of the products formed are HCl and C_3H_7Cl.

What type of reaction takes place when C_3H_8 reacts with chlorine?

....

Give the formula of one other product of this reaction.

....
[2]

(iii) Describe the colour change when C_3H_6 reacts with bromine.

....

.... [1]

(d) **(i)** Suggest a possible structure for C_4H_8.

(ii) Draw the partial structure of poly(butene) that shows at least two repeat units.

42. Jun/2020/Paper_22/No.10

Fractional distillation and cracking are important processes in the conversion of petroleum (crude oil) into useful hydrocarbons.

(a) Fractional distillation separates petroleum (crude oil) into fractions such as bitumen and naphtha.

(i) Which physical property allows the petroleum (crude oil) to be separated into fractions?

.... [1]

(ii) Describe the separation of petroleum (crude oil) by fractional distillation.

....

....

....

.... [2]

(iii) Give one use of the bitumen fraction.

.... [1]

(b) The naphtha fraction is used as a chemical feedstock.

One of the hydrocarbons in naphtha has the molecular formula $C_{10}H_{22}$.

Use the general formula for an alkane to show that $C_{10}H_{22}$ is an alkane.

(c) In an experiment $C_{10}H_{22}$ is cracked to form products **A**, **B** and **C**.

(i) Product **A** gives a squeaky pop when ignited with a burning splint.

Identify product **A**.

.... [1]

(ii) Product **B** has a relative molecular mass of 98 and decolourises aqueous bromine.

Suggest the molecular formula for **B**.

Explain your answer.

molecular formula ....

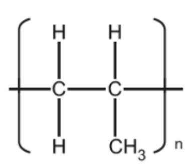
explanation ....

....

....

[2]

(iii) Product **C** can be polymerised to give the polymer shown.



Draw the structure of product **C**.