17.1 Organic chemistry

LEARNING OUTCOMES

- Define the terms *homologous series* and *functional group*
- Name and draw the structures of methane, ethane, ethanol and ethanoic acid

Most organic compounds char or burn when heated in air. Most inorganic compounds just melt or vaporise.

EXAMINER SAYS...

When drawing the full structural formula of an organic compound you should show all atoms and all bonds. Don't forget that there is a bond in the alcohol functional group –O – H.

Organic chemistry

About two hundred years ago the Swedish chemist Jöns Jakob Berzelius divided chemicals into two main groups: organic and inorganic chemicals. Most organic chemicals burn or char (go black) when heated. Most inorganic chemicals just melt on heating.

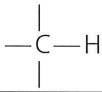
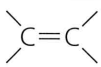
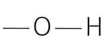
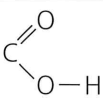
All **organic compounds** contain carbon. They usually contain hydrogen and may contain other elements as well. Millions of organic compounds are known. So we have to make rules for naming them. Fortunately for us, many organic compounds can be put into groups. A group of organic molecules with similar chemical properties is called a **homologous series**. Two homologous series are **alcohols** and **carboxylic acids**. Here are the names and formulae of some compounds in these two homologous series:

alcohol homologous series		*carboxylic acid homologous series*	
methanol	CH_3OH	methanoic acid	$HCOOH$
ethanol	C_2H_5OH	ethanoic acid	CH_3COOH
propanol	C_3H_7OH	propanoic acid	C_2H_5COOH

You can see that all the alcohols have an -OH group and that all the carboxylic acids have a -COOH group. We call this group the **functional group**. A functional group is an atom or group of atoms that gives a compound particular properties. Carboxylic acids behave in a different way from alcohols but each carboxylic acid has very similar chemical properties.

More about homologous series

We can tell which homologous series a compound belongs to by the ending of its name. For example, the members of the alcohol homologous series all end in –ol. The table gives a list of some of these endings.

homologous series	name ending	functional group	example
alkane	-ane		ethane C_2H_6
alkene	-ene		ethene, C_2H_4
alcohol	-ol		ethanol C_2H_5OH
carboxylic acid	-oic acid		ethanoic acid CH_3COOH

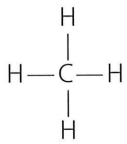
Extension

We can show that a homologous series has the same general characteristics in several ways:

- We can give each homologous series a general formula which applies to all members of the homologous series. For example, all members of the alkane homologous series have the general formula C_nH_{2n+2}, where n is the number of carbon atoms. The alkane with five carbon atoms is called pentane. Its formula is $C_5H_{(2x5)+2}$, which is C_5H_{12}. All members of the alkene homologous series have the general formula C_nH_{2n}.
- As the number of carbon atoms in a homologous series increases by one, the number of hydrogen atoms increases by two. For example: CH_3OH, C_2H_5OH, C_3H_7OH – each differs from the next by a CH_2 group.
- The members of a homologous series have very similar chemical properties because they all have the same functional group.
- The physical properties in a homologous series change in a regular way as the number of carbon atoms increases. For example, the boiling points of the alkanes (see Unit 18.1).

DID YOU KNOW?

Until Friedrich Wöhler made urea in 1828, scientists thought that compounds in the body differed from inorganic compounds because they had a special 'life force' in them.



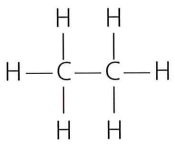
The full structural formula of methane.

Formulae of organic compounds

The full structural formula for methane shows how the atoms are bonded by covalent bonds. This type of formula is sometimes called the displayed formula.

The molecular formula shows the actual number of each type of atom in a compound without showing the bonds. The molecular formula for methane is CH_4.

The full structural and molecular formulae for ethane are:

full structural formula  molecular formula C_2H_6

We sometimes abbreviate the structural formula to show each carbon atom with its attached hydrogen atoms one by one but without showing the single bonds. For ethane this type of structural formula is written CH_3CH_3.

SUMMARY QUESTIONS

1 Copy and complete using the words below:

atom chemical compound ethane functional homologous

Methane and _____ belong to the same _____ series. They have the same _____ group. A functional group is an _____ or group of atoms that gives a _____ its particular _____ properties.

2 Draw:

a the full structural formula of methane

b the molecular formula of ethanol.

Extension

3 State three characteristics of a homologous series.

KEY POINTS

1 A functional group is an atom or group of atoms that gives an organic compound its particular chemical properties.

2 A homologous series is a group of organic compounds with the same functional group and similar properties.

3 A homologous series has particular characteristics.

Extension

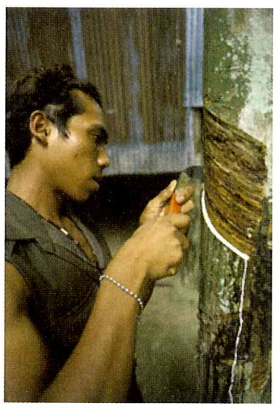
17.2 Hydrocarbons

LEARNING OUTCOMES

- Define the term *hydrocarbon*

Extension

- Name and draw the structures of alkanes having up to four carbon atoms
- Describe and identify structural isomerism



Natural rubber is a very useful hydrocarbon which is obtained from the sap of certain trees.

DID YOU KNOW?

The compound BHC (hexachlorocyclohexane) has eight different isomers but only one of the eight acts as an insecticide.

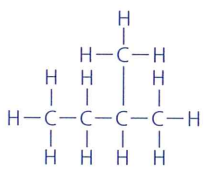
EXAMINER SAYS...

When drawing alkenes make sure that there are not too many hydrogen atoms around the carbon atoms that form the double bond. Check to see that each carbon has four bonds.

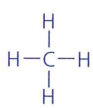
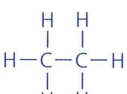
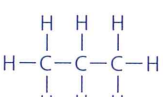
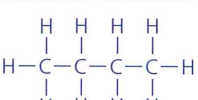
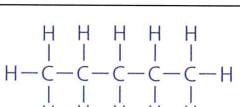
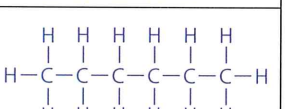
A **hydrocarbon** is a compound which contains only carbon and hydrogen atoms. The **alkanes** and the **alkenes** are two important homologous series of hydrocarbons. Alkanes only have single covalent bonds but alkenes can have one or more double bonds between their carbon atoms.

Naming alkanes

What do all compounds with names starting with meth- have in common? The answer is that they have only one carbon atom. A compound beginning with eth- has two carbon atoms in its chain. A compound with three carbon atoms has a name beginning with prop-. The prefix tells us how many carbon atoms there are in the longest chain. The compound on the right has a name starting with but- because the longest chain has four carbon atoms. The names of the first six alkanes are shown below. You will only need to remember the first four of these (or the first two if you are doing the core paper). But it is good to be familiar with the other names because you are certain to come across them.



Alkyl groups

prefix	number of carbon atoms	name and molecular formula	full structural formula
meth-	1	methane, CH_4	
eth-	2	ethane, C_2H_6	
prop-	3	propane, C_3H_8	
but-	4	butane, C_4H_{10}	
pent-	5	pentane, C_5H_{12}	
hex-	6	hexane, C_6H_{14}	

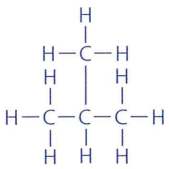
Extension

When we remove a hydrogen atom from an alkane chain we have a group called an alkyl group. So the alkyl group from ethane, C_2H_6, is C_2H_5–. The alkyl group from butane, C_4H_{10}, is C_4H_9–. The general formula for an alkyl group is C_nH_{2n+1}. Alkyl groups are named after the hydrocarbons by changing the -ane ending of the hydrocarbon to -yl. So we call C_2H_5– an ethyl group and C_4H_9– a butyl group.

Structural isomers

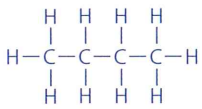
The carbon chain in alkanes and other organic compounds can be branched.

2-methyl propane



(branched chain)

butane

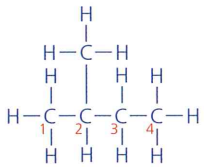


(straight chain)

2-Methylpropane has four carbon atoms and has the same molecular formula as butane, C_4H_{10}. But it is not butane because the carbon atoms are arranged differently. Compounds with the same molecular formula but with a different structural formula are called **isomers**.

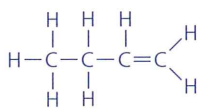
We say that the isomer of butane with the CH_3- group sticking out has a branched chain. Isomers may have the same chemical properties but they have different physical properties. The boiling point of straight-chained butane is 0 °C but the branched chain isomer has a boiling point of –12 °C.

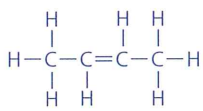
The rules for naming branched-chain alkanes can be quite complicated. You do not have to learn these but it is useful to be able to recognise why we use numbers in the names of some organic compounds. Using the compound below as an example:



- You find the longest carbon chain and name the compound after the number of carbon atoms in the longest chain. There are four carbon atoms in the longest chain. So it is named after butane.
- You then look for the alkyl side chain. In this case it is a methyl group. So the compound is methylbutane.
- You then have to number the alkyl group side chain by counting the numbers of the carbon atoms from one end of the carbon chain. You count from the end of the carbon chain that gives you the lowest number. In this case counting from the left, the alkyl group is on the second carbon atom. So the compound is 2-methylbutane.

All members of the alkene homologous series have the general formula C_nH_{2n}. These can also form isomers where the position of the double bond changes. These structural isomers are called position isomers:





KEY POINTS

1 A hydrocarbon is a compound containing carbon and hydrogen only.

2 The prefixes meth-, eth-, prop-, amongst others, tell us the number of carbon atoms in the main chain of an organic compound.

3 Structural isomers are compounds with the same molecular formula but different structural formulae.

4 Compounds with alkyl groups sticking out from the main carbon chain are called branched-chain compounds.

Extension

SUMMARY QUESTIONS

1 Copy and complete using the words below:

butane chain members number pent- prefixes prop- three

The different _____ of a homologous series can be identified by the _____ meth-, eth-, _____, but-, _____ and so on. These prefixes show the _____ of carbon atoms in the main _____ of the compound. For example, _____ has four carbon atoms in its carbon chain and propane has _____.

2 Name:

a the straight-chained alkane with four carbon atoms

b the alkene with three carbon atoms.

3 Draw the full structural formula for the two isomers of butane.

Extension

17.3 Fuels

LEARNING OUTCOMES

- Name a range of gaseous, liquid and solid fuels
- Describe what makes a good fuel
- Describe the fuels obtained from petroleum

The **fossil fuels** coal, petroleum (crude oil) and natural gas all contain **hydrocarbons**. We cannot use petroleum (crude oil) as a fuel because it is a sticky black liquid that is difficult to set alight. When it does burn, it produces clouds of poisonous black smoke. Petroleum is a mixture of many types of hydrocarbons having different lengths of carbon chain. Some of the chains are branched and there may even be compounds with rings of carbon atoms.

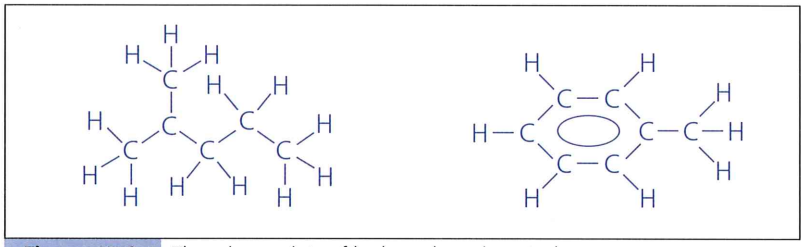


Figure 17.3.1 There is a variety of hydrocarbons in petroleum.

Natural gas is methane.

Fractional distillation is used to separate the hydrocarbon molecules in petroleum into groups that have similar boiling points. These groups of molecules are called **fractions**. Each contains hydrocarbons having a certain range of carbon atoms. Apart from the refinery gases, all these fractions are liquids. Many of these fractions are used as fuels:

fraction	number of carbon atoms	type of fuel
refinery gas	1–4	methane, propane, butane for gas cylinders
gasoline (petrol)	5–10	petrol for cars
kerosene	10–16	for aircraft
diesel	16–20	diesel for cars and larger vehicles
fuel oil	20–30	for ships and home heating

EXAMINER SAYS...

Don't get confused between petroleum and petrol. Petroleum is crude oil. Petrol, also known as gasoline, is a fraction obtained when we distil petroleum.

There is a variety of other fuels that we can use:

- Wood – We can use wood for heating and cooking but we obviously cannot use it as a fuel for cars. Some scientists, however, are working to try to produce liquid fuel from very young trees.
- Biofuels – Some plants such as oilseed rape and corn produce plant oils that can be modified for use in diesel engines. Other plants such as sugar cane and sugar beet can be used to produce ethanol by the process of **fermentation**. Ethanol can be used as a fuel in cars (see Unit 20.4).
- Solid waste – This can be burnt in some small power stations. But great care has to be taken that the poisonous chemicals formed in the furnace at high temperatures are not released into the atmosphere.

- Methane (natural gas) – As well as being found under the ground, methane is also produced by the decomposition of materials in rubbish sites. In some places, the gas can be piped out from the rubbish site and used for heating.
- Hydrogen – A good fuel because it releases a lot of energy per gram and is non-polluting. However, it is usually made by using energy from other fuels (see Unit 7.4).

On burning in a good supply of oxygen, hydrocarbons fuels form carbon dioxide and water.

PRACTICAL

What's formed when fuels burn?

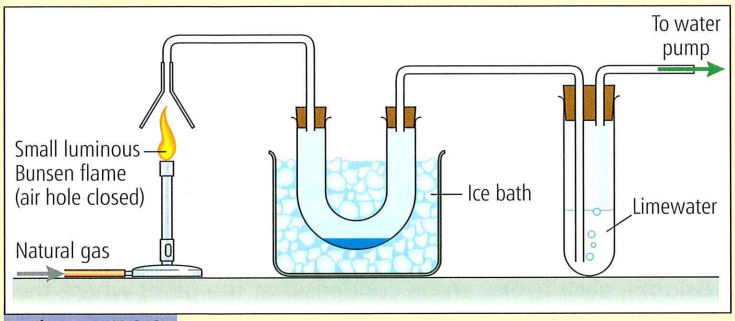


Figure 17.3.2

We test the products formed when a fuel burns using this apparatus. We burn the fuel under the funnel. The gases produced are sucked through the apparatus by a pump. Water collects in the U-shaped tube. You can test that this is water using white anhydrous copper sulfate which turns blue. The limewater turns milky showing that carbon dioxide is produced.

What makes a good fuel?

There are several things we take into account when we choose a fuel for a particular job:

- How much heat does it gives out? Most hydrocarbon fuels give out a similar amount of energy per gram but hydrogen produces a lot more energy per gram.
- Is it polluting? Coal is very polluting, oil is less polluting and natural gas does not produce much pollution. But all these fuels produce the greenhouse gas carbon dioxide when burnt.
- Is it easy to use? Solid fuels such as coal and wood are not as easy to use as liquid fuels.
- Is it readily available? Many people are worried that the supply of petroleum and natural gas will run out over the next 100 years. This means that we will have to use more biofuels.
- Is it cheap? The price depends on many things: how easy it is to extract and transport, how available the fuel is and politics.
- Is it easy and safe to transport? Many fuels are flammable so care has to be taken when transporting them and using them.

DID YOU KNOW?

Travelling by air produces nearly twenty times more greenhouse gases than travelling the same distance by train.

KEY POINTS

1 A good fuel releases a lot of heat energy per gram, is non-polluting and is easy to transport.

2 The fractional distillation of petroleum provides us with a variety of liquid and gaseous fuels.

3 The products of the complete combustion of a hydrocarbon fuel are carbon dioxide and water.

SUMMARY QUESTIONS

1 Copy and complete using the words below:

excess fractional lighter petroleum water

Many of the _____ fractions of hydrocarbons produced by the _____ distillation of _____ are useful fuels. When you burn a hydrocarbon in _____ air, carbon dioxide and _____ are formed.

2 Write word equations for the complete combustion of:

a methane

b carbon

c hydrogen.

3 State three characteristics of a good fuel.

17.4 Petroleum

LEARNING OUTCOMES

- Describe the separation of petroleum into different fractions by fractional distillation
- State some uses of these fractions

Petroleum undergoes fractional distillation in an oil refinery.

In an oil refinery the mixture of hydrocarbons in petroleum is separated into smaller groups. Each of these groups with a limited range of carbon atoms is called a **fraction**. For example, the gasoline fraction contains hydrocarbons with about five to ten carbon atoms.

The hydrocarbon fractions are separated by **fractional distillation**. We sometimes call this **fractionation**. Fractional distillation separates the hydrocarbons using the difference in their boiling points. Larger hydrocarbons have higher boiling points than smaller hydrocarbons.

The petroleum is first heated so that all the hydrocarbons are present as gases. The petroleum is then fed into a tall tower called a **fractionating column**. The column is kept hot at the bottom (about 350 °C) but it is cooler at the top. So there is a range of temperatures in the column.

Near the bottom of the column those hydrocarbons with higher boiling points condense. Hydrocarbons with lower boiling points are still gases. These move further up the column. As they move up the column, each hydrocarbon condenses at the point where the temperature in the column falls just below the boiling point of the hydrocarbon.

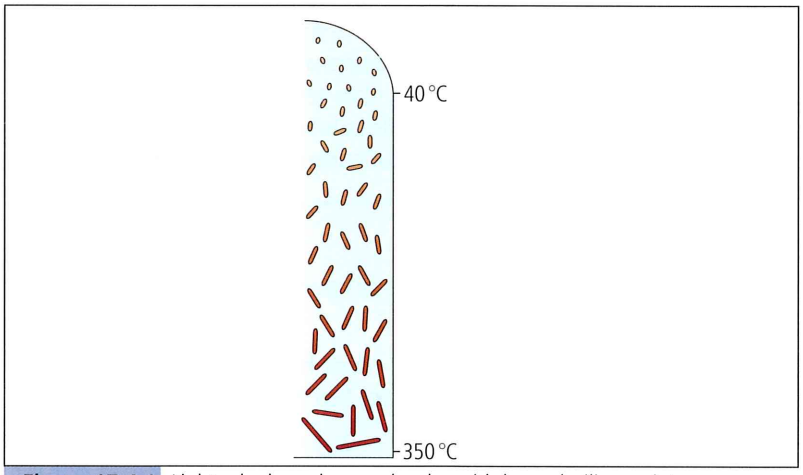


Figure 17.4.1 Lighter hydrocarbon molecules with lower boiling points move further up the fractionating column.

Hydrocarbons with similar boiling points are collected as fractions. Some of the hydrocarbons do not condense. They come off as gases at the top of the column. These are the *refinery gases* such as methane, ethane, propane and butane. In many oil refineries these are removed from the petroleum before fractionation.

DID YOU KNOW?

One quarter of the world's petroleum comes from Saudi Arabia.

The useful fractions

Fractional distillation separates petroleum into different fractions with a range of boiling points. Each fraction has a particular use.

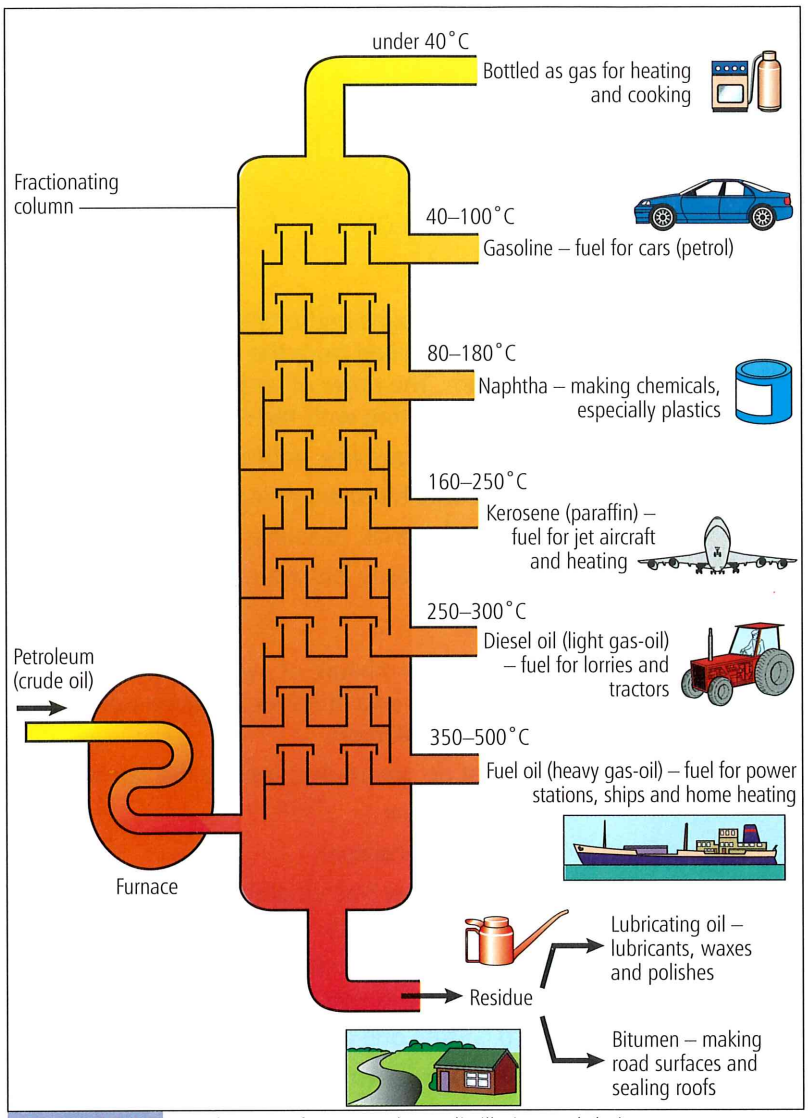


Figure 17.4.2 The fractions from petroleum distillation and their uses.

EXAMINER SAYS...

You do not have to remember the boiling range or typical number of carbon atoms in each fraction. But you do have to know the uses of each fraction and where they condense in the fractionating column.

SUMMARY QUESTIONS

1 Copy and complete using the words below:

boiling condense fractionating fractions higher hydrocarbons

Petroleum is separated into different _____ in an oil refinery. Each fraction is a group of _____ with similar _____ points. The hydrocarbon molecules move up the _____ tower. Hydrocarbons with _____ boiling points _____ lower in the tower.

2 Draw a flow diagram to show the main stages in the fractional distillation of petroleum.

3 Give one use for each of these fractions:

a fuel oil **b** kerosene **c** naphtha.

KEY POINTS

1 Petroleum is separated into different fractions by fractional distillation.

2 Each fraction has hydrocarbons with similar boiling points.

3 The hydrocarbons in petroleum are separated by fractional distillation because of the difference in their boiling points.

4 Each fraction obtained from petroleum has a particular use.

SUMMARY QUESTIONS

1 Match each petroleum fraction on the left with their use on the right.

naphtha	fuel for diesel engines
bitumen	jet fuel
light gas-oil	surfacing roads
kerosene	making chemicals

2 Copy and complete using the words from the list below.

alcohols alkanes alkenes ethane functional homologous

Methane and _____ belong to the _____ series called the _____. A homologous series is a family of similar compounds with the same _____ group. For example, _____ always have the –OH functional group and _____ have the C=C functional group.

3 Put the following fractions in order of decreasing boiling point:

bitumen; fuel oil; kerosene; naphtha; refinery gas.

4 Match each word on the left with its description on the right.

methane	a group of molecules with a similar range of boiling points
coal	a thick liquid mixture of hydrocarbons
petroleum	a solid fuel that often contains sulfur
fraction	the main constituent of natural gas
hydrogen	a gaseous fuel that forms only water when it burns

5 Write the formula of the functional group present in:

(a) alcohols **(b)** alkenes

(c) alkanes **(d)** carboxylic acids.

Extension

6 (a) What do you understand by the term *isomer*?

(b) Draw two isomers of:

(i) an alkane having 5 carbon atoms

(ii) an alkene having 4 carbon atoms

(iii) an alcohol having 4 carbon atoms.

7 State three general characteristics of a homologous series.

EXAM-STYLE QUESTIONS

1 Which one of the following molecules is an alkene:

A CH_3COOH

B $CH_3CH{=}CH_2$

C $CH_3CH_2CH_3$

D $CH_3CH_2CH_2OH$

(Paper 1) *[1]*

2 Bitumen, gasoline and refinery gases are fractions obtained from the distillation of petroleum. The order of volatility of these fractions, starting with the most volatile, is:

A Bitumen, gasoline, refinery gases

B Gasoline, bitumen, refinery gases

C Refinery gases, gasoline, bitumen

D Refinery gases, bitumen, gasoline

(Paper 1) *[1]*

3 Petroleum is a mixture of hydrocarbons which are separated into different fractions by fractional distillation.

(a) What do you understand by the terms

(i) *fraction*

(ii) *hydrocarbon*? *[2]*

(b) Explain how fractional distillation separates hydrocarbons into different fractions. *[3]*

(c) Kerosene is a fraction obtained from the distillation of petroleum.

(i) State one use of kerosene. *[1]*

(ii) Name two other petroleum fractions. For each of these fractions give one use. *[4]*

(d) Copy and complete the following sentences about petroleum fractionation using words from the list. (Not all words are used.)

condense evaporate fractions higher longer lower mass shorter

Hydrocarbon _____ higher in the distillation column have _____ hydrocarbon chains and _____ relative molecular _____ than hydrocarbons lower in the column. The fractions with higher boiling points _____ lower in the column. *[5]*

(Paper 2)

4 When fuels burn they release energy.

(a) What is the name given to a chemical reaction that releases heat energy? *[1]*

(b) (i) State the name of:

(1) a gaseous fuel

(2) a liquid fuel

(3) a solid fuel. *[3]*

(ii) For each fuel that you have chosen in part **(i)**, state one disadvantage of that fuel. *[3]*

(c) Many fuels are alkanes.

(i) What do you understand by the term *alkane*? *[1]*

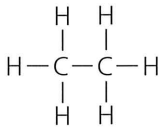
(ii) Write the molecular formula for ethane. *[1]*

(iii) Draw the full structural formula for methane, showing all atoms and bonds. *[1]*

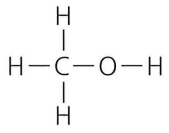
(d) The alkanes are a homologous series of compounds. What do you understand by the term *homologous series*? *[1]*

(Paper 2)

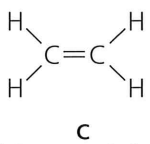
5 The diagram shows four organic compounds.



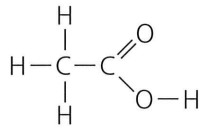
A



B



C



D

(a) Which two of these compounds are hydrocarbons? *[1]*

(b) Which compound is an alkene? *[1]*

(c) Which compound is an alcohol? *[1]*

(d) Name compound D. *[1]*

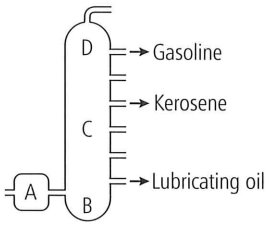
(e) Write the molecular formula for compound B. *[1]*

(f) Write the full structural formula for another member of the same homologous series as compound A. *[1]*

(g) Write the formula for the functional groups present in **(i)** compound B **(ii)** compound D. *[2]*

(Paper 2)

6 The diagram shows a fractionation column for the separation of petroleum fractions.



(a) What do you understand by the term *petroleum*? *[2]*

(b) Where in the diagram, A, B, C or D, is the temperature lowest? *[1]*

(c) Where in the diagram is the petroleum turned to vapour. *[1]*

(d) Which fraction labelled in the diagram has the lowest boiling point? *[1]*

(e) State the name of two other fractions that are not shown on the diagram. For each of these fractions state **(i)** where they condense in the column and **(ii)** a use of the fraction. *[4]*

(Paper 2)

7 The alkanes and the alcohols are both homologous series.

(a) What do you understand by the term *homologous series*? *[1]*

(b) Write the general formula for the alcohol homologous series. *[1]*

(c) Write the molecular formula for the fifth and sixth members of the alkane homologous series. *[2]*

(d) (i) Draw the full structural formula for butanol, showing all atoms and bonds. *[1]*

(ii) Draw the structure of another isomer of butanol. *[1]*

(iii) What do you understand by the term *isomer*? *[1]*

(Paper 3)