Edexcel IGCSE Chemistry

CODE: (4CH1)

Unit 04

Organic Chemistry

4.1 Introduction to organic chemistry

Hydrocarbons

The simplest organic compounds are **hydrocarbons**. These are molecules that contain carbon and hydrogen only.

The carbon atoms are joined together with single, double, or triple bonds. Carbon atoms are joined to hydrogen atoms by single bonds.

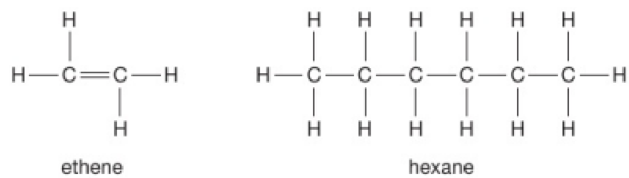


Figure 22.4 Examples of hydrocarbons

KEY POINT

Organic compounds can be described as **saturated** (containing only single C–C bonds) or **unsaturated** (containing double or triple C–C bonds). This is discussed in Chapters 24 and 25.

Types of formular for organic molecules

Empirical formulae

An **empirical formula** tells you the simplest whole number ratio of the atoms in a compound. It can be calculated from experimental data. Without more information, it is not possible to identify the 'true' or 'molecular' formula. Sometime the empirical formula is the same as the molecular formula.

Molecular formulae

A molecular formula counts the actual number of each type of atom present in a molecule.

Figure 22.5 These two compounds have the same molecular formula but different structures.

Molecular formulae are used are very rarely in organic chemistry because they don't give any useful information about the bonding in the molecule.

General formulae

There are many different families of organic compounds, known as **homologous series**. Examples of homologous series are alkanes, alkenes, alcohols, carboxylic acids and esters.

Members of a homologous series can be represented using a **general formula.** The first few members of the alkane series are shown in Table 22.1.

A functional group is an atom or a group of atoms that determine the chemical properties of a compound. All compounds in the same homologous series have the same functional group.

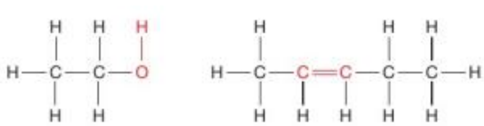


Figure 22.6 Alcohols contain the –OH functional group and alkenes contain the C=C functional group.

Table 22.1 The first few members of the alkane, alkene and alcohol homologous series

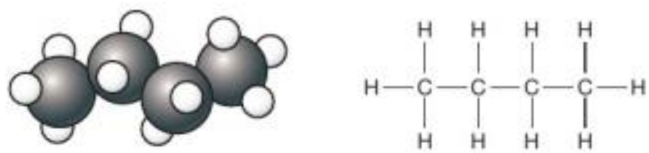
Alkanes	Alkenes	Alcohols
CH_4		CH_4O
C_2H_6	C_2H_4	C_2H_6O
C_3H_8	C_3H_6	C_3H_8O
C_4H_{10}	C_4H_8	$C_4H_{10}O$

structural formulae

A **structural formula** shows how the atoms in a molecule are joined together. There are two ways of representing structural formulae: they can be drawn as a **displayed formula** (full structural formula), or they can be written out in **condensed form** (condensed structural formula) by omitting all the carbon-carbon single bonds and carbon-hydrogen single bonds.

Displayed formulae

Displayed formulas, or full structural formulas, represent bonds in a molecule as individual lines, representing shared electron pairs in a covalent bond. They are drawn straightened out and flattened, but accurately depict the atoms' joined togetherness.

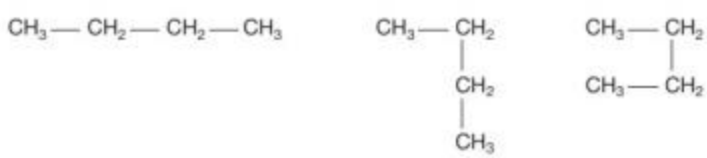


▲ Figure 22.7 Butane. The angles between neighbouring C–H bonds in butane are shown as 90° in the two-dimensional displayed formula. In reality they are about 109.5° in a tetrahedral arrangement in three dimensions, similar to the arrangement of C–C bonds in a diamond structure (see Chapter 8, page 93).

How to draw a structural formula

For anything other than the smallest molecules, drawing a fully displayed formula is very time-consuming. You can simplify the formula by writing, for example, CH, or CH2 instead of showing all the carbon-hydrogen bonds.

All the structures in Figure 22.8 represent butane: even though they look different they are the same molecule.



▲ Figure 22.8 All three structures represent butane. The convention is to write the structure with all the carbon atoms in a straight line.

Naming organic compounds

Organic compounds' names are codes that describe the molecule, including carbon atom count, carbon-carbon double bonds, and other specific details.

Coding the chain length

For example, **but**ane has a chain of four carbon atoms. **Prop**ane has a chain of three carbon atoms.

Table 22.2 Coding the chain length

Code letters	Number of carbons in chain
meth	1
eth	2
prop	3
but	4
pent	5
hex	6

Coding for the type of compound

ALKANES

Alkanes are a homologous series of similar hydrocarbons (compounds of carbon and hydrogen only) in which all the carbons are joined to each other with single covalent bonds. Compounds like this are coded with the ending 'ane'

ALKENES

Alkenes are a homologous series of hydrocarbons which contain a carbon-carbon double bond. This is shown in their name by the ending 'ene'.

How do you know which end of the chain to number from? The rule is that your number from the end which produces the smaller numbers in the name.

Table 22.3 Indicating the position of the double bond in the name of alkenes

Formula	Name	Description
$CH_2{=}CHCH_2CH_3$	but-1-ene	a four-carbon chain with a double bond starting on the first carbon
$CH_3CH{=}CHCH_3$	but-2-ene	a four-carbon chain with a double bond starting on the second carbon

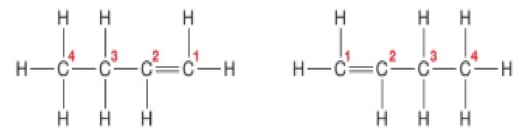


Figure 22.11 Both structures represent but-1-ene.

Coding for branched chain

Hydrocarbon chains can have side branches on them. You are only likely to come across two small side chains, shown in Table 22.4.

. The name of a molecule is determined by its longest chain, with the position of the side chain determined by numbering the carbon atoms from the end. For example, a compound with four carbon atoms and no double bonds is called 2-methylbutane. For compounds with multiple side chains, the position of each is described. Reversing this process can result in a structural formula.

Table 22.4 Coding for branched chains

Side chain	Coded
CH_3-	methyl
CH_3CH_2-	ethyl

Structural isomerism

Structural isomers are molecules with the same molecular formula, but different structural formulae.

Structural isomerism in the alkanes

<u>ISOMERS OF C_5H_{12}</u>

If you had some molecular models and picked out five carbon atoms and 12 hydrogen atoms, you would find it was possible to join them together in more than one way. The different molecules formed are known as i**somers**. All have the molecular formula C_5H_{12}, but different structures.

The straight chain isomer is called pentane. The branched chain isomer in the middle, which has a four-carbon chain ('butane') and a methyl group on the second carbon, is called 2-methylbutane. The final branched chain isomer, which has a three-carbon chain ('propane') and two methyl groups on the second carbon, is called 2,2-dimethylpropane. The prefix 'di' indicates the presence of two identical branches in the molecule.

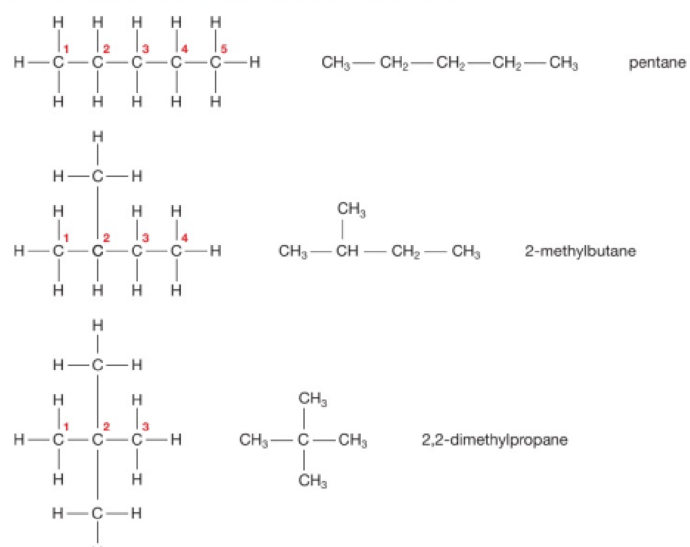
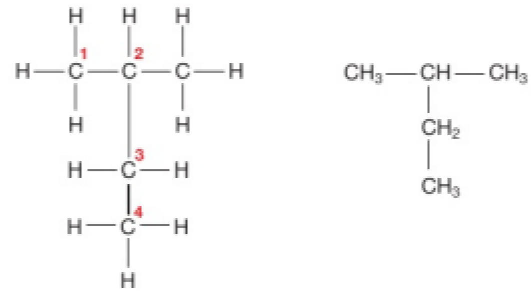


Figure 22.15 There are three isomers for C_5H_{12}. These can be shown as either displayed formulae or structural formulae.

Students frequently think they can find another isomer as well. If you look closely at this 'fourth' isomer (Figure 22.16) you will see that it is just 2-methylbutane rotated in space.

To avoid this sort of problem, always draw your isomers so that the longest carbon chain is drawn horizontally (or draw them out again without the H atoms).



▲ Figure 22.16 There is no fourth isomer for C_5H_{12}.

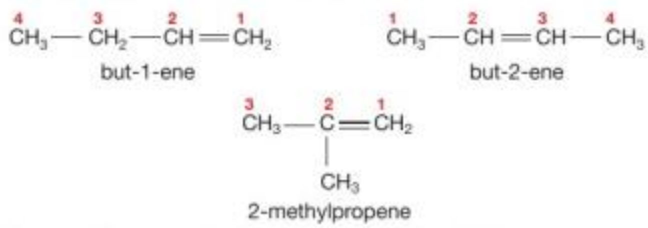
Structural isomerism in the alkanes

<u>Ethane and propane</u>

Ethene, $CH_2{=}CH_2$, doesn't have any isomers. Propene, $CH_3CH{=}CH_2$, doesn't have a structural isomer that is still an alkene.

Isomers of C_4H_8

There are three structural isomers with the molecular formula C_4H_8 and containing a carbon-carbon double bond.



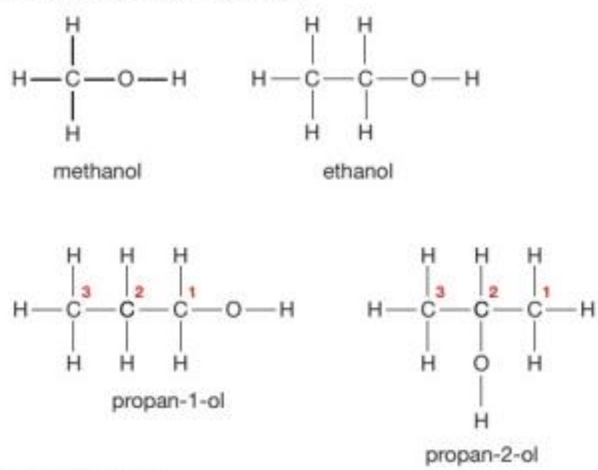
▲ Figure 22.20 Structural isomers with the molecular formula of C_4H_8.

A quick introductory look at the alcohols

Alcohols are a homologous series of compounds which all contain an -OH functional group attached to a hydrocarbon chain. This is coded for in the name by the ending '-ol'.

Propanol molecules have -OH functional groups and two forms: propan-1-ol and propan-2-ol. The -OH group can be attached to the end or second carbon, making them structural isomers. Bending or twisting one molecule results in the other, as bonds must be broken.

Figure 22.21 shows four small alcohols.



▲ Figure 22.21 Four small alcohols

Some chemical reactions of organic compounds

Combustion

All organic compounds that you will meet at International GCSE undergo combustion reactions. Combustion is just another way of saying burning and involves a reaction with oxygen.

Combustion of hydrocarbons in excess oxygen gives rise to carbon dioxide and water, together with the release of a large amount of heat energy.

Substitution

A substitution reaction occurs when an atom or group of atoms is replaced by a different atom or group of atoms. For example, the hydrogen atoms in an alkane can be replaced by halogen atoms.

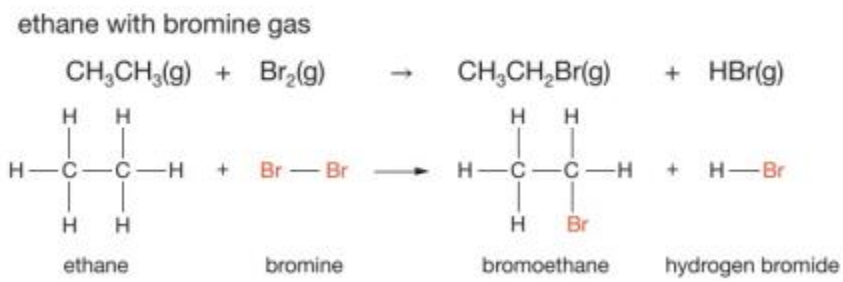


Figure 22.23 A substitution reaction between an alkane and a halogen

Addition

In an addition reaction something is added to a molecule without taking anything away. Alkenes undergo addition reactions. For example, ethene reacts with bromine:

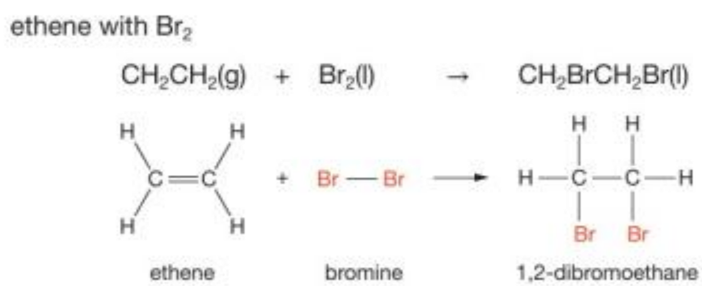


Figure 22.24 An addition reaction between an alkene and a halogen.

4.2 crude oil

What is crude oil?

The origin of crude oil

Millions of years ago, plants and animals living in the sea died and fell to the bottom. Layers of sediment formed on top of them. Their shells and skeletons formed limestone. The soft tissue was gradually changed by heat and high pressure into **crude oil.**

Crude oil contains hydrocarbons

Crude oil is a mixture of hydrocarbons, compounds containing carbon and hydrogen only. There are lots of different hydrocarbons of various sizes in crude oil, ranging from molecules with just a few carbon and hydrogen atoms to molecules containing over 100 atoms.

How the physical properties of hydrocarbons change with molecule size

As hydrocarbon molecules increase in carbon atoms, their physical properties change due to stronger intermolecular forces, making it harder to separate molecules.

As the molecules become bigger, the following changes occur.

■Boiling point increases: the larger the molecule, the higher the boiling point.

■The liquids become less volatile: the bigger the hydrocarbon, the more slowly it evaporates at room temperature.

■The liquids become more viscous and flow less easily: liquids containing small hydrocarbon molecules are runny. Those containing large molecules flow less easily because of the stronger forces of attraction between their molecules.

■The liquids become darker in colour.

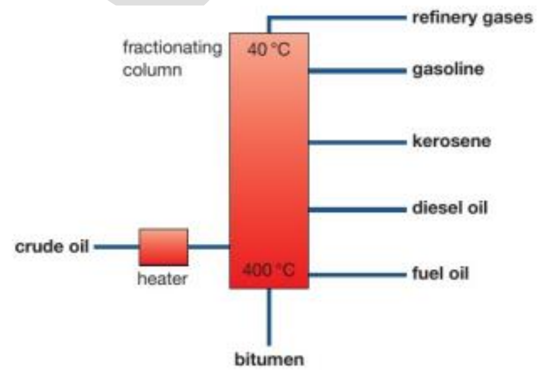
■Bigger hydrocarbons do not burn as easily as smaller ones. This limits the use of the bigger ones as fuels

Separating crude oil

Crude oil itself has no uses and it must be separated into fractions before it can be used. These fractions are all mixtures, but each one contains a narrow range of sizes of hydrocarbons with similar boiling points. We use **fractional distillation** to separate crude oil into fractions. This is carried out in an oil refinery.

Fractional distillation

Crude oil is heated to boil, passing through a **fractionating column**. The column's temperature, cooler at the top and hotter at the bottom, determines the distance a hydrocarbon moves. As it rises, it condenses into a liquid, separating crude oil into different fractions based on its boiling point.



▲ Figure 23.3 Fractional distillation of crude oil

Uses of the fractions

<u>As fuels</u>

All hydrocarbons burn in air (oxygen) to form carbon dioxide and water and release a lot of heat in the process. The various fractions can therefore be used as **fuels.**

A fuel is a substance which, when burned, releases heat energy.

If there isn't enough air (or oxygen), you get **incomplete combustion.** This leads to the formation of carbon (soot) or carbon monoxide instead of carbon dioxide.

Carbon monoxide, formed from incomplete hydrocarbon combustion, is dangerous due to its colorless, odourless, and poisonous nature, as it reduces oxygen transport in the blood, leading to illness or death.

<u>Refinery gases</u>

Refinery gases are a mixture of methane, ethane, propane and butane, which can be separated into individual gases if required. These gases are commonly used as liquefied petroleum gas (LPG) for domestic heating and cooking.

Gasoline
As with all the other fractions, petrol is a mixture of hydrocarbons with similar boiling points. It is used as a fuel in cars.

Kerosine
Kerosene is used as a fuel for jet aircraft, as domestic heating oil and as 'paraffin' for small heaters and lamps.

Diesel
This is used as a fuel for buses, lorries, some cars, and some railway engines. Some is also converted to other more useful organic chemicals, including petrol, in a process called cracking.

KEY POINT

Fossil fuels include coal, gas and fuels derived from crude oil. These all come from things that were once alive.

Fuel oil
This is used as a fuel for ships and for industrial heating.

Bitumen
Bitumen is a thick, black material, which is melted and mixed with small pieces of rock to make the top surface of roads.

Environmental problems associated with the burning of fossil fuels from crude oil

Burning fossil fuels, particularly crude oil, produces greenhouse gases, trapping Earth's surface heat and potentially leading to climate change.

Acid rain: sulfur dioxide and oxides of nitrogen

Acid rain is formed when water and oxygen in the atmosphere react with sulfur dioxide to produce sulfuric acid (H_2SO_4), or with various oxides of nitrogen, NO_x to give nitric acid (HNO_3). SO_2, and NO_x, come mainly from power stations and factories burning fossil fuels, or from motor vehicles.

Fossil fuels contain a small amount of sulfur. When the fuel is burned, the sulfur reacts with oxygen, producing sulfur dioxide:

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

Reactions in the atmosphere with oxygen and water can convert this to *sulfuric acid (H_2SO_4)*, a strong acid and an important component of acid rain:

$$2SO_2(g) + 2H_2O(l) + O_2(g) \rightarrow 2H_2SO_4(aq)$$

Note: when sulfur dioxide reacts with water, a weaker acid called *sulfurous acid (H_2SO_3)* is formed:

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

In petrol engines, sparks are used to ignite the petrol–air mixture to power the car. The temperature reached in the engine is high enough to allow nitrogen and oxygen in the air to combine to produce oxides of nitrogen. For example:

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

These nitrogen oxides can be converted to *nitric acid (HNO_3)* in the atmosphere and therefore contribute to acid rain.

Acid rain is a significant issue, causing significant damage to trees, lake life, limestone buildings, marble statues, and iron-based metals, and even causing irreversible death in some lakes.
Reaction between limestone and sulfuric acid:

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2O(l) + CO_2(g)$$

The solution to acid rain involves removing sulfur from fuels (this is usually done for petrol used in cars), **'scrubbing'** the gases from power stations and factories to remove SO_2 and NO_x and using catalytic converters in cars.

Cracking

Although most of the fractions from the fractional distillation of crude oil are useful as fuels, some fractions are more useful and more profitable to sell than others.

The amounts of each fraction obtained will depend on the proportions of the various hydrocarbons in the original crude oil, not the amounts in which they are needed. The problem is:

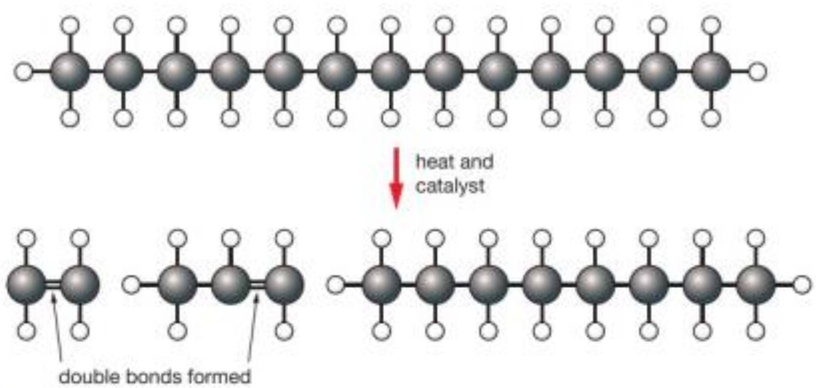
■There are far too many long-chain hydrocarbons, which are not in such high demand and are not as profitable to sell
■There are not enough shorter-chain hydrocarbons that can be used as fuel for cars.

Cracking is a process in which long-chain alkanes are converted to alkenes and shorter-chain alkanes. The big hydrocarbon molecules in fuel oil.

How catalyst cracking works

Fuel oil is heated to form a gas and passed over a silicon dioxide and aluminium oxide catalyst at 600-700°C. Cracking, an example of thermal decomposition, breaks C-C single bonds and forms new C=C double bonds.

The molecules are broken up in a fairly random way. One possibility is shown in Figure 23.11.



▲ Figure 23.11 How cracking works.

As an equation, this would read:

$$C_{13}H_{28}(l) \rightarrow C_2H_4(g) + C_3H_6(g) + C_8H_{18}(l)$$

Cracking produces a mixture of alkanes and alkenes. In this case, two different alkenes are produced: ethene and propene. Octane, an alkane, is also formed. This cracking reaction has therefore produced two types of useful molecules for the chemical industry.
There are therefore two important reasons why oil companies carry out cracking:

■To produce more petrol
■To produce more alkenes that can be used for making polymers (plastics) (alkenes are more reactive than alkanes and have other uses).

4.3 Alkanes

Isomers of alkanes

Isomers are compounds with the same molecular formula but different structural formulae, including straight-chain alkanes, unbranched chains, and branched isomers of butane and pentane.

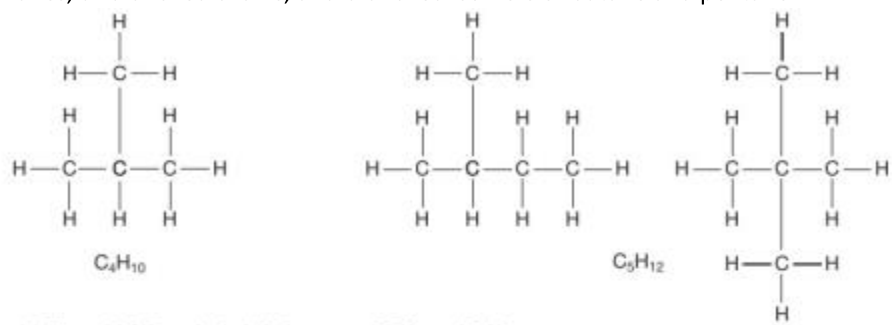


Figure 24.2 Branched chain isomers of C_4H_{10} and C_5H_{12}.

Homologous series

The alkanes form a homologous series. A homologous series is a series of compounds that:

- Have the same functional group
- Have similar chemical properties
- Show a trend (gradation) in physical properties
- Can be described by the same general formula
- Differ from the next by a -CH2- unit.

The alkanes form the simplest homologous series. The alkanes do not really have a functional group as they just contain single C-C and C-H bonds, which are the basis of all other organic compounds.

Members of a homologoues series have the same general formula

In the case of the alkanes, if there are n carbons, there are 2n + 2 hydrogens. The general formula for the alkanes is $C_n H_{2n+2}$

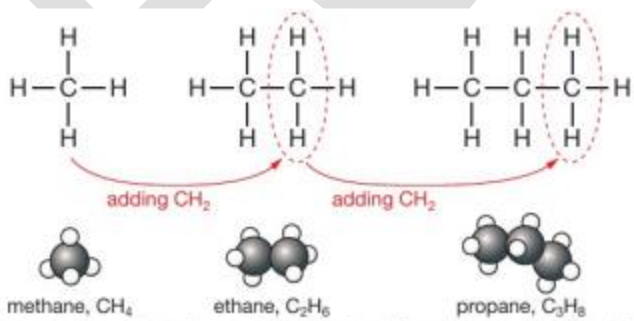


Figure 24.3 The three smallest alkanes. Each member differs from the next by a $-CH_2-$ unit.

Members of a homologous series show a trend (gradation) in physical properties

The first four alkanes are gases at room temperature, while the other alkanes are liquids. Solids appear around C18H38-. As molecules increase in size, intermolecular forces of attraction increase, requiring more energy to break attraction, resulting in regular increases in boiling points.

Figure 24.4 shows the boiling points of the first eight alkanes.

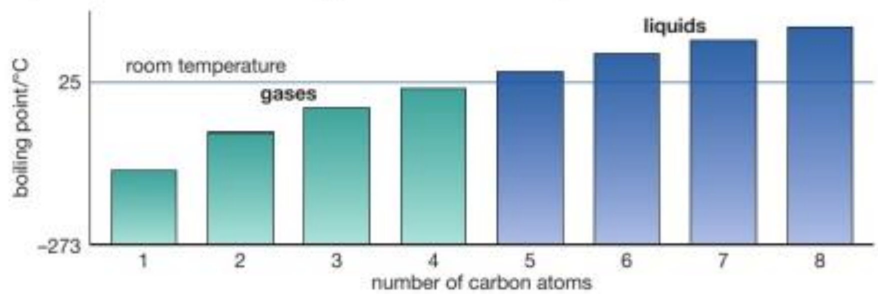


Figure 24.4 Boiling points of the first eight alkanes

Members of a homologoues series have similar chemical properties

Alkanes, with their strong carbon-carbon single and carbon-hydrogen bonds, are considered inert organic compounds due to their chemical properties, which are influenced by their functional groups and bonding.

To reactions of the alkanes

All alkanes burn in air or oxygen. If there is enough oxygen, they burn completely to give carbon dioxide and water.

If there isn't enough oxygen, there is incomplete combustion of the hydrocarbon, and you obtain carbon monoxide or carbon (soot) instead of carbon dioxide,

Substitution

Alkanes react with halogens in the presence of **ultraviolet radiation (UV light).**

Mono-substitution occurs when only one hydrogen atom in the alkanes is replaced by a halogen atom.

When propane reacts with bromine, it is possible to form two organic products even when only mono substitution occurs. The two products are structural isomers of each other, they have the same molecular formula but different structural formulae.

Halogenoalkanes are products formed from substitution reactions of alkanes with halogens, named x-haloalkane, where x indicates halogen atom position in longest carbon chain.

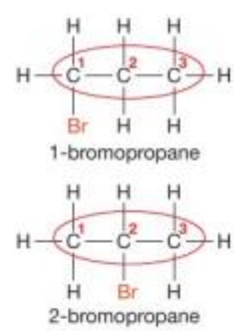


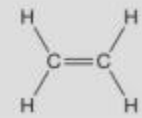
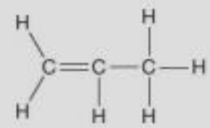
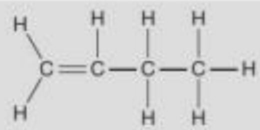
Figure 24.6 Two isomers of bromopropane, formed from the mono-substitution of propane with bromine.

4.4 Alkenes

The alkenes are a homologous series of hydrocarbons which contain a carbon-carbon double bond. The C=C bond is the functional group of the alkenes.

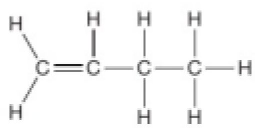
The first three members of the alkene series are shown in Table 25.1.

Table 25.1 The first three alkenes

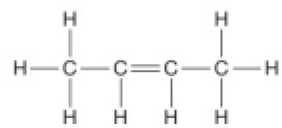
Name	Molecular formula	Empirical formula	Structural formula	Displayed formula
ethene	C_2H_4	CH_2	$CH_2{=}CH_2$	
propene	C_3H_6	CH_2	$CH_2{=}CHCH_3$	
but-1-ene	C_4H_8	CH_2	$CH_2{=}CHCH_2CH_3$	

Isomers

There are two straight-chain isomers with the formula C_4H_8:

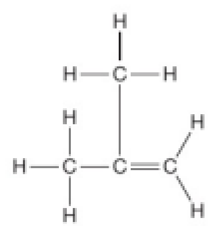


but-1-ene



but-2-ene

and one branched-chain isomer:



Unsaturated hydrocarbons

Alkenes are unsaturated compounds because they contain a C=C bond. A saturated compound contains single C-C bonds only whereas an unsaturated compound contains one or more double or triple C-C bonds.

The general formula

Alkenes have the general formula C_nH_{2n}. The number of hydrogen atoms is twice the number of carbon atoms. This means that all alkenes have the same empirical formula, CH_2.

The alkene with 11 carbon atoms will have 22 hydrogen atoms and the molecular formula $C_{11}H_{12}$

Physical properties

These are very similar to those of the alkanes. Remember that the small alkanes with up to four carbon atoms are gases at room temperature. The same is true for the alkenes. They are gases up to C_4H_8, and the next dozen or so are liquids. Again, the members of the homologous series show a trend in physical properties.

Chemical reaction of the alkenes

COMBUSTION

In common with all hydrocarbons, alkenes burn in air or oxygen to give carbon dioxide and water,

ADDITION

The C=C double bond is the functional group. The functional group determines the chemical properties of a compound. Alkenes have characteristic chemical properties which are different from those of alkanes. Alkenes are much more reactive than alkanes.

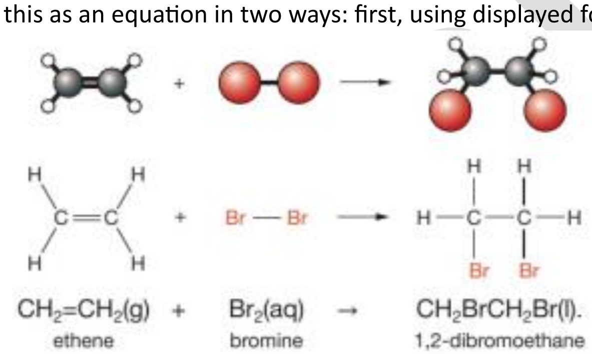
Alkenes undergo addition reactions. Part of the double bond breaks to become a single C-C bond and the electrons are used to join other atoms onto the two carbon atoms.

The addition of bromine

Bromine adds to alkenes without any need for heat, light or a catalyst. The reaction is often carried out using bromine water (aqueous bromine solution).

You know a reaction has happened because bromine water is orange but the product, called 1,2-dibromoethane, is a colourless liquid.

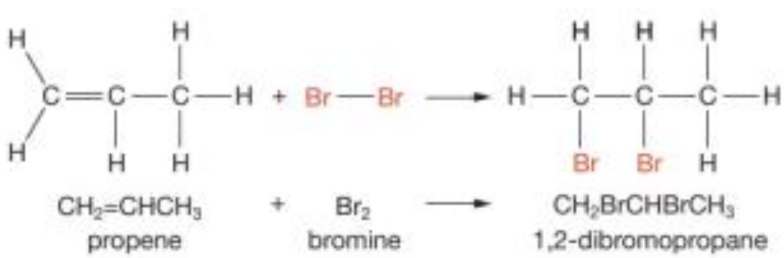
You can write this as an equation in two ways: first, using displayed formulae and second, using structural formulae.



▲ Figure 25.2 An addition reaction: an alkene plus bromine

The test for unsaturated compounds

Compounds with a carbon-carbon double bond react with bromine in a similar way to ethene, indicating the presence of a carbon-carbon double bond. This can be tested by decolourizing orange bromine water with bromine water, or by introducing a gas through bromine water. Alkanes do not decolourize bromine water, as they do not contain a carbon-carbon double bond. The addition reaction between bromine and propene is like ethene.



▲ Figure 25.4 An addition reaction of propene with bromine

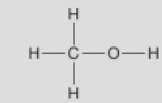
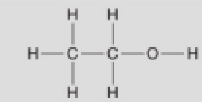
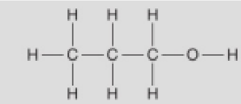
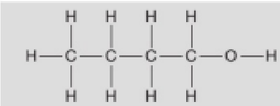
4.5 Alcohols

Drawing and naming the alcohols

We are only going to look at the four simplest alcohols: methanol, ethanol, propan-1-ol and butan-1-ol. These are shown in Table 26.1.

The names of alcohols, such as propan-1-ol and butan-1-ol, indicate the number of carbon atoms, the presence of an -OH functional group, and the position of the -OH group in the carbon chain. Propan-1-ol and propan-2-ol are structural isomers of each other, while butan-1-ol and butan-2-ol are represented by ethanol.

Table 26.1 Formulae and names of the first four members of the alcohol homologous series

Name	Molecular formula	Structural formula	Displayed formula
methanol	CH_4O	CH_3OH	
ethanol	C_2H_6O	CH_3CH_2OH	
propan-1-ol	C_3H_8O	$CH_3CH_2CH_2OH$	
butan-1-ol	$C_4H_{10}O$	$CH_3CH_2CH_2CH_2OH$	

The oxidation of ethanol

<u>Ethanol burns in air</u>

All alcohols burn to form carbon dioxide and water. With ethanol:

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

Ethanol is a **biofuel**, that is, a fuel that is made from biological sources, such as sugar cane or corn. Mixtures of petrol with ethanol are increasingly used in countries. Other countries are introducing biofuels such as ethanol to reduce dependence on fossil fuels, which are finite **non-renewable resources.**

Ethanol oxidized by the air in the presence of microbes (microbial oxidation)

A bottle of wine left open to the air turns sour. The French for sour wine is vin aigre, which has been distorted into vinegar. The ethanol in the wine is oxidised by air with the help of microorganisms such as bacteria or yeast to form ethanoic acid, CH_3COOH.

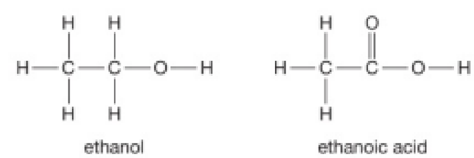


Figure 26.3 Displayed formulae of ethanol and ethanoic acid

Ethanol can be oxidized by heating with potassium dichromate in dilute sulfuric acids

The lab typically uses a mixture of potassium dichromate (VI) and dilute sulfuric acid as an oxidising agent for ethanol and other alcohols. The acid's H+ ions are crucial for the reaction, and the solution is heated in a hot water bath.

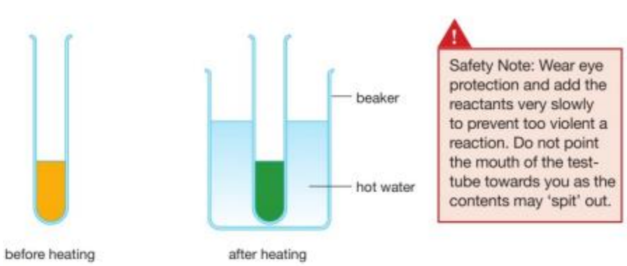
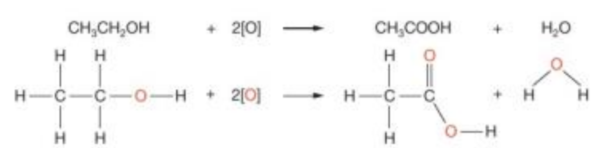


Figure 26.4 Oxidation of ethanol by heating with potassium dichromate(VI) and dilute sulfuric acid.



Starting materials: ethanol and potassium dichromate(VI) in dilute sulfuric acid

Conditions: heat under reflux

Figure 26.5 Oxidation of ethanol to ethanoic acid

The production of ethanol

Making ethanol by fermentation

Yeast is added to a sugar (or starch) solution and left in the warm (about 30°C) for several days in the absence of air (anaerobic conditions). **Enzymes** (biological catalysts) in the yeast convert the sugar into ethanol and carbon dioxide. This process is known as **fermentation.**

The absence of air and the temperature are both important. In the presence of air (aerobic conditions), enzymes in the yeast produce carbon dioxide and water instead of ethanol. The enzymes are protein catalysts and if the temperature is increased much above 40°C they lose their structure and don't work any longer. The proteins are said to be **denatured**.

Making ethanol by the hydration of ethane

Ethanol is also made by reacting ethene with steam, a process known as **hydration.**

$$CH_2{=}CH_2(g) + H_2O(g) \rightarrow CH_3CH_2OH(g)$$

Starting materials:	ethene and steam
Temperature:	300 °C
Pressure:	60–70 atmospheres
Catalyst:	phosphoric acid (H_3PO_4)

Comparing the who methods of producing ethanol

	Fermentation	Hydration of ethene
Use of resources	Uses renewable resources: sugar beet or sugar cane, corn and other starchy materials	Uses finite, non-renewable resources: once all the oil has been consumed, there won't be any more
Type of process	A batch process: everything is mixed together in a reaction vessel and then left for several days That batch is then removed and a new reaction is set up This is inefficient	A continuous flow process: a stream of reactants is constantly passed over the catalyst This is more efficient than a batch process
Rate of reaction	Slow, taking several days for each batch	Quick
Quality of product	Produces very impure ethanol which needs further processing	Produces much purer ethanol
Reaction conditions	Uses gentle temperatures and atmospheric pressure	Uses high temperatures and pressures, requiring a high input of energy

4.6 Carboxylic acids

Acids such as ethanoic acid are known as **carboxylic acids,** and they all contain the functional group -COOH.

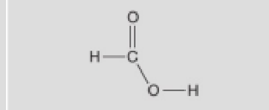
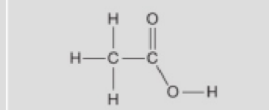
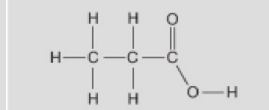
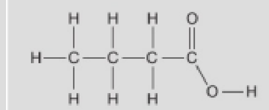
The most familiar one is ethanoic acid (old name acetic acid). **Vinegar** is an aqueous solution containing ethanoic acid.
Carboxylic acids are formed by oxidation of the corresponding alcohols,

Drawing and naming acids

Again, we are only going to be looking at the four simplest carboxylic acids: methanoic acid, ethanoic acid, propanoic acid and butanoic acid. These are shown in Table 27.1.

Acids properties of the carboxylic acids

Ethanoic acid and the other carboxylic acids are weak acids with a pH of about 3-5, depending on the concentration of the solution. They will turn blue litmus paper red, and react with all the things you expect acids to
react with.

Name	Molecular formula	Structural formula	Displayed formula
methanoic acid	CH_2O_2	HCOOH	
ethanoic acid	$C_2H_4O_2$	CH_3COOH	
propanoic acid	$C_3H_6O_2$	CH_3CH_2COOH	
butanoic acid	$C_4H_8O_2$	$CH_3CH_2CH_2COOH$	

<u>Reactions with metals</u>

Dilute ethanoic acid reacts with metals in the same way as other dilute acids such as hydrochloric acid or sulfuric acid, only more slowly.

For example, dilute ethanoic acid reacts with magnesium with a lot of fizzing to produce a salt and hydrogen. The salt formed is magnesium ethanoate, which is soluble in water and so you get a colourless solution:

$$Mg(s) + 2CH_3COOH(aq) \rightarrow (CH_3COO)_2Mg(aq) + H_2(g)$$

Reactions with carbonates

Carbonates react with acids to give a salt, carbon dioxide and water and ethanoic acid behaves like any other acid. For example, with sodium carbonate you get a lot of fizzing and a colourless solution of sodium ethanoate:

$$Na_2CO_3(s) + 2CH_3COOH(aq) \rightarrow 2CH_3COONa(aq) + CO_2(g) + H_2O(l)$$

With calcium carbonate you again get lots of fizzing and a colourless solution - this time containing calcium ethanoate:

$$2CH_3COOH(aq) + CaCO_3(s) \rightarrow (CH_3COO)_2Ca(aq) + CO_2(g) + H_2O(l)$$

4.7 Esters

Esters are organic compounds formed by the reaction of an alcohol with a carboxylic acid. They have the functional group.

Making a simplest ester: ethyl ethanoate

Heating a mixture of ethanoic acid and ethanol with a few drops of concentrated sulfuric acid produces a liquid called ethyl ethanoate.

$$\underset{\text{ethanoic acid}}{CH_3COOH(l)} + \underset{\text{ethanol}}{CH_3CH_2OH(l)} \rightleftharpoons \underset{\text{ethyl ethanoate}}{CH_3COOCH_2CH_3(l)} + \underset{\text{water}}{H_2O(l)}$$

Starting materials: ethanol and ethanoic acid
Catalyst: concentrated sulfuric acid
Conditions: heat

The concentrated sulfuric acid isn't written into the equation because it is a catalyst, and it isn't consumed in the reaction.

The reaction is called **esterification**. It can also be described as a **condensation** reaction because water is made when two molecules are joined together.

Drawing and naming esters

To work out the structure of the ester formed when an alcohol and a carboxylic acid react together, it is easier to start by drawing the alcohol and carboxylic acid so that their OH groups are next to each other. Now remove H_2O and join what is left.

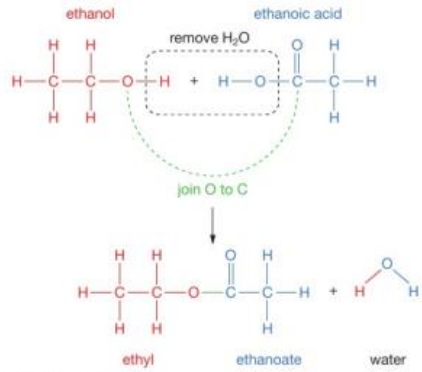


Figure 28.2 Formation of an ester

An ester can be drawn either way round (see Figure 28.3) but the name is always written the same way round: ethyl ethanoate.

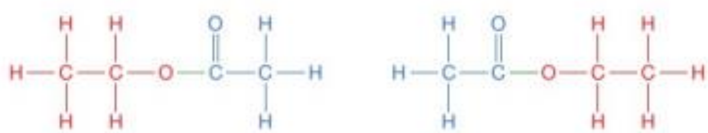


Figure 28.3 Different ways of drawing ethyl ethanoate

You also need to be able to reverse this and work out which carboxylic acid and alcohol you would have to react together to produce a given ester. To do this, break apart the molecule between the C and O and add OH to one side and H to the other so that you have two OH groups.

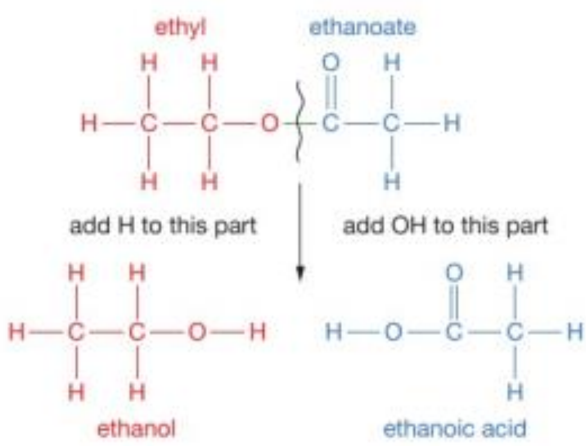


Figure 28.4 Splitting an ester

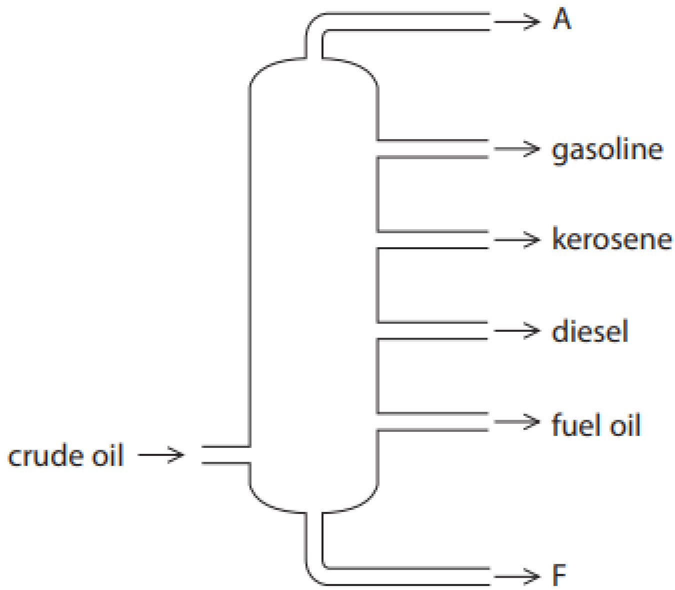
$$\underset{\text{ethyl ethanoate}}{CH_3COOCH_2CH_3(l)} + \underset{\text{water}}{H_2O(l)} \rightleftharpoons \underset{\text{ethanoic acid}}{CH_3COOH(l)} + \underset{\text{ethanol}}{CH_3CH_2OH(l)}$$

Uses of esters

Esters, volatile liquids with distinctive smells, are commonly used in food flavourings and perfumes. They are used in chemists to create artificial flavors and perfumes.

Revision questions

1) The diagram shows a typical fractionating column used to separate crude oil into fractions.



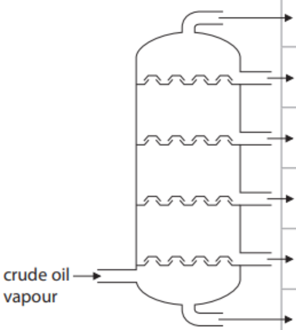
(a) The diagram shows the names of some of the fractions. State the name of fraction A and the name of fraction F
(b) Most compounds in crude oil are hydrocarbons. State the meaning of the term hydrocarbons.
(c) Describe how the boiling point, colour and viscosity of the fuel oil fraction differ from those of the gasoline fraction
(d) Some fuel oil undergoes catalytic cracking. This involves the conversion of long-chain alkanes into alkenes and short-chain alkanes.
(i) A temperature of about 650°C is used in this process. Identify a catalyst that is used.
(ii) The alkane tridecane can be cracked to produce octane and two different alkenes. Complete the equation to show the formulae of the two alkenes

$C_{13}H_{28} \rightarrow C_8H_{18} +$ .... $+$ ....

(e) When hydrocarbons undergo incomplete combustion, a poisonous gas can form.
(i) State the condition that causes incomplete combustion
(ii) Identify the poisonous gas.
(iii) Explain why this gas is poisonous

2) The diagram shows the separation of crude oil into fractions.
(a) What is the name of this method of separation?
(b) Complete the table by giving the correct fraction, A, B, C, D, E or F, for each description.

You may use each letter once, more than once or not at all.



Fraction	Typical number of carbon atoms per molecule
A	1 – 4
B	5 – 10
C	11 – 16
D	17 – 20
E	21 – 30
F	more than 30

Fraction	Description
	contains only gases
	is the most viscous
	contains bitumen

(c) State the relationship between the number of carbon atoms per molecule and the boiling point of the fraction.

3) This question is about hydrochloric acid.
(a) Dilute hydrochloric acid, HCl(aq), reacts with many metals. A student observes the reaction of dilute hydrochloric acid with four metals, P, Q, R and S. She uses the same amount of metal in each case.

The table shows her observations

Metal	Observations
P	very few bubbles produced very slowly
Q	many bubbles produced very quickly
R	many bubbles produced quickly
S	few bubbles produced slowly

(i) Use the information in the table to place the four metals in order of reactivity. Place the most reactive first

most reactive ☐ ☐ ☐ ☐ least reactive

(ii) Give the names of the two products formed when magnesium reacts with dilute hydrochloric acid.
Product 1 ....
Product 2 ....
(b) Describe a test to show that dilute hydrochloric acid contains chloride ions.

(4) Alkanes are saturated hydrocarbons that can be obtained from crude oil. The general formula of the homologous series of alkanes is C_nH_{2n+2}
(a) (i) What is the meaning of the term saturated?
(ii) What is the meaning of the term hydrocarbons?
(b) (i) Octane (C_8H_{18}) is an alkane that is present in petrol. When octane burns completely in oxygen it forms carbon dioxide and water. Write a chemical equation for the complete combustion of octane.
(ii) Give the name of a toxic gas that may be produced by the incomplete combustion of octane.

5) The table shows the percentage composition of the mixture of gases in the exhaust fumes of a car

Name of gas	Percentage of the gas in the exhaust fumes
carbon dioxide	14.0
carbon monoxide	2.0
hydrocarbons	0.3
nitrogen oxides	0.2
sulfur dioxide	trace amounts
water vapour	12.0
gas Z	71.5

(a) Identify gas Z

(b) The carbon dioxide is produced from the combustion of hydrocarbons such as octane. Complete the word equation for the complete combustion of octane.

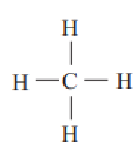
octane + ... → carbon dioxide + ...

(c) How is the carbon monoxide in the exhaust fumes produced?

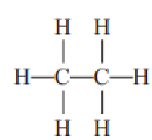
(d) (i) Write a chemical equation to show how nitrogen dioxide (NO_2) is produced in a car engine.

(ii) State one problem caused by nitrogen dioxide in the atmosphere

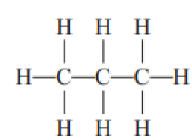
6) These are the displayed formulae of six organic compounds



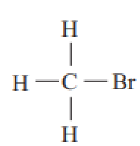
P



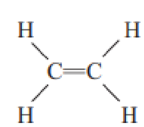
Q



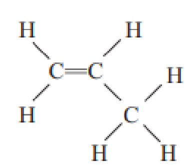
R



S



T



U

(a) Use the letters above to select (i) the compound that is not a hydrocarbon

(ii) one compound with the empirical formula CH_2

(iii) one compound that can form a polymer.

(b) Describe a test that will distinguish between compounds Q and T, and state the observation made with compound T.

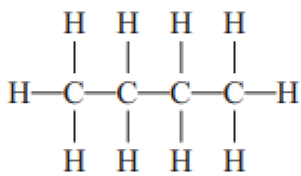
(c) Draw the displayed formula of an alkene containing four carbon atoms.

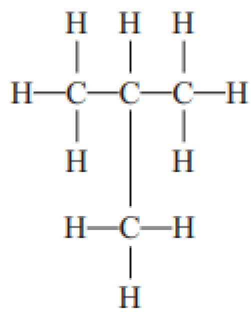
(d) Three of the compounds belong to the alkane homologous series. All the alkanes in this homologous series have the same general formula.

(i) What is the general formula of the alkanes?

(ii) State two other features of a homologous series

(e) The displayed formulae below represent isomers.





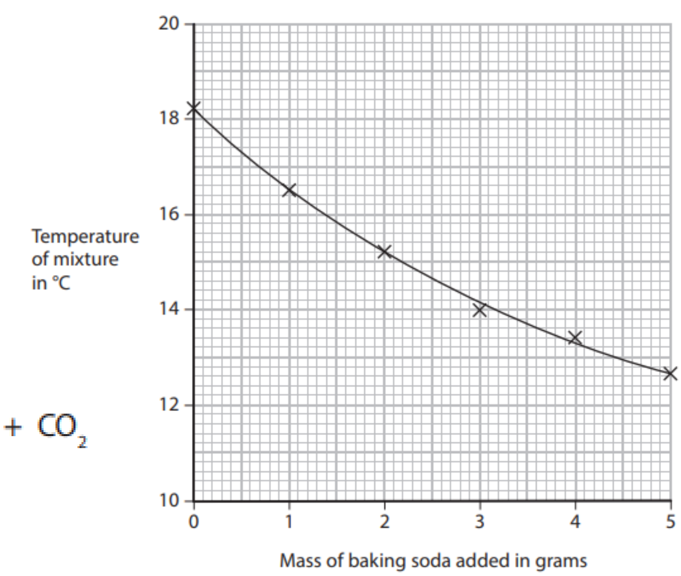
Explain what isomers are

7)A teacher asked her students to suggest some experiments that could be done using chemicals found in the home. One student planned an experiment to measure the temperature change when baking soda is added to vinegar.

She wrote this plan.

■Pour 100 cm3 of vinegar into a polystyrene cup
■Weigh out five separate 1 g portions of baking soda measure the temperature of the vinegar
■Add 1 g of baking soda to the vinegar and stir
■Record the new temperature
■Add the other portions of baking soda, stirring and recording the temperature after each portion is added

The graph shows her results



(a) The student said that the reaction in her experiment was not complete. How does the graph support her statement?

(b) The student used a polystyrene cup rather than a glass beaker. Why is it better to use a polystyrene cup?

(c) Vinegar contains ethanoic acid. Baking soda contains sodium hydrogencarbonate. The student found this equation for the reaction:

$$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$$

(i) There is no colour change during this reaction. Suggest one observation, other than the change in temperature, that could be made during the reaction.

(ii) The compound CH_3 COOH is an acid and the compound CH_3 COONa is a salt. The graph shows that the temperature goes down during the reaction. Use this information to state the two types of reaction occurring.

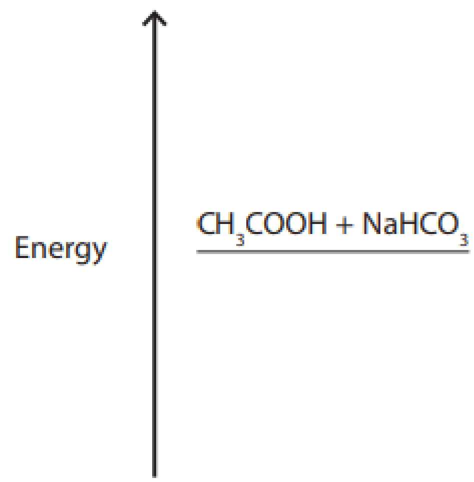
(d) (i) Complete the energy level diagram by showing the products of the reaction.
(ii) Label the diagram to show the energy change, ΔH, for the reaction
(e) The student repeated the experiment using the same method with a different sample of vinegar. She recorded these results.

Volume of vinegar = 100 cm^3

Mass of baking soda = 5.0 g

Temperature at start = 18.7 °C

Temperature at end = 13.2 °C

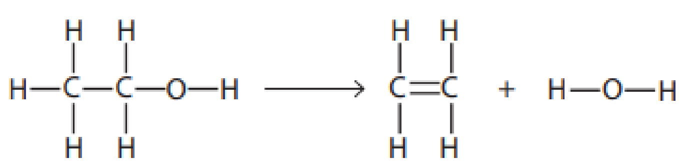


(i) Calculate the heat energy change in this experiment using the expression

heat energy change = volume of vinegar × 4.2 × temperature change

(ii) The student wanted to calculate the amount, in moles, of ethanoic acid in the vinegar. Apart from the volume of vinegar, what other information would she need to be able to calculate the amount of ethanoic acid?

8) (a) Wine can be made from grapes. The grapes are crushed to produce an aqueous solution containing glucose. Yeast is then added to this solution. The solution is kept at a constant temperature for a period. The glucose is converted into ethanol.
(i) Name the process in which glucose is converted into ethanol
(ii) What is the purpose of the yeast?
(b) Grape vines can be attacked by a fungus that ruins the grapes. The fungus can be killed using Bordeaux mixture, a solid containing copper (II) sulfate and calcium hydroxide.
(i) State a test to show that Bordeaux mixture contains calcium ions.
(ii) A sample of Bordeaux mixture is dissolved in water.
Describe separate tests to show that this solution contains copper (II) ions and sulfate ions.
(c) Ethanol can be manufactured by passing a hot mixture of ethene and steam, at a high pressure, over a catalyst.
State the pressure used and name the catalyst
(d) The equation for the conversion of ethanol into ethene can be written using displayed formulae



The table gives some average bond energies
Use information from the table to calculate the enthalpy change, in kJ/mol, for the conversion of ethanol into ethene.

Use information from the table to calculate the enthalpy change, in kJ/mol, for the conversion of ethanol into ethene.

Bond	Average bond energy in kJ/mol
C—C	348
C═C	612
C—H	412
C—O	360
O—H	463

9) Fractional distillation and cracking are important steps in processing crude oil.
(a) Place ticks in the columns to show which statements apply to each step. You may place a tick in one column, in both columns and in neither column. The first one has been done for you.

Statement	Fractional distillation	Cracking
Crude oil is heated	✓	
A catalyst may be used		
Alkenes are formed		
Decomposition reactions occur		
Fuels are obtained		
Separation is the main purpose		

(b) The formula $CH_3\ CH_2\ CH_2\ CH_2\ CH_3$ represents one of the compounds in crude oil
(i) Give the molecular formula of this compound.
(ii) Give the displayed formula of this compound
(iii) Give the empirical formula of this compound
(iv) Give the name of this compound.
(v) Give the general formula of the homologous series that contains this compound
(c) The products of the complete combustion of hydrocarbons are carbon dioxide and water.
(i) Balance the equation to show the complete combustion of ethene (C_2H_4).

$$C_2H_4 + \text{.........}O_2 \rightarrow \text{.........}CO_2 + \text{.........}H_2O$$

(ii) Draw a dot and cross diagram to show the bonding in an ethene molecule. Show only the outer electrons in each atom.