12 Organic chemistry 1

FOCUS POINTS

- ★ What is a homologous series?
- ★ What are the similarities and differences between saturated and unsaturated hydrocarbons?
- ★ What are polymers and why are they useful?
- ★ How do plastics cause environmental challenges?

You will have seen earlier in Chapter 6 that important substances, called hydrocarbons, are obtained from petroleum. These hydrocarbons are mainly used as fuels of different types. In this chapter you will study two families, or homologous series, of these hydrocarbons, the alkanes and alkenes. You will examine their different structures and different physical and chemical properties. You will see that it is possible to produce alkenes from alkanes in a process called cracking. Finally, you will learn about a very important set of materials that are made from alkenes called polymers, better known as plastics, and the problems that are created by overuse of these polymers.

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**. All living things are made from organic compounds based on chains of carbon atoms which are not only covalently bonded to each other but also covalently bonded to hydrogen, oxygen and/or other elements. The organic compounds are many and varied. Some scientists suggest that there are more than ten million known organic compounds.

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

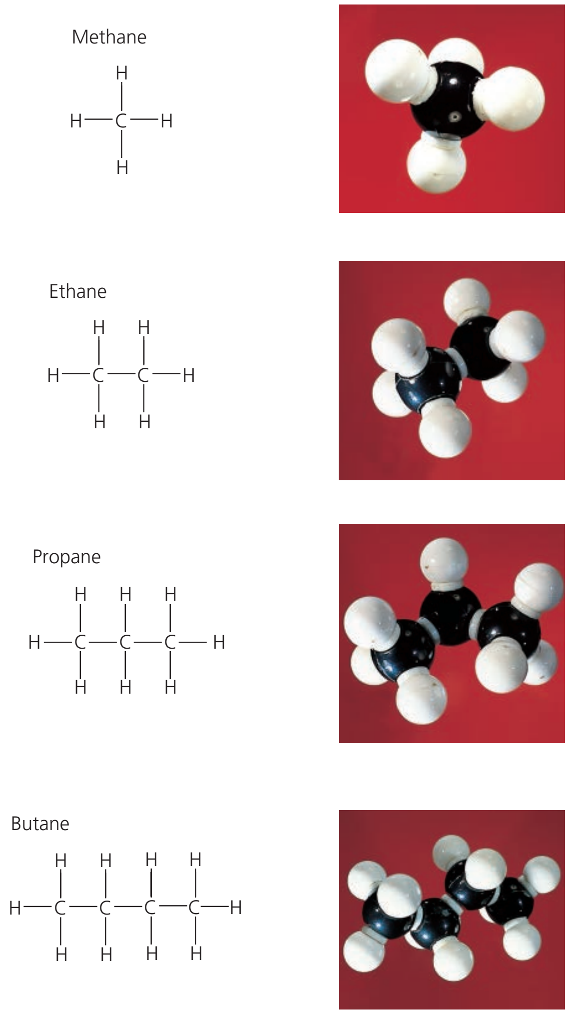
12.1 Alkanes

Most of the hydrocarbons in petroleum belong to the family of compounds called **alkanes**. The molecules within the alkane family contain carbon atoms covalently bonded to four other atoms by single bonds as shown in Figure 12.2, which shows the fully **displayed formulae** of some alkanes. Because these molecules possess only carbon–carbon single covalent bonds, they are said to be **saturated hydrocarbons**, as no further atoms can be added. This can be seen in the bonding scheme for methane (Figure 12.3). The physical properties of the first six members of the alkane family are shown in Table 12.1 (p. 190).

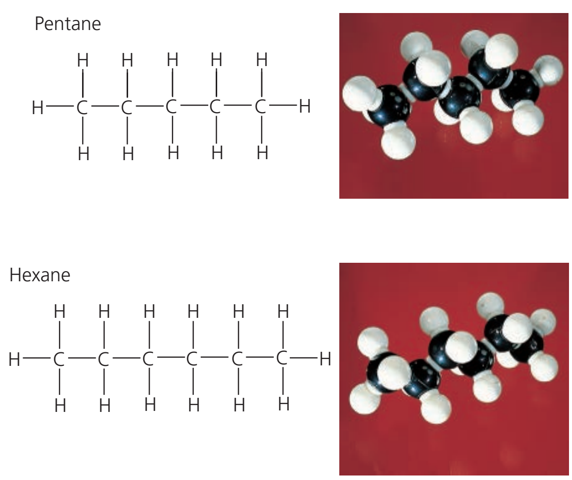
Key definition

A **displayed formula** shows how the various atoms are bonded and shows all the bonds in the molecule as individual lines.

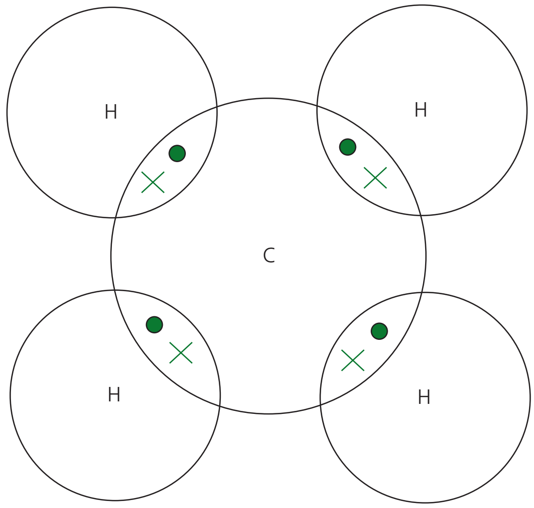
You will notice from Figure 12.2 and Table 12.1 that the compounds have a similar structure and similar name endings. They also behave chemically in a similar way. A family with these factors in common is called a **homologous series**.



Going further



▲ **Figure 12.2** The fully displayed formulae and molecular models of the first six alkanes



Methane molecule (CH_4)

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

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}

where n is the number of carbon atoms present.

> As you go up a homologous series, in order of increasing number of carbon atoms, the physical properties of the compounds gradually change. For example, the melting and boiling points of the alkanes shown in Table 12.1 gradually increase. This is due to an increase in the intermolecular forces as the size and mass of the molecule increases (Chapter 3, p. 43). As you can see from Figure 12.2 and Table 12.1, the increase in size and mass of the molecule is due to the addition of a CH_2 group as you descend the homologous series.

The compounds within a homologous series possess similar chemical properties through their **functional group**. A functional group is usually an atom or group of atoms that are present within the molecules of the homologous series. In the case of the alkanes, they are unusual in that they do not have a functional group. For a further discussion of functional groups, see Chapter 13, p. 206.

Under normal conditions, molecules with up to four carbon atoms are gases, those with between five and 16 carbon atoms are liquids, while those with more than 16 carbon atoms are solids.

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.

▼ **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

Going further

Alkane	Molecular formula	Melting point/°C	Boiling point/°C	Physical state at room temperature
Pentane	C_5H_{12}	–130	36	Liquid
Hexane	C_6H_{14}	–95	69	Liquid

Test yourself

1 Estimate the boiling points for the alkanes with formulae:
- **a** C_7H_{16}
- **b** C_8H_{18}.

2 Name the alkane that has the formula C_7H_{16}.

Naming the alkanes

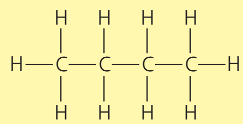
All the alkanes have names ending in *-ane*. The rest of the name tells you the number of carbon atoms present in the molecule. For example, the compound whose name begins with:

- *meth-* has one carbon atom
- *eth-* has two carbon atoms
- *prop-* has three carbon atoms
- *but-* has four carbon atoms

and so on.

Structural isomerism

Sometimes it is possible to write more than one displayed formula to represent a molecular formula. The displayed formula of a compound shows how the atoms are joined together by the covalent bonds. For example, there are two different compounds with the molecular formula C_4H_{10}. The displayed and structural formulae of these two substances, along with their names and physical properties, are shown in Figure 12.4.

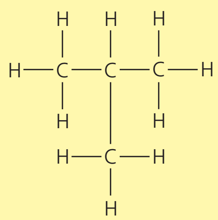


Melting point −138°C

Boiling point 0°C

$CH_3CH_2CH_2CH_3$

a Butane



Melting point −159°C

Boiling point −12°C

$CH_3CH(CH_3)CH_3$

b 2-methylpropane

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

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. The isomers in Figure 12.4 have the same molecular formula, C_4H_{10}, but different structural and displayed formulae. Butane (Figure 12.4a) has the structural formula $CH_3CH_2CH_2CH_3$ and 2-methylpropane (Figure 12.4b) has the structural formula $CH_3CH(CH_3)CH_3$. The brackets show the formula of the branch. The different structures of the compounds shown in Figure 12.4 have different melting and boiling points. Molecule **b** contains a branched chain and has a lower melting point than molecule **a**, which has no branched chain. All the alkane molecules with four or more carbon atoms possess isomers. Perhaps now you can see why there are so many different organic compounds!

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.

Test yourself

3 Draw the displayed formulae for the isomers of C_5H_{12}.

For further insight into isomerism, see p. 195 and Chapter 13, p. 207.

12.2 The chemical behaviour of alkanes

Alkanes are rather unreactive compounds. For example, they are generally not affected by alkalis, acids or many other substances. Their most important property is that they burn or combust easily.

Gaseous alkanes, such as methane, will burn in a good supply of air, forming carbon dioxide and water as well as plenty of heat energy.

$$\text{methane} + \text{oxygen} \rightarrow \underset{\text{dioxide}}{\text{carbon}} + \text{water} + (\Delta H)$$

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

The gaseous alkanes are some of the most useful fuels. As you saw in Chapter 6, they are obtained by the fractional distillation of petroleum. Methane, better known as natural gas, is used for cooking as well as for heating offices, schools and homes (Figure 12.5a). Propane and butane burn with very hot flames and they are sold as liquefied petroleum gas (LPG). In rural areas where there is no supply of natural gas, central heating systems can be run on propane gas (Figure 12.5b). Butane, sometimes mixed with propane, is used in portable blowlamps and in gas lighters.

a This is burning methane

b Central heating systems can be run on propane

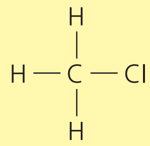
▲ **Figure 12.5**

As stated, alkanes are generally unreactive but, like all homologous series, they will undergo similar chemical reactions. They will react with halogens such as chlorine. Chlorine is quite a reactive non-metal and will react with, for example, methane in the presence of sunlight or ultraviolet light. This is known as a photochemical reaction, with the UV light providing the activation energy (E_a) for the reaction (see Chapter 6, p. 93). The overall chemical equation for this process is:

methane + chlorine → chloromethane + hydrogen chloride

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

We can see that one hydrogen atom of the methane molecule is substituted by a chlorine



▲ **Figure 12.6** Chloromethane

atom to form chloromethane (see Figure 12.6). This type of reaction is known as a **substitution reaction.** In a substitution reaction, one atom or group of atoms is replaced by another atom or group of atoms: this is know as monosubstitution.

Going further

Chloromethane is used extensively in the chemical industry. For example, chloromethane is used to make silicones. Silicones are used in building and construction. They are able to bond and seal materials such as concrete, glass, granite, plastics and steel (see Figure 12.7). This enables them to work better and last longer. There are dangers associated with substances containing chloromethane. It is a harmful substance and should be treated with caution.

▲ **Figure 12.7** Silicones are used carefully as adhesives as well as sealants

Early anaesthetics relied upon trichloromethane, $CHCl_3$, or chloroform. Unfortunately, this anaesthetic had a severe problem since the lethal dose was only slightly higher than that required to anaesthetise the patient. In 1956, halothane was discovered by chemists working at ICI. This is a compound containing chlorine, bromine and fluorine which has been used as an anaesthetic in recent years. Its formula is $CF_3CHBrCl$. However, even this is not the perfect anaesthetic since evidence suggests that prolonged exposure to this substance may cause liver damage. The search continues for even better anaesthetics.

A group of compounds called the chlorofluorocarbons (CFCs) were discovered in the 1930s. Because of their inertness they had many uses, especially as a propellant in aerosol cans. CFC-12 or dichlorodifluoromethane, CF_2Cl_2, was one of the most popular CFCs in use in aerosols. Scientists believe that CFCs released from aerosols are destroying the ozone layer and steps are being taken to reduce this threat.

The ozone hole problem

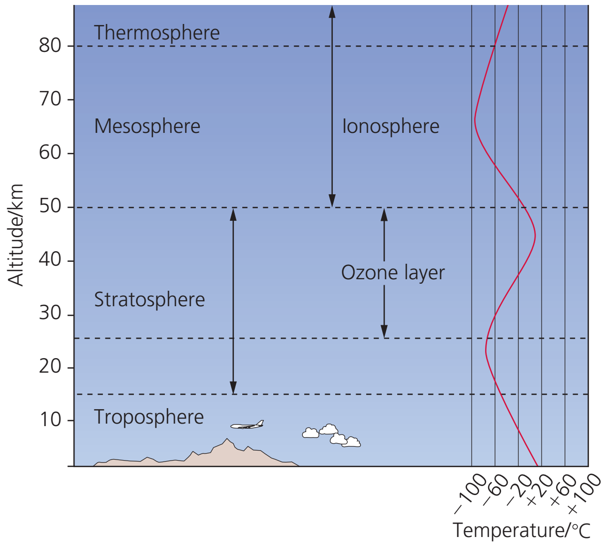
Our atmosphere protects us from harmful ultraviolet radiation from the Sun. This damaging radiation is absorbed by the relatively thin ozone layer found in the stratosphere (Figure 12.8).

Large holes have been discovered in the last 30 years in the ozone layer over Antarctica, Australasia and Europe (Figure 12.8a). Scientists think that these holes have been produced by CFCs such as CFC-12. CFCs escape into the atmosphere and, because of their inertness, remain without further reaction until they reach the stratosphere and the ozone layer. In the stratosphere, the high-energy ultraviolet radiation causes a chlorine atom to split off from the CFC molecule. This chlorine atom, or free radical, then reacts with the ozone.

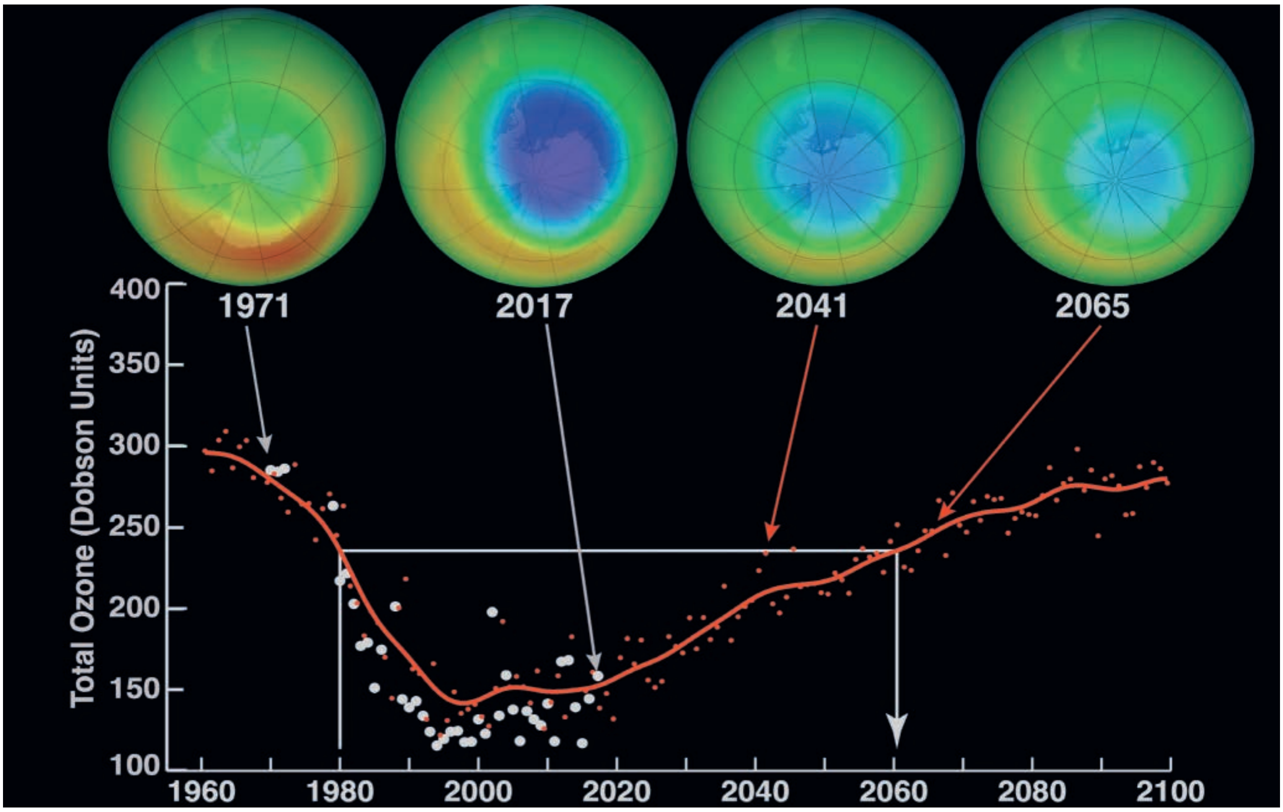
$$Cl(g) + O_3(g) \rightarrow OCl(g) + O_2(g)$$

This is not the only problem with CFCs. They are also significant greenhouse gases (Chapter 11, p. 183). The ozone depletion and greenhouse effects have become such serious problems that an international agreement known as the Montreal Protocol on Substances that Deplete the Ozone Layer was agreed in 1987.

Research into replacements has taken place since then, producing better alternatives called hydrochlorofluorocarbons (HCFCs). These have lower ozone-depletion effects and are not effective greenhouse gases. The protocols of the 1980s have been superseded by the Kyoto Protocol of 1997 and the 2016 Paris Agreement, which has been signed by 197 countries. It is believed that if the intended agreements are adhered to then the ozone layer will recover by 2050.



b The ozone layer is between 25 km and 50 km above sea level



a This diagram comes from NASA's ozone monitoring programme, TOMS (Total Ozone Mapping Spectrometer). The ozone hole over the Antarctic (shown in purple and pink on the diagram) is largest in the Antarctic spring. Note: Dobson units are a measure of the total amount of ozone in a vertical column from the ground to the top of the atmosphere

▲ **Figure 12.8**

Other uses of alkanes

Besides their major use as fuels (p. 191), some of the heavier alkanes are used as waxes in candles, as lubricating oils and in the manufacture of another family of hydrocarbons – the alkenes.

Test yourself

4 Write a balanced chemical equation to represent the combustion of propane.
5 In what mole proportions should chlorine and methane be mixed to produce chloromethane?
6 Draw the covalent bonding diagram for chloromethane, CH_3Cl.

Methane – another greenhouse gas

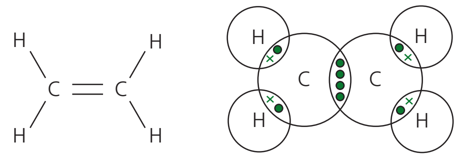
Methane, the first member of the alkanes, occurs naturally. Cows produce it in huge quantities when digesting their food. It is also formed by growing rice. Like carbon dioxide, it is a greenhouse gas (Chapter 11, p. 183) because it acts like the glass in a greenhouse – it will let in heat from the Sun but will not let all of the heat back out again. It is thought that the greenhouse effect may contribute to global warming, which could have disastrous effects for life on this planet. A great debate is going on at the moment as to how we can reduce the amount of methane released into the atmosphere and hence reduce the effects of global warming.

Test yourself

7 Use your research skills and your textbook to find out:
 a any other sources of methane found in nature
 b how climate change might affect your particular environment.

12.3 Alkenes

Alkenes form another homologous series of hydrocarbons of the general formula C_nH_{2n} where n is the number of carbon atoms. The alkenes are more reactive than the alkanes because they each contain a double carbon–carbon covalent bond between the carbon atoms (Figure 12.9). Molecules that possess a carbon–carbon double covalent bond, or even a triple covalent bond, are said to be **unsaturated hydrocarbons**, because it is possible to break one of the two bonds to add extra atoms to the molecule. This feature of alkenes is very important and is responsible for the characteristic properties of these organic compounds. This feature is, for the alkenes, known as their functional group.



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

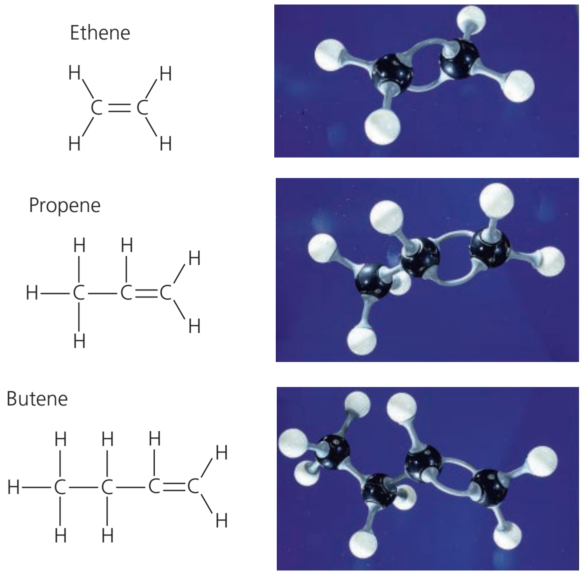
The chemical test to show the difference between saturated and unsaturated hydrocarbons is discussed on p. 197.

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

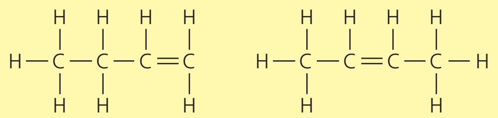


▲ **Figure 12.10** Displayed formula and shape of the first three alkenes

The structural formula of ethene is $CH_2{=}CH_2$ and the structural formula of propene is $CH_2{=}CHCH_3$.

Structural isomerism in alkenes

You saw when studying the alkanes that sometimes it is possible to write more than one displayed or structural formula to represent a molecular formula (p. 190). These are known as structural isomers. Butene and the higher alkenes also show structural isomerism. For example, there are three different compounds with the molecular formula C_4H_8. The displayed formulae of two of these substances along with their names and structural formulae are shown in Figure 12.11. The structural formulae of the isomers but-1-ene and but-2-ene give an unambiguous description of the way the atoms are arranged, including the location of the C=C double bond or functional group. The structural formulae are $CH_3CH_2CH{=}CH_2$ (but-1-ene) and $CH_3CH{=}CHCH_3$ (but-2-ene).



$CH_3\ CH_2\ CH{=}CH_2$ $\quad$ $CH_3CH{=}CHCH_3$

But-1-ene $\quad$ But-2-ene

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

Going further

The different isomers shown in Figure 12.11 have different melting and boiling points due to their different structures. All the alkene molecules with four or more carbon atoms possess isomers.

Test yourself

8 Draw the displayed formulae for the isomers of C_5H_{10}.

Where do we get alkenes from?

Very few alkenes are found in nature. Most of the alkenes used by the petrochemical industry are obtained by breaking up larger, less useful alkane molecules obtained from the fractional distillation of petroleum. This is usually done by a process called **catalytic cracking**. In this process the alkane molecules to be 'cracked' (split up) are passed over a mixture of aluminium and chromium oxides heated to 550°C.

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

$$\underset{\text{(found in kerosene)}}{C_{12}H_{26}(g)} \longrightarrow \underset{\text{shorter alkane}}{C_{10}H_{22}(g)} + \underset{\text{alkene}}{C_2H_4(g)}$$

Another possibility is:

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

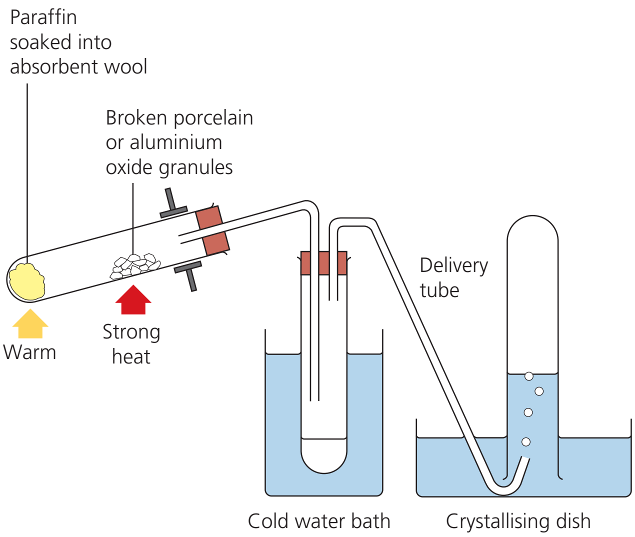
In these reactions, hydrogen may also be formed during cracking. The amount of hydrogen produced depends on the conditions used. Since smaller hydrocarbons are generally in greater demand than the larger ones, cracking is used to match demand (Table 12.3).

▼ **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

This means that oil companies are not left with large surpluses of fractions containing the larger molecules.

Figure 12.12 shows the simple apparatus that can be used to carry out **thermal cracking** reactions in the laboratory. You will notice that in the laboratory we may use a catalyst of broken, unglazed pottery. This experiment should only ever be carried out as a teacher demonstration.



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

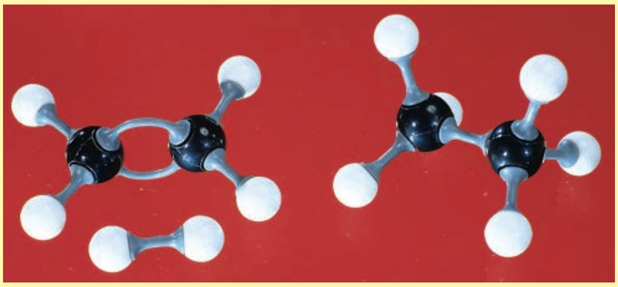
Test yourself

9 Using the information in Table 12.2 (p. 194), estimate the boiling point of pentene.

10 Write a balanced chemical equation to represent the process that takes place when decane is cracked.

12.4 The chemical behaviour of alkenes

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**. The usefulness of this type of reaction is that only one product is formed.



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

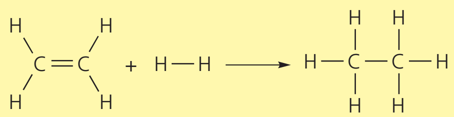
Addition reactions

Hydrogenation

Hydrogen adds across the C=C double bond in ethene. This reaction is called hydrogenation. The conditions necessary for this reaction to take place are a temperature of 200°C in the presence of a nickel catalyst.

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

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



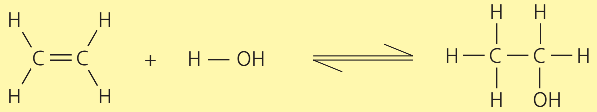
Hydrogenation reactions like the one shown with ethene are used in the manufacture of margarines from vegetable oils.

Hydration

Another important addition reaction is the one used in the manufacture of ethanol. Ethanol has important uses as a solvent and a fuel. It is formed when water (as steam) is added across the double bond in ethene in the presence of an acid catalyst. For this reaction to take place, the reactants have to be passed over a catalyst of phosphoric(V) acid (absorbed on silica pellets) at a temperature of 300°C and pressure of 6000 kPa (1 atmosphere = 1 × 10^5 pascals).

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

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



This reaction is reversible as is shown by the equilibrium ($\rightleftharpoons$) sign. The conditions have been chosen to ensure the highest possible yield of ethanol. In other words, the conditions have been chosen so that they favour the forward reaction. The percentage yield is high at approximately 96%. It should be noted, however, that the ethene is a non-renewable resource.

For a further discussion of ethanol and alcohols generally, see Chapter 13, p. 206.

This method of manufacturing ethanol is a continuous process. In a continuous process, reactants are continually fed into the reaction vessel or reactor as the products are removed. Generally, continuous processing is employed if the substance being made is needed on a large scale.

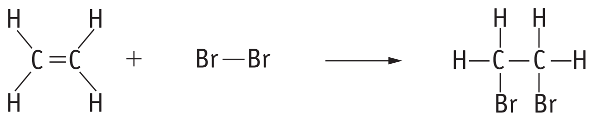
As you have seen, during addition reactions only one product is formed.

Halogenation – a test for unsaturated compounds

The addition reaction between bromine dissolved in an organic solvent, or water, and alkenes is used as a chemical test for the presence of a double bond between two carbon atoms. When a few drops of this bromine solution are shaken with the hydrocarbon, if it is an alkene (such as ethene), a reaction takes place in which bromine joins to the alkene double bond. This results in the bromine solution losing its red/brown colour. If an alkane, such as hexane, is shaken with a bromine solution of this type, no colour change takes place (Figure 12.14). This is because there are no double bonds between the carbon atoms of alkanes.

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

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



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

Test yourself

11 What is meant by the term 'addition reaction'?

12 How would you test the difference between ethane and ethene?

13 Write the displayed formula for pentene.

14 Which of the following organic chemicals are alkanes and which are alkenes?
- Propene, C_3H_6
- Octane, C_8H_{18}
- Nonane, C_9H_{20}
- Butene, C_4H_8

State why you have chosen your answers.

Practical skills

Alkanes and alkenes

For safe experiments/demonstrations which are related to this chapter, please refer to the *Cambridge IGCSE Chemistry Practical Skills Workbook*, which is also part of this series.

Safety

- Eye protection must be worn.

A student wrote the following account of an experiment carried out by the teacher to test which of two liquid hydrocarbons was an alkane and which was an alkene.

To a few drops of each liquid in separate test tubes, they added a few drops of red aqueous bromine solution from a measuring cylinder. They then corked the test tubes and shook them a little. In one test tube the solution went colourless showing this hydrocarbon to be an alkane, while there was no change in colour of the other, so this must be the alkene.

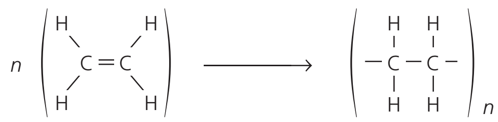
Some statements in the student's account have been underlined by the teacher.

Answer these questions to identify how the experiment could be improved.

1 Which major safety precaution did they forget to mention at the start of the experiment?
2 Do you think the teacher would have added a few drops from a measuring cylinder? Explain your answer.
3 What would be the actual colour of the aqueous bromine solution?
4 How would the teacher have shaken the test tubes?
5 Would you expect only one layer in the solution after adding the aqueous bromine solution? Explain your answer.
6 Has the student got the identification of the alkane and the alkene correct? Explain your answer.

12.5 Polymers

Polythene is a **plastic** that was discovered by accident. Through the careful examination of this substance, when it was accidentally discovered, the plastics industry was born. Polythene is now produced in millions of tonnes worldwide every year. It is made by heating ethene to a relatively high temperature under a high pressure in the presence of a catalyst.



In a chemical equation for this process, we show that a large number of ethene molecules are adding together by using the letter *n* to indicate very large numbers of monomer molecules. The polymer formed, in the chemical equation, is shown as a repeat unit which repeats *n* times to form the polymer chain.

When small molecules like ethene join together to form long chains of atoms, called **polymers**, the process is called **polymerisation**. The small molecules, like ethene, which join together in this way are called **monomers**. A polymer chain, a very large molecule or a macromolecule, often consists of many thousands of monomer units and in any piece of plastic there will be many millions of polymer chains. Since in this polymerisation process the monomer units add together to form only one product, the polymer, the process is called **addition polymerisation**.

Key definitions

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

Plastics are made from polymers.

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

Poly(ethene), like many other addition polymers has many useful properties including: being tough, easy to mould and an excellent insulator. One of the drawbacks however, as you will see later in this section, is that it is not affected by the weather and does not corrode, and therefore has disposal problems.

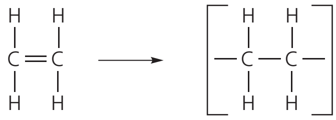
It can be found as a substitute for natural materials in plastic bags, sandwich boxes, washing-up bowls, wrapping film, milk-bottle crates and washing-up liquid bottles (Figure 12.16).

▲ **Figure 12.16** These crates are made from poly(ethene)

Other alkene molecules can also produce substances like poly(ethene); for example, propene produces poly(propene), which is used to make ropes and packaging.

In theory, any molecule that contains a carbon-to-carbon double covalent bond can form an addition polymer. For example, ethene, $CH{=}CH_2$, will undergo an addition reaction to form poly(ethene).

The actual structure of the polymer can only be shown/represented by drawing the monomer as shown in Figure 12.17. In this figure, you will see that the double bond has been replaced by a single bond and there are two extension bonds drawn on either side, which show that the polymer chain extends in both those directions.



Ethene (monomer)

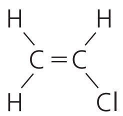
Repeat unit in the polymer

▲ **Figure 12.17** Addition polymerisation of ethene

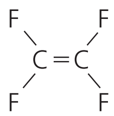
Going further

Other addition polymers

Many other addition polymers have been produced. Often the plastics are produced with particular properties in mind, such as PVC (polyvinyl chloride or poly(chloroethene) and PTFE (poly(tetrafluoroethene)). Both of these plastics have monomer units similar to ethene.

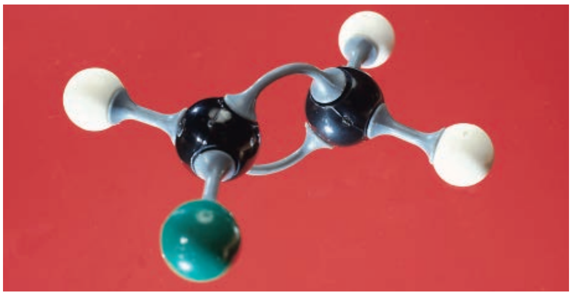


PVC monomer (vinyl chloride or chloroethene)

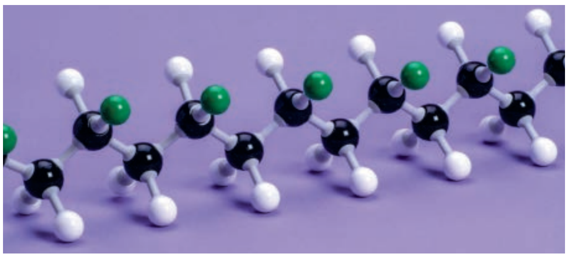


PTFE monomer (tetrafluoroethene)

If we use chloroethene (Figure 12.18a), the polymer we make is slightly stronger and harder than poly(ethene) and is particularly good for making pipes for plumbing (Figure 12.19).

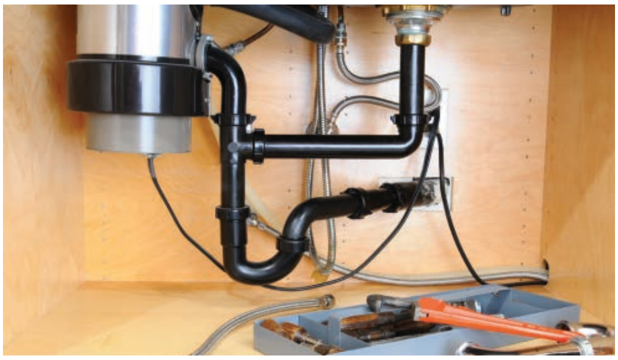


a Model of chloroethene, the PVC monomer



b Model of part of a PVC polymer chain

▲ **Figure 12.18**



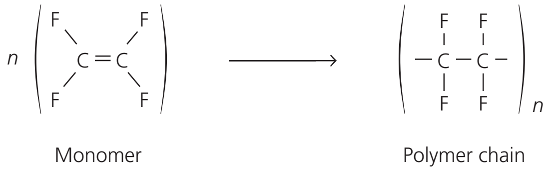
▲ **Figure 12.19** These pipes are made from PVC

PVC is the most versatile plastic and is the second most widely used, after poly(ethene). Worldwide more than 27 million tonnes are produced annually.

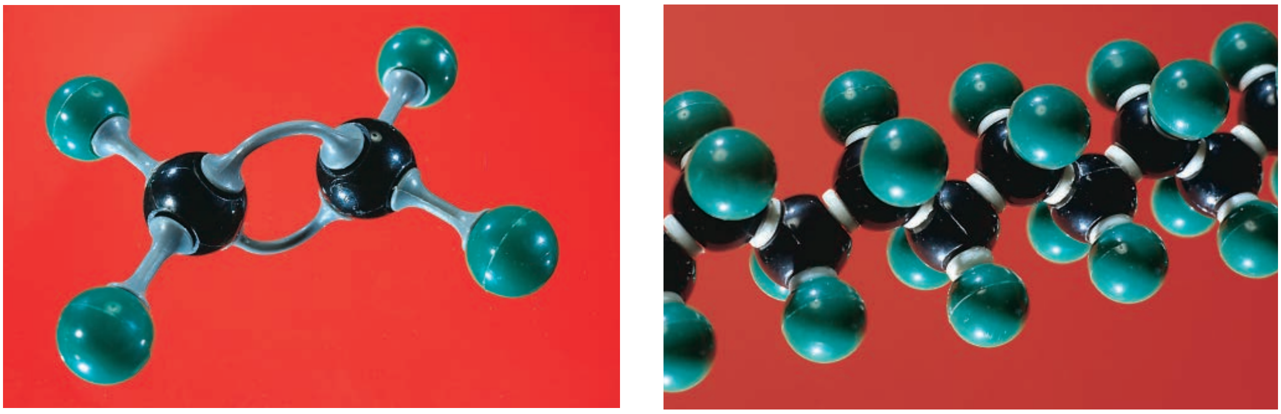
If we start from tetrafluoroethene (Figure 12.20a), the polymer we make, PTFE, has some slightly unusual properties:

- it will withstand very high temperatures, of up to 260°C
- it forms a very slippery surface
- it is hydrophobic (water repellent)
- it is highly resistant to chemical attack.

These properties make PTFE an ideal 'non-stick' coating for frying pans and saucepans. Every year more than 50 000 tonnes of PTFE are made.



The properties of some addition polymers along with their uses are given in Table 12.4.



a Model of tetrafluoroethene, the PTFE monomer

b Model of part of a PTFE polymer chain

▲ **Figure 12.20**

▼ **Table 12.4** Some addition polymers

Plastic	Monomer	Properties	Uses
Poly(ethene)	$CH_2{=}CH_2$	Tough, durable	Carrier bags, bowls buckets, packaging
Poly(propene)	$CH_3CH{=}CH_2$	Tough, durable	Ropes, packaging
PVC	$CH_2{=}CHCl$	Strong, hard (less flexible than poly(ethene))	Pipes, electrical insulation, guttering
PTFE	$CF_2{=}CF_2$	Non-stick surface, withstands high temperatures	Non-stick frying pans, soles of irons
Polystyrene	$CH_2{=}CHC_6H_5$	Light, poor conductor of heat	Insulation, packaging (especially as foam)
Perspex	$CH_2{=}C(CO_2CH_3)CH_3$	Transparent	Used as a glass substitute

Environmental challenges of plastics

In the last 30 to 40 years, plastics have taken over as replacement materials for metals, glass, paper and wood, as well as for natural fibres such as cotton and wool. This is not surprising since plastics are light, cheap, relatively unreactive, can be easily moulded and can be dyed bright colours. Unfortunately, as you saw earlier in this section, they are not affected by the weather and so do not corrode. This is both an advantage, in the way they can be used, and a disadvantage, as it makes plastics so difficult to dispose of safely. Plastics have contributed significantly to the household waste problem, at least 10% in some countries, and it is getting worse (Figure 12.21)!

▲ **Figure 12.21** This plastic waste is ready to go to landfill

In the recent past, much of our plastic waste has been used as landfill in, for example, disused quarries. However, all over the world these sites are getting very much harder to find and it is becoming more and more expensive to dispose of the waste. Also the older landfill sites are now beginning to produce gases, including methane (which is a greenhouse gas), which contribute to global warming. The alternatives to dumping plastic waste are certainly more economical and more satisfactory but also create their problems.

- Incineration schemes have been developed to use the heat generated from burning waste for heating purposes (Figure 12.22). However, problems with the combustion process (which can result in the production of toxic gases) mean that especially high temperatures have to be employed during the incineration process, driving energy costs up.
- Recycling produces large quantities of black plastic bags and sheeting for resale. However there are problems with recycling in that some plastics cannot be recycled because of their properties.
- **Biodegradable** plastics, as well as those polymers that degrade in sunlight (photodegradable, Figure 12.23a), have been developed. Other common categories of degradable plastics include synthetic biodegradable plastics which are broken down by bacteria, as well as plastics which dissolve in water (Figure 12.23b). The property that allows plastic to dissolve in water has been used in relatively new products, including soluble capsules containing liquid detergent. Very recently, chemists have found ways of involving carbon dioxide and sugars in the production of plastics that are also broken down by bacteria. However, the vast majority of polymers are still non-biodegradable.

There is a further huge global problem which has been highlighted recently. That is, there are extreme pollution problems caused by non-biodegradable plastics and their accumulation in the world's oceans (see Figure 12.24). Aquatic life is being decimated in some regions of the world. The problems with plastics are causing a dramatic rethink of the role of plastics in our society!

▲ **Figure 12.22** A plastic incineration plant

a This plastic bag is photodegradable

b This plastic dissolves in water

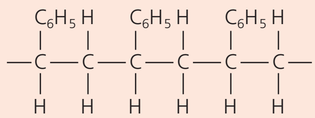
▲ **Figure 12.23**

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

Test yourself

15 Draw the structure of the repeat unit of the addition polymer formed from $CH_3{-}CH_2CH{=}CH_2$.

16 Draw the displayed formula of the monomer from which the addition polymer below has been produced.



Revision checklist

After studying Chapter 12 you should be able to:

- ✔ Draw and interpret the displayed formula of a molecule to show all of the atoms and all of the bonds.
- ✔ Write and interpret general formulae to show the ratio of atoms in the molecules of the compounds in a homologous series.
- ✔ Identify a functional group as an atom or group of atoms that determine the chemical properties of a homologous series.
- ✔ State that a structural formula is a description of the way the atoms in a molecule are arranged, including $CH_2{=}CH_2$.
- ✔ Define structural isomers as compounds with the same molecular formula, but different structural formulae, including C_4H_{10} as $CH_3CH_2CH_2CH_3$ and $CH_3CH(CH_3)CH_3$, and C_4H_8 as $CH_3CH_2CH{=}CH_2$ and $CH_3CH{=}CHCH_3$.
- ✔ Describe a homologous series as compounds that have the same functional group, the same general formula, differ from one member to the next by a $-CH_2-$ unit , show a trend in physical properties and have similar chemical properties.

- ✔ State that a saturated compound has molecules in which all carbon–carbon bonds are single bonds.
- ✔ State that an unsaturated compound has molecules in which one or more carbon–carbon bonds are double bonds or triple bonds.

- ✔ Name and draw the structural and displayed formulae of unbranched alkanes and alkenes and the products of their reactions containing up to four carbon atoms per molecule.

- ✔ State the type of compound present given the chemical name ending in -ane, -ene, or from a molecular, structural or displayed formula.
- ✔ State that the bonding in alkanes is single covalent and that alkanes are saturated hydrocarbons.
- ✔ Describe the properties of alkanes as being generally unreactive, except in terms of combustion and substitution by chlorine.

- ✔ State that in a substitution reaction, one atom or group is replaced by another atom or group.
- ✔ Describe the substitution reaction of alkanes with chlorine as a photochemical reaction, with UV light providing the activation energy, and draw the structural or displayed formulae of the products, limited to monosubstitution.

- ✔ State that the bonding in alkenes includes a double carbon–carbon covalent bond and that alkenes are unsaturated hydrocarbons.
- ✔ Describe the manufacture of alkenes and hydrogen by the cracking of larger alkanes using a high temperature, 550°C, and a catalyst.
- ✔ Describe the reasons for the cracking of larger alkanes.
- ✔ Distinguish between saturated and unsaturated hydrocarbons using aqueous bromine.

- ✔ State that in an addition reaction, only one product is formed.
- ✔ Describe the properties of alkenes in terms of addition reactions with bromine, hydrogen and steam, and draw the structural or displayed formulae of the products.

- ✔ Define polymers as large molecules built up from many small units called monomers.
- ✔ Describe the formation of poly(ethene) as an example of addition polymerisation.

- ✔ Identify the repeat units and/or linkages in polymers.
- ✔ Deduce the structure or repeat unit of an addition polymer from a given alkene and vice versa.

- ✔ State that plastics are made from polymers.
- ✔ Describe how the properties of plastics have implications for their disposal.
- ✔ Describe the environmental challenges caused by plastics in terms of their disposal in landfill, accumulation in oceans and formation of toxic gases from burning.

Exam-style questions

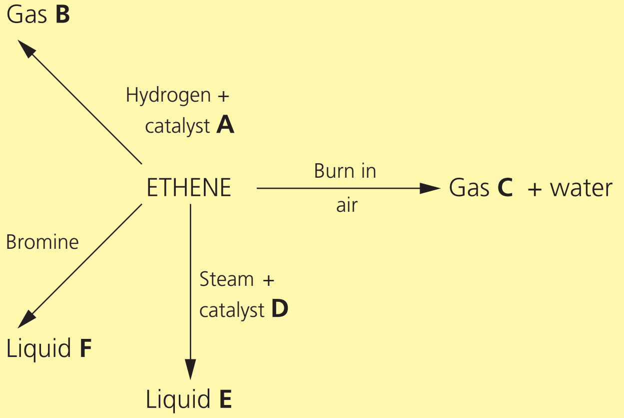
1 Explain the following statements.

a Ethene is called an unsaturated hydrocarbon. [2]

b The cracking of larger alkanes into simple alkanes and alkenes is important to the petrochemical industry. [3]

c The conversion of ethene to ethanol is an example of an addition reaction. [2]

2 The following question is about some of the reactions of ethene.



a Give the names and formulae for substances **A** to **F**. [12]

b **i** Give a word and balanced chemical equation to represent the reaction in which liquid **E** is formed. [4]

ii Identify the reaction conditions required for the process to take place. [3]

c Give the homologous series that gas **B** belongs to. [1]

d Describe a chemical test which would allow you to identify gas **C**. [2]

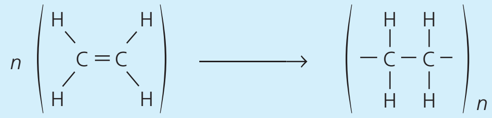
3 **a** Petroleum is a mixture of *hydrocarbons* which belong to the *homologous series* called the *alkanes*.
Explain the meaning of the terms in italics. [6]

b Alkanes can be converted into substances which are used as solvents. To do this the alkane is reacted with a halogen, such as chlorine, in the presence of ultraviolet light.

i Give a word and balanced chemical equation for the reaction between methane and chlorine. [4]

ii Identify the type of reaction taking place. [1]

4 Ethene, C_2H_4, is the starting material for making plastic carrier bags.



a Identify the type of chemical change taking place in the diagram above. [1]

b Identify the product formed by this reaction. [1]

c **i** The alkene, ethene, is made by cracking large alkane molecules. Describe a simple chemical test to show that ethene is present. [2]

ii Draw the displayed formula of any products formed in part **c i**. [1]

5 **a** The majority of plastic carrier bags are difficult to dispose of.

i Explain why carrier bags should not just be thrown away. [2]

ii Explain why plastic carrier bags should be recycled. [2]

iii Give one advantage that a plastic carrier bag has over one made out of paper. [1]

b A label like the one below is found on some plastic carrier bags.

'This plastic carrier bag is made from a substance that is made from the chemical *elements* carbon and hydrogen only. When the carrier bag is burned, it produces carbon dioxide and water. These substances are natural and will not harm the environment.'

i Give the meaning of the term 'element'. [2]

ii Identify the name given to the type of compound that contains the elements carbon and hydrogen only. [1]

iii When the plastic bag burns, heat energy is given out. Give the name used to describe reactions that give out heat energy. [1]

iv The plastic bag will probably give off a toxic gas when it is burned in a limited supply of air. Give the name and formula of this gas. [2]

6 **a** Identify which of the following formulae represent alkanes, which are alkenes, and which represent neither.

CH_3	$C_{12}H_{24}$
C_6H_{12}	$C_{20}H_{42}$
C_5H_{12}	C_2H_4
C_6H_6	C_8H_{18}
C_9H_{20}	C_3H_7

[3]

b Draw the displayed formulae for all the possible isomers which have the molecular formula C_6H_{14}. [10]