B ORGANIC MOLECULES

1 Carbon in organic compounds

The history of organic chemistry

The term **organic chemistry** came from the word 'organism'. Before 1828, all organic compounds had been obtained from organisms or their remains. The scientific philosophy back then was that organic compounds could only be produced within living matter while inorganic compounds were synthesised from non-living matter. At the time, a theory known as 'vitalism' stated that a 'vital force' from a living organism was necessary to make an organic compound. But in 1828, German chemist Friedrich Wöhler (1800–1882) amazed the science community by using an inorganic compound to make an organic molecule.

$$\underset{\text{ammonium cyanate}}{NH_4CNO} \xrightarrow{\text{heat}} \underset{\text{urea}}{CO(NH_2)_2}$$

Today there are over six million organic compounds characterised, including the foods we eat (made of carbohydrates, lipids, proteins and vitamins), furs and feathers, hides and skins, and the organisms they come from. Many more are found in plastics, synthetic and natural fibres, dyes and drugs, insecticides and herbicides, ingredients in perfumes and flavouring agents, and petroleum products.

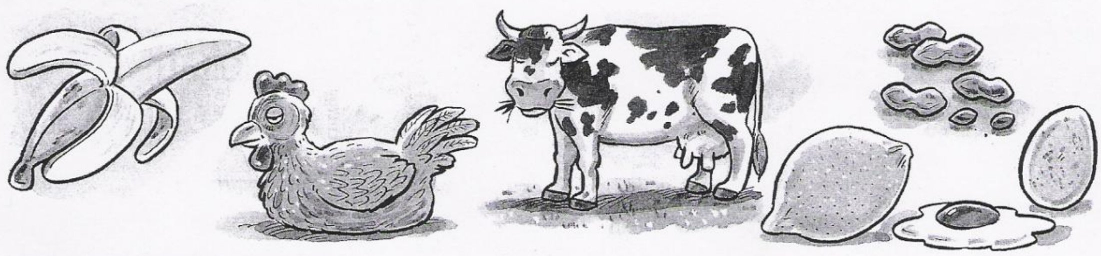
You will answer these questions:

1. What is the modern definition of organic chemistry?
2. Why is carbon so important?

You will practise these skills:

- applying prior knowledge in new contexts
- evaluating and applying understanding of the nature of science.

In 1828, Friedrich Wöhler observed in the laboratory the formation of synthetic urea from the inorganic raw materials. His synthesis of urea showed the possibility of fabricating such materials, which up until then had been looked upon as the products of living organisms alone. Since then, thousands of organic substances have been investigated and additional thousands have been produced.



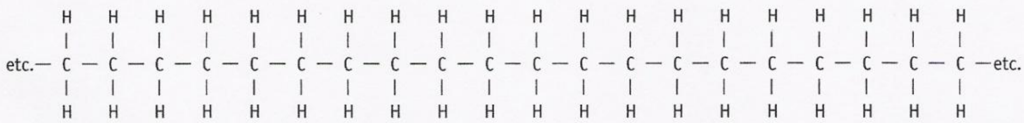
Think it through

1. What is an organic compound?
2. What special properties of carbon make it so important?
3. Scientists develop theories (for example 'vitalism'), which change and are replaced by new theories. If theories do change, why is it that we bother to learn about scientific theories?

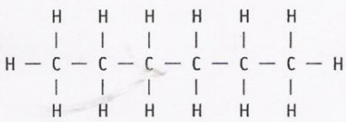
GET THE FACTS

Carbon bonds

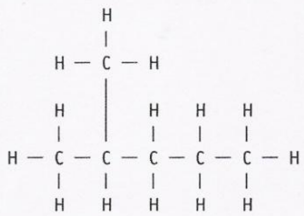
- The great number of carbon compounds that exist is possible because of the ability of carbon atoms to form strong covalent bonds to each other while also strongly holding the atoms of other non-metals. Sulphur atoms, for example, can also form long chains, but they are unable to hold the atoms of any other elements strongly at the same time. (Recall what you learned in previous grades about chemical bonding, strong and weak bonds between atoms, and single and multiple bonds.)
- Carbon atoms have the special properties to bond with each other to form chains, rings, spheres and tubes. Chains of carbon atoms can be thousands of atoms long, as in polyethene.
- Carbon has four valence electrons. While elements to the right and left of carbon in the periodic table form ionic bonds, carbon forms predominantly covalent bonds.
- The carbon–hydrogen (C–H) bonds and carbon–carbon (C–C) bonds are purely covalent. This is because the difference between the electronegativities of carbon and hydrogen is very small. According to the Pauling scale, carbon's is 2,5 and hydrogen's is 2,1.
- Carbon has the ability to form long chain structures through the linking together of carbon atoms. These chains can be unbranched or branched. In some cases, carbon atoms link together and form ring structures.



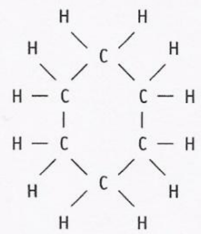
Polyethene chain



Unbranched structure

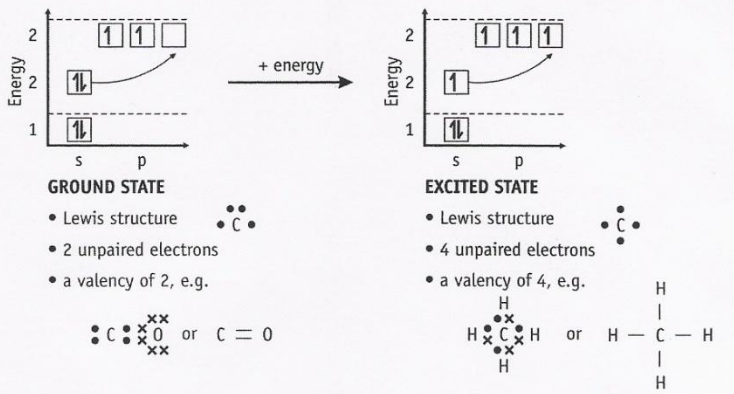


Branched structure



Ring structure

- The valence electrons of carbon, which do not take part in the formation of carbon–carbon covalent bonds, are available for the formation of covalent bonds with hydrogen, oxygen, sulphur, nitrogen and other atoms of elements that are sometimes present in organic compounds.



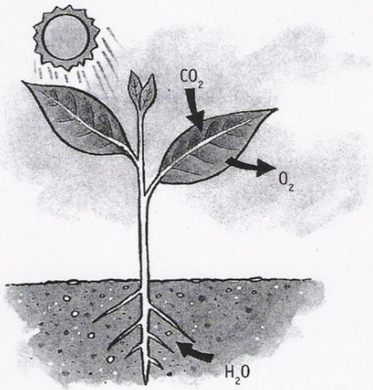
Energy diagrams showing how carbon can form covalent bonds with other atoms

GET THE FACTS

Sources of organic compounds

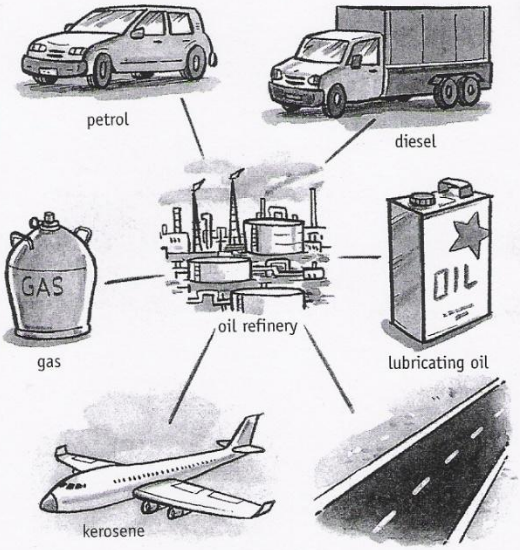
- Photosynthesis is the chief source of organic compounds. The process of photosynthesis is represented as follows:

$$6CO_2 + 6H_2O \xrightarrow[\text{in the presence of chlorophyll}]{\text{energy from sunlight}} C_6H_{12}O_6 + 6O_2$$



Carbon dioxide and sunlight energy entering the leaves, and the roots absorbing water during photosynthesis

- The other source of organic compounds is fossil fuels, which are coal, petroleum and natural gas.



Organic products from fossil fuels

PRACTISE IT NOW

Understanding organic compounds

1. State three reasons why such a huge number of stable organic compounds exists.
2. Do fossil fuels really 'store' energy? Explain.
3. Make a list of ten organic substances that you use or see around you.

INVESTIGATE IT NOW

Design a poster

Oil is produced in different countries and used by almost all countries in the world.

Working in groups of four, make a poster that shows the process of refining crude oil into its usable products (fuels). Take the following into account:

- Indicate other uses of chemicals that are found in oil.
- Present only key information.
- Use photographs and/or drawings.
- The poster should be clear and readable from a distance of 2 m.

Assessment task

This research project is a good opportunity for formal assessment, which can be part of your programme of assessment. Show that you can:

- work together in a group without close supervision
- collect and collate information
- follow the steps necessary to complete a research project according to given criteria.

2 Organic groups or families

Classification of organic compounds

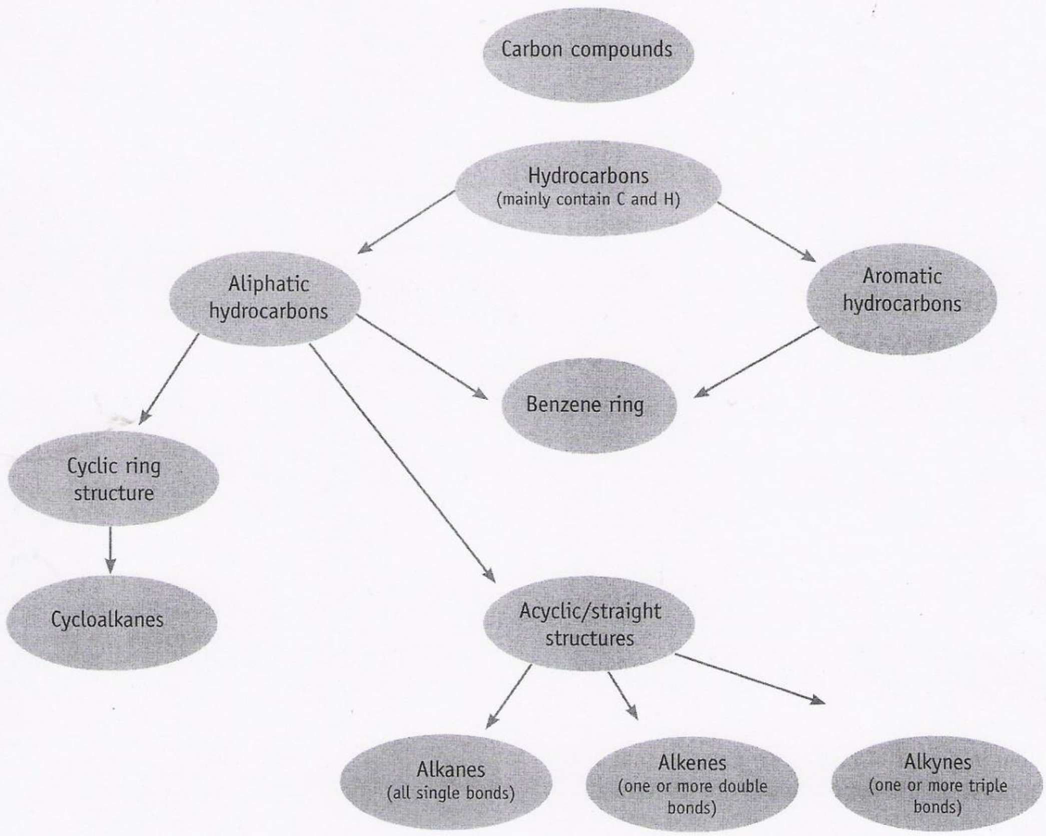
Organic compounds are classified mainly according to their types of bonds, for example whether they have single, double or triple bonds. They can also be classified according to their structures. Some groups have branched-chain structures, some have unbranched or straight-chain structures, and others form rings.

You will answer these questions:

1. What are saturated and unsaturated compounds?
2. What is a functional group?

You will practise these skills:

- recalling important information
- classifying objects
- applying knowledge.



Think it through

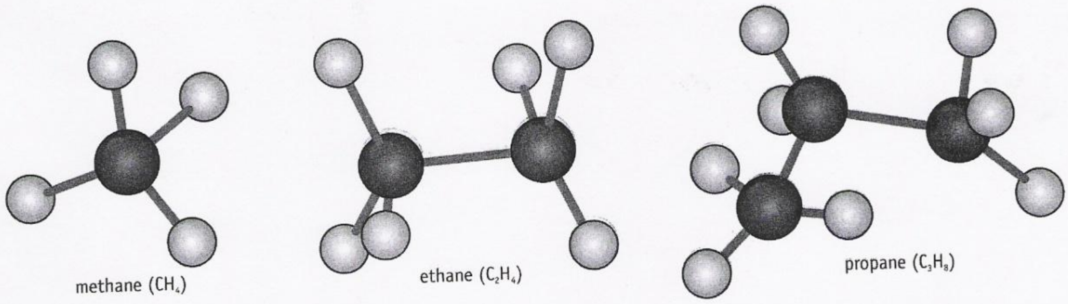
1. Does the concept map above make sense to you?
2. Can you think of other ways in which to classify organic compounds?

We will concentrate on aliphatic **hydrocarbons** and their derivatives. Compounds that have only single bonds between the carbons are classified as **saturated**. Those that have double or triple bonds are said to be **unsaturated**.

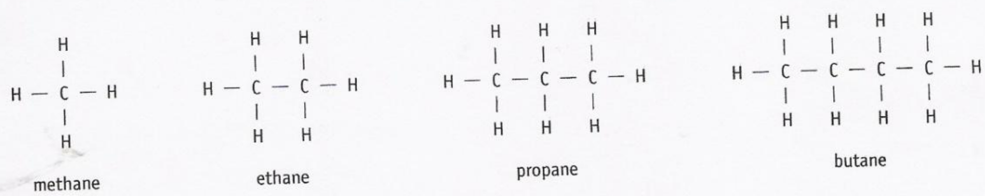
GET THE FACTS

Alkanes

- The **alkane** series of hydrocarbons have only single bonds between the carbon atoms, and are therefore saturated.
- The simplest alkane is called methane, which consists of one carbon atom bonded to four hydrogen atoms in single bonds.
- Here is a series of alkanes as more and more carbon and hydrogen atoms are added. Their **structural formulae** are shown:



Ball-and-stick models



Structural formulae

- In each of these compounds, each carbon atom is bonded to another atom by four covalent bonds.
- The bond between a carbon atom and a hydrogen atom is a single covalent bond.
- To save space and time, **condensed structures** may be used to simplify the drawing and writing of structural formulae of organic compounds. For example:

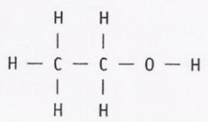
CH_4	CH_3CH_3	$CH_3CH_2CH_3$	$CH_3CH_2CH_2CH_3$
methane	ethane	propane	butane

Condensed structural formulae

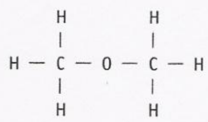
- Each member of these compounds differs from the previous one by a CH_2 group. In this way, they form a **homologous series**, called alkanes.
- The names of alkanes all end in '-ane'. The first four names in the alkane series have been long-established. The compounds that follow them have Greek prefixes that refer to the number of carbons in the chain, as shown on page 152.

Alkane name	No. of carbons	Condensed formula	Prefix meaning
Pentane	5	$CH_3(CH_2)_3CH_3$	'pent-' means five
Hexane	6	$CH_3(CH_2)_4CH_3$	'hex-' means six
Heptane	7	$CH_3(CH_2)_5CH_3$	'hept-' means seven
Octane	8	$CH_3(CH_2)_6CH_3$	'oct-' means eight
Nonane	9	$CH_3(CH_2)_7CH_3$	'non-' means nine
Decane	10	$CH_3(CH_2)_8CH_3$	'dec-' means ten

- The alkane group can be represented by a general **molecular formula**, C_nH_{2n+2}, where n represents the number of carbons.
- For example, if $n = 1$, then the compound will be $CH_{2 \times 1 + 2}$ or CH_4, which is methane.
- Some hydrocarbons are **structural isomers** with one another. This is because their molecular formulae are the same, but their structural formulae differ.
- Their structures give them different properties. For example, the organic compounds ethanol (ethyl alcohol) and dimethyl ether both have the formula C_2H_6O, but differ in structure. They are two very different substances, with different physical properties, even though they have the same molecular formula:



ethanol
(boiling point: 78 °C;
freezing point: -117 °C)



dimethyl ether
(boiling point: -25 °C;
freezing point: -138 °C)

PRACTISE IT NOW

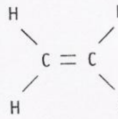
Understanding alkanes

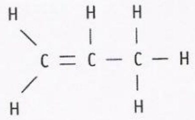
1. Define the following terms: saturated compounds, unsaturated compounds, homologous series, structural isomer.
2. Give the general molecular formula of alkanes.
3. Write the condensed structure of an octane molecule.
4. Write the structural formulae of three isomers of hexane (C_6H_{14}).

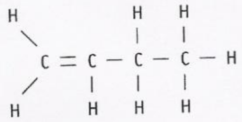
GET THE FACTS

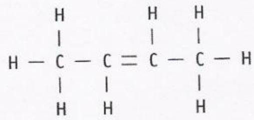
Alkenes

- In this homologous series of hydrocarbons, the compounds contain one carbon–carbon double bond. An **alkene** is therefore unsaturated because it does not contain the maximum number of hydrogen atoms.
- The names of all alkenes end in '-ene'. The first three in the series are shown on page 153.
- Notice how butene is named when the double bond occurs between carbon atoms 1 and 2 in the chain (1-butene) and when the double bond occurs between carbon atoms 2 and 3 in the chain (2-butene).

 or $CH_2 = CH_2$ ethene

 or $CH_2 = CHCH_3$ propene

 or $CH_2 = CHCH_2CH_3$ 1-butene

 or $CH_3CH = CHCH_3$ 2-butene

INVESTIGATE IT NOW

Alkene general formula

Like alkanes, alkenes have a general formula.

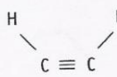
Work with a partner.

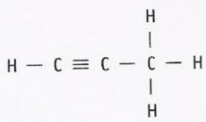
1. For each alkane in the table on page 152, derive an alkene by removing two hydrogens and creating a double bond. Draw the structural formulae and name the alkene compounds. (Ignore the position of the double bond for now.)
2. From your alkenes, write the general formula of alkenes.

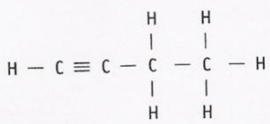
GET THE FACTS

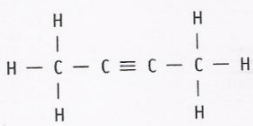
Alkynes

- **Alkynes** are unsaturated hydrocarbons that contain a triple bond.
- The names of all alkynes end in '-yne'. The first three are shown below.
- The general formula for alkynes is C_nH_{2n-2}.

 or $CH \equiv CH$ ethyne

 or $CH \equiv CCH_3$ propyne

 or $CH_2 \equiv CCH_2CH_3$ 1-butyne

 or $CH_3C \equiv CCH_3$ 2-butyne

PRACTISE IT NOW

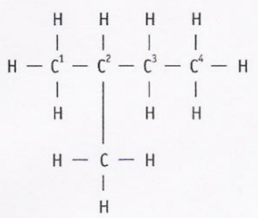
Getting to know alkynes

1. Create a table similar to the one on page 146, but make this one for alkynes.
2. Compare your work with that of a partner.

GET THE FACTS

Straight and branched chains

- In the examples of alkanes, alkenes and alkynes studied thus far, the chain of carbon atoms were unbranched, or **straight**.
- Carbon chains can also be **branched**, which means that a hydrogen atom is replaced by an **alkyl group**. An alkyl group consists of an alkane minus one hydrogen.
- Here is an example of a branched chain:



2-methylbutane

- The base name of this hydrocarbon is butane. (There are four carbons in a chain of single bonds. The carbons in the main chain are numbered 1 to 4.) However, one hydrogen of butane is replaced by a CH_3 alkyl group, which creates a branched chain.
- The names of alkyl groups are based on the names of alkane groups, but end in 'yl':

Alkyl group structure	Alkyl name
CH_3 –	Methyl
CH_3CH_2 –	Ethyl
$CH_3CH_2CH_2$ –	Propyl
$CH_3CH_2CH_2CH_2$ –	Butyl

- The alkyl group on the hydrocarbon alongside is called methyl. Because it is bonded to the second carbon in the main butane chain, the name of the compound is 2-methylbutane.

PRACTISE IT NOW

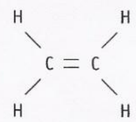
Making sense of hydrocarbons

1. Describe the structural difference between saturated and unsaturated hydrocarbon molecules.
2. Classify the organic compounds (a) to (f) below. Explain why you would classify them in this way.
3. Using pentane and 2-methylbutane as examples, explain the meaning of isomerism.

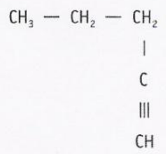
a) $CH_3CH_2CH_3$

b) $CH_2=CHCH_3$

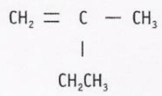
c)



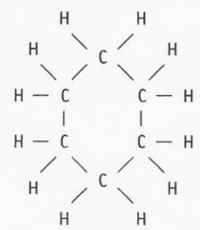
d)



e)



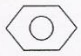
f)



GET THE FACTS

Hydrocarbon derivatives

- For the purpose of classification, all other hydrocarbons are taken to be derived from alkanes, alkenes, alkynes and aromatic hydrocarbons.
- The table below shows some organic compounds and their derivatives.
  R and R′ represent hydrocarbon groups (alkyl groups).

Hydrocarbon family (only C and H)	Structural characteristics	Examples
Alkanes	Single bonds only	CH_3CH_3
Alkenes	C = C, double bonds	$CH_2 = CH_2$
Alkynes	C ≡ C, triple bonds	HC ≡ CH
Aromatic	Benzene ring	
Hydrocarbon derivatives	**Structural characteristics**	**Examples**
Alcohols	ROH	CH_3CH_2OH
Ethers	ROR′	CH_3OCH_3
Aldehydes	O ‖ RCH	O ‖ CH_3CH
Ketones	O ‖ RCR′	O ‖ CH_3CCH_3
Carboxylic acids	O ‖ RCOH	O ‖ CH_3COH
Esters	O ‖ RCOR′	O ‖ CH_3COCH_3
Amines	RNH_2, RNHR′, RNR′R′	CH_3NH_2, CH_3NHCH_3, CH_3 | CH_3NCH_3
Amides	O ‖ RC –NR′ (H)	O ‖ CH_3CNH_2

- The type of properties associated with a compound is different depending on the family to which it belongs. For example, alkanes have just C–C and C–H single bonds. Since C and H are so alike in electronegativity, they are least able to attract ions or polar molecules, and are least able to interact with them.

GET THE FACTS

Functional groups

- **Functional groups** are small structural units within molecules at which most of the compound's chemical reactions occur.
- Functional groups are important in determining the reactivity of the compound and the way in which it is named.
- The C–C single bond, C=C double bond and C≡C triple bond are the functional groups of alkanes, alkenes and alkynes respectively.
  See the table below for examples of various functional groups.

Group name	Example	Structural formula	Functional group
Alkane	Ethane	H H | | H – C – C – H | | H H	| | – C – C – | |
Alkene	Ethene	H H | | C = C | | H H	| | C = C | |
Alkyne	Ethyne	H – C ≡ C – H	– C ≡ C –
Haloalkane	Chloroethane	H H | | H – C – C – Cl | | H H	– Cl
Alcohol	Ethanol	H H | | H – C – C – OH | | H H	– OH
Carboxylic acid	Ethanoic acid	H O | ‖ H – C – C – OH | H	O ‖ – C – OH
Ester	Methyl ethanoate	H O H | ‖ | H – C – O – C – C – H | | H H	O ‖ – O – C –

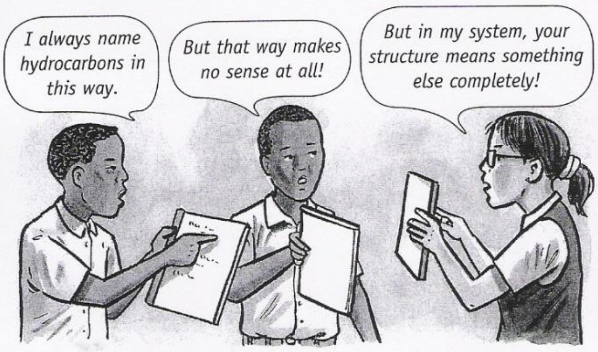
B

ORGANIC MOLECULES

3 Naming and representing organic compounds

Following rules

In the previous unit, you learned about how carbon and hydrogen atoms can bond and form endless chains. The thousands of compounds that can form can be represented in different ways. Imagine the confusion that could be created if no rules existed for naming and representing all these compounds!



You will answer these questions:

1. What system is used to name organic compounds?
2. Why is it important to use rules?

You will practise these skills:

- applying rules in naming organic compounds
- communicating your ideas.

Think it through

1. Is it important to have and keep rules? Why or why not?
2. Do you think every law should be constitutional or be based on a certain model?
3. Share your ideas with the rest of the class.

GET THE FACTS

Rules for naming organic compounds

- In naming and organising organic compounds, we still follow the rules that scientists drew up a long time ago. Before we even look at the rules, you need to do the following:
  - Learn how to recognise a compound's functional group.
  - Learn the prefixes that are used to indicate the number of carbon atoms in a main or branched chain.

  The table on page 158 will help you to do this.
- The International Union of Pure and Applied Chemistry (IUPAC) has agreed on rules for naming compounds. This is called the IUPAC system of nomenclature. The reason for applying this system is to allow only one name for each compound and the drawing of only one structure from a name.
- In general, an IUPAC name will have three essential features:
  - a root or base indicating a major chain or ring of carbon atoms found in the molecular structure
  - a suffix or other element(s) designating functional groups that may be present in the compound
  - names of substituent groups, other than hydrogen, that complete the molecular structure.
- For this grade, we will concentrate on naming hydrocarbons.

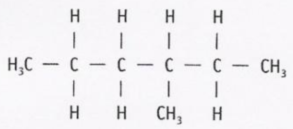
Hydrocarbons and their substituents

No. of carbon atoms	Alkane	Alkene	Alkyne	Substituents (Alkyl group)
1	Methane	Methene	Methyne	Methyl
2	Ethane	Ethene	Ethyne	Ethyl
3	Propane	Propene	Propyne	Propyl
4	Butane	Butene	Butyne	Butyl
5	Pentane	Pentene	Pentyne	Pentyl
6	Hexane	Hexene	Hexyne	Hexyl
7	Heptane	Heptene	Heptyne	Heptyl
8	Octane	Octene	Octyne	Octyl
9	Nonane	Nonene	Nonyne	Nonyl
10	Decane	Decene	Decyne	Decyl

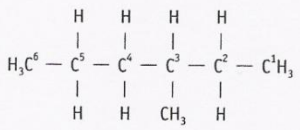
GET THE FACTS

IUPAC nomenclature

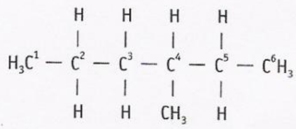
The system for naming hydrocarbons works as follows, using this example:



Example: The numbering on the left is correct.



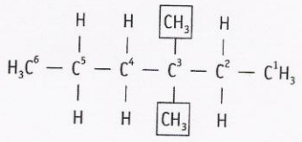
Carbon chain correctly numbered



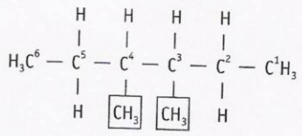
Incorrectly numbered

1. Identify the functional group of the compound, which determines the ending of the name.
   Example: All the carbon bonds are single, making the hydrocarbon an alkane. So its name will end in '-ane'.
2. Find the longest continuous carbon chain (straight or branched) and allocate its prefix according to the number of carbon atoms in the chain. If there is a double or a triple bond, this must be part of the longest chain.
   Example: There are six carbons in the chain, making the base name of the compound hexane.
3. Number the longest carbon chain. If there are only single bonds, start at the end nearest the first branched group so that the carbon atom that is bonded to the branched group receives the lowest possible number.
   If there are double or triple bonds, start numbering the carbon atoms so that these bonds receive the lowest possible numbers. Double or triple bonds take priority over branched groups in terms of lowest carbon number.
4. Name the branched group according to the number of carbon atoms it has, and give a number according to where it is located on the longest carbon chain.
   Example: The branched group is methyl and it is located at carbon 3 on the hexane chain. Therefore, the name of the compound is 3-methylhexane. (Note that the branch name and the base name are written as one word, and that a hyphen separates it and the number.)
5. If there is more than one branched group of the same kind, we use the Greek prefixes *di-*, *tri-*, *tetra-*, *penta-* and so on, to show the presence of two, three, four or five identical alkyl groups respectively.

For example:

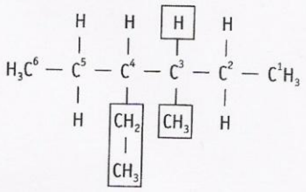


3,3-dimethylhexane

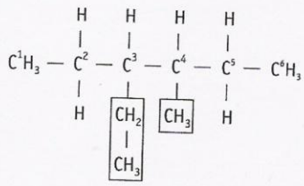


3,4-dimethylhexane

6. If multiple branched groups are not identical, write them in alphabetical order. Numbers and letters are separated by hyphens (-) and numbers by commas. For example:



4-ethyl-3-methylhexane

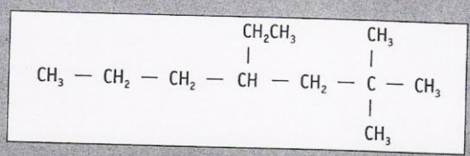


3-ethyl-4-methylhexane

Remember, the above rules will also apply in naming all other organic compounds. The difference, of course, will be the ending of the name, which will depend on the functional group.

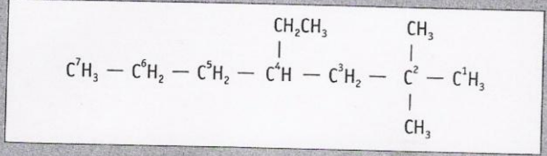
Worked example

Name the structure on the right according to the IUPAC system.



Answer

- The compound is an alkane, because it is a hydrocarbon with only single bonds.
- The ending of the name must be '-ane'.
- This chain is seven carbon atoms long, so it is a heptane.
- We have to number the chain from the right to the left, as follows, in order to reach the first branch with the lowest number.



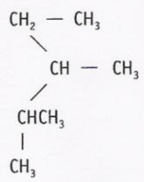
- At carbon 2, there are two methyl groups.
- At carbon 4, there is one ethyl group.
- Alphabetically, ethyl comes before methyl, so the name is:
  4-ethyl-2,2-dimethylheptane

PRACTISE IT NOW

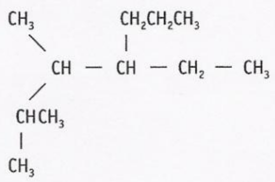
IUPAC names

1. Write the IUPAC names of compounds (a) to (c) below. In searching for the parental (longest) chain, be sure to look at the longest continuous chain of carbons, even if the chain twists and goes around the corner.
2. While doing this exercise, write notes highlighting the following:
   - challenges that you experienced while doing the exercise
   - what method you used to overcome those challenges.
3. Share your results with your group.
4. Has the way you feel about the need for rules changed at all? Why or why not?

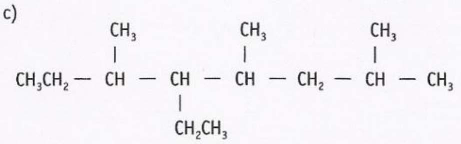
a)



b)



c)



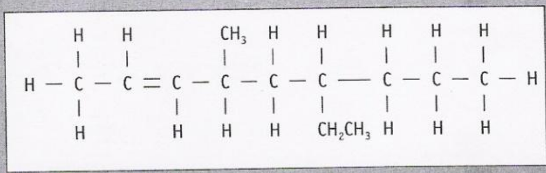
GET THE FACTS

IUPAC system and other substituents

- Other substituent groups, such as halogens, alcohols, carboxylic acids, and so on, are easily accommodated into the IUPAC system of nomenclature.
- If a substituent group is a **halogen**, it is treated the way an alkyl group would be. Note the prefixes used for halogens: fluoro- (F), chloro- (Cl), bromo- (Br) and iodo- (I). For example, $(CH_3)_2CHCH_2CH_2Br$ would be named 1-bromo-3-methylbutane.
  If the halogen is bonded to a simple alkyl group, an alternative 'alkyl halide' name may be used. For example, C_2H_5Cl may be named chloroethane or ethyl chloride.
- For **alcohols**, the ending of the base name is replaced with '-ol', for example ethanol or propanol. If there are two or more (-OH) groups, the ending will be '-diol', '-triol', and so on. For example: 1,2,3-propantriol.
- For **carboxylic acids**, the ending of the base name is replaced with '-oic acid'. The carbon atom in the functional group, from where we start numbering the carbon chain, is always given the number 1.
- **Esters** are named from the alcohol and carboxylic acid from which they are made. The name of an ester will end in '-ate'.

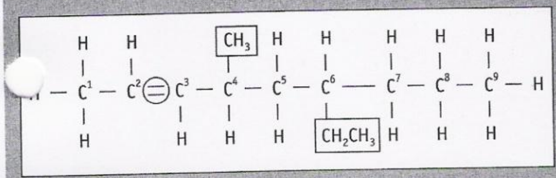
Worked example 1

Name the compound alongside according to the IUPAC system.



Answer

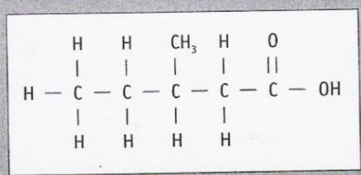
- The compound has a double bond and therefore is an alkene.
- The chain is nine atoms long when it includes the double bond, so it is a nonene.
- We number the chain from left to right so that the double bond is on the lowest-numbered carbon as possible.
- The double bond is carbon 2. So the name will end in '2-nonene'.



- At carbon 4, there is a methyl group. So '4-methyl' will appear in the name.
- At carbon 6, there is an ethyl group. So '6-ethyl' will appear in the name.
- Alphabetically, ethyl comes before methyl. So the name of the compound is: 6-ethyl-4-methyl-2-nonene

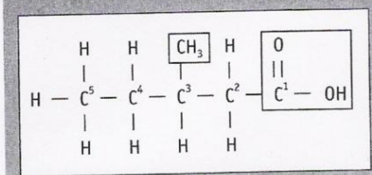
Worked example 2

Name the compound alongside according to the IUPAC system.



Answer

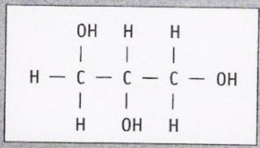
- The carboxyl functional group is clearly seen in the chain. So the name of the compound will end in '-oic acid'.
- There are five carbons in the chain. So the name will end in 'pentanoic acid'.
- We number the carbon chain from the carboxyl functional group. So, in this case, we number the five carbons from right to left.

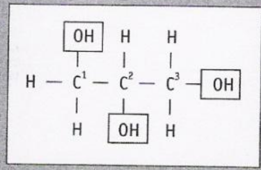


- At carbon 3, there is a methyl group.
- There are no other functional groups.
- The name of the compound is: 2-methylpentanoic acid

Worked example 3

Name the compound below left according to the IUPAC system.





Answer

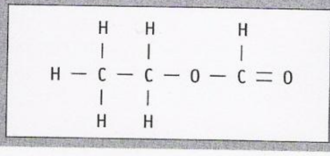
- The OH functional group is clearly seen in the chain, making it an alcohol. So the name of the compound will end in '-ol'.
- There are three OH groups in the compound. So the name will end in '-triol'.
- There are three carbons in the chain. So the name will end in 'propantriol'.
- We number the carbon chain from the OH functional group. In this case, each carbon in the chain has an OH functional group attached to it, so it does not really matter how we number the carbon chain.
- There is an OH group at carbon 1, carbon 2 and carbon 3. So the name of the compound is: 1,2,3-propantriol

Worked example 4

Draw the structural formula of ethyl methanoate.

Answer

- The compound is an ester, because its name ends in '-ate'.
- Esters are derived from an acid and an alcohol and are named accordingly. So the alcohol was ethanol (from the name 'ethyl') and the acid was methanoic acid (from the name 'methano-').
- The 'ethyl' part of the compound means that it contains a two-carbon chain.
- The 'methano' part of the compound means that the ester functional group is attached to a chain that has one carbon only.
- So this is the structure of the compound:

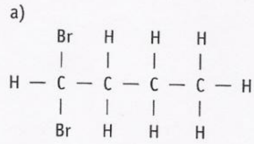


PRACTISE IT NOW

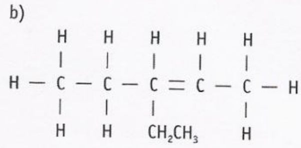
Naming more compounds

1. Give the IUPAC names of the compounds alongside.
2. Draw the structural formula for each of these compounds:
   a) propanoic acid
   b) octanol
   c) the ester that forms when propanoic acid reacts with butanol
   d) 4,5-dimethyl-2-heptyne.

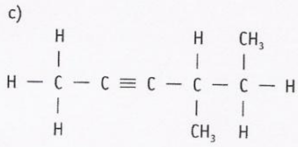
a)



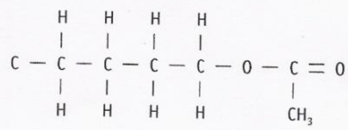
b)



c)



d)



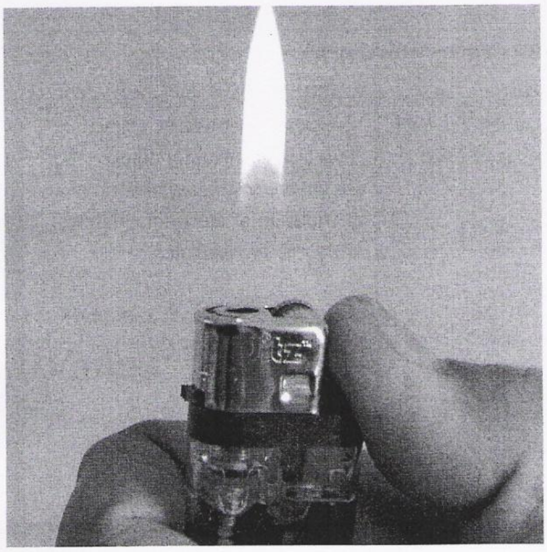
B

ORGANIC MOLECULES

4 Properties of organic molecules

Fuels

Liquefied alkanes provide a convenient fuel supply for portable appliances.



A cigarette lighter

You will answer these questions:

1. What properties do aliphatic compounds have?
2. How useful are organic compounds in our society?

You will practise these skills:

- applying knowledge
- comparing reactions and kind of products produced
- comparing properties of compounds and drawing conclusions.

Think it through

1. In pairs, discuss the statement about alkanes above and give two examples of other appliances that use fuel.
2. Which fuel is used in cigarette lighters?

GET THE FACTS

General properties

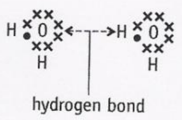
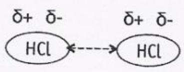
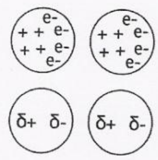
- Most organic substances are gases and liquids. The solid substances have very low melting and boiling points, due to the weak **intermolecular forces** existing in the molecules.
- Since organic molecules are non-polar in nature, they are either slightly soluble in water or completely insoluble. Remember, 'like dissolves like'. The hydrocarbons dissolve in non-polar solvents such as ether, benzene and carbon tetrachloride (tetrachloromethane).
- All organic compounds contain carbon. Therefore, when heated, most of them form carbon as one of the products.
- According to collision theory (see Module 5 Section A), the rate of a reaction depends on the number of collisions that occur. Since organic molecules are generally non-polar, few effective collisions occur, which result in reactions that are often very slow and that do not produce a large yield (product). The percentage yield of a reaction is of great importance, particularly if the reaction has application in industry.
- During the organic reaction a large number of by-products are often formed.
- Carbon has a unique feature of forming long chains, which result in the large number of organic compounds that exist compared to inorganic compounds.
- Most organic reactions are non-stoichiometric in nature. This means that the masses of reactants or products cannot be calculated from the equation.

Revision

Intermolecular forces

Intermolecular forces are forces between the molecules (particles) of a substance. These are relatively weak forces exerted in all directions, acting over short-range distances. They act only between the portions of different molecules that are in close contact, that is between the surfaces of molecules. This means that the larger the molecule (within a family), the larger the surface area, and hence the stronger the intermolecular forces.

Examples of intermolecular forces are Van der Waal forces (ion–dipole, dipole–dipole and London forces) and hydrogen bonds. Here is a summary of the electrostatic forces between centres of positive and negative charges on adjacent molecules:

Hydrogen bonds (directional)	Van der Waal forces (non-directional)	
	Dipole–dipole forces	London forces
An electrostatic attraction between a lone pair of electrons on an oxygen (nitrogen fluorine) atom covalently bonded to a hydrogen atom in a molecule and the hydrogen atom of an adjacent molecule. 	An electrostatic attraction between oppositely charged ends of polar molecules. 	Very weak electrostatic attraction, caused by momentary dipoles set up due to the asymmetric distribution of electrons in atoms or non-polar molecules. 

GET THE FACTS

Alkanes

- The carbon atoms in this group of compounds are bonded together only by single covalent bonds. Because of this, alkanes are not very reactive compared with other chemical species. For example, gasoline, which is a mixture of the alkanes octane and nonane, is explosive, but unlike many other chemicals can be stored and transported easily. It is only when it is ignited that it has enough energy to continue reacting.
- This property makes it difficult for alkanes to be converted into other types of organic molecules. (There are only a few ways to do this.)
- Alkanes are less dense than water, thus they float in water.
- Since alkanes have only carbon and hydrogen atoms, no polar bonds are present. Alkanes are non-polar. Therefore, alkanes are **immiscible** (unable to mix or dissolve) in water and other polar compounds, but freely miscible in other non-polar solvents such as ether, benzene or carbon tetrachloride (tetrachloromethane).
- Because alkanes contain only carbon and hydrogen, combustion produces compounds that contain only carbon, hydrogen and/or oxygen. Like other hydrocarbons, combustion under most circumstances produces mainly carbon dioxide and water.
- However, alkanes require more heat to combust and do not release as much heat as other classes of hydrocarbons when they combust. Therefore, combustion of alkanes produces higher concentrations of organic compounds containing oxygen, such as aldehydes and ketones, when combusting at the same temperature as other hydrocarbons.
- A table of the boiling and melting points of

some alkanes is shown below. Notice that the boiling points and the melting points of the alkanes increase as the molecular mass (size) increases. As the molecular mass of a molecule increases, so does its surface area, and so does the strength of the intermolecular forces. The stronger the forces between the molecules, the higher the temperature needed to break the bonds between them.

- Melting points and boiling points can serve as a measure of the attracting force between the molecules of the compound. The higher the melting point of a compound, the stronger the attracting forces between the molecules.
- For the bigger alkanes, the boiling point and melting point rises between 20 and 30 °C for each carbon that is added to the chain.

Name	Molecular structure	Melting point (°C)	Boiling point (°C)	Phase
Methane	CH_4	-182,5	-161,5	Gas
Ethane	C_2H_6	-183,3	-88,6	Gas
Propane	C_3H_8	-189,7	-42,1	Gas
Butane	C_4H_{10}	-138,4	-0,5	Gas
Pentane	C_5H_{12}	-129,7	36,1	Liquid
Hexane	C_6H_{14}	-95,3	68,7	Liquid

GET THE FACTS

Alkenes

- These unsaturated hydrocarbons are sometimes called olefins, which means 'oil-forming'.
- They are made by cracking an alkane. This entails heating a long-chain alkane in the presence of a catalyst so that it breaks into smaller molecules.
- The controlled cracking of ethane, for example, yields ethene, commonly called ethylene.

$$CH_3CH_3 \xrightarrow{\text{high temperatures}} CH_2 = CH_2 + H_2$$

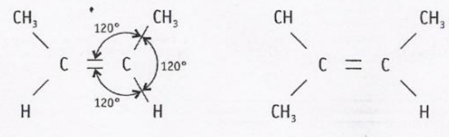
- In this process, two hydrogen atoms are eliminated and a double bond is formed. The double bond makes alkenes more reactive than alkanes.
- Alkenes, like alkanes, exhibit similar physical properties. They are non-polar and only slightly soluble in **polar solvents**, but soluble in non-polar solvents such as ether, benzene and carbon tetrachloride. Their densities increase as the molecular structure increase in size, but levels up at about 0,8, which is less than water's density. Therefore alkenes are also able to float in water.
- An alkene can also undergo a reaction in which it adds to itself to form a long chain of carbon atoms. This happens in the presence of a suitable catalyst.

monomer: $CH_2 = CH_2$

dimer (2 molecules): $CH_3CH_2CH = CH_2$

polymer (*n* molecules): $CH_3CH_2(CH_2CH_2)_nCH = CH_2$

- When a double bond forms between two carbon atoms, valence shell electron pair repulsion (VSEPR) theory predicts that the valence shell electrons that form the two single bonds and the double bond will be spread as far apart as possible. This implies that the bonds will be in the same plane and at an angle of 120° to each other around each of the central carbon atoms. No rotation can take place about the double bond. This leads to the formation of **geometric isomers**, which are molecules with the same molecular formula and same structural formulae but which differ in spatial orientation.
- For example, *trans*-2-butene and *cis*-2-butene are geometric isomers of each other. They not only have the same molecular formula, C_4H_8, but also the same skeletons and the same organisation of atoms and bonds: $CH_3CH{=}CHCH_3$. They differ in the directions taken by two CH_3 groups attached at the double bond.



Trans-2-butene, BP 3,72 °C and *cis*-2-butene, BP 0,88 °C

- As with alkanes, the melting and boiling points of alkenes increase as the molecular size increases.

Name	Molecular structure	Melting point (°C)	Boiling point (°C)	Phase
Ethene	C_2H_4	-169	-104	Gas
Propene	C_3H_6	-185	-47	Gas
Butene	C_4H_8	-185	-6	Gas
Pentene	C_5H_{10}	-138	30	Liquid
Hexene	C_6H_{12}	-140	63	Liquid

GET THE FACTS

Alkynes

- The alkynes contain a triple bond, which makes them highly reactive compared to the alkanes.
- Alkynes, like alkanes and alkenes, exhibit similar physical properties – an increase in boiling and melting points as molecular size increases, densities lower than that of water, and being soluble in non-polar solvents.
- The table alongside shows some of these properties.

Name	Molecular structure	Melting point (°C)	Boiling point (°C)	Phase
Ethyne	C_2H_2	-82	-75	Gas
Propyne	C_3H_4	-101,5	-23	Gas
Butyne	C_4H_6	-122	9	Gas
Pentyne	C_5H_8	-98	40	Liquid
Hexyne	C_6H_{10}	-124	72	Liquid

PRACTISE IT NOW

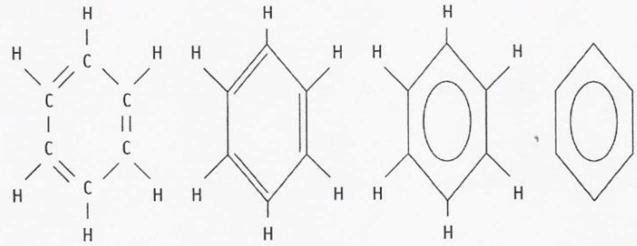
Understanding alkanes, alkenes and alkynes

1. Differentiate between alkanes, alkenes and alkynes. Use suitable examples.
2. Explain the meaning of each of the following terms, and give examples:
   a) straight chain
   b) branched chain
   c) functional group
   d) polymerisation
   e) isomer.
3. How would you distinguish between an ethane and an ethene molecule?
4. Explain why melting points and boiling points of hydrocarbons increase with the increase of their molecular sizes within the family.
5. Name three properties that alkanes, alkenes and alkynes have in common.

GET THE FACTS

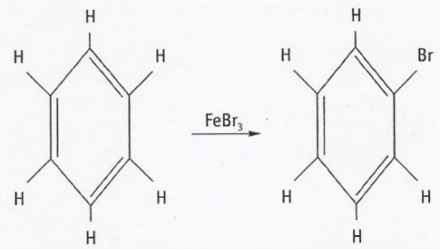
Aromatic hydrocarbons

- The word 'aroma' refers to the characteristic smell of this group of compounds.
- This group consists of unsaturated benzene ring structures. A benzene ring has six carbons with alternating double and single carbon–carbon bonds. A benzene ring can be represented in the ways shown alongside.



Four representations of benzene

- The aromatic compounds are very stable and their molecules are carcinogenic (causing cancer).
- One would expect aromatic compounds to react like alkenes, and break their double bonds during reactions. However, the theory suggests that each carbon–carbon bond in benzene is alike, and each bond is only a partial double bond.
- Benzene most commonly undergoes reactions in which a hydrogen atom is substituted by another atom group.



Bromine replaces a hydrogen atom in this reaction of benzene.

Science in our world

'Leaded' or 'unleaded' petrol

Petrol consists of a mixture of the alkanes between pentane (5-carbon chain) and decane (10-carbon chain). These liquids are activated (under certain conditions) into gaseous form since the combustion reactions of alkanes occur in gaseous form. The article on page 168 tells us about the effect on our environment of an additive in petrol.

New toxic additive in petrol

Previously, lead was added to petrol to prevent the type of engine combustion known as 'knocking', which damages the engine of a vehicle. But numerous international studies have found that leaded petrol has contributed to high levels of lead in the environment, which is particularly harmful to young children. It can interfere with the development of the brain and other organs.

In 2005, the South African government set the date of 1 January 2006 as the deadline by which leaded petrol in South Africa would be phased out completely. This meant that petrol would no longer contain lead – it would be unleaded. The advantage would be reducing the release of harmful substances into the environment.

Most cars manufactured after 1996 are able to use unleaded petrol, but cars older than these can't run on unleaded petrol. In order to solve this problem, another metal that performs the same function as lead did in petrol is added to unleaded petrol. The problem is that this metal, a form of manganese, could be as damaging to people and the environment as lead. Manganese is toxic in high doses, so the health risk that this manganese additive poses is a huge concern.

Environmentalists and health experts say that other better options are available, as they exist in other countries. Such fuels do not contain any heavy metals, and therefore reduce harmful emissions. However, the petrochemical industry says that it is too expensive to implement those processes here.

Questions

Answer these questions using the article above and by doing any other necessary research.

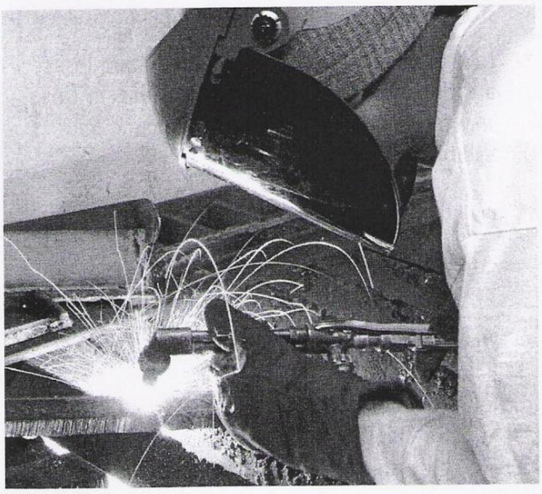
1. From what date did South Africa decide to stop using leaded petrol?
2. a) Why is tetraethyl lead (IV), $Pb(CH_3CH_2)_4$, added to petrol?
   b) Why have many countries legislated to reduce or suspend this practice?
3. Unleaded petrol has been introduced in South Africa, replacing leaded petrol. What benefits does it have in order for it to be regarded as the better fuel?
4. With which metal has lead been replaced?
5. The replacement of lead with other metals is still a controversial issue.
   a) Why is this issue controversial?
   b) Do you think South Africa has made the best choice in introducing unleaded petrol? Explain your answer.
6. All petrol is damaging to human health and the environment, even petrol with no toxic heavy metals.
   a) Do you agree or disagree with the above statement? Explain your answer.
   b) What other engine emissions have an impact on human health and the environment?
   c) What best transport mode can you suggest for South Africa? Give the advantages and disadvantages. You can refer to other countries.

5 Reactions of hydrocarbons

Addition, elimination and substitution reactions

While pure hydrocarbons undergo certain classes of reactions, hydrocarbon derivatives undergo many more reactions, which are determined by their functional groups. The basic organic chemistry reaction types are addition reactions, elimination reactions, substitution reactions, rearrangement reactions and organic redox reactions (combustion).

The simplest alkyne, ethyne, is used to form plastics and other chemical compounds. Ethyne is also commonly called acetylene, which can produce a very hot flame when it burns with oxygen.



An oxyethyne torch being used to cut through metal

You will answer these questions:

1. Which types of reactions do hydrocarbons undergo?
2. What determines the type of reaction?
3. Which organic compounds are highly reactive?

You will practise these skills:

- identifying types of reactions and reaction sites
- comparing the reactivity of organic compounds.

Think it through

In the Grade 11 course, you have seen that the hexane (an alkane) did not readily react with bromine, but hexene reacted readily and the colour changed rapidly.

1. Write the reaction of cyclohexane with bromine.
2. Write the reaction of cyclohexene with bromine.

GET THE FACTS

Reactions of alkanes

- Each carbon atom in an alkane is linked to four hydrogen atoms. This makes the carbon atom completely full, and hence it is called saturated.
- Owing to this saturated nature of the bonds, this homologous series of compounds is unreactive compared to other substances.
- Alkanes undergo combustion and halogenation or **substitution reactions** and, under extreme conditions, they **isomerise** – they break down partially and then recombine into different hydrocarbon isomers.

Oxidation reactions

- Alkanes readily combine with oxygen in a process called combustion. (Most of the energy used by humans is produced in this process.)
- Alkanes react with oxygen in the air, forming carbon dioxide and water, and in the process energy is released. These type of reactions, where heat is given off, are called **exothermic reactions.**
- Here are some examples:
  Methane burns with a blue flame:
  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + energy

  Propane and butane are used in laboratories, and react as follows:
  $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ + energy
  $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ + energy

  Hexane, a liquid alkane and one of the forms of petrol, reacts with oxygen as follows:
  $2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$ + energy

Elimination reactions

- Saturated compounds can produce unsaturated compounds through **elimination reactions.**
- For example, the controlled cracking of ethane gives ethene (or ethylene), one of the most important raw materials in the organic chemistry industry:

  $$CH_3CH_3 \xrightarrow{\text{high temperature}} CH_2 = CH_2 + H_2$$

  In the above reaction, a hydrogen molecule is produced. The hydrogens have been eliminated from the ethane molecule.
- In dehydration reactions of alcohols, a water molecule is eliminated in the presence of a suitable catalyst, leaving behind a carbon–carbon double bond:

  $$CH_3CH_2OH \xrightarrow[\text{heat}]{\text{acid catalyst}} CH_2 = CH_2 + H_2O$$

- In the following reaction, a **haloalkane** loses a hydrogen atom and a chlorine atom, in this way forming an unsaturated compound and hydrochloric acid:

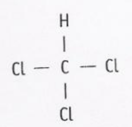
  $$CH_2Cl\text{–}CH_2Cl \rightarrow CH_2 = CH_2 + HCl$$

Substitution reactions

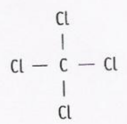
- In substitution reactions, a hydrogen atom is replaced by a halogen atom (fluorine, chlorine, bromine or iodine) or nitrogen–oxygen group. In this way, a new family of compounds, called haloalkanes or alkyl-halides, are formed.
- In order for this type of reaction to take place, energy in the form of heat or sunlight is necessary. The reaction of methane with chlorine to form chloromethane can be represented by the following equation:

  $$CH_4 + Cl_2 \xrightarrow{\Delta \text{ or } hf} CH_3Cl$$

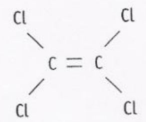
  (hf represents light energy, and Δ heat energy)
- When more than one hydrogen is replaced by a halogen (chlorine in the previous example), the following compounds are formed:
  - two chlorines – dichloromethane, CH_2Cl_2
  - three chlorines – trichloromethane (or chloroform), $CHCl_3$
  - four chlorines – tetrachloromethane (carbon tetrachloride), CCl_4.
- Haloalkanes are important solvents and reactants in a laboratory. Some of the important haloalkanes are shown on the next page.
- Chloroform has been replaced by halothane as an anaesthetic and carbon tetrachloride replaced by tetrachloroethene as a dry-cleaning agent. These haloalkanes were replaced because it was discovered that they are toxic and cause liver cancer.



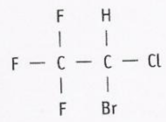
trichloromethane
(chloroform)



tetrachloromethane
(carbon tetrachloride)



tetrachloroethene



halothane

- The following two saturated molecules can also be interconverted by substitution:
  $CH_3CH_3CH_3OH + HBr \rightarrow CH_3CH_3CH_3Br + H_2O$ (1)
  $CH_3CH_3CH_3Br + KOH \rightarrow CH_3CH_3CH_3OH + KBr$ (2)

In reaction 1, the halogen substituted the alcohol group. In reaction 2, the alcohol group substituted the halogen.

GET THE FACTS

Addition reactions of alkenes

- Unsaturated compounds can undergo **addition reactions** to form saturated compounds.
- In an addition reaction, atoms of reactant becomes separately attached to the carbons at the ends of the double bond. Ethene, for example, readily reacts with hydrogen chloride and with bromine as follows:
  $CH_2{=}CH_2 + H{-}Cl\ (g) \rightarrow Cl{-}CH_2{-}CH_3$
  $CH_2{=}CH_2 + Br_2 \rightarrow Br{-}CH_2{-}CH_2{-}Br$
- **Hydrogenation** (addition of hydrogen) is another example of an addition reaction:
  $$\underset{\text{ethene}}{CH_2{=}CH_2} + H_2\ (aq) \xrightarrow[\text{catalyst}]{Pt} \underset{\text{ethane}}{CH_3{-}CH_3}$$
- Vegetable oils containing double bonds (unsaturated fat) are hardened through hydrogenation. In this process, the oil is made more saturated.

Addition polymerisation

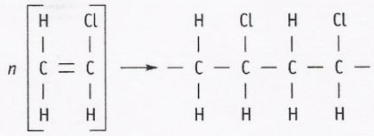
- The petrochemical industry produces the gases ethene (ethylene) and propene (propylene) in vast amounts.
- They are turned into hundreds of other chemicals and, in particular, into polyethene through the process of **polymerisation**. This is when the compound is able to add to itself (self-addition) when in the presence of a suitable catalyst, and form what is called a **polymer**.
- For example, polypropene is formed through the process of addition polymerisation, where propene molecules join up and form a long chain of repeating units, as shown below.
- Polyethene is formed in a similar way from ethene units. It is the plastic most encountered in daily life.

$$\text{etc.}{-}CH_2CH(CH_3){-}CH_2CH(CH_3){-}CH_2CH(CH_3){-}CH_2CH(CH_3){-}CH_2CH(CH_3){-}\text{etc.}$$

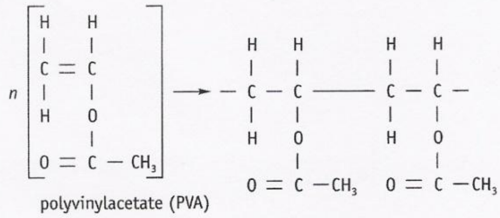
Polypropene consists of a long chain of repeating units.

- Here are the structures of more polymers that we commonly encounter:

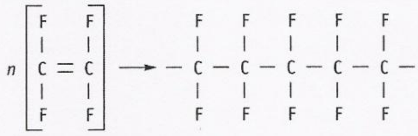
PVC, PVA, Teflon structures



polyvinyl chloride (PVC)



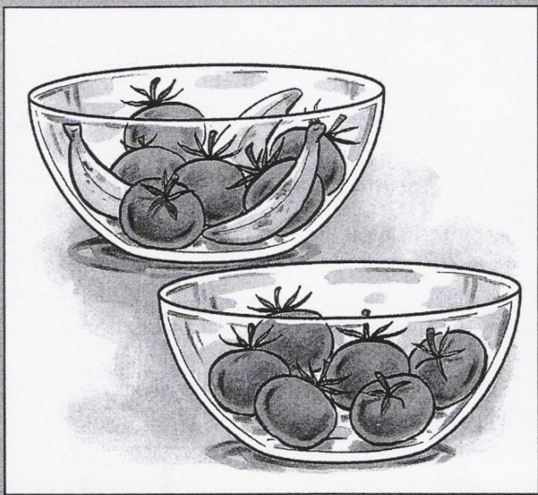
polyvinylacetate (PVA)



Teflon

Science in our world

Ethene



While ethene is used as a raw material for many chemical processes, it also plays a key role in nature. In the 1930s, biochemists realised that ethene was produced during many stages in a plant's life cycle – germination, growth, blooming, fruit ripening, ageing, leaf loss – and in response to damages caused by extreme temperature and drought.

The concentration of ethene in plants is normally low, but can reach as much as 2 000 ppm (0,2%) in ripe fruit. Plants make their ethene from methionine (amino acid).

Questions

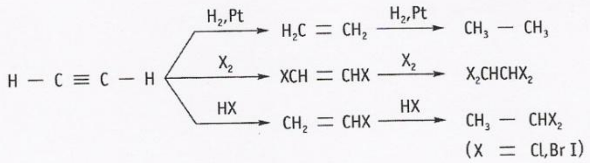
Do any research neccessary to answer these questions:

1. How can the industrial companies copy nature and make use of ethene to their advantage?
2. If we stop drawing from the world's fossil reserves, could all the polyethene we need be produced from renewable resources?
3. Try this in your class:
   a) Buy some unripe tomatoes.
   b) Put some of the tomatoes in a dish with ripe bananas, and put the others in a dish with no bananas.
   c) Observe the time it takes for the two groups of tomatoes to ripen. What do you notice?
   d) What caused the tomatoes to ripen?
   e) Compare the scientific explanation to any other explanation you may have heard of.

GET THE FACTS

Reactions of alkynes

- Ethyne (acetylene) can be prepared by adding water to calcium carbide:
  $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$
- Ethyne is used, together with oxygen, in an oxyethyne torch, which is used to cut metals at a very high temperature. The following equation represents this oxidation reaction:
  $2C_2H_2 + 5O_2 \rightarrow 4CO_2 + H_2O$
  (ΔH = -1 310 kJ·mol^{-1} ethyne)
- Addition reactions of alkynes are similar to those of alkenes. In the presence of catalysts, the alkyne undergoes a large range of addition reactions, which can produce saturated hydrocarbons. Below is the summary of reactions:



PRACTISE IT NOW

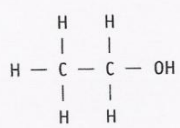
Understanding aliphatic reactions

1. Why do alkanes undergo mainly substitution reactions, while alkenes are characterised by addition reactions?
2. Write the structures of the products that form when 2-butene reacts with each of the following substances by an addition reaction. (Assume that the required catalyst or other conditions are provided.)
   a) H_2 b) Cl_2
   c) Br_2 d) HCl (g)
   e) HBr (g) f) H_2O (in acid)
3. What is the main use of each of the following?
   a) alkane
   b) ethane
   c) ethyne

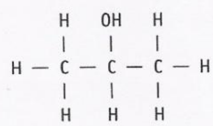
GET THE FACTS

Hydrocarbon derivatives: alcohols

- Alcohols contain the hydroxyl group, –OH, substituted for hydrogen. The suffix '-ol' is used and the general formula is R–OH, where R stands for an alkyl group. Hydrogen bonding in the –OH group causes alcohols to have a high boiling point and makes them polar and cause the hydrogen bonds to form between –OH groups with adjacent alcohol groups.
- Since an alcohol molecule also contains a non-polar hydrocarbon molecule section, alcohols are fairly good solvents for both polar and non-polar solutes.



ethanol
(ethylalcohol)



2–propanol

Methanol

- Methanol (CH_3OH), is the simplest member of the alcohol family. Methanol used to be produced by the dry distillation of wood, but today it is prepared on a large scale in industries by the catalytic hydrogenation of carbon monoxide:

$$CO + 2H_2 \xrightarrow{\text{catalyst}} CH_3OH$$

- It is a very poisonous liquid and it is mainly used as a solvent (for gums and varnishes) and in the preparation of methanal (formaldehyde).

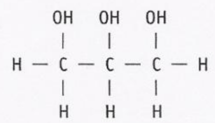
Ethanol

- Ethanol (CH_3CH_2OH) can be oxidised into ethanoic acid (sour wine). This reaction can be done in a laboratory using a strong oxidising agent such as $KMnO_4$ or $K_2Cr_2O_7$.
- For example, ethanol is oxidised to ethanal (acetaldehyde) by $K_2Cr_2O_7$ in acid medium, according to the following equation:
$3CH_3CH_2OH + 8H^+ + Cr_2O_7^{2-} \rightarrow 3CH_3CHO + 2Cr_3^+ + 7H_2O$
- Ethanol is present in alcoholic drinks and is prepared by the fermentation of solutions containing starch or sugar in the presence of certain enzymes. The final result is as follows:
$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + H_2O$
- Once the concentration of alcohol in the solution exceeds about 15%, the yeast cells become poisoned and die so that fermentation ceases.
- The concentration of the alcohol solution above this level is accomplished by fractional distillation.
- Ethanol plays an important role as a solvent used in the production of paints, plastics, medicines and many organic compounds.

Examples of alcohols

Glycerol

- Gycerol is commonly called glycerine. It can also be named 1,2,3-propantriol. (Look at its structure to see why this is so.)



1,2,3-propantriol or glycerine

- It is used as a lubricant and as a moistening agent for food, tobacco, soaps and cosmetics.
- Glycerol has a high **viscosity** (resistance to flow) and boiling point (290 °C) because of the high degree of hydrogen bonding within the liquid.

INVESTIGATE IT NOW

Oxidising ethanol

You will need:
- 2 cm^3 of ethanol
- 4 cm^3 (3 $mol \cdot dm^{-3}$) of diluted sulphuric acid (a dilution is approximately 1:4)
- 1% solution of $K_2Cr_2O_7$ or $KMnO_4$
- a 10 ml measuring cylinder
- a medicine dropper
- a spirit lamp
- a test tube
- a test tube holder.

1. Pour 2 cm^3 of ethanol in a test tube.
2. Add 4 cm^3 of diluted sulphuric acid (3 $mol \cdot dm^{-3}$).
3. Gently heat the contents of the test tube.
4. Record your observations.
5. Explain the colour change in this reaction.
6. a) Carefully smell the contents of the test tube.
   b) What can you tell from the smell?
7. Write a balanced equation for the reaction.

GET THE FACTS

Oxidation of ethanol

- For the previous investigation, the colour change would be as shown in this table, depending on which solution you used.
- The product in the reaction between an oxidising agent and an alcohol is an organic acid.
- The smell of vinegar indicates the acid called ethanoic acid (acetic acid).

Solution	Colour before the reaction	Colour during and after the reaction
$K_2Cr_2O_7$	Orange ($Cr_2O_7^{2-}$ ion)	Green (reduced to Cr^{3+} ion)
$KMnO_4$	Purple (MnO_4^- ion)	Colourless (Mn^{2+} ion)

GET THE FACTS

Elimination reactions of alcohols

- The dehydration of alcohol is another kind of organic reaction, in which water molecules are eliminated from the alcohol molecule.
- In the presence of a strong acid, such as concentrated sulphuric acid, an alcohol molecule undergoes the loss of a water molecule, leaving behind a carbon–carbon double bond.

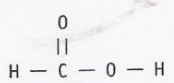
$$\underset{\text{ethanol}}{CH_3CH_2OH} \xrightarrow[\text{heat}]{\text{acid catalyst}} \underset{\text{ethene}}{CH_2{=}CH_2} + H_2O$$

$$\underset{\text{1-propanol}}{CH_3CH_2CH_2OH} \xrightarrow[\text{heat}]{\text{acid catalyst}} \underset{\text{propene}}{CH_3CH{=}CH_2} + H_2O$$

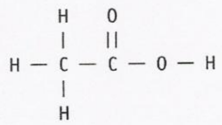
GET THE FACTS

Carboxylic acids

- The carboxylic acids contain a COOH group, also called the carboxyl group.



methanoic acid



ethanoic acid

- They are called weak acids, and occur freely in nature together with their derivatives.
- The dissociation of these acids in water takes place to a small extent. Therefore, carboxylic acids ionise only partially in water. The equilibrium in this reaction lies far to the left:

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

- As the length of the chain increases, organic acids become less soluble in water and more soluble in non-polar solvents.

Preparation of carboxylic acids

- Methanoic acid is commercially prepared by the oxidation of methanol as follows:

$$5CH_3OH + MnO_4^- + 12H^+ \rightarrow 5HCOOH + 4Mn^{2+} + 11H_2O$$

- The oxidation of ethanal to produce ethanoic acid is the most important industrial method. It is prepared by reacting ethanal (CH_3CHO) with oxygen in the presence of a catalyst, usually $(CH_3COO)_2Co^-$, cobalt(II) acetate:

$$2CH_3CHO + O_2 \xrightarrow{\text{catalyst}} 2CH_3COOH$$

- The other possible method is to allow methanol to combine with carbon monoxide under pressure and use $Co_2(CO)_8$ as the catalyst:

$$CH_3HO + CO \xrightarrow{\text{catalyst}} CH_3COOH$$

- Ethanoic acid is a constituent of vinegar and is used in the production of artificial fibres.

INVESTIGATE IT NOW

Reactions with carboxylic acids

Investigate whether carboxylic acids display the characteristic properties of inorganic acids.

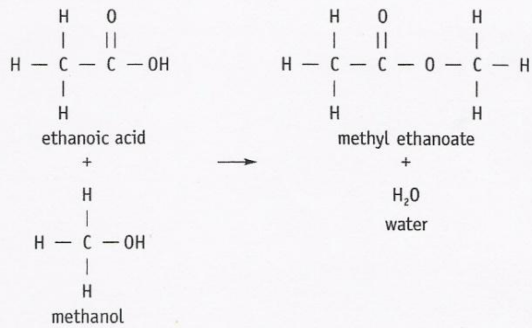
1. Design and conduct simple experiments to see whether methanoic and ethanoic acids:
   a) react with magnesium to form hydrogen
   b) are neutralised by sodium hydroxide
   c) react with sodium carbonate to produce carbon dioxide.
2. Record your findings and present them in class.

GET THE FACTS

Esters

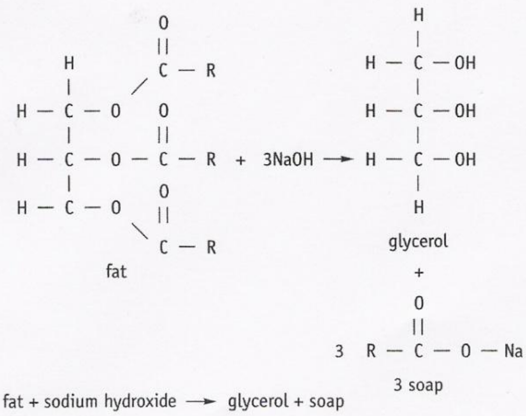
- Esters are the product of a reaction between an alcohol and a carboxylic acid. The reaction is usually accelerated by using sulphuric acid as a catalyst. (See the reaction alongside.)
- Esters have a pleasant smell. They are normally used as synthetic scents, and are used in foodstuffs.

ethanoic acid + methanol → methyl ethanoate + H_2O

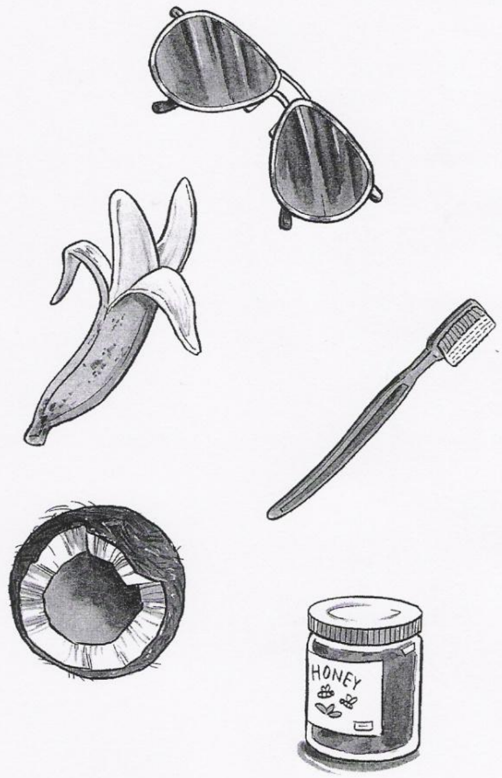


Some important esters

- Animal and vegetable fats are esters made of long-chain organic acids (fatty acids).
- Reacting a fat with NaOH splits the fat into glycerol and a sodium salt. This sodium salt is soap. (See the reaction below.)
- Soaps form 'scum' in hard water. 'Scum' is a precipitate of Ca^{2+} and Mg^{2+} of soap.
- Detergents contain polyphosphorus ions, which tie up the Ca^{2+} and Mg^{2+} ions so that the detergent can do its work.



fat + sodium hydroxide → glycerol + soap



Esters occur naturally and in manufactured products.

PRACTISE IT NOW

Understanding aliphatic compounds

1. For compounds (a) to (d) below:
   - write the structural formula
   - identify the group of compounds to which it belongs
   - name the compound.

   a) CH_3Br
   b) $CH_2OHCH_2CH_3$
   c) CH_3COOH
   d) CH_3COOCH_3
2. Why are the boiling points of alcohols relatively high?
3. Explain why the properties of haloalkanes are different from those of the inorganic halides.
4. Consider a soap, sodium stearate ($C_{17}H_{35}COONa$). Explain the action of soap, using sodium stearate to illustrate the process.

Review it now

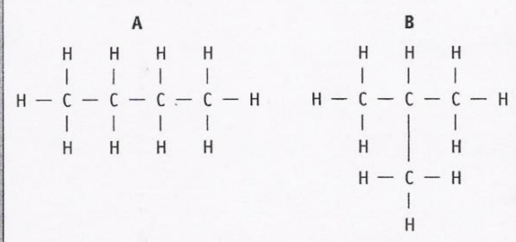
Make sure you know the meaning of each of these terms. You will find them in the glossary at the back of the book:

addition reaction
alcohols
alkane
alkene
alkyl group
alkyne
branched chain
carboxylic acids
condensed structural formula
elimination reaction
ester
exothermic reaction
functional group
geometric isomer
haloalkanes
halogen
homologous series
hydrocarbons
hydrogenation
immiscible
intermolecular forces
isomerise
molecular formula
organic chemistry
polar solvents
polymer
polymerisation
saturated compounds
straight chain
structural formula
structural isomer
substitution reactions
unsaturated compounds
viscosity

1. Which of the following compounds are inorganic?
   a) CH_3OH
   b) CO
   c) CCl_4
   d) $NaHCO_3$
   e) K_2CO_3
2. In general, there are many organic compounds. Explain why this is so.
3. The hydrocarbons consist of alkanes, alkenes and alkynes.
   a) Give the general formula of each of the three types of hydrocarbons mentioned.
   b) The alkane pentane (C_5H_{12}) is flammable in oxygen. Write a balanced equation for the reaction that takes place.
4. Explain the meaning of the following terms:
   a) straight chain
   b) branched chain
   c) functional group
   d) polymerisation
   e) trimer.
5. Which of the following structures is possible, given the numbers of bonds that various atoms can form? Explain your choice.
   a) $CH_2CH_2CH_3$
   b) $CH_3{=}CHCH_2CH_3$
   c) $CH_3CH{=}CH_2CH_2CH_3$
6. Give the property that enables us to distinguish between each pair of compounds:
   a) C_2H_2 and CH_4
   b) C_2H_5OH and CH_3COOH

c) CH_3OH and H_2O
d) C_2H_2 and O_2

7. Bromine reacts with hydrocarbons in the presence of a suitable catalyst. Using structural formulae, write an equation for the reaction that occurs.
8. Write down the full and condensed structural formulae for:
   a) 2,4-dimethyl-2-hexene
   b) 3-ethylpentanoic acid.
9. Answer the following questions about this compound: $H_2C{=}CH_2$.
   a) Name the homologous series to which the compound belongs.
   b) Give the general formula for the compound.
   c) Is the compound saturated or unsaturated? Explain.
   d) If you react this compound with water, what will be the product?
   e) Name the type of reaction described in (d).
   f) Is the product in (d) saturated or unsaturated? Explain.
10. Write a balanced equation for the oxidation of propane.
11. a) Name the two organic compounds which, when reacted with each other, will produce the ester ethyl propanoate.
    b) Write the equation for this reaction.
12. a) There are two main reasons why soap cleans dirt. State these reasons and explain your answer.
    b) Explain why soaps form 'scum' in hard water.
13. Using the IUPAC system, name this compound: $CH_3{-}CH{=}CHCH_3$
14. Explain why the boiling point of methane (-161,5 °C) is lower than that of propane (-42 °C).
15. Consider the following compounds and answer the questions below:



    a) Why are these two molecules regarded as isomers?
    b) Name compound B according to the IUPAC system.
16. Supply the formula of the carboxylic acid and the alcohol that should be used in the preparation of this ester: $CH_3COOCH_2CH_2CH_3$
17. Describe the difference between a substitution reaction and an addition reaction, using appropriate examples.