VERSION 1 CAPS

GRADE 12
PHYSICAL SCIENCES

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EVERYTHING SCIENCE BY

SIYAVULA

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basic education

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MMI HOLDINGS

4.1 What are organic molecules? ESCK3

Organic chemistry is the branch of chemistry that deals with **organic molecules**. An organic molecule is one which contains **carbon**, although not all compounds that contain carbon are organic molecules. Noticeable exceptions are carbon monoxide (CO), carbon dioxide (CO_2), carbonates (e.g. calcium carbonate), carbides (e.g. calcium carbide) and cyanides (e.g. sodium cyanide). Pure carbon compounds such as diamond and graphite are also **not** organic compounds. Organic molecules can range in size from simple molecules to complex structures containing thousands of atoms!

Although carbon is present in all organic compounds, other elements such as hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and phosphorus (P) are also common in these molecules.

DEFINITION: *Organic molecule*

An organic molecule is a molecule that contains carbon atoms (generally bonded to other carbon atoms as well as hydrogen atoms).

Organic compounds are very important in daily life and they range from simple to extremely complex (Figure 4.1).

Organic molecules make up a big part of our own bodies, they are in the food we eat and in the clothes we wear. Organic compounds are also used to make products such as medicines, plastics, washing powders, dyes, along with a long list of other items. There are millions organic compounds found in nature, as well as millions of synthetic (man-made) organic compounds.

Figure 4.1: A simple organic molecule, propane, can be used in a gas lamp (left). The complex organic molecule DNA carries the genetic code of a person and can be used to identify them.

4.2 Organic molecular structures ESCK4

Special properties of carbon ESCK5

Carbon has a number of unique properties which influence how it behaves and how it bonds with other atoms:

- Carbon (Figure 4.2) has *four valence electrons* which means that each carbon atom can form a maximum of four bonds with other atoms. Because of the number of bonds that carbon can form with other atoms, organic compounds can be very complex.
  - Carbon can form bonds with other carbon atoms to form single, double or triple covalent bonds.
  - Carbon can also form bonds with other atoms like hydrogen, oxygen, nitrogen and the halogens.
  - Carbon can bond to form straight chain, branched, and cyclic molecules.

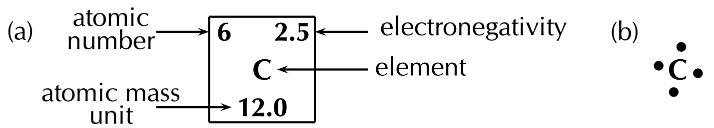


Figure 4.2: Carbon **(a)** as seen on the periodic table and **(b)** a Lewis dot representation.

TIP
Do not confuse organic compounds with *naturally produced* food. Organic compounds are often produced in a laboratory.

- Because of this, long *chain structures* can form. This is known as **catenation** - the bonding of atoms of the same element into longer chains. These chains can either be *unbranched* (Figure 4.3) or *branched* (have a branched group, Figure 4.4) and can contain single carbon-carbon bonds only, or double and triple carbon-carbon bonds as well.

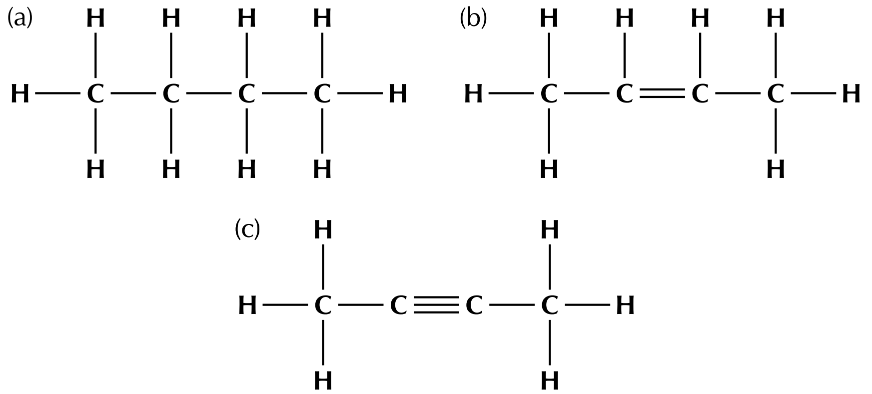


Figure 4.3: Unbranched carbon chains with **(a)** single carbon-carbon bonds, **(b)** single and double carbon-carbon bonds and **(c)** single and triple carbon-carbon bonds.

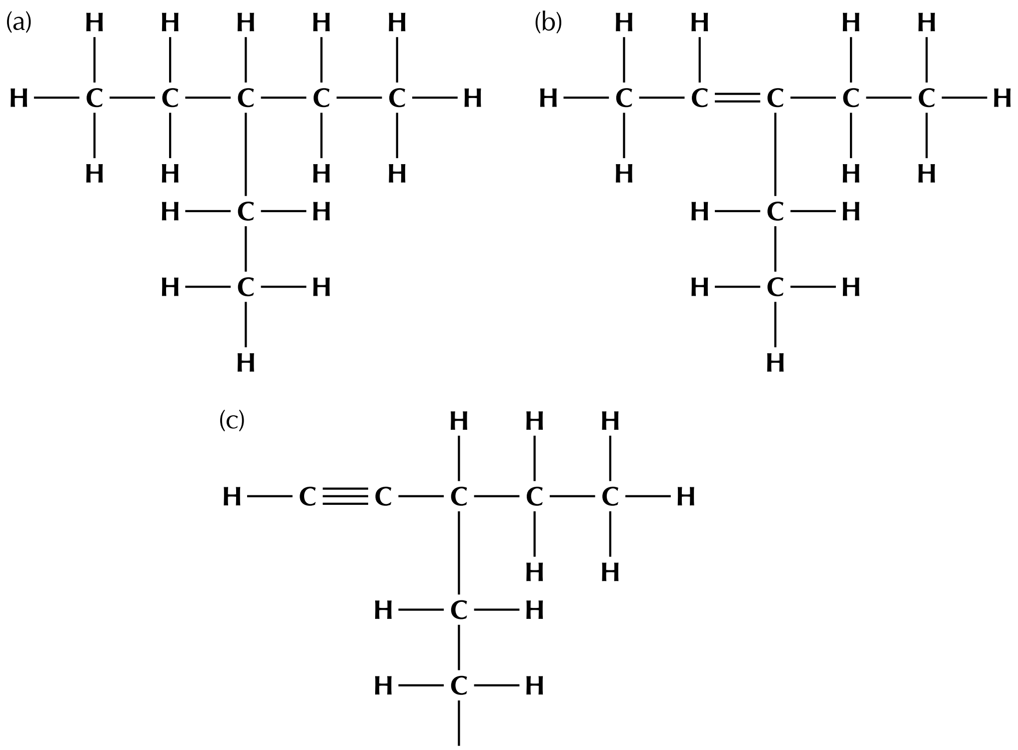


Figure 4.4: Branched carbon chains with **(a)** single carbon-carbon bonds, **(b)** single and double carbon-carbon bonds and **(c)** single and triple carbon-carbon bonds.

- Because of its position on the periodic table, most of the bonds that carbon forms with other atoms are *covalent*. Think for example of a C – C bond. The difference in electronegativity between the two atoms is zero, so this is a pure covalent bond. In the case of a C – H bond, the difference in electronegativity between carbon (2,5) and hydrogen (2,2) is so small that C – H bonds are almost purely covalent. The result of this is that most organic compounds are non-polar. This affects some of the properties of organic compounds.

Sources of carbon

The main source of the carbon in organic compounds is **carbon dioxide** in the atmosphere. Plants use sunlight to convert carbon dioxide and water (inorganic compounds) into sugar (an organic compound) through the process of **photosynthesis**.

$6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

Plants are therefore able to make their own organic compounds through photosynthesis, while animals feed on plants or plant products in order to gain the organic compounds that they need to survive.

Other important sources of carbon are **fossil fuels** such as coal, petroleum and natural gas. This is because fossil fuels are themselves formed from the decaying remains of dead organisms (refer to Grade 11 for more information on fossil fuels).

Representing organic molecules ESCK6

There are a number of ways to represent organic compounds. It is useful to know all of these so that you can recognise a molecule regardless of how it is shown. There are four main ways of representing a compound in two dimensions (on your page). We will use the examples of two molecules called 2-methylpropane and butane to help explain the difference between each.

- **Structural formula**
  The structural formula of an organic compound shows every bond between every atom in the molecule. Each bond is represented by a line. The structural formulae of 2-methylpropane and butane are shown in Figure 4.5.

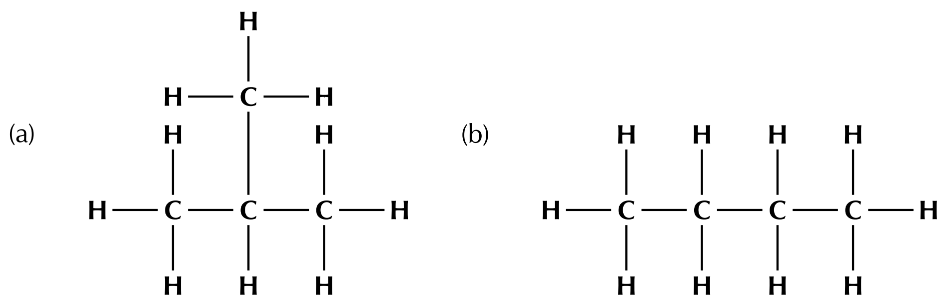


Figure 4.5: The structural formula of **(a)** 2-methylpropane and **(b)** butane.

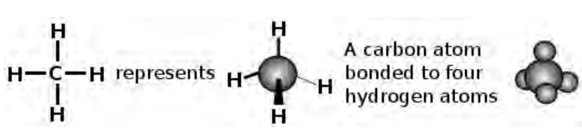


Figure 4.6: Different ways of representing a carbon atom bonding to four hydrogen atoms.

- **Semi-structural formula**

  It is possible to understand the structure of an organic molecule without writing out all the carbon-hydrogen bonds. This way of writing a structure is called a semi-structural formula and is shown in Figure 4.7.

$$\text{(a)}\quad \mathbf{CH_3-\underset{}{\overset{\displaystyle CH_3}{\overset{|}{CH}}}-CH_3} \qquad \text{(b)}\quad \mathbf{CH_3-CH_2-CH_2-CH_3}$$

Figure 4.7: The semi-structural formulae of **(a)** 2-methylpropane and **(b)** butane.

  Compare these semi-structural representations with the structural representations shown in Figure 4.5.

- **Condensed structural formula**

  It is also possible to represent a molecule without showing any bonds between atoms at all. This is called a **condensed structural formula** (Figure 4.8). As for a semi-structural representation, the carbon atoms are grouped with the hydrogen atoms bonded directly to it. The bonds between these groups are not shown. Branched or substituent groups are shown in brackets after the carbon atom to which they are bonded.

(a) $\mathbf{CH_3CH(CH_3)CH_3}$ (b) $\mathbf{CH_3CH_2CH_2CH_3}$

Figure 4.8: The condensed structural formulae of **(a)** 2-methylpropane and **(b)** butane.

  Note that in Figure 4.8 (b) the two CH_2 groups can be abbreviated to $(CH_2)_2$. Compare these condensed structural representations with the structural (Figure 4.5) and the semi-structural representations (Figure 4.7).

- **Molecular formula**

  The molecular formula of a compound shows how many atoms of each type are in a molecule. The number of each atom is written as a subscript after the atomic symbol. The molecular formula of 2-methylpropane is:

  $\mathbf{C_4H_{10}}$

  This means that each molecule of 2-methylpropane consists of four carbon atoms and ten hydrogen atoms. The molecular formula of butane is also C_4H_{10}. Molecular formula gives no structural information about the compound.

TIP

A substituent is an atom or group of atoms that replaces a hydrogen atom on the main chain of an organic molecule. Therefore a brached group is a substituent. A halogen atom can also be a substituent.

Of course molecules are not two-dimensional so shown below are a few examples of different ways to represent methane (CH_4, Figure 4.9) and ethane (C_2H_6, Figure 4.10).

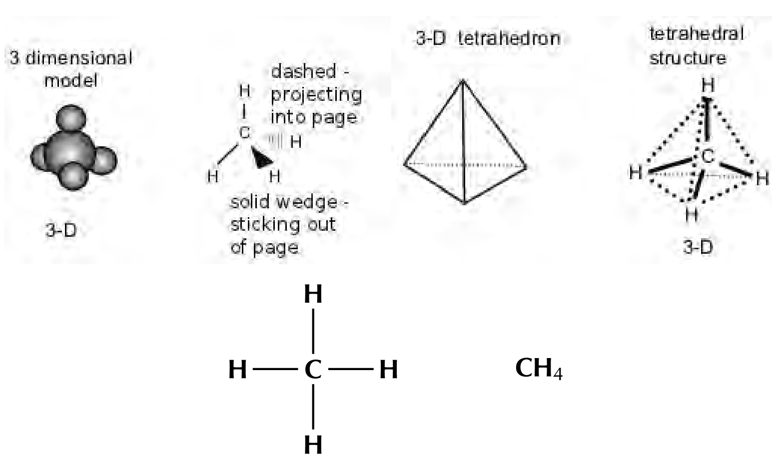


Figure 4.9: Different ways of representing methane.

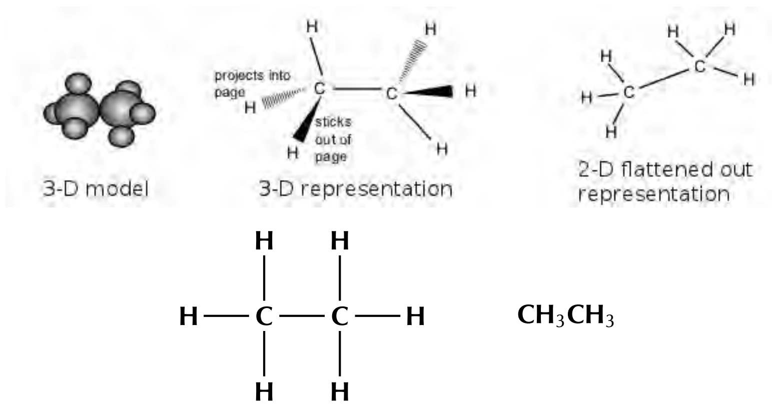
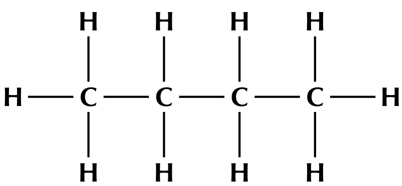


Figure 4.10: Different ways of representing ethane.

This means that butane can be represented in two dimensions as shown in Figure 4.11 (a) but it actually looks more like the three-dimensional representation given in Figure 4.11 (b).

(a)



(b)

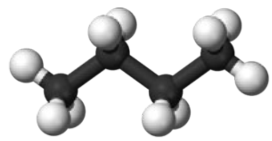


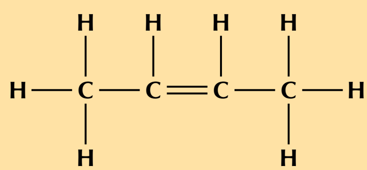
Figure 4.11: **(a)** Two-dimensional and **(b)** three-dimensional representations of butane.

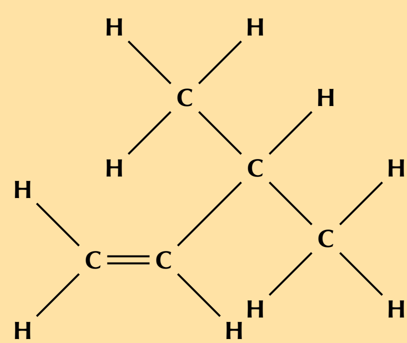
Exercise 4 – 1: Representing organic compounds

1. For each of the following, give the **structural formula** and the **molecular formula**.

   a) $CH_3CH_2CH_3$ b) $CH_3CH_2CH(CH_3)CH_3$ c) CH_3CH_3

2. For each of the following organic compounds, give the **condensed structural formula** and the **molecular formula**.

   a) 

   b) 

3. Give two possible structural formulae for the compound with a molecular formula of C_4H_{10}.

4. More questions. Sign in at Everything Science online and click 'Practise Science'.

Check answers online with the exercise code below or click on 'show me the answer'.

1. 27KT 2. 27KV 3. 27KW

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Functional groups ESCK7

The way in which a compound will react is determined by a particular characteristic of a group of atoms and the way they are bonded (e.g. double C–C bond, C–OH group). This is called the **functional group**. This group is important in determining how a compound will react. The same functional group will undergo the same or similar chemical reaction(s) regardless of the size of the molecule it is a part of. Molecules can have more than one functional group.

> **DEFINITION:** *Functional group*
>
> In organic chemistry a functional group is a specific group of atoms (and the bonds between them) that are responsible for the characteristic chemical reactions of those molecules.

In one group of organic compounds, called the **hydrocarbons**, the single, double and triple bonds between carbon atoms give rise to the alkanes, alkenes and alkynes, respectively. The double carbon-carbon bonds (in the alkenes) and triple carbon-carbon bonds (in the alkynes) are examples of functional groups.

In another group of organic compounds, called the **alcohols**, an oxygen and a hydrogen atom are bonded to each other to form the functional group (in other words an alcohol has an OH in it). All alcohols will contain an oxygen and a hydrogen atom bonded together in some part of the molecule. Table 4.1 summarises some of the common functional groups. We will look at these in more detail later in this chapter.

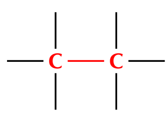
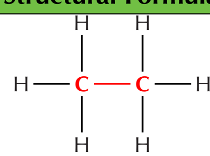
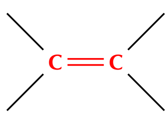
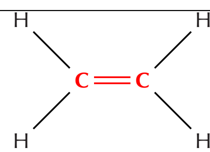
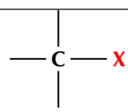
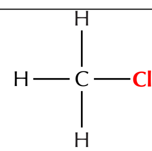
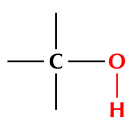
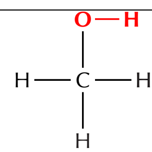
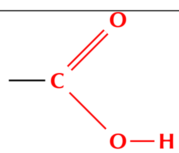
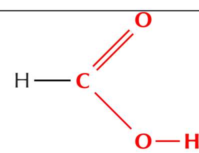
Name of group	Functional group	Example	Structural Formula
Alk*ane*		Eth*ane*	
Alk*ene*		Eth*ene*	
Alk*yne*	—C≡C—	Eth*yne*	H—C≡C—H
Haloalkane/alkyl halide	 (X = F,Cl,Br,I)	Chloromethane	
Alcoh*ol* / alkan*ol*		Methan*ol*	
Carboxylic acid		Methan*oic acid*	

Table 4.1: Some functional groups of organic compounds.

There are some important points to note as we discuss functional groups:

- The beginning of a compound name (prefix) comes from the number of carbons in the longest chain:

meth-	1 carbon atom
eth-	2 carbon atoms
prop-	3 carbon atoms
but-	4 carbon atoms

- The end of a compound name (suffix) comes from the functional group, e.g. an alkane has the suffix -ane. Refer to the examples in Table 4.1.

For more information on naming organic molecules see Section 4.3.

Saturated and unsaturated structures ESCK8

Hydrocarbons that contain only single bonds are called **saturated** hydrocarbons because each carbon atom is bonded to as many hydrogen atoms as possible. Figure 4.12 shows a molecule of ethane, which is a saturated hydrocarbon.

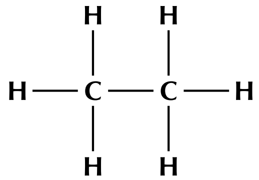


Figure 4.12: A saturated hydrocarbon, ethane.

DEFINITION: *Saturated compounds*

A **saturated** compound has no double or triple bonds (i.e. they have single bonds only). All carbon atoms are bonded to four other atoms.

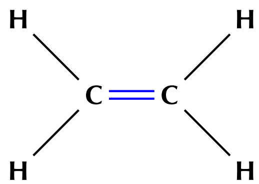
Hydrocarbons that contain double or triple bonds are called **unsaturated** hydrocarbons because they don't contain as many hydrogen atoms as possible.

DEFINITION: *Unsaturated compounds*

An **unsaturated** compound contains double or triple bonds. A carbon atom may therefore be bonded to only two or three other atoms.

Figure 4.13 shows molecules of ethene and ethyne which are unsaturated hydrocarbons. If you compare the number of carbon and hydrogen atoms in a molecule of ethane and a molecule of ethene, you will see that the number of hydrogen atoms in ethene is *less* than the number of hydrogen atoms in ethane despite the fact that they both contain two carbon atoms. In order for an unsaturated hydrocarbon compound to become saturated, one of the two (or three) bonds in a double (or triple) bond has to be broken, and additional atoms added.

(a)



(b)

Figure 4.13: Unsaturated hydrocarbons: **(a)** ethene and **(b)** ethyne.

See video: 27KX at www.everythingscience.co.za