DEPARTMENT OF EDUCATION

GRADE 12

CHEMISTRY

MODULE 4

CARBON COMPOUNDS

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CHEMISTRY

MODULE 4

CARBON COMPOUNDS

IN THIS MODULE YOU WILL LEARN ABOUT:

12.4.1: HYDROCARBON

12.4.2: ALCOHOLS

12.4.3: ALDEHYDES

12.4.4: KETONES

12.4.5: CARBOXYLIC ACIDS AND ESTERS

Acknowledgement

We acknowledge the contributions of all secondary teachers who in one way or another have helped to develop this Course.

Our profound gratitude goes to the former Principal of FODE, Mr. Demas Tongogo for leading FODE team towards this great achievement.

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DIANA TEIT AKIS
PRINCIPAL

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SECRETARY'S MESSAGE

Achieving a better future by individual students and their families, communities or the nation as a whole, depends on the kind of curriculum and the way it is delivered.

This course is a part of the new Flexible, Open and Distance Education curriculum. The learning outcomes are student-centred and allows for them to be demonstrated and assessed.

It maintains the rationale, goals, aims and principles of the national curriculum and identifies the knowledge, skills, attitudes and values that students should achieve.

This is a provision by Flexible, Open and Distance Education as an alternative pathway of formal education.

The course promotes Papua New Guinea values and beliefs which are found in our Constitution, Government Policies and Reports. It is developed in line with the National Education Plan (2005 -2014) and addresses an increase in the number of school leavers affected by the lack of access into secondary and higher educational institutions.

Flexible, Open and Distance Education curriculum is guided by the Department of Education's Mission which is fivefold:

- To facilitate and promote the integral development of every individual
- To develop and encourage an education system that satisfies the requirements of Papua New Guinea and its people
- To establish, preserve and improve standards of education throughout Papua New Guinea
- To make the benefits of such education available as widely as possible to all of the people
- To make the education accessible to the poor and physically, mentally and socially handicapped as well as to those who are educationally disadvantaged.

The college is enhanced through this course to provide alternative and comparable pathways for students and adults to complete their education through a one system, two pathways and same outcomes.

It is our vision that Papua New Guineans' harness all appropriate and affordable technologies to pursue this program.

I commend all the teachers, curriculum writers and instructional designers who have contributed towards the development of this course.

UKE KOMBRA, PhD
Secretary for Education

MODULE 4: CARBON COMPOUNDS

INTRODUCTION

Hydrocarbons belong to a group of compounds containing carbon whether they occur in living or non-living is called **organic compounds**. The study of such compounds is called **organic chemistry**. Millions of different organic compounds exist in all shapes and sizes, some in long chains and others in rings. This ability of carbon to form big molecules has enabled nature to form living matter, starting from simple cells to complex tissues.

Do you know that the food we eat, the clothing we wear, and even our bodies are composed of organic substances? In an oil refinery, petroleum is separated into its components such as kerosene, diesel, and petrol. Petroleum is used as fuel and to manufacture vitamins, plastics, rubber, and many other materials important to our modern lifestyles. All these substances contain carbon. In organic chemistry, we study substances that contain carbon.

An oil refinery and chemical manufacturing plant

Medicines are examples of organic compounds.

The study of organic chemistry is important and has many wide applications. It has improved our living by synthesizing new materials like plastics, detergents, medicines, and drugs. However, the uses of some of these new products, like plastics and designer drugs (harmful drugs) such as “ecstacy” and “ice”, have had a great impact on the environment and on society.

Good luck in studying this course module. Hope you will find the unit interesting to achieve success in the end.

Learning Outcomes

After going through the module, you are expected to:

- understand the general pattern of the structure of carbon compounds.
- write formulas, draw structures, and name according to International Union of Pure and Applied Chemistry (IUPAC) system: hydrocarbons (aliphatic and aromatic), alcohols, aldehydes, ketones, carboxylic acids, esters, and amines.

Time Frame

Suggested Time Frame is 11 weeks

This module should be completed within 11 weeks.

If you set an average of 3 hours per day, you should be able to complete the module comfortably by the end of the assigned week.

Try to do all the learning activities and compare your answers with the ones provided at the end of the module. If you do not get a particular exercise right in the first attempt, you should not get discouraged, but instead, go back and attempt it again. If you still do not get it right after several attempts then you should seek help from your friend or even your tutor.

DO NOT LEAVE ANY QUESTION UN-ANSWERED.

Terminologies

Before you get into the thick of things, let us make sure you know some of the terminologies that are used throughout this module.

Aliphatic compounds	Are also known as non- aromatic compounds. Carbon atoms are joined together in straight chains, branched chains, or **non-aromatic rings** (called **alicyclic**).
Amines	Are derivatives of ammonia in which one or more of the hydrogen atoms has been replaced by an alkyl group.
Aromatic hydrocarbon	Or **arene** is a hydrocarbon with alternating double and single bonds between carbon atoms forming rings.
Benzene	Is an organic aromatic compound that contains a benzene ring or has certain benzene-like properties.
Complete combustion	Needs a plentiful supply of air so that elements in the fuel react fully with oxygen forming carbon dioxide and water.
Cycloalkanes	Are saturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n}}$.
Cycloalkenes	Are unsaturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n-4}}$. They form a close ring.
Esterification	Is a process when a carboxylic group reacts with an alcohol.
Full structural formula	Shows all the bonds between atoms and molecules.
Functional group	Is a group of atoms that is responsible for the characteristic chemical properties of a homologous series.
Homologous series	Is a family of organic compounds with similar chemical properties.
Hydrocarbons	Are organic compounds that contain only hydrogen and carbon.
Incomplete combustion	Occurs when the supply of air or oxygen is poor producing carbon monoxide and water.
Isomers	Are compounds that have the same molecular formulas but different structural formulas.
Organic compounds	Are hydrocarbons belong to a group of compounds containing carbon whether they occur in living or non-living.
Organic chemistry	Is the study of hydrocarbon compounds.
Structural formula	Is the formula which shows how atoms are arranged in a molecule.

12.4.1 Hydrocarbons

All organic compounds contain the element carbon. Most of them also contain hydrogen. Organic compounds may also contain other elements such as oxygen and nitrogen.

Not all carbon-containing compounds are organic. For example, carbon dioxide, carbon monoxide, and carbonates are not classified as organic compounds.

Organic compounds that contain only hydrogen and carbon are called hydrocarbons.

Homologous series

There are millions of different organic compounds. The study of organic chemistry is difficult without some sort of classification. Chemists group related organic compounds into families or homologous series.

What is a homologous series?
A **homologous series** is a family of organic compounds with similar chemical properties. Examples are alkanes, alkenes, alcohols, and carboxylic acids. We will discuss and explain them in the succeeding lessons. Compounds of the same homologous series contain the same functional group.

What is a functional group?
A functional group is a group of atoms that is responsible for the characteristic chemical properties of a homologous series. For example, alcohols have the –OH functional group, carboxylic acids have the –COOH functional group and alkenes all contain a C ⫗C bond.

Characteristics of a homologous series of hydrocarbon

- They have the same general formula.
- They show similar chemical properties, because they have the same functional group.
- Each member differs from the previous one by a CH_2.
- They show a slow change in density (mass or solidity), viscosity (thickness), flammability, melting point, and boiling point.

Alkanes, alkenes, alcohols and carboxylic acids are examples of homologous series.

We will discuss the properties of each homologous series and the basic naming of carbon compounds in greater detail in the next few topics.

Naming Carbon Compounds

The systematic naming of carbon compounds is in two parts:

1. A **stem (prefix)** to show the number of carbon atoms.

C_1	meth-	C_6	hex-
C_2	eth-	C_7	hep-
C_3	prop-	C_8	oct-
C_4	but-	C_9	non-
C_5	pent-	C_{10}	dec-

2. An **ending (suffix)** to show the grouping of atoms or functional group.

   For hydrocarbons with:
   - single bonds (alkane) **-ane**
   - a double bond (alkene) **-ene**
   - a triple bond(alkyne) **-yne**

The information below shows the four homologous series and their respective functional groups.

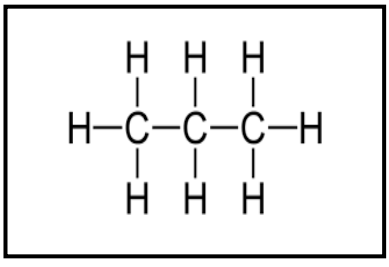
1. Alkanes
   - They have the general formula $\mathbf{C_nH_{2n+2}}$, where **n** is the number of carbon atoms.
   - Alkane has no functional groups. They are only **C – C and C – H** bonds.

   We have said that alkane has the general molecular formula $\mathbf{C_nH_{2n+2}}$.

   If an alkane contains one carbon atom, n = 1. It has the molecular formula $\mathbf{C_1H_{(2X1)+2} = CH_4}$. This is **methane**.

   Similarly, the alkane with two carbon atoms has the molecular formula $\mathbf{C_2H_{(2X2)+2} = C_2H_6}$. This is **ethane**.

   Example:
   The structural formula of **propane** is drawn below. It has a molecular formula **of $\mathbf{C_3H_{2x3}+2 = C_3H_8}$.**

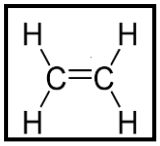


The same rules of naming carbons apply to the rest of homologous series of carbon.

2. Alkenes
   - They have the general formula $\mathbf{C_nH_{2n}}$, where **n** is the number of carbon atoms.
   - The functional group of alkene is **carbon to carbon double**, **C =C.**

Example:

The structural formula for **ethene** is shown below. It has a molecular formula **of $\mathbf{C_2H_{2x2}}$ = $\mathbf{C_3H_4}$**.



3. Alcohols
   - They have the general formula $\mathbf{C_nH_{2n+1}OH}$.
   - The use of prefixes (meth, eth, prop and so on) will remain the same as in the given examples above. Only the suffixes **-ane** from alkane and **-ene** from alkene will be changed to **-ol** to name an alcohol compound.
   - The functional group of alcohol is **-OH group** called **hydroxyl group**.

Example:

The structural formula for **ethanol** is shown below. Using the general formula $\mathbf{C_nH_{2n+1}OH}$,

The molecular formula of **ethanol is:**

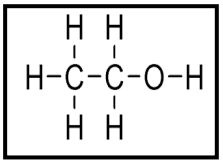
= $C_nH_{2n+1}OH$

= C_2H_{2x2} +1 OH

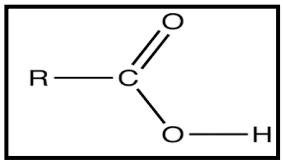
= C_2H_4 +1 OH

= $\mathbf{C_2H_5OH}$

The structural formula is:



4. Carboxylic acids
   - They have the formula $\mathbf{C_nH_{2n+1}COOH}$.
   - The use of prefixes (meth, eth, prop and so on) will remain the same as in the given examples above. Only the suffixes **–ane** from alkane and **–ene** from alkene will be changed to **–oic acid to** name a carboxylic acid compound.
   - The functional group is – **COOH** called **carboxylic group** as shown below:



From the general formula for carboxylic acid, $\mathbf{C_nH_{2n+1}COOH}$, you must learn that:

$\mathbf{C_n H_{2n+1} COOH}$

The number of carbon atom **n** will become **n-1** because 1 carbon from -COOH group will be added to have the actual number of carbons in a carboxylic compound.

For example, ethane has 2 carbon atoms. We know it has 2 carbon atoms (from **n**).

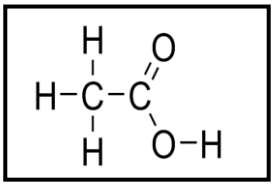
Therefore, **n-1** will be **2 – 1 = 1 carbon atom** remaining from the $\mathbf{C_n}$ **in the formula** $\mathbf{C_nH_{2n}}$ (from $\mathbf{C_nH_{2n+1}}$ COOH). This 1 carbon atom will become 2 carbon atoms after adding it with the carbon atom in the –**C**OOH group.

Example:
The structural formula for ethanoic acid is shown below. Using the general formula $\mathbf{C_nH_{2n+1}COOH}$.

The molecular formula of **ethanoic acid is:**

= C_nH_{2n+1} COOH
= C_1H_{2x1+1} COOH
= $\mathbf{CH_3COOH}$

The structural formula is:



ORGANIC COMPOUNDS AND THEIR USES

Organic compounds	Uses
Drugs	For medicines.
LPG (liquefied petroleum gas)	For cooking
LNG (liquefied natural gas)	For running vehicles.
Margarine, butter, or cream	Use in bread and cooking.
Vegetable oils	Found in the kitchen.
Plastics	For packaging purposes.
Bleaching agents	For cleaning and disinfectants.
Paints, varnishes, liquid soaps and other toiletries.	Used as solvent due to the presence of ethanol (C_2H_5OH)
Polyunsaturated oil	Also found in the kitchen such as oils from sunflower, palm, fish, soya, linseed and nut.
Vinegar	Used as food preservative and additive to tomato sauce.

Two types of hydrocarbons

A. Aliphatic hydrocarbons
B. Aromatic hydrocarbons

Aliphatic compounds are also known as non- aromatic compounds. Carbon atoms are joined together in straight chains, branched chains, or **non- aromatic rings** (called **alicyclic**). They are saturated, joined by single bonds (alkanes), or unsaturated, with double bonds (alkenes) or triple bonds (alkynes). Besides hydrogen, other elements are bound to the carbon chain, the most common being oxygen, nitrogen, sulphur, and chlorine.

The simplest aliphatic compound is **methane (CH_4).** Aliphatics includes alkanes, alkenes, and alkynes. Fatty acids consist of an unbranched aliphatic tail attached to a carboxylic acid functional group. Most aliphatic compounds are flammable, allowing the use of hydrocarbons as fuel and as liquefied natural gas (LNG) and acetylene in welding.

Aromatic hydrocarbon or **arene** is a hydrocarbon with alternating double and single bonds between carbon atoms forming rings. The term aromatic was assigned before the physical mechanism, determining aromaticity (smell) was discovered because many of the compounds have a sweet and pleasant odour. The configuration of six carbon atoms in aromatic compounds is known as a **benzene ring**. The simplest of them is **benzene** (**C_6H_6**) itself. The next simplest is **methylbenzene** (old name **toluene**).

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 1

20 minutes

Answer the following questions.

1. What is organic compound?

   _____
   _____
   _____

2. Give four examples of homologous series.
   (i) _____
   (ii) _____
   (iii) _____
   (iv) _____

3. Write the functional group of:
   a. alkenes _____
   b. alcohols _____
   c. carboxylic acids _____

4. Write the general formula of:
   a. alkanes _____
   b. alkenes _____
   c. alcohols _____
   d. carboxylic acids _____

5. List the types of hydrocarbons:
   (i) _____
   (ii) _____

Thank you for completing your learning activity 1. Check your work. Answers are at the End of this module.

12.4.1.2 Alkanes and Cycloalkanes (C_1 to C_{10})

The alkanes are a family of hydrocarbons. All alkanes share the following characteristics:

- They have the general formula $\mathbf{C_nH_{2n+2}}$.
- Their names end with **-ane** .
- The carbon atoms are joined by single covalent bonds.
- They are said to be saturated (with single bonds) as no other atoms can be added to the carbon atoms without first removing some other atoms.

It is important to know that each member of the alkane homologous series differs from the next by a CH_2 unit.

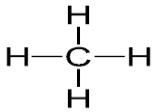
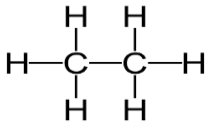
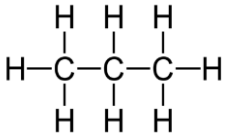
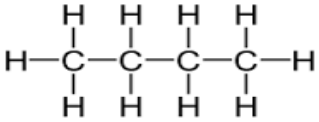
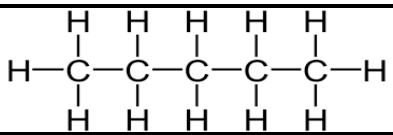
For example, ethane differs from methane by having an additional CH_2 unit.

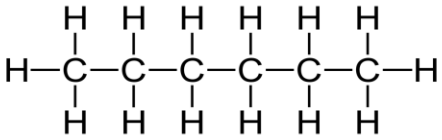
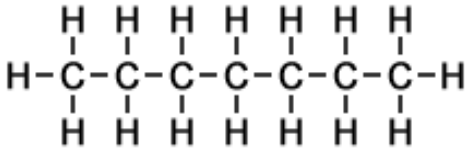
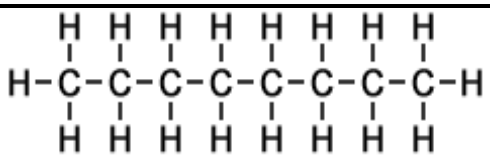
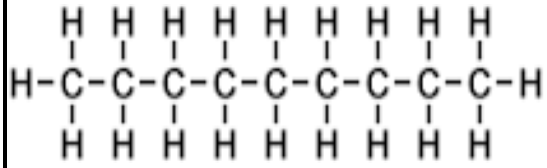
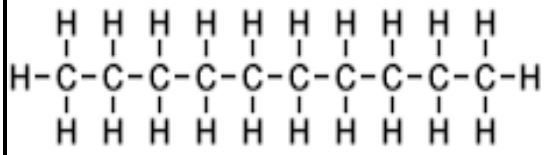
Methane + $-CH_2-$ → ethane

CH_4 + $-CH_2-$ → C_2H_6

Alkane has the general molecular formula C_nH_{2n+2}. If an alkane contains one carbon atom, n = 1, it has the molecular formula $C_1H_{(2x1)+2} = CH_4$. This is called methane.

THE FIRST TEN MEMBERS OF ALKANE HOMOLOGOUS SERIES

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Methane (1 carbon atom)	CH_4	CH_4	
Ethane (2 carbon atoms)	C_2H_6	CH_3CH_3	
Propane (with 3 carbon atoms	C_3H_8	$CH_3CH_2CH_3$	
Butane (4 carbon atoms)	C_4H_{10}	$CH_3(CH_2)_2CH_3$	
Pentane (5 carbon atoms)	C_5H_{12}	$CH_3(CH_2)_3CH_3$	

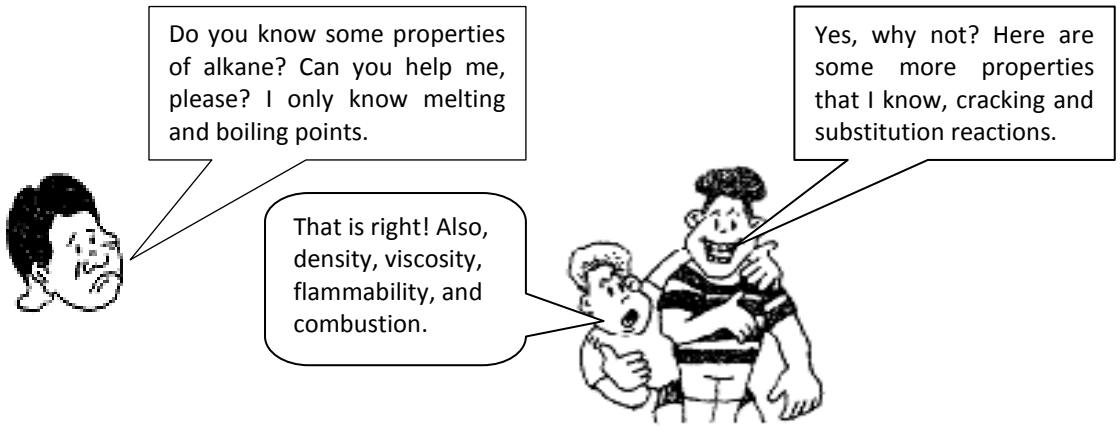
Hexane (6 carbon atoms)	C_6H_{14}	$CH_3(CH_2)_4CH_3$	
Heptane (7 carbon atoms)	C_7H_{16}	$CH_3(CH_2)_5CH_3$	
Octane (8 carbon atoms)	C_8H_{18}	$CH_3(CH_2)_6CH_3$	
Nonane (9 carbon atoms)	C_9H_{20}	$CH_3(CH_2)_7CH_3$	
Decane (10 carbon atoms)	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$	

A structural formula is the formula that shows how atoms are arranged in a molecule, and a full structural formula shows all the bonds between atoms and molecules.

Why are alkanes called saturated hydrocarbons?

Alkanes are called **saturated hydrocarbons** because they contain only **single carbon– carbon** covalent bonds. Each carbon atom in an alkane molecule uses all its valence electrons (the electrons found in the outer shell of an atom) in forming single bonds with four other atoms.

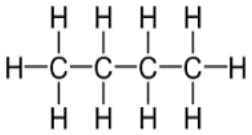
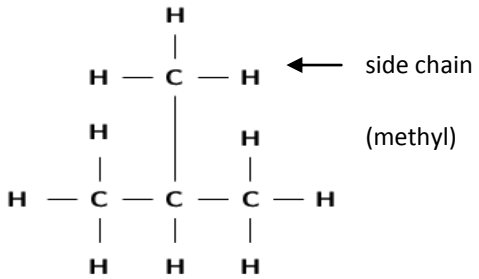
For example, the carbon atom in methane has four electrons in its outer shell. It forms four single bonds with hydrogen and attains the stable electronic structure of a noble gas.



What are isomers?

Compounds that have the same molecular formulas but different structural formulas are called **isomers**. If they are in the same homologous series, they would have similar chemical properties, but slightly different physical properties such as melting and boiling points. Isomers can also be in two different homologous series. In this case, both their physical and chemical properties are different.

Look carefully at the following structures of alkane hydrocarbons. How are they similar or different?

Butane (C_4H_{10})	2 – methyl propane (iso –butane), (C_4H_{10})
	

The isomers of butane

The isomers of butane are similar because they have the same molecular formulas of **C_4H_{10}**. They are different because they have different structural formulas.

Why the isomer of butane, iso- butane is named as 2-methyl propane?

Chemists follow what is known as the **IUPAC (International Union of Pure and Applied Chemistry)** rule. In iso-butane, the longest carbon chain has only three carbon atoms, so it is a derivative of propane.

Attached to the central atom of this chain of three carbons is a **methyl (–CH_3) group**. If you number the three carbon atoms as 1, 2, and 3, the **methyl group** is on **carbon atom number 2**. Hence, the compound is called methyl **2-propane.** The IUPAC rule says that **when we number the carbon atoms, we must always start from the side that gives us the smallest number.**

Therefore, **butane** and **methyl propane** are isomers. It is important to realize that isomers are different chemical compounds. They have different structures.

Butane is a straight chain alkane, because all the carbon atoms are joined up in a row. 2 - methyl propane is a branched chain alkane, because it has a branch or a side chain, CH_3 called **methyl**. The side chains are **called alkyl groups**.

An **alkyl group** is obtained by removing a hydrogen atom from an alkane. It has general formula C_nH_{2n+1}.

For example:
The general formula of alkane is $\mathbf{C_nH_{2n+2}}$. Methane has 1 carbon atom. Its molecular formula is $\mathbf{C_1H_{2x1+2} = CH_4}$. Therefore, to find the alkyl group methyl, you will use the general formula of $\mathbf{C_nH_{2n+1}}$. Methyl will have the molecular formula of $\mathbf{C_1H_{2x1+1} = CH_3}$.

The same rule applies to all the formulas of alkyl group.

The typical alkyl groups are:

- Methyl (CH_3 –)
- Ethyl (CH_3CH_2 –)
- Propyl ($CH_3CH_2CH_2$ –)
- Butyl ($CH_3CH_2CH_2CH_2$ –)
- Pentyl ($ch_3ch_2ch_2ch_2ch_2$ –)
- Hexyl ($ch_3ch_2ch_2ch_2ch_2ch_2$ –)
- Heptyl ($ch_3ch_2ch_2$ $ch_2ch_2ch_2ch_2$ –)
- Octyl ($ch_3ch_2ch_2ch_2ch_2ch_2ch_2ch_2$ –)
- Nonyl ($ch_3ch_2ch_2ch_2ch_2ch_2ch_2ch_2ch_2$ –)
- Decyl ($ch_3ch_2ch_2ch_2ch_2ch_2ch_2ch_2ch_2ch_2$ –)

The systematic naming of carbon compounds is in two parts:

- **A stem(prefix) to show the number of carbon atoms.**

C_1	**meth-**	**C_6**	**hex-**
C_2	**eth-**	**C_7**	**hep-**
C_3	**prop-**	**C_8**	**oct-**
C_4	**but-**	**C_9**	**non-**
C_5	**pent-**	**C_{10}**	**dec-**

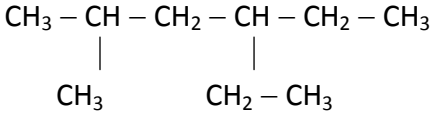
- **An ending (suffix) to show the grouping of atoms or functional group.**
  For hydrocarbons with:
  (i) single bonds -ane
  (ii) a double bond -ene
  (iii) a triple bond -yne

Rules for naming branched chain alkanes

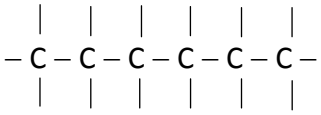
1. Find the longest chain of carbon atoms in the molecule. Use the chain like a surname.
2. Name any branch (side) chains as the alkyl group.
3. Number the side chain from the end of the parent chain, which will give them the lowest number.
4. When there is more than one side chain, they are listed alphabetically.
5. If the same side chain occurs more than once, prefixes, di- (two), tri-(three), tetra-(four) are used.
6. In naming alkanes, the number and names are separated with the use of a hyphen (-) and any 2 numbers are separated by a comma (,) followed by the second side chain and so on.

Example 1

(i) To name the compound drawn below, find the longest chain of carbon atoms in a molecule.



Step 1. Draw the longest carbon chain.



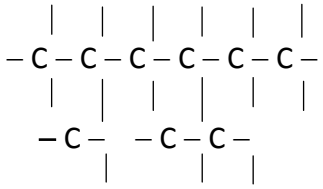
Use the chain like a surname.

…… **hexane**

Step 2 Name the side chain in alphabetical order.

- ethyl
- methyl

Step 3. Number from the end of the skeleton to give the lowest number for side chains. Naming of branches is alphabetical before numerical.



Step 4 There are two side chains, so list them alphabetically with the use of a hyphen in between the number and the first side chain followed by a comma(,) then the second side chain and so on.

The name of the compound is **4-ethyl,2-methylhexane**.

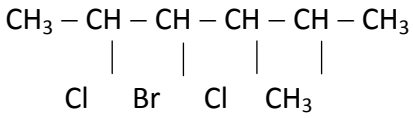
Haloalkanes

Compounds in which one or more hydrogen atoms of alkanes have been replaced by halogen atoms (F,Cl,Br,I) are called **haloalkanes**.

Rules for Naming Haloalkanes

1. Find the longest chain of carbon atoms in the molecule. Use the chain like a surname.
   - Prefixes bromo-, chloro-, flouro-, and iodo- are used with the parent hydrocarbon.
   - Name any branch (side) chains as the alkyl group.
   - The carbon chain is numbered so that the halogen atom has the smallest possible number.
2. Number the side chain from the end of the parent chain, which will give them the lowest number. **Halogen atoms are functional groups**, therefore, they are numbered in preference to any side chains.
3. If only one type of halogen atom is present, each is numbered, and di, tri, and so on are used and listed alphabetically.
4. In naming halo alkanes, the number and names are separated with the use of a hyphen (-) and any 2 numbers are separated by a comma (,) followed by the second side chain and so on.

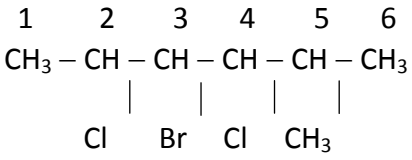
Example:
Name the compound below:



Step 1. Find the longest straight carbon chain.

- …… hexane
- prefixes bromo, chloro are present.
- methyl (CH_3) is also present.

Step 2. Number from the end that will make the halogens the lower.



Step 3. Arrange the halogen atoms first before any side chain that is present in alphabetical order.

- bromo
- chloro
- methyl

Step 4. Name and number any side chains present.

3- bromo, 2,4- dichloro, 5-methyl hexane

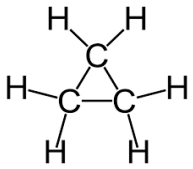
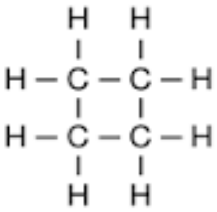
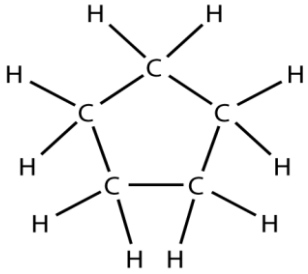
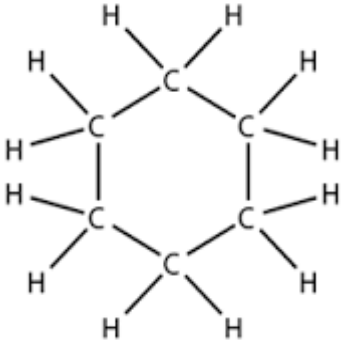
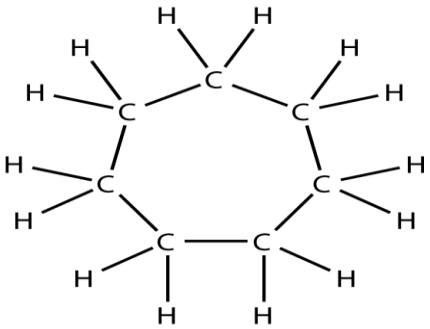
Cycloalkanes

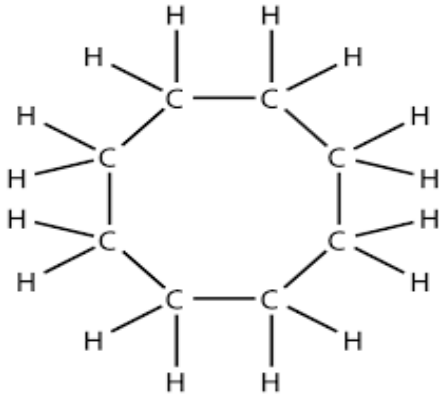
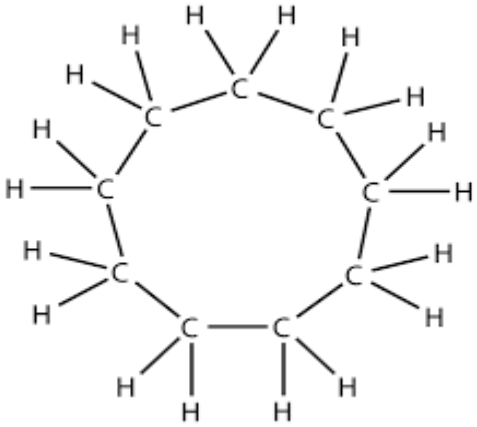
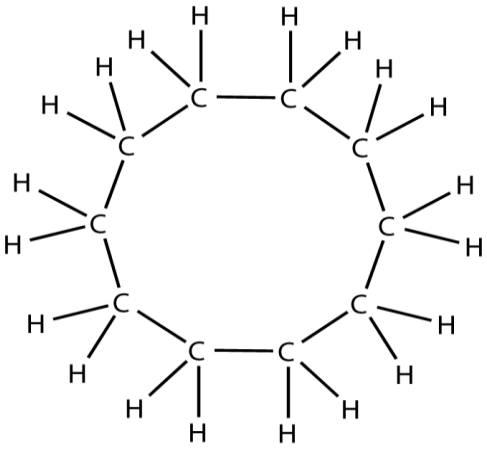
- Cycloalkanes are saturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n}}$.

  For example:
  Propane has 3 carbon atoms. Using the general formula for cycloalkane,$\mathbf{C_nH_{2n}}$. The molecular formula of cyclopropane is $\mathbf{C_3H_{2x3}}$ = $\mathbf{C_3H_6}$. Its structural formula is shown in the table below.

- They form a close carbon rings.

THE STRUCTURES OF CYCLOALKANE COMPOUNDS OF CARBON 3 TO 10

Name	Molecular Formula	Full Structural formula
Cyclopropane (3 carbon atoms)	C_3H_6	
Cyclobutane (4 carbon atoms)	C_4H_8	
Cyclopentane (5 carbon atoms)	C_5H_{10}	
Cyclohexane (6 carbon atoms)	C_6H_{12}	
Cycloheptane (7 carbon atoms)	C_7H_{14}	

Cyclooctane (8 carbon atoms)	C_8H_{16}	
Cyclononane (9 carbon atoms)	C_9H_{18}	
Cyclodecane (10 carbon atoms)	$C_{10}H_{20}$	

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 2

30 minutes

Answer the following questions.

1. Give the four characteristics of alkane homologous series.

(i) _____

(ii) _____

(iii) _____

(iv) _____

2. Using the general formula, $C_nH_{2n+2,}$ write the name and molecular formula of the first four members of homologous series of alkane.

Name	Formula
a.	
b.	
c.	
d.	

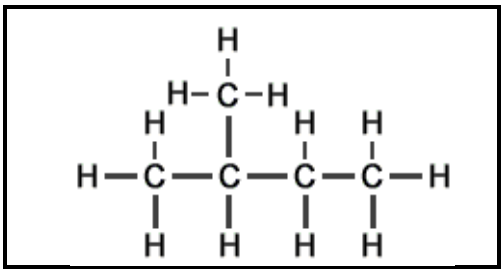
3. Complete the table below, about the first three members of alkane homologous series.

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula

4. Complete the table below, about the third member of cycloalkane.

Name	Molecular formula	Full Structural Formula

5. Name this isomer of pentane.



The isomer is named as _____

Thank you for completing your learning activity 2. Check your work. Answers are at the end of this module.

12.4.1.3 Alkenes and cycloalkenes (C_1 to C_{10})

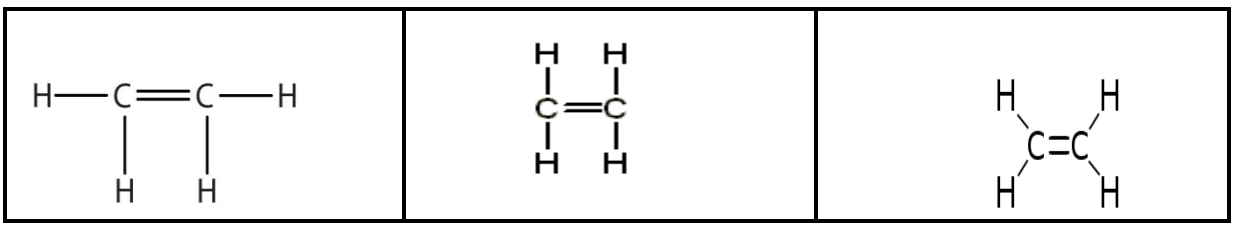
The alkenes are another family of hydrocarbons starting with **ethene** (**C_2H_4**) having 2 carbon atoms.

All alkene share the following characteristics:

- They have the general formula **C_nH_{2n}**.
- Their names end with -**ene**.
- There is a **carbon to carbon double bond** present in a molecule.
- They are said to be unsaturated, as other atoms can be added to the molecule when the carbon to carbon double bond opens up.

The first member of the alkene homologous series, ethene (C_2H_4), contains two carbon atoms. There is no organic compound with the formula CH_2. Just like the alkanes, as the number of carbon atoms increases, the molecules become bigger and heavier. As the number of carbon atoms increases, the density, melting point, and boiling point increases. The first three alkenes are gases, the next few are liquids, and the rest are solids.

Unlike alkanes, alkenes have a carbon to carbon double covalent bond. The structure of ethene is shown below as an example. All representations are correct and there is no preferred structure.

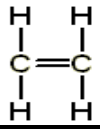
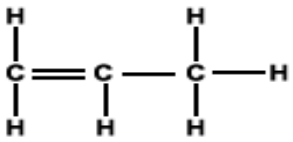
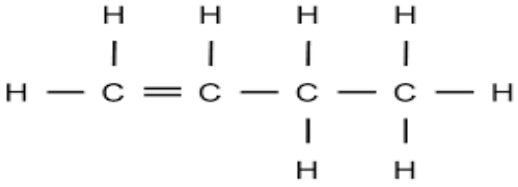
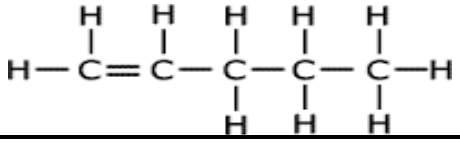
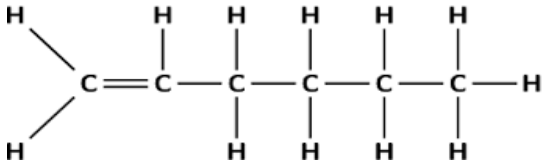
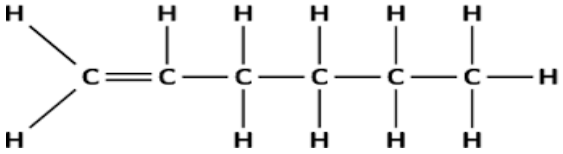


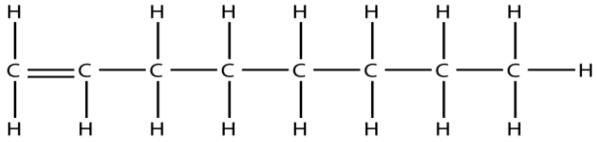
Different ways to represent the structural formula of ethene (C_2H_4).

Alkene has the general molecular formula C_nH_{2n} . If an alkene contains two carbon atoms, n = 2, it has the molecular formula $C_2H_{(2x2)}$ = C_2H_4. This is called ethene.

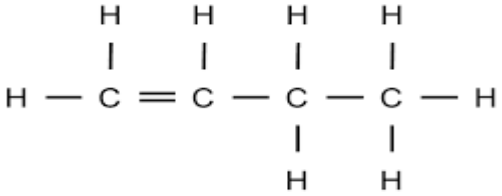
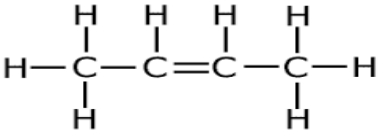
It is important to know that after propene (C_3H_6), the double bond between two carbon atoms (**C=C**) can be placed anywhere, along the carbon chain as long as each carbon atom has four bonds. You will be given few examples on this later on.

The table below shows the various formulae of the members of the alkene homologous series, showing the position of the double bond between the **first and the second carbon atoms.**

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Ethene	C_2H_4	CH=CH	
Propene	C_3H_6	CH_2=$CHCH_3$	
But-1-ene (1-butene)	C_4H_8	CH_2=$CHCH_2CH_3$	
Pent-1-ene (1-pentene)	C_5H_{10}	CH_2=$CH(CH_2)_2CH_3$	
Hex-1-ene (1-hexene)	C_6H_{12}	CH_2=$CH(CH_2)_3CH_3$	
Hep-1-tene (1-heptene)	C_7H_{14}	$CH_2CH(CH_2)_4CH_3$	

Oct-1-ene (1-octene)	C_8H_{16}	$CH_2CH(CH_2)_5CH_3$	

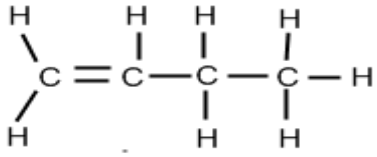
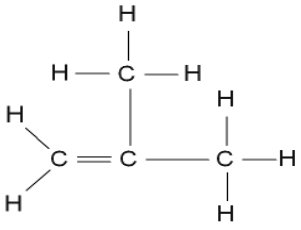
The table below shows butene (C_4H_8) with two different positions of carbon to carbon double bond.

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
But-1-ene (1-butene)	C_4H_8	$CH_2=CHCH_2CH_3$	
But-2-ene (2-butene)	C_4H_8	$CH_3CH=CHCH_3$	

The different structural formulas of butene.

For alkenes, the double bond between two carbon atoms can be placed anywhere along the carbon chain, as long as each carbon atom has four bonds.

Look carefully at the following isomer structures of alkene hydrocarbons. How are they similar or different?

Butene (C_4H_8)	2 – methylpropene,(C_4H_8)
	

The isomers of butene

The isomers of butene are similar because they have the same molecular formulas of C_4H_8. They are different because they have different structural formulas.

Butene or but -1 –ene is a straight chain unsaturated hydrocarbon while **2-methylpropene** is a branched chain unsaturated hydrocarbon. Butene and 2-methylpropene have different melting and boiling points. **2-methylpropene is an isomer of butene**.

Polyunsaturated foods as alkenes

If you go to the supermarkets, you may come across advertisements to buy polyunsaturated food products, as they are supposed to be healthier. As mentioned earlier, unsaturated hydrocarbons contain carbon – carbon double bonds.

Polyunsaturated oils are oils that contain two or more C=C bonds in the molecules. Hence, it is harder to pack the molecules closely together. They are liquids at room temperature and they flow.

On the other hand, saturated oils that are mostly straight chains molecules are more easily packed and exist as solids at room temperature. According to scientists, saturated fats such as animal fats, oils, butter, and cream are **unhealthy** in the diet. They raise the blood cholesterol of a person.

Polyunsaturated oils and fats, on the other hand, are **healthier** as they do not clot the blood vessels. Some examples of polyunsaturated oils are found in sunflower oil, palm oil, fish oil, soya oil, linseed oil, and nuts.

Similarities of alkanes and alkenes

- Both alkanes and alkenes are compounds that contain only carbon and hydrogen.
- Both alkanes and alkenes are flammable. On complete combustion, they form carbon dioxide and water.

The table below shows the differences of alkanes and alkenes:

Properties	Alkanes	Alkenes
Molecular structure	They contain only single bonds between carbon atoms.	They contain double bonds between carbon atoms.
Reactivity	They are generally unreactive.	They are very reactive.
Type of reaction	They undergo substitution reactions but do not undergo polymerisation.	They undergo addition polymerisation.
Reaction with aqueous bromine	They do not react with aqueous bromine under normal conditions.	They rapidly decolorize aqueous bromine.
Combustion	They produce a smoky flame during combustion reaction.	They will not produce a smoky flame during combustion

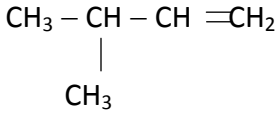
		reaction.

Rules for Naming Alkenes

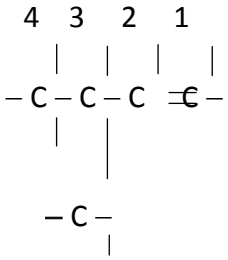
1. Find and draw the longest consecutive chain of carbon atoms that includes the double bond, and name it as parent alkene.
2. Name the chain as a surname and any branch (side) chains as the alkyl group.
3. Name any branch (side) chains as the alkyl group.
   - When there is more than one side chain, they are listed alphabetically.
   - If the same side chain occurs more than once, prefixes, di, tri , tetra and so on are used.
4. Number the chain from the end that gives the double bond its smaller number.
5. In naming alkenes, the number and names are separated with the use of a hyphen (-) and any 2 numbers are separated by a comma (,) followed by the second side chain and so on.

Example:

Name the compound below.



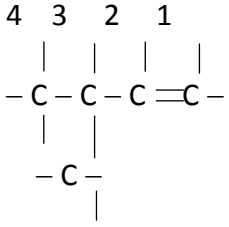
Step 1. Draw the longest carbon chain that contains the double bond.



Step 2. Use the chain as a surname. Number the chain.

……1 – butene or but -1- ene

Step 3. Name and number any side chain, using the numbering system as for the double bond.



Step 4. The name is **3-methyl,1-butene or 3-methyl but-1-ene**.

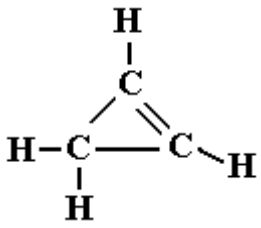
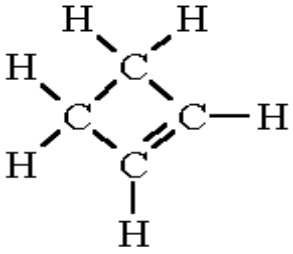
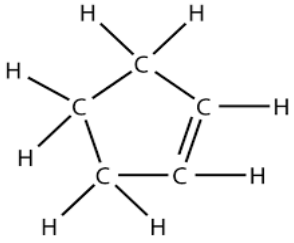
Cycloalkenes

Cycloalkenes are unsaturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n-2}}$.

For example:

- Propene has 3 carbon atoms. Using the general formula for cycloalkene, $\mathbf{C_nH_{2n-2}}$. The molecular formula of cyclopropene is $\mathbf{C_3H_{2x3-2}} = \mathbf{C_3H_4}$. Its structural formula is shown in the table next page.
- They form a close carbon rings.

THE STRUCTURES OF CYCLOALKENES (CARBON 3 TO 10)

Name	Molecular Formula	Full Structural formula
Cyclopropene	C_3H_4	
Cyclobutene	C_4H_6	
Cyclopentene	C_5H_8	

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 3

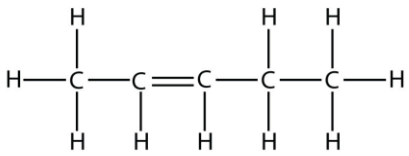
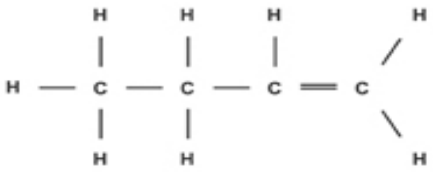
30 minutes

Answer the following questions:

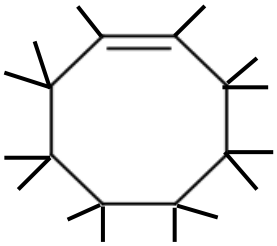
1. Draw the structural formula of 1- pentene or pent-1-ene.

2. Draw the structural formula of cyclobutene.

3. Write the names of these two alkene compounds:

A.	B.
	

4. What is the name of this cycloalkane? What is its molecular formula?



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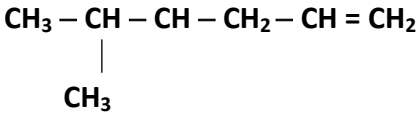
5. What is the name of this compound?



Thank you for completing your learning activity 3. Check your work. Answers are at the end of this module.

12.4.1.4 Alkynes and Cycloalkynes (C_1 to C_{10})

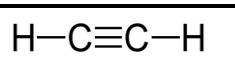
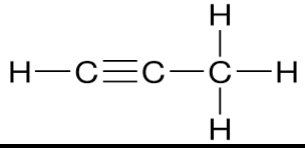
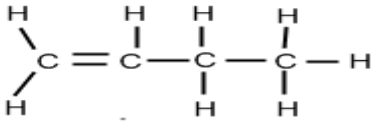
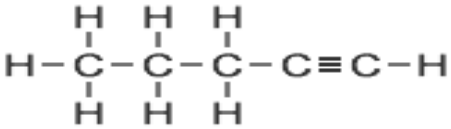
The alkynes are another family of hydrocarbons. All alkynes share the following characteristics:

- They have the general formula $\mathbf{C_nH_{2n-2}}$.
- Their names end with **-yne**.
- There is a **carbon to carbon triple bond (C≡C),** its functional group present in a molecule.
- They are said to be unsaturated, as other atoms can be added to the molecule when the carbon to carbon triple bond opens up.

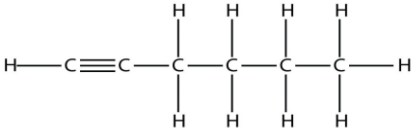
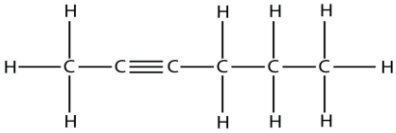
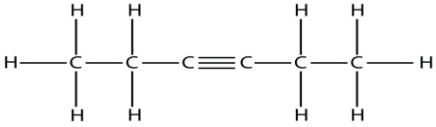
It is important to know that after propyne (C_3H_4), the triple bond between two carbon atoms (**C≡ C**) can be placed anywhere along the carbon chain, as long as each carbon atom has four bonds. You will be given few examples on this later on.

The table below shows the various formulas of the members of the alkyne homologous series, showing the position of the triple bond between the **first and the second carbon atoms.**

THE STRUCTURES OF ALKYNES HOMOLOGOUS SERIES

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Ethyne	C_2H_2	$CH \equiv CH$	
Propyne	C_3H_4	$CH \equiv CCH_3$	
But-1-yne (1-butyne)	C_4H_6	$CH \equiv CCH_2CH_3$	
Pent-1-yne (1-pentyne)	C_5H_8	$CH \equiv C(CH_2)_2CH_3$	

The table below shows examples of hexyne (C_6H_{10}) with three different positions of carbon to carbon triple bond.

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Hex-1-yne (1-hexyne)	C_6H_{10}	$CH \equiv C(CH_2)_3CH_3$	
Hex-2-yne (2-hexyne)	C_6H_{10}	$CH_3C \equiv C(CH_2)_2CH_3$	
Hex-3-yne (3-hexyne)	C_6H_{10}	$CH_3\,CH_2\,C \quad CCH_2CH_3$	

The different structures of hexyne.

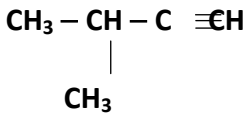
For alkynes, the triple bond between two carbon atoms can be placed anywhere along the carbon chain,as long as each carbon atom has four bonds.

Rules for Naming Alkynes

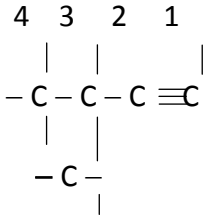
1. Find and draw the longest consecutive chain of carbon atoms that includes the triple bond, and name it as parent alkyne.
2. Name the chain as a surname.
3. Name any branch (side) chains as the alkyl group.
   - When there is more than one side chain, they are listed alphabetically.
   - If the same side chain occurs more than once, prefixes, di , tri , tetra and so on are used.
4. Number the chain from the end that gives the triple bond its smaller number.
5. In naming alkynes, the number and names are separated with the use of a hyphen (-), and any 2 numbers are separated by a comma (,), followed by the second side chain and so on.

Example 1

Name the compound with a side chain below.



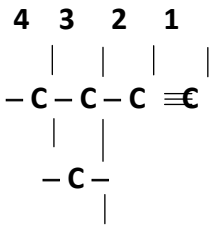
Step 1. Draw the longest carbon chain that contains the triple bond.



Step 2. Use the chain as a surname. Number the chain.

……1–butyne or but–1–yne

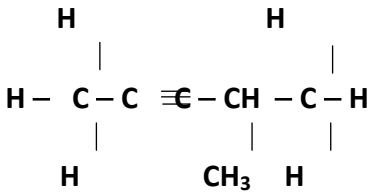
Step 3. Name and number any side chain, using the numbering system locating the position of triple bond.



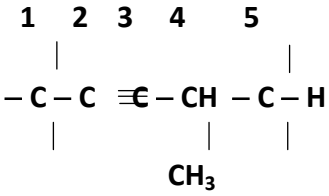
Step 4. The name is **3-methyl,1-butyne or 3-methyl but-1-yne**.

Example 2

The full structural formula for the compound $CH_3C{\equiv}CCH(CH_3)CH_3$ is drawn below:



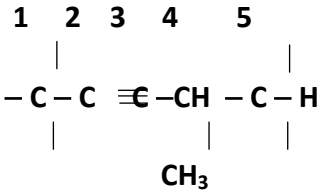
Step 1. Draw the longest carbon chain that contains the triple bond.



Step 2. Use the chain as a surname. Number the chain.

…… 2 –pentyne or pent-2-yne

Step 3. Name and number any side chain, using the numbering system locating the position of triple bond.



Step 4. The name of the compound is **4-methylpent-2-yne.**

Cycloalkynes

- Cycloalkynes are unsaturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n-4}}$.
  For example:
  Propene has 3 carbon atoms. Using the general formula for cycloalkene, $\mathbf{C_nH_{2n-4}}$. The molecular formula of cyclopropene is $\mathbf{C_3H_{2x3-4}} = \mathbf{C_3H_2}$. Its structural formula is shown in the table next page.
- They form a close carbon rings.

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 4

30 minutes

Answer the following questions.

1. Write down the molecular formula for the alkynes with:
   a. 4 carbon atoms.
   b. 6 carbon atoms.
   c. 10 carbon atoms.

---

2. Name the following alkynes.

   a. $H-C\equiv C-H$

   b. $CH_3-C\equiv C-H$ (with CH_3 branch on the second carbon)

   c. $CH_3-C\equiv C-C(Br)-CH_3$

---

3. Draw the compound cyclobutyne and write its molecular formula.

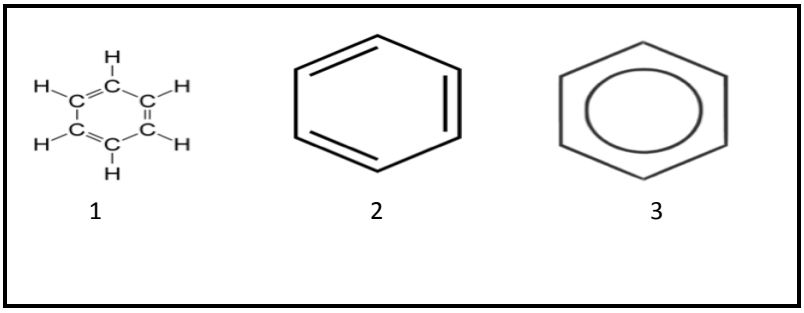
Thank you for completing your learning activity 4. Check your work. Answers are at the end of this module.

12.4.1.5 Benzene

Benzene is an organic aromatic compound that contains a benzene ring or has certain benzene-like properties. Unlike aliphatic (straight chain carbons) or other cyclic organic compounds, the structure of benzene allows them and its derived products to be useful in fields such as health and other applications such as rubber synthesis.

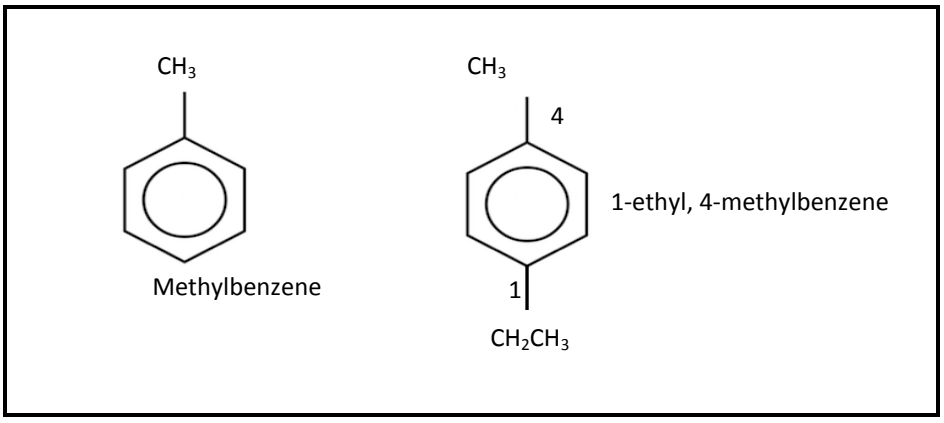
Benzene is a special type of ring molecule. It is a cyclic hydrocarbon that has the chemical formula **C_6H_6**. They are well known to be pleasantly fragrant. For this reason, organic compounds containing benzene rings were classified as being **"aromatic" (sweet smelling).**

The diagrams below, show the different structures of benzene.



Ways to represent benzene (C_6H_6)

The hydrogen atoms of benzene can be replaced by different alkyl groups forming substances such as methylbenzene and 1-ethyl,4-methylbenzene as seen in the diagrams below:



Properties of Benzene

- It boils at 80^{o}C rather higher than other hydrocarbons of similar molecular size (pentane and hexane for example).
- Its melting point is 5.5^{o}C.
- It is insoluble in water. Benzene is quite large compared with water molecule. In order for benzene to dissolve, it would have to break lots of existing hydrogen bonds between water molecules.
- It is resistant to addition reactions. Adding something new to the ring would need you to use some of the delocalized electron, to form bonds with whatever you are adding. Benzene mainly undergoes substitution reactions, replacing one or more hydrogen atoms by something new. That leaves the delocalised electrons as they were.

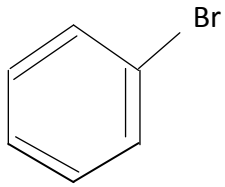
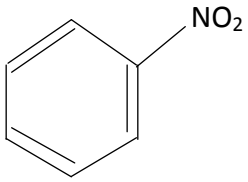
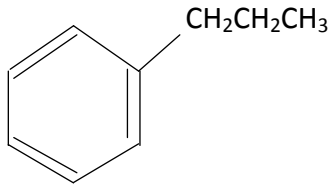
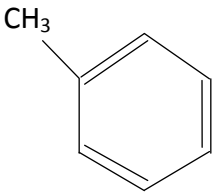
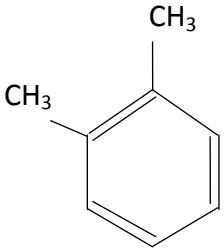
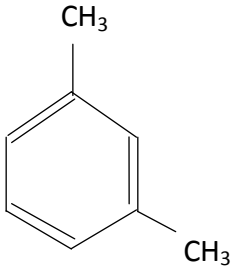
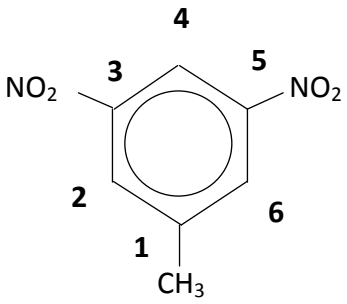
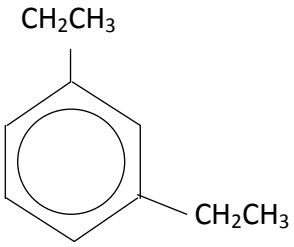
Characteristics of Benzene

- colourless liquid hydrocarbon.
- highly inflammable.
- cancer-causing (carcinogenic).
- simplest aromatic compound.
- less reactive than alkenes making them useful industrial solvents.
- characterize by a sooty yellow flame due to high ratio of carbon to hydrogen.

Naming Aromatic Compounds (Benzene with more substituents)

- If the alkyl chain is smaller than the ring, use the ring as the parent.
- Choose numbers for the lowest possible values.
- List group alphabetically (hyphenated between numbers).
- Common names, such as **toluene** can serve as root name (as in **TNT or trinitrotoluene**).

Examples of benzene compounds:

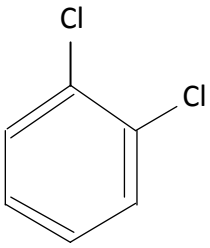
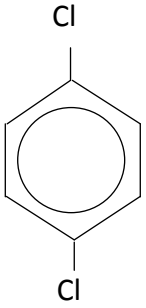
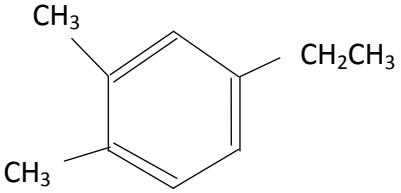
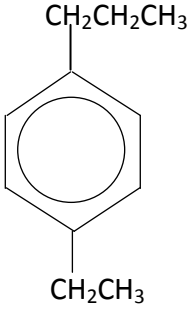
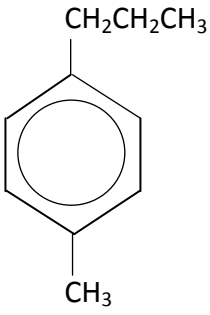
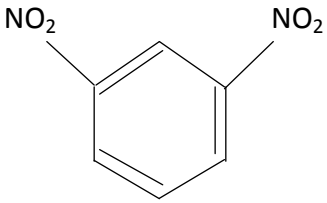
 bromobenzene	 nitrobenzene
 propylbenzene	 methylbenzene
 1,2-dimethylbenzene	 1,3-dimethylbenzene
 3,5-dinitromethylbenzene Nitro (NO_2) will take preference before any side chains.	 1,3-diethylbenzene

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 5 **40 minutes**

Answer the following questions.

1. Name the following benzene compounds.

a. 	b.  .....
c. 	d.  .....
e. 	f.  .....

2. Draw the structural formula of the following benzene compounds.

a. 1-ethyl,2-methylbenzene	b. 1-ethyl,3-methylbenzene
c. 1,2-diethylbenzene	d. 1-methyl,3-propylbenzene
e. 1,3-dipropylbenzene	f. ethylbenzene

3. Write two characteristics of benzene.
   (i) _____
   (ii) _____

Thank you for completing your learning activity 5. Check your work. Answers are at the end of this module.

12.4.1.6 Saturated and unsaturated hydrocarbons

The differences of saturated and unsaturated hydrocarbons:

Saturated hydrocarbons	Unsaturated hydrocarbons
• They are compounds of carbon and hydrogen where adjacent (end to end) carbon atoms contain only one carbon to carbon bond. . • The carbon and hydrogen bonds are single covalent bonds. • The four bonds of carbon atoms are fully utilized and no more hydrogen or other atoms are attached to it. • They can undergo only substitution reaction. • They are representative of open-chain aliphatic hydrocarbon called **alkanes**.	• They are compounds of carbon and hydrogen that contain one double covalent bond between carbon atoms or a triple covalent bond between carbon atoms. • All the bonds of carbon are fully utilized by hydrogen atoms and more of these can be attached to them. • They undergo addition reaction (add on hydrogen), as they have two or more hydrogen atoms less than alkanes (saturated hydrocarbons). • They are divided into alkenes and alkynes depending on the presence of double and triple bonds.

The differences of saturated and unsaturated hydrocarbons

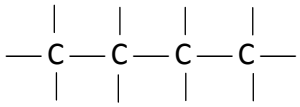
The table below shows the properties of saturated and unsaturated hydrocarbons

Saturated hydrocarbons	Unsaturated hydrocarbons
• They contain single carbon –carbon covalent bonds. • These compounds are less reactive due to the presence of all single covalent bonds. • Saturated compounds undergo substitution reactions. Example: methane + chlorine $\rightarrow$ chloromethane + hydrogen chloride $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ • The number of hydrogen atoms is more when compared to its corresponding unsaturated hydrocarbons.	• They contain at least one double or triple covalent bonds. • These compounds are more reactive due to the presence of double or triple covalent bonds. • Unsaturated compounds undergo addition reactions. Example: ethene + chlorine $\rightarrow$ 1,2-dichloroethane $C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$ • The number of hydrogen atoms is less when compared to its corresponding saturated hydrocarbons.

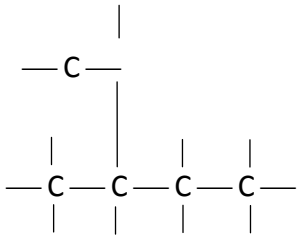
The chains of carbon atoms maybe linear (straight) or branched (open), or cyclic rings (close), sheets and three dimensional lattices (frameworks).

Examples:

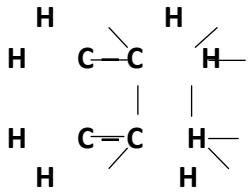
Linear chain



Branched chain

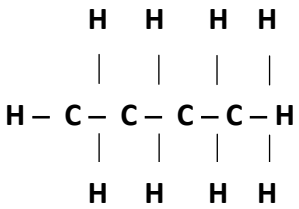
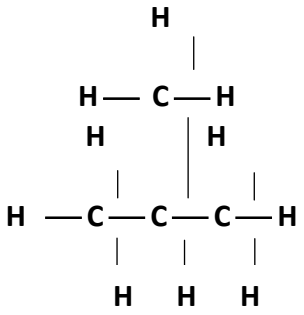


Cyclic ring

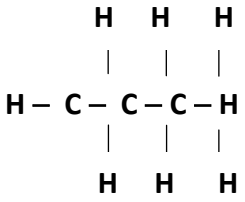
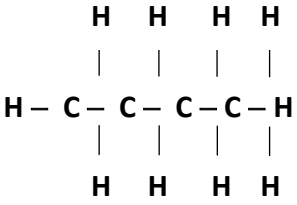


The compounds can be branched, when the carbon atoms are more than three like butane (C_4H_{10}) as shown in the examples below:

Butane, C_4H_{10}

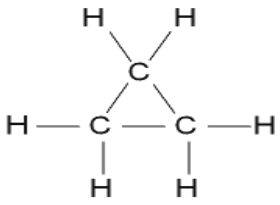
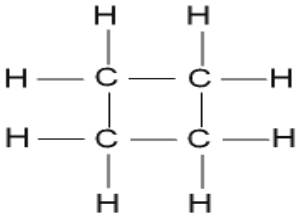
Linear chain	**Branched chain**
	

The table below, shows the **linear (straight) structures of alkanes (propane and butane)** as saturated hydrocarbons with single covalent bond between carbon atoms.

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Propane (3 carbon atoms)	C_3H_8	$CH_3CH_2CH_3$	
Butane (4 carbon atoms)	C_4H_{10}	$CH_3(CH_2)_2CH_3$	

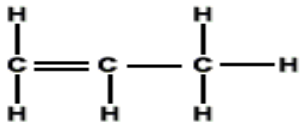
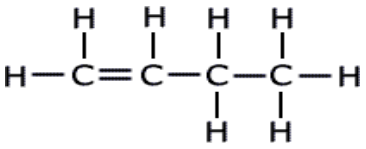
The linear structures of alkanes (propane and butane) as saturated hydrocarbons

The table below, shows examples of the **cyclic structures of alkanes (cyclopropane and cyclobutane)** as saturated hydrocarbons.

Name	Molecular Formula	Full Structural formula
Cyclopropane	C_3H_6	
Cyclobutane	C_4H_8	

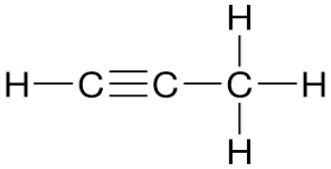
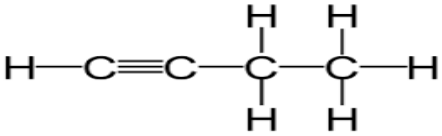
The cyclic structures of alkanes (cyclopropane and cyclobutane) as saturated hydrocarbons

The table below, shows the **linear (straight) structures of the alkene** homologous series **(propene and but-1-ene or 1-butene)** as unsaturated hydrocarbons with a double covalent bond between carbon atoms.

Name	Molecular Formula	Structural Formula	Full Structural Formula
Propene	C_3H_6	$CH_2=CH_2CH_3$	
But-1-ene (1-butene)	C_4H_8	$CH_2=(CH_2)_2CH_3$	

The linear structures of alkenes (propene and but-1-ene or 1- butane)as unsaturated hydrocarbons with double bonds between carbon atoms.

The table below, shows the **linear structures of alkynes** homologous series **(propyne and butyne)** as unsaturated hydrocarbons with triple covalent bonds between carbon atoms.

Name	Molecular Formula	Structural Formula	Full Structural Formula
Propyne	C_3H_4	$CH \equiv CCH_3$	
But-1-yne (1-butyne)	C_4H_6	$CH \equiv CCH_2CH_3$	

The linear structures of alkynes (propyne and but-1-yne or 1- butyne) as unsaturated hydrocarbons showing the triple covalent bonds between carbon atoms.

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 6

40 minutes

Answer the following questions.

1. Define:
   (i) saturated hydrocarbon

   _____

   (ii) unsaturated hydrocarbon

   _____

---

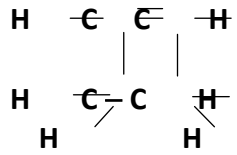
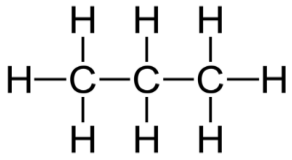
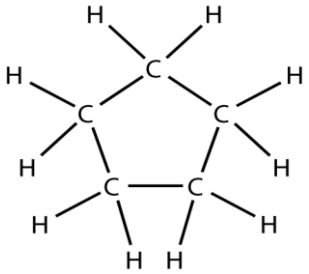
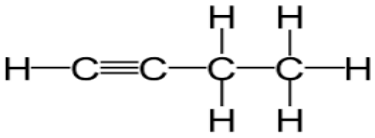
2. Identify the following lists of hydrocarbons as saturated or unsaturated.
   (i) pentane _____
   (ii) butyne _____
   (iii) ethene _____
   (iv) cyclohexane _____
   (v) cyclopropyne _____
   (vi) cyclopentyne _____

---

3. Write the properties of saturated and unsaturated hydrocarbons.

Saturated hydrocarbon	Unsaturated hydrocarbon
(i)	(i)
(ii)	(ii)
(iii)	(iii)
(iv)	(iv)

4. Name the following hydrocarbon compounds.

a.  ……	**b.**  ……
c.  ……	**d.**  ……

Thank you for completing your learning activity 6. Check your work. Answers are at the end of this module.

12.4.1.7 Combustion of alkanes and alkenes

Alkanes and alkenes are both families of hydrocarbons. Alkanes are useful as fuels and alkenes are used, to make chemicals such as plastics. Both hydrocarbons go through combustion reactions to release energy in the form of heat and light. About 21% of the air is oxygen.

There are **two types of combustion reactions** based on the amount of oxygen:
1. Complete combustion
2. Incomplete combustion

Complete combustion
Complete combustion needs a **plentiful supply of air** so that elements in the fuel react completely with oxygen. Fuels such as natural gas and petrol contain hydrocarbons which are compounds of hydrogen and carbon only.

When hydrocarbons burn completely:
(i) The carbon oxidises to carbon dioxide.
(ii) The hydrogen oxidises to water (remember the water, H_2O, is an oxide of hydrogen).

General equation form for complete combustion:

hydrocarbon + **oxygen** → **carbon dioxide** + **water**

Incomplete combustion
Incomplete combustion occurs when the supply of **air or oxygen is poor**. Water is still produced, but **carbon monoxide** is produced instead of carbon dioxide. The presence of glowing carbon particles in a flame turns it yellow, and black carbon is visible in the smoke. Carbon monoxide is produced as a colourless poisonous gas, which is one reason why complete combustion is preferred to incomplete combustion.

As a simple way of thinking about it, the hydrogen in the hydrocarbon gets the first chance at the oxygen, and the carbon gets whatever is left over. The **carbon** is released as soot.

General equation form for incomplete combustion:

hydrocarbon + **oxygen** → **carbon monoxide** + **water**

Why carbon monoxide is poisonous?
Oxygen is carried around the blood by haemoglobin. Unfortunately, carbon monoxide binds to exactly the same site on the haemoglobin that oxygen does. The difference is that carbon monoxide binds permanently, making that particular molecule of haemoglobin useless for carrying oxygen. If you breathe in enough carbon monoxide, you will die from a sort of internal suffocation.

Combustion reactions of alkanes and alkenes
In general, alkanes and alkenes are highly flammable. They undergo combustion reaction. Alkanes burn in plentiful of oxygen to release energy to produce carbon dioxide and water. If oxygen supply is restricted, both alkanes and alkenes will produce a poisonous gas, carbon monoxide and water.

Incomplete combustion is more common with alkenes. Alkenes have a higher ratio of carbon to hydrogen than what is found in alkanes. Some of the carbon cannot be oxidised properly, thus, forming soot.

The following chemical equations are examples of **complete combustion of alkanes:**

1. methane + oxygen → carbon dioxide + water
   CH_4 + $2O_2$ → CO_2 + $2H_2O$

2. ethane + oxygen → carbon dioxide + water
   $2C_2H_6$ + $7O_2$ → $4CO_2$ + $6H_2O$

3. propane + oxygen → carbon dioxide + water
   C_3H_8 + $5O_2$ → $3CO_2$ + $4H_2O$

4. butane + oxygen → carbon dioxide + water
   $2C_4H_{10}$ + $13O_2$ → $8CO_2$ + $10H_2O$

The following chemical equations are examples of **incomplete combustion of alkanes**:

1. methane + oxygen → carbon monoxide + water
   $2CH_4$ + $3O_2$ → $2CO$ + $4H_2O$

2. ethane + oxygen → carbon monoxide + water
   $2C_2H_6$ + $5O_2$ → $4CO$ + $6H_2O$

3. propane + oxygen → carbon monoxide + water
   $2C_3H_8$ + $7O_2$ → $6CO$ + $8H_2O$

4. butane + oxygen → carbon monoxide + water
   $2C_4H_{10}$ + $9O_2$ → $8CO$ + $10H_2O$

Can you write the chemical equations for the **complete and incomplete combustion** of the remaining members of the **alkane homologous series**?

The following chemical equations are examples of **complete combustion of alkenes**:

1. ethene + oxygen → carbon dioxide + water
   C_2H_4 + $3O_2$ → $2CO_2$ + $2H_2O$

2. propene + oxygen → carbon dioxide + water
   $2C_3H_6$ + $9O_2$ → $6CO_2$ + $6H_2O$

3. butene + oxygen → carbon dioxide + water
   C_4H_8 + $6O_2$ → $4CO_2$ + $4H_2O$

The following chemical equations are examples of **incomplete combustion of alkenes**:

1.	ethene	+	oxygen	→	carbon monoxide	+	water
	C_2H_4	+	$2O_2$	→	2CO	+	$2H_2O$
2.	propene	+	oxygen	→	carbon monoxide	+	water
	C_3H_6	+	$3O_2$	→	3CO	+	$3H_2O$
3.	butene	+	oxygen	→	carbon monoxide	+	water
	C_4H_8	+	$4O_2$	→	4CO	+	$4H_2O$

Can you write the chemical equations for the **complete and incomplete combustion** of the remaining members of the **alkene homologous series**?

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 7

40 minutes

Answer the following questions:

1. Give the meaning of:

a. Complete combustion

_____
_____
_____
_____

b. Incomplete combustion.

_____
_____
_____
_____

2. Give the use of:
   (i) alkane _____
   (ii) alkene _____

---

3. Write a balanced equation for the complete combustion of pentane. States are not required.

_____

4. Write a complete balanced equation for the incomplete combustion of pentane. States are not required.

_____

5. Write a complete balanced equation for the complete combustion of octane. States are not required.

_____

6. Write a complete balanced equation for the incomplete combustion of decane. States are not required.

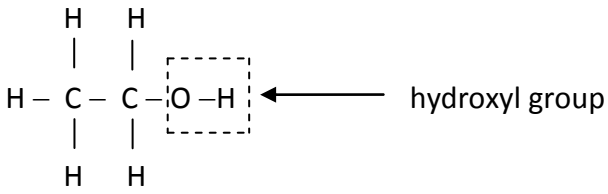
_____

Thank you for completing your learning activity 7. Check your work. Answers are at the end of this module.

12.4.2 Alcohol

All alcohol belong to a family of organic compounds that contain the **–OH group** of atoms. This group of atoms is called the **hydroxyl group**, which gives the alcohol its specific chemical properties. It is called the **functional group of alcohols**.

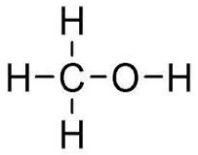
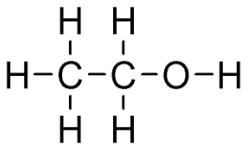
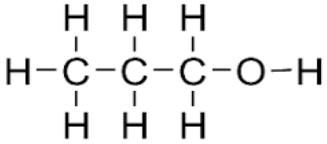
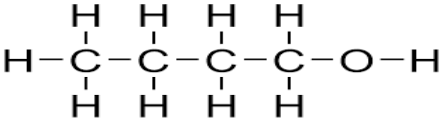
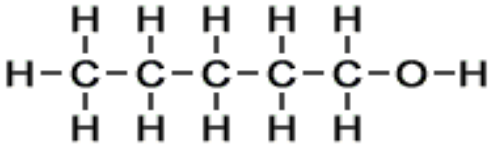
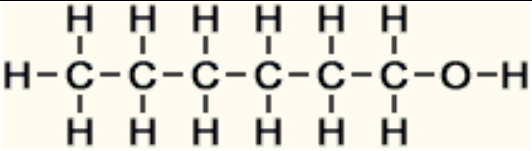
An example of ethanol (with 2 carbon atoms) is given below, showing the –OH functional group of alcohol.

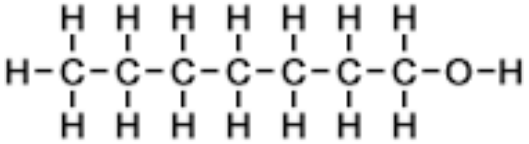


The name of each alcohol in the homologous series is derived from the corresponding alkane by replacing the letter **e** in **-ane** to **-ol**. For example, methane to methanol and ethane to ethanol. They have low melting points and boiling points.

The members of the alcohol homologous series have the following features:
(i) They have the general formula: $\mathbf{C_nH_{2n+1}OH}$.
(ii) They have a hydroxyl functional group **-OH**.
(iii) Their names end with **-ol**.
(iv) The formula of each member differs from the previous one by a $-CH_2$.

STRUCTURES OF THE FIRST SEVEN MEMBERS OF ALCOHOL

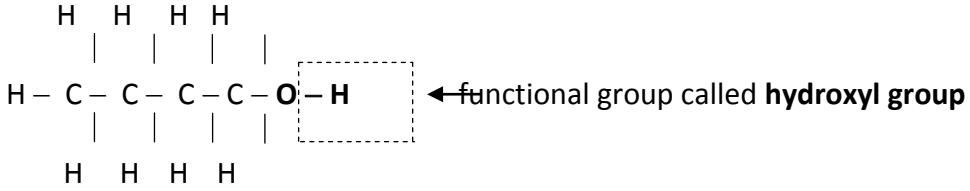
Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Methanol (1 carbon atom)	CH_3OH	CH_3OH	
Ethanol (2 carbon atoms)	C_2H_5OH	CH_3CH_2OH	
Propanol (3 carbon atoms)	C_3H_7OH	$CH_3(CH_2)_2OH$	
Butanol (4 carbon atom)	C_4H_9OH	$CH_3(CH_2)_3OH$	
Pentanol (5 carbon atoms)	$C_5H_{11}OH$	$CH_3(CH_2)_4OH$	
Hexanol (6 carbon atoms)	$C_6H_{13}OH$	$CH_3(CH_2)_5OH$	

Heptanol (7 carbon atoms)	$C_7H_{15}OH$	$CH_3(CH_2)_6OH$	

Chemical Properties of Alcohol

(i) Alcohol contains the –OH group but they are not alkalis. In fact, they are neutral.

(ii) Alcohol is more reactive than alkanes because the **C – O and O – H bonds** in alcohols is more reactive than the **C – C and C – H bonds** in alkanes.



Characteristics of Alcohols

- Alcohol is very soluble in water, but their solubility decreases as the molecular sizes increases. For example, methanol is very soluble in water, but butanol is only slightly soluble in water.
- Unlike the first four alkanes and alkenes (gases at room temperature), the first four alcohol is liquid at room temperature and pressure.
- All alcohol has similar chemical properties. Alcohols can take part in these combustion and oxidation reactions.

How is the combustion of alcohols useful to us?

Alcohols can be used as a fuel. Some of the race cars run on methanol. Methanol is less volatile (less explosive) than petrol. It is less likely to explode in an accident. Methanol is also a clean fuel. It does not produce soot on combustion. Do you think it is good to use alcohol as a fuel instead? Alcohol is also burnt on some foods such as fruit cake to give it a distinct flavour.

Useful alcohol:

- Ethanol is a constituent of alcoholic beverages such as wines and whisky.
- Ethanol is used widely as a solvent in paints, varnishes, liquid soap, and other toiletries.
- Ethanol is blended with petrol and used as a fuel for motorcars in many countries. It is better than petrol, because it does not produce other harmful gases other than carbon dioxide and water vapour.

- Ethanol can be oxidised into ethanoic acid that is used to manufacture plastic and drugs.

Naming Alcohols

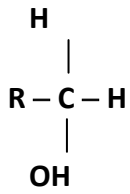
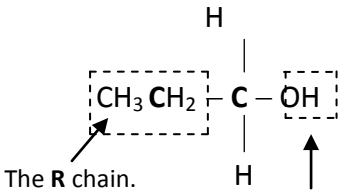
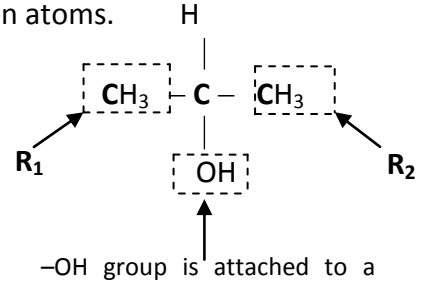
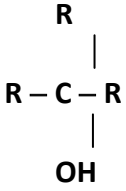
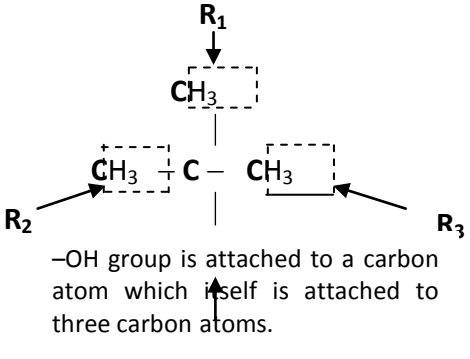
Steps	Example
Step 1. Identify the parent chain. This is the longest chain with the –OH group attached.	CH_3 $\mathbf{CH_3 - CH - CH - CH_3}$ OH Parent chain has 4 carbon atoms. The name is **butanol**.
Step 2. Identify the branch chain(s).	$\mathbf{CH_3}$ ← The branched chain is **methyl.** $CH_3 - CH - CH - CH_3$ OH
Step 3. Number the chain so that the –OH group has the lowest possible number. Give the position of the branch(es).	Branched chain in carbon 3 → $\mathbf{CH_3}$ 4 **3** 2 1 $CH_3 - CH - CH - CH_3$ **OH** ← -OH group in carbon 2
Step 4. Write the full name as: Branched position, hyphen, branched name, parent name, hyphen,-OH position, hyphen then ol.	The name of the alcohol compound is **3-methylbutan-2-ol**

Steps in naming alcohol

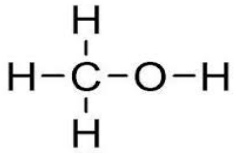
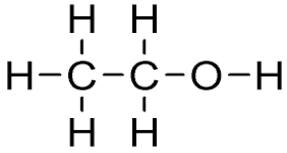
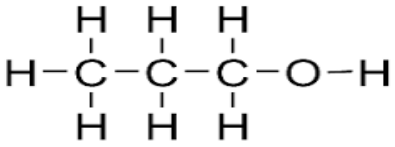
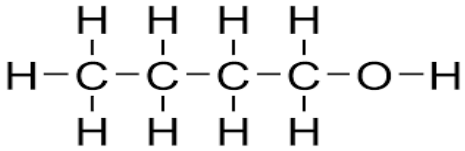
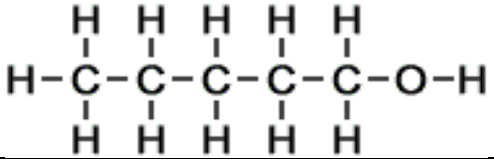
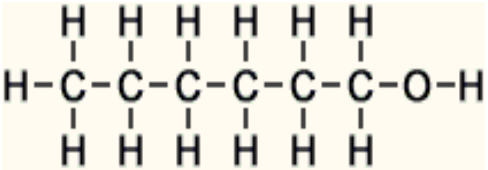
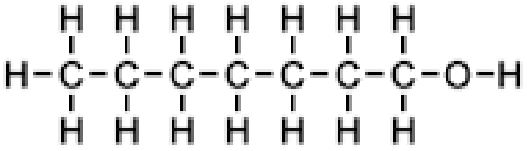
12.4.2.1 Types of alcohol

Alcohol is classified depending on the number of carbon atoms attached to the carbon atom to which the – OH group is attached.

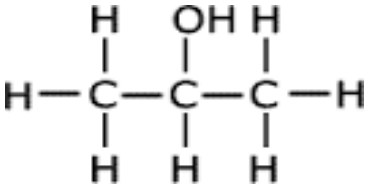
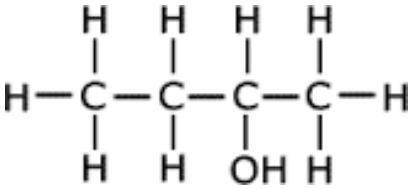
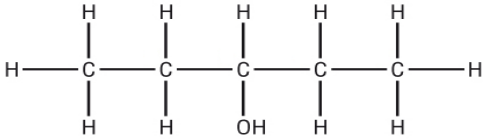
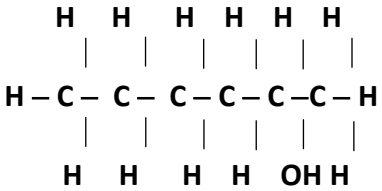
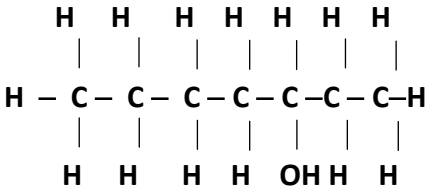
THE NAMING OF PRIMARY, SECONDARY AND TERTIARY ALCOHOLS

Types of Alcohols	Examples
Primary alcohol is one in which the carbon atom with the –OH group is attached to one other carbon atom. Its general formula is **RCH_2OH**. ***R*** is a chain of hydrocarbon. **General structural formula:**  	**Propan-1-ol ($CH_3CH_2CH_2OH$)** is a primary alcohol, since the – OH group is attached to a carbon atom which itself is attached to only one carbon atom. The – OH group is at the end of the chain. 
Secondary alcohol is one in which the carbon atom with the –OH group is attached to two other carbon atoms. Its general formula is **R_2CHOH** or **RCHOHR** .***R*** is a chain of hydrocarbons. **General structural formula:**  	**Propan-2-ol ($CH_3CH(OH)CH_3$)** is a secondary alcohol, since the –OH group is attached to a carbon atom which itself is attached to two carbon atoms. 
ertiary alcohol is one in which the carbon atom with the –OH group is attached to three other carbon atoms. Its general formula is **R_3COH** or ***R*** is a chain of hydrocarbon. **General structural formula:**  	**Methylpropan-2-ol ($CH_3C(CH_3)OHCH_3$)** is a tertiary alcohol, since the –OH group is attached to a carbon atom which itself is attached to three carbon atoms. 

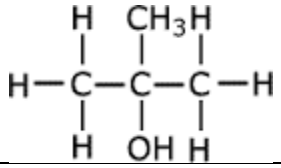
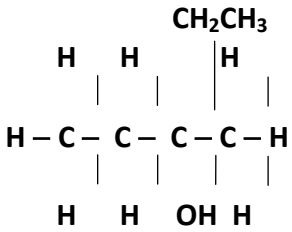
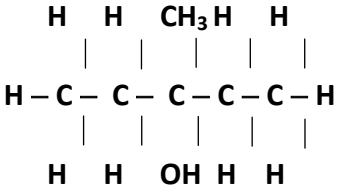
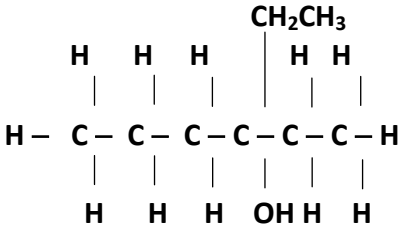
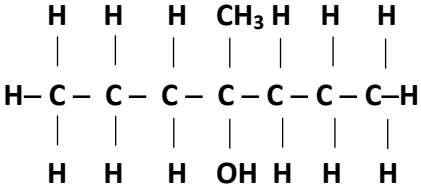
THE PRIMARY ALCOHOL OF CARBON 1 TO 7

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Methanol	CH_3OH	CH_3OH	
Ethan-1-ol	C_2H_5OH	CH_3CH_2OH	
Propan-1-ol	C_3H_7OH	$CH_3CH_2CH_2OH$	
Butan-1-ol	C_4H_9OH	$CH_3(CH_2)_3OH$	
Pentan-1 ol	$C_5H_{11}OH$	$CH_3(CH_2)_4OH$	
Hexan-1-ol	$C_6H_{13}OH$	$CH_3(CH_2)_5OH$	
Heptan-1-ol	$C_7H_{15}OH$	$CH_3(CH_2)_6OH$	

THE SECONDARY ALCOHOL OF CARBON 1 TO 7

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Propan-2-ol	C_3H_7OH	$CH_3CH(OH)CH_3$	
Butan-2-ol	C_4H_9OH	$CH_3CH_2CH(OH)CH_3$	
Pentan-3- ol	$C_5H_{11}OH$	$CH_3CH_2CH(OH)CH_2CH_3$	
Hexan-2-ol	$C_6H_{13}OH$	$CH_3(CH_2)_3CH(OH)CH_3$	
Heptan-3-ol	$C_7H_{15}OH$	$CH_3(CH_2)_3CH(OH)CH_2CH_3$	

THE TERTIARY ALCOHOL OF CARBON 1 TO 7

Name	Condensed Structural Formula	Full Structural Formula
2-methylpropan-2-ol	$CH_3C(CH_3)OHCH_3$	
2-ethylbutan-2-ol	$CH_3CH_2C(CH_2CH_3)OHCH_3$	
3-methylpentan-3-ol	$CH_3CH_2C(CH_3)OHCH_3$	
3-ethylhexan-3-ol	$CH_3(CH_2)_2C(CH_2CH_3)OHCH_2CH_3$	
4-methylheptan-2-ol	$CH_3(CH_2)_2C(CH_3)OHCH_2CH_3$	

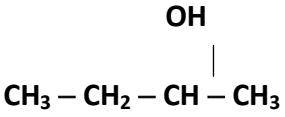
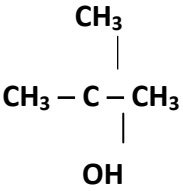
Now, check what you have just learnt by trying out the learning activity below!

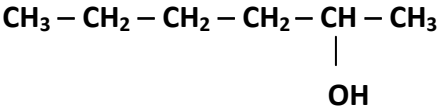
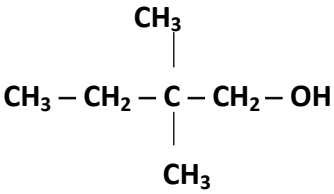
Learning Activity 8

60 minutes

Answer the following questions.

1. Name each of the following alcohol:

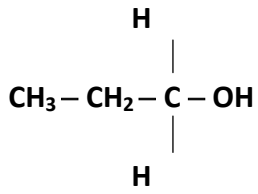
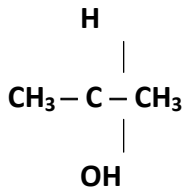
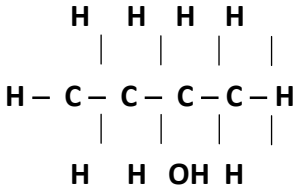
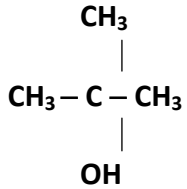
a. 	**b.**  .....
c. 	**d.**  .....

e. 	**f.**  .....

2. Draw the condensed structural formulas of the following:

a. 2- methylpropan-1-ol	b. 3-methylbutan-2-ol
c. methanol	d. 3,4-dimethylpentan-2-ol

3. Identify each as primary, secondary or tertiary alcohol:

a.  ……	**b.**  ……
c.  ……	**d.**  ……

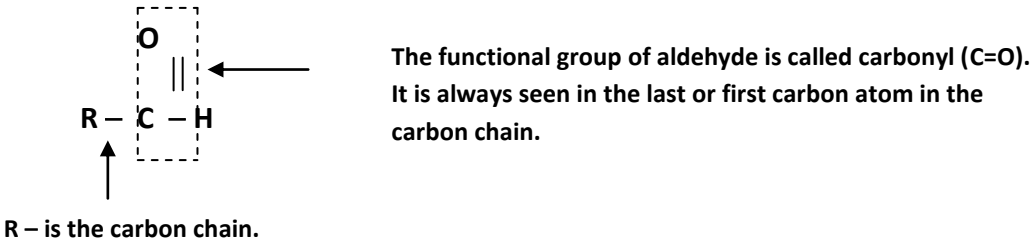
Thank you for completing your learning activity 8. Check your work. Answers are at the end of this module.

12.4.3 Aldehydes (Alkanals)

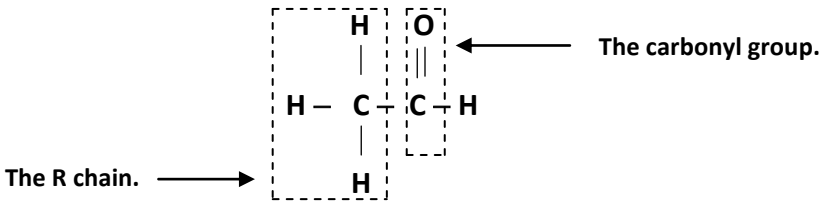
Aldehydes are organic chemical compounds. The general formula for the aldehydes also called **alkanals** is **RCHO** (where **R** is the carbon chain).

The functional group is **C=O** or **carbonyl group** (an oxygen atom that attached to a carbon atom by a double covalent bond) and a hydrogen atom attached to the same carbon atom as is attached to the carbonyl group. The carbonyl group must always be attached to the **first** or **last carbon atom** in the chain of hydrocarbon. It distinguishes aldehydes or alkanals from a similar category of organic compounds called **ketones**.

The general structural formula for aldehyde is shown below:



Ethanal as an aldehyde with two carbon atoms has the structural formula shown below:



Names of aldehydes in general

Aldehydes are named according to the same system as other organic compounds, with the suffix **–al** used to designate the presence in the molecule of a carbonyl group, functional group of aldehydes (that is, a **carbon atom is attached to an oxygen atom with a double covalent bond**), and a single hydrogen atom, rather than a second chain of carbon atoms attached to a carbon atom, at the end of the chain of carbon atoms.

The exception to this rule is **formaldehyde** (also known as **methanal**), the first member of aldehyde, because there is only one single carbon atom in the molecule, hence, the carbonyl group, C=O is found **"at the end of a chain of carbon atoms".**

Ethanal being based on a chain of two carbon atoms, **propanal** being based on a chain of three carbon atoms, **butanal** being based on the chain of four carbon atoms, and so on.

The first step to consider, when working out the name of an aldehyde molecule, is the number of carbon atoms forming a chain. If they are attached together in a linear (unbranched) chain, then the number of carbon atoms is indicated according to the same system as used in naming alkanes.

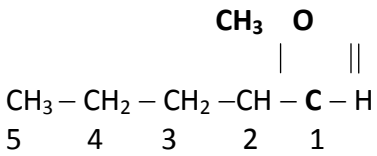
If the carbon atoms do not form a linear chain but include branches, the longest linear chain of carbon atoms within the molecule, determines the name of the compound, followed by naming the branches (for example, **methyl** which usually indicates a branch consisting of just **one carbon atom** attached to the main chain or **ethyl,** which indicates a branch of **two carbon atoms** in length) and their positions along the longest linear carbon chain (for example, attached to the second carbon atom, third carbon atom, and so on).

Here are simple IUPAC rules for naming aldehydes:

- The stem names of aldehyde (and ketones also) are derived from those of the parent alkanes, defined by the longest continuous chain (LCC) of carbon atoms, that contains the functional group.
- For an aldehyde, drop the –e from the alkane name and add the ending –**al**. The International Union of Pure and Applied Chemistry (IUPAC) name for m**ethanal** is formaldehyde and for **ethanal** is acetaldehyde.
- To indicate the position of a branch chain of an aldehyde, the **carbonyl** carbon atoms are always considered to be $\mathbf{C_1}$ or located in the **first carbon atom**. It is unnecessary to designate this group by number.

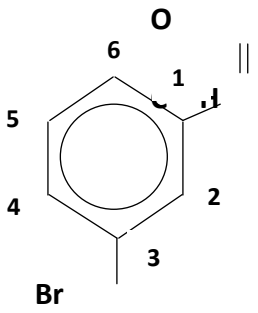
Examples:

1. In the compound below:



- There are five carbon atoms in the longest continuous chain (LCC).
- The **methyl group CH_3** as a branch chain is located on the **second carbon atom** (from the right) of the chain.
- The aldehyde carbon atom which is the **functional carbonyl group** is **always C_1**.
- The name is derived from **pentane** because it has 5 carbon atoms in the chain.
- Dropping the **–e** and adding the ending **–al** gives **pentanal**.
- The methyl group on the second carbon atom makes the name **2-methylpentanal.**

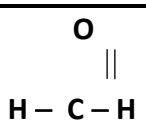
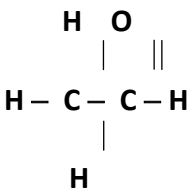
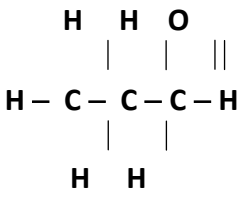
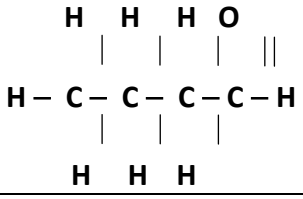
2. You can also use the benzene ring to name an aldehyde compound like the one below:

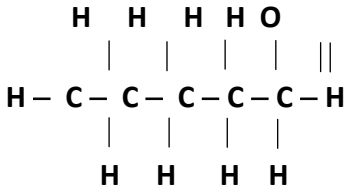
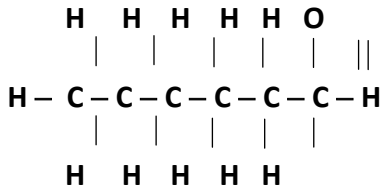
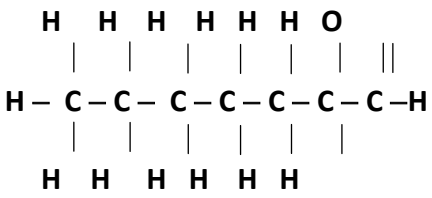


Since the carbonyl group will be designated as C_1, then, the counting will be clockwise. The name of the compound is **3-bromobenzaldehyde**.

12.4.4.1 Aldehydes of one to seven carbon chain

THE ALDEHYDES (CARBON 1-7) AND THEIR STRUCTURES

Number of carbon atoms in chain	Name and simple formula	Simple structure
1	Methanal (CH_2O) or HCOH	
2	Ethanal (C_2H_4O) or CH_3COH	
3	Propanal (C_3H_6O) or CH_3CH_2COH	
4	Butanal (C_4H_8O) or $CH_3(CH_2)_2COH$	

5	Pentanal ($C_5H_{10}O$) or $CH_3(CH_2)_3COH$	
6	Hexanal ($C_6H_{12}O$) or $CH_3(CH_2)_4COH$	
7	Heptanal ($C_7H_{14}O$) or C $H_3(CH_2)_5COH$	

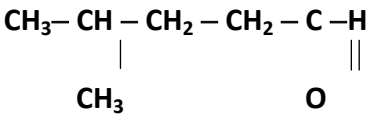
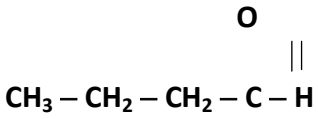
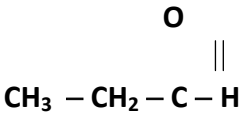
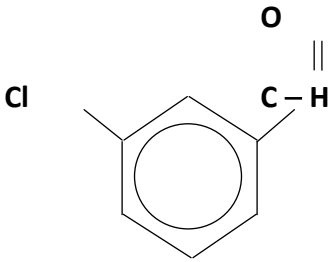
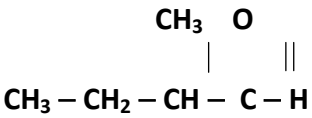
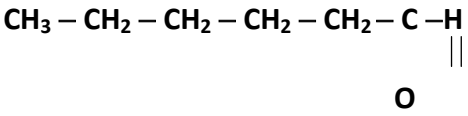
Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 9

60 minutes

Answer the following questions:

1. Name the following aldehyde compounds:

a. 	**b.**  .....
c. 	**d.**  .....
e. 	**f.**  .....

2. Draw the following aldehyde compounds:

a. pentanl	b. 3-methylbutanal
c. benzaldehyde	d. heptanal

3. What is the name of the functional group of aldehyde? _____

4. What is the other name for aldehyde group? _____

5. Where can you find the aldehyde's functional group in the longest chain of carbon atoms? _____

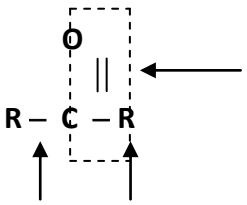
Thank you for completing your learning activity 9. Check your work. Answers are at the end of this module.

12.4.4 Ketones

Ketones also called **alkanone with** the general formula of **RCOR**. **R** is the chain of carbon. They are organic chemical compounds that include a **carbonyl group (an oxygen atom attached to a carbon atom by a double covalent bond)** like the aldehyde group. Their names end in **–one.**

The carbonyl group is attached to any carbon atom in the chain except in the **first or the last carbon atom** which means that, the **carbonyl group (C = O**) is found in the **middle of the carbon chain.** Unlike the aldehyde, the carbonyl group is attached only to the first carbon atom in the chain of carbons.

The general structural formula for ketone is shown below:



The functional group of ketone is called carbonyl (C=O). It is always seen in the middle carbon atom in the carbon chain.

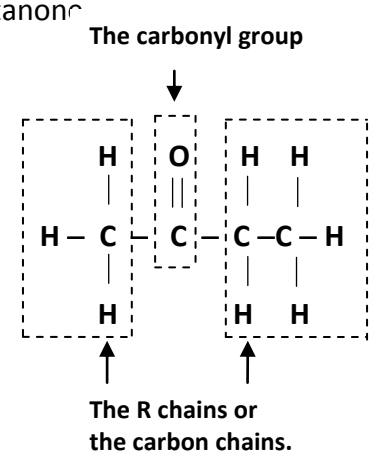
R – is the carbon chain.

The following examples below are all representations of butanone with a **carbonyl group attached to a second carbon atom.**

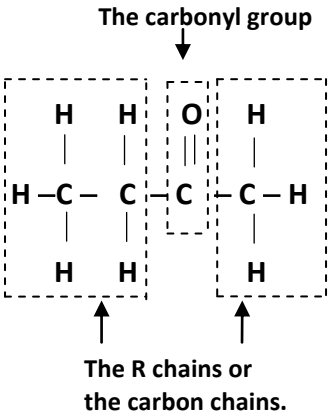
Note: Carbon atoms are counted from the right side of molecules but these structures could equally have been drawn the other way around, with carbon atoms counted from the left-side.

The diagrams below, are equivalent and both represent the same structure of 2- butanone.

2 - butanone

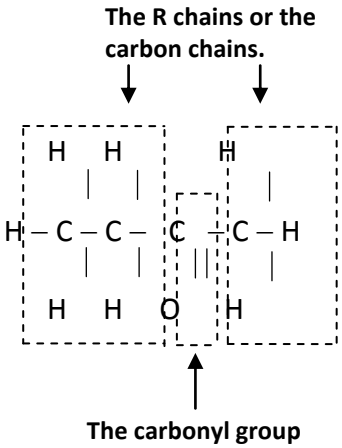


2 – butanone

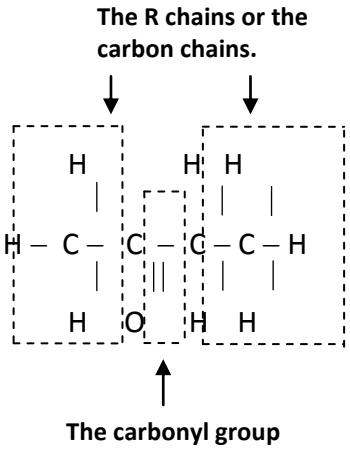


Likewise the following two representations are also equivalent ways of drawing the same structure of 2-butanone as those represented previously:

2 - butanone



2 - butanone



Names of Ketones in General

The first step to consider when working out the name of ketone molecule, is the number of carbon atoms forming the longest straight chain within the molecule. Having identified the longest unbranched carbon chain within the molecules in terms of the number of carbon atoms in the chain, the main stem of the name of the chemical is as per the system used for naming alkanes.

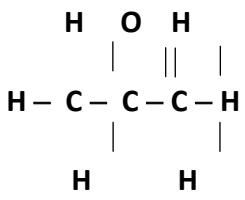
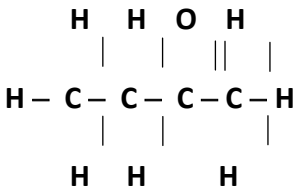
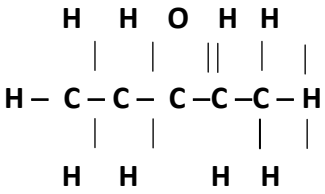
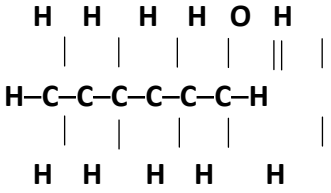
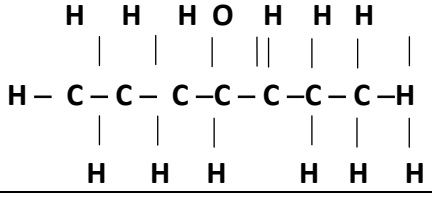
If the carbon atoms do not form a linear (straight) chain but include branches, the longest linear chain of carbon atoms within the molecules determines the name of the compound, followed by naming the branches.

Summary of Naming Ketones

- Ketones take their names from their parent alkane chains. The ending **–e** is removed and replaced with **–one**.
- A ketone carbonyl function maybe located anywhere within a chain or ring and its position is usually given by a location number.
- Chain numbering normally starts from the end nearest the carbonyl group.
- The attached alkyl group are arranged in the name alphabetically.

12.4.4.1 Ketones of Three to Seven Carbon Chain

THE STRUCTURES OF KETONES (CARBON 3 TO 7)

Name and simple formula	Simple structure
2-propanone CH_3COCH_3	
2-butanone $CH_3CH_2COCH_3$	
3-pentanone $CH_3CH_2COCH_2CH_3$	
2-hexanone $CH_3CH_2CH_2\ CH_2COCH_3$	
4-heptanone $CH_3CH_2CH_2COCH_2CH_2CH_3$	

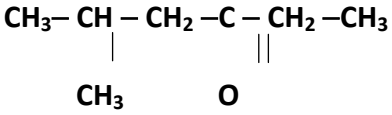
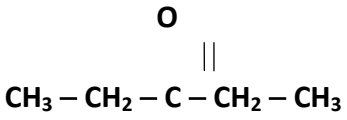
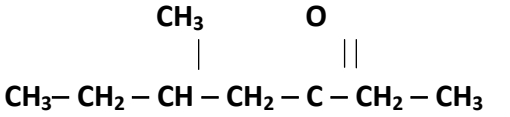
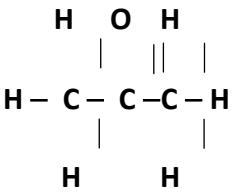
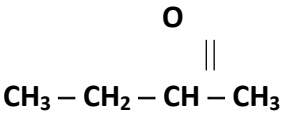
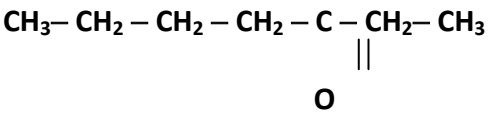
Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 10

60 minutes

Answer the following questions:

1. Name the following ketone compounds:

a.  ……	**b.**  ……
c.  ……	**d.**  ……
e.  ……	**f.**  ……

2. Draw the following ketone compounds:

a. 3- hexanone	b. 3-methyl-2-pentanone
c. 3-pentanone	d. 4-propyl -3-hexanone

3. What is the name of the functional group of Ketone? _____

4. What is the other name for Ketone group? _____

5. Where will you find the Ketone's functional group in the longest chain of carbon atoms? _____

Thank you for completing your learning activity 10. Check your work. Answers are at the end of this module.

12.4.5 Carboxylic Acids and Esters

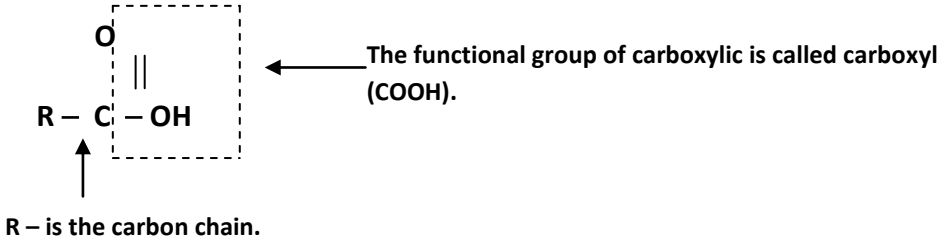
What are carboxylic acids?

The carboxylic acid is also called **alkanoic acid**. They are homologous series of organic compounds with the **carboxyl functional group** that is reactive. For simplicity, the functional group is often written as **–COOH**. Carboxylic acids are weak acids. They are a class of organic acids.

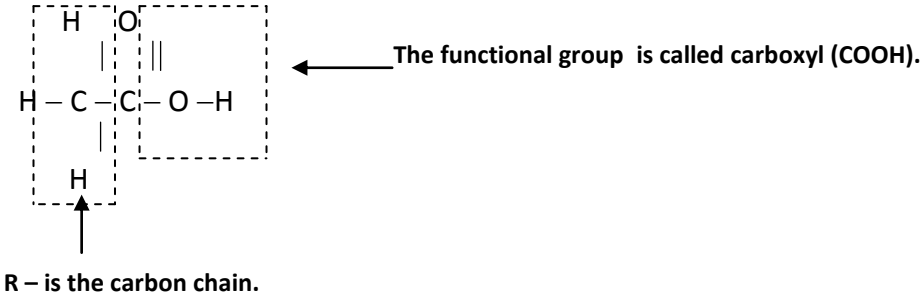
What is the general formula of carboxylic acids?

The general formula of carboxylic acids is written as **RCOOH**. **R** is the carbon chain**.**

The general structural formula for carboxylic acid is shown below:

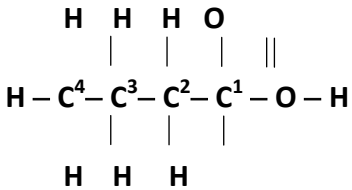


Ethanoic acid is an example of a carboxylic acid and has the structural formula shown below:



Naming Carboxylic Acid

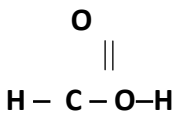
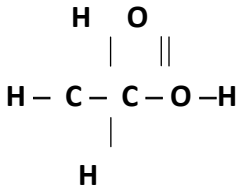
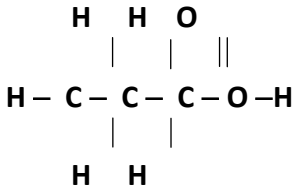
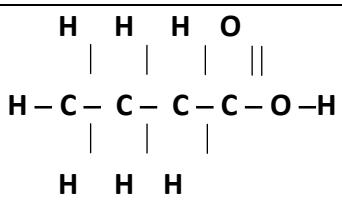
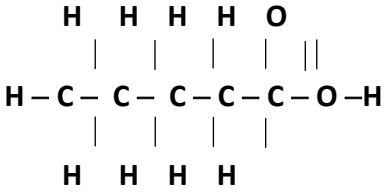
- Number the longest carbon chain starting with the number of carbon atom of the -COOH functional group.

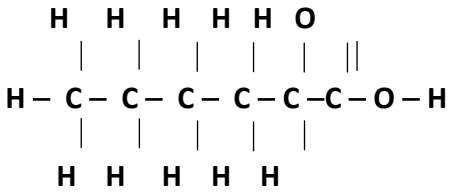
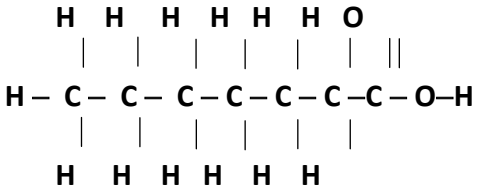


- Number the carbon atom as the alkane. For example, if one carbon atom as meth, 2 as eth, 3 as prop and so on.
- Drop the **–e** from the name of the alkane. For example, **butane** becomes **butan**.
- Add the suffix **-oic acid**. For example, **butan** becomes **butanoic acid**.

2.4.5.1 Carboxylic acid of One to Seven Carbon Chain

THE STRUCTURES OF CARBOXYLIC ACIDS (CARBON 1 TO 7)

Number of carbon atoms in chain	Name and Simple formula	Simple structure
1	Methanoic acid HCOOH	
2	Ethanoic acid CH_3COOH	
3	Propanoic acid CH_3CH_2COOH	
4	Butanoic acid $CH_3(CH_2)_2COOH$	
5	Propanoic acid $CH_3(CH_2)_3COOH$	

6	Hexanoic acid $CH_3(CH_2)_4COOH$	
7	Heptanoic acid $CH_3(CH_2)_5COOH$	

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 11

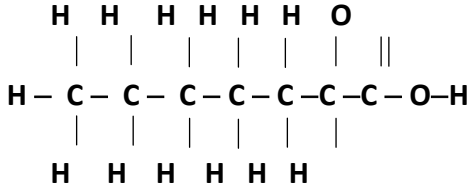
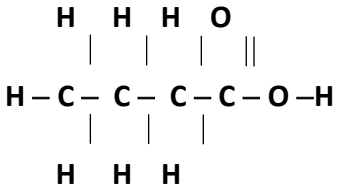
30 minutes

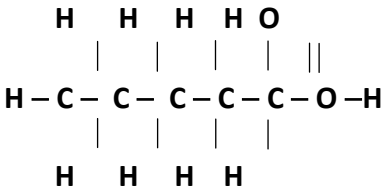
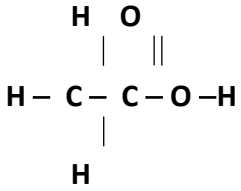
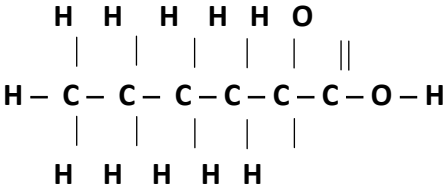
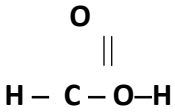
Answer the following questions.

1. Write the name and formula for the functional group of carboxylic acid.
   Name _____ Formula _____

2. What the name of the 5th carboxylic acid? _____

3. Name the following carboxylic acids.

a. 	**b.**  .....

c.  ……	**d.**  ……
e.  ……	**f.**  ……

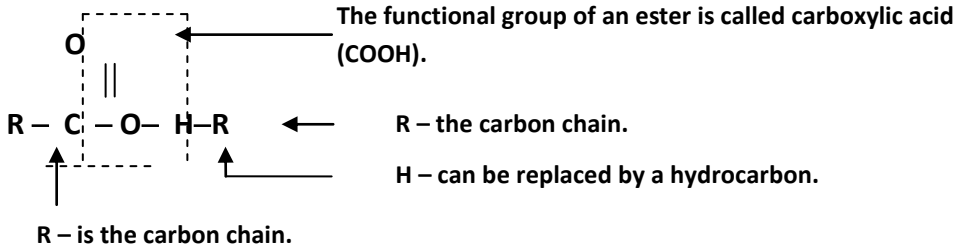
Thank you for completing your learning activity 11. Check your work. Answers are at the end of this module.

12.4.5.2 Esters Made from Acids and Alcohols

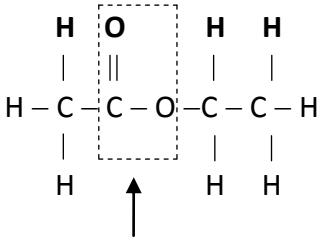
What are esters?

A carboxylic acid group is a compound with a general formula of **RCOOHR**. **R** is the carbon chain. When a carboxylic acid reacts with an alcohol, an organic compound that will form called an **ester**. This reaction is called **esterification**. Esters are derived from carboxylic acids. A carboxylic acid contains the **–COOH group**. In an ester, the **hydrogen in this group is replaced by a hydrocarbon group of some kind.**

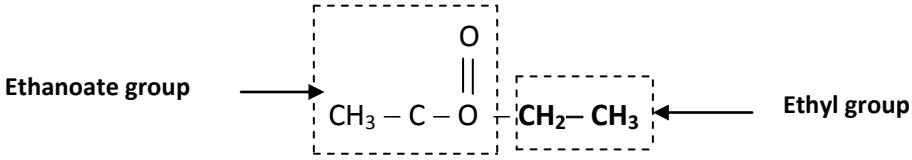
The general structural formula for carboxylic acid is shown below:



The functional group of a common ester, **ethyl ethanoate ($CH_3(COO)CH_2CH_3$)** is shown below:



In the above structural formula, the **hydrogen** in the –COOH group (from the functional group) has been replaced by an **ethyl group**.
The condensed structural formula for **ethyl** ethanoate is:



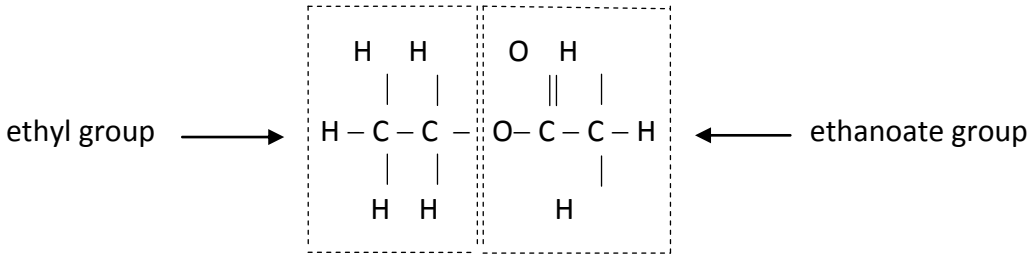
Note: **Read the ethyl group first before the carboxylic group**. Notice that the ester is named the opposite way around from the way the formula is written. The **'ethanoate' (CH_3COO^-)** comes from the **ethanoic acid.** The **'ethyl'** comes from the **ethyl group** on the end.

How do we name an ester?
The name of an ester consists of two parts.

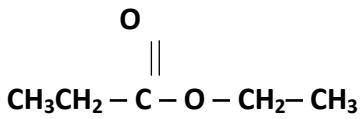
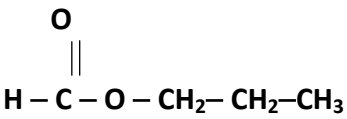
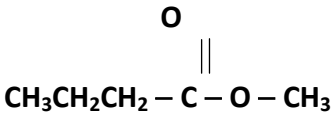
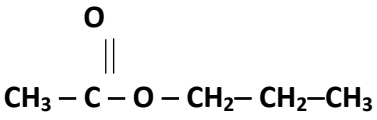
For example:

ethyl ethanoate

The first part tells us that the alcohol, ethanol, was used to prepare the ester.	The second part tells us that the carboxylic acid, ethanoic acid, was used to prepare the ester.



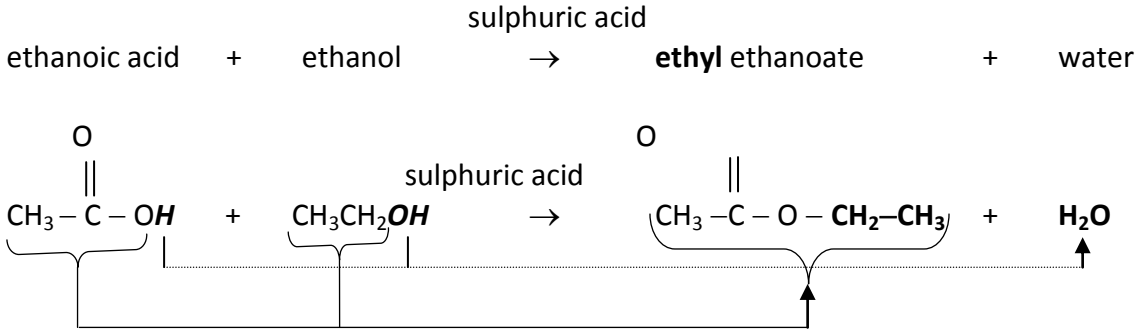
Some examples of esters:

 **ethyl propanoate**	 **propyl methanoate**
 **methyl butanoate**	 **propyl ethanoate**

Making esters from carboxylic acids and alcohols

Esters are produced when carboxylic acids are heated with alcohols in the presence of an acid catalyst. The catalyst is usually concentrated sulphuric acid (H_2SO_4).

So, for example, if you are making **ethyl ethanoate from ethanoic acid and ethanol** with sulphuric acid as a catalyst, the equation would be:



From the above equation it shows that:

- **Ethanoate (CH_3COO)** from ethanoic acid will combine with **ethyl (CH_3CH_2)**from ethanol to form **ethyl ethanoate ($CH_3COOCH_2CH_3$)**.
- The **hydrogen (H)** from ethanoic acid and the **hydroxide (OH)** from ethanol will combine for **water (H_2O).**

The table below, shows the names of some common esters, together with the alcohol and carboxylic acid used to prepare them.

Name of ester	Structural formula	Alcohol used	Carboxylic acid used
ethyl ethanoate	$CH_3COOCH_2CH_3$	ethanol	ethanoic acid
methyl ethanoate	CH_3COOCH_3	methanol	ethanoic acid
ethyl methanoate	$HCOOCH_2CH_3$	ethanol	methanoic acid

Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 12

30 minutes

Answer the following questions.

1. What is an ester?

   _____

2. Draw the condensed structural formulas of the following esters.

a. methyl butanoate	b. propyl propanoate
c. pentyl methanoate	d. butyl ethanoate
e. ethyl methanoate	f. ethyl butanoate

Thank you for completing your learning activity 12. Check your work. Answers are at the end of this module.

12.4.5.3 Amines

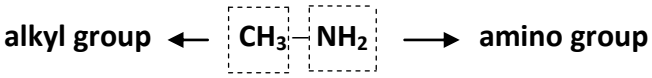
What are amines?

Amines are derivatives of ammonia in which one or more of the hydrogen atoms has been replaced by an alkyl group. The naming of amines is complicated by the fact that several different naming systems exist, and there is no clear preference for one over the others. The terms primary, secondary and tertiary are used to classify amines in a completely different manner, than they were used for alcohols or alkyl halides. When applied to amines, these terms refer to the number of alkyl substituents bonded to the nitrogen atom, whereas in other cases, they refer to the nature of an alkyl group.

Amines fall into different classes depending on how many of the hydrogen atoms are replaced.

Primary amines

In primary amines, only one of the hydrogen atoms in the ammonia molecule (NH_3) has been replaced. That means that the formula of the primary amine will be **RNH_2** where **"R"** is an alkyl group.



Examples include:

$CH_3 - NH_2$ methylamine or methanamine or aminomethane	$CH_3 - CH_2 - NH_2$ ethylamine or ethanamine or aminoethane	$CH_3 - CH_2 - CH_2 - NH_2$ propylamine or propanamine or aminopropane	$CH_3 - \underset{\displaystyle NH_2}{\underset{\vert}{CH}} - CH_3$ 2-aminopropane

Naming amines can be quite confusing because there are so many variations on the names. For example, the simplest amine, **CH_3-NH_2**, can be called **methylamine**, **methanamine**, or **aminomethane**. **The commonest name at this level is methylamine**.

Where there might be confusion about where the **$-NH_2$ (amino group)** is attached to a chain, the simplest way of naming the compound is to use the **"amino"** form.

For example:

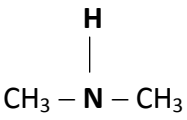
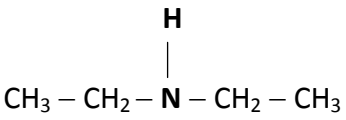
- $CH_3 - CH_2 - CH_2 - NH_2$ is called **1-aminopropane**.
- $CH_3 - \underset{\displaystyle NH_2}{\underset{\vert}{CH}} - CH_3$ is called **2- aminopropane**.

Secondary amines

In a secondary amine, two of the hydrogens in an ammonia molecule (NH_3) have been replaced by hydrocarbon groups. That means that the formula of the secondary amine will be **RNHR** where **"R"** is an alkyl group.

At this level, you are only likely to come across simple ones where both of the hydrocarbon groups are alkyl groups and both are the same.

For example:

 dimethylamine	 diethylamine

There are other alternatives on the names, but this is the commonest and simplest way of naming these small secondary amines.

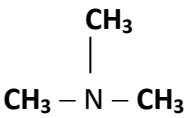
Tertiary amines

In tertiary amine, all of the hydrogen atoms in ammonia molecule (NH_3) have been replaced by hydrocarbon groups. That means that the formula of the secondary amine will be **RNRR** or **RRNR** where **"R"** is an alkyl group.

Again, you are only likely to come across simple ones where all three of the hydrocarbon groups are alkyl groups and all three are the same.

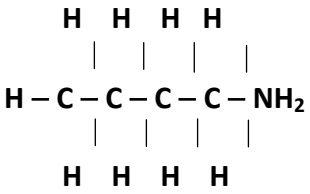
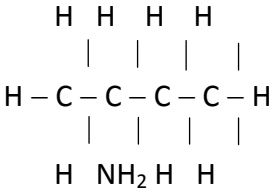
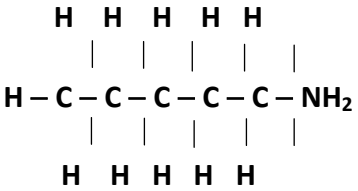
The naming is similar to secondary amines.

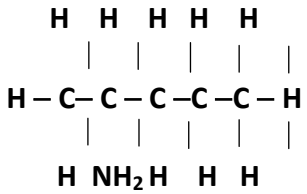
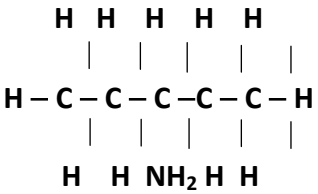
For example:



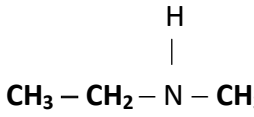
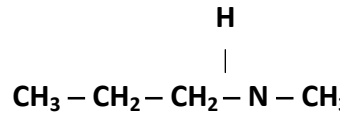
This is called **trimethylamine** because there are 3 methyl groups**.**

STRUCTURES OF SOME PRIMARY AMINES

Names of Primary Amine	Structural Formula
1-aminobutane (butylamine)	 ○ NH_2 or amino group is located in the first carbon atom. ○ There are 4 carbon atoms. ○ The name is **1-aminobutane or butylamine.**
2-aminobutane	 ○ NH_2 or amino group is located in the second carbon atom. ○ There are 4 carbon atoms. ○ The name is **2-aminobutane.**
1-aminopentane (pentylamine)	 ○ NH_2 or amino group is located in the second carbon atom. ○ There are 5 carbon atoms. ○ The name is **1-aminobutane or pentylamine.**

2-aminopentane	 ○ NH_2 or amino group is located in the second carbon atom. ○ There are 5 carbon atoms. ○ The name is **2–aminobutane.**
3-aminopentane	 ○ NH_2 or amino group is located in the third carbon atom. ○ There are 5 carbon atoms. ○ The name is **3–aminobutane.**

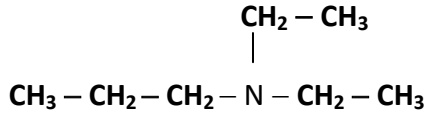
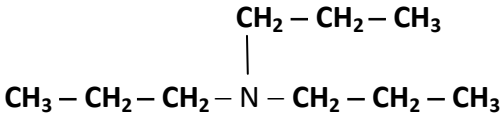
STRUCTURES OF SOME SECONDARY AMINES

Names of Secondary Amine	Structural Formula
ethylmethylamine	 ○ From ammonia (NH_3), 2 hydrogen atoms are replaced by alkyl groups. ○ The 2 alkyl groups in alphabetical order are: ethyl (CH_2CH_3) and methyl (CH_3). ○ The name is **ethylmethylamine**.
methylpropylamine	 ○ From ammonia (NH_3), 2 hydrogen atoms are replaced by alkyl groups. ○ The 2 alkyl groups in alphabetical order are: methyl (CH_3) and propyl ($CH_2CH_2CH_3$). ○ The name is **methypropylamine**.

ethylpropylamine	**H** | **$CH_3 - CH_2 - CH_2 - N - CH_2 - CH_3$** ○ From ammonia ($NH_3$), 2 hydrogen atoms are replaced by alkyl groups. ○ The 2 alkyl groups in alphabetical order are: ethyl (CH_2CH_3) and propyl ($CH_2CH_2CH_3$). ○ The name is **ethylpropylamine**.
dipropylamine	H | **$CH_3 - CH_2 - CH_2 -$** N **$- CH_2 - CH_2 - CH_3$** ○ From ammonia (NH_3), 2 hydrogen atoms are replaced by alkyl groups. ○ The 2 alkyl groups are both propyl ($CH_2CH_2CH_3$). ○ The name is **dipropylamine**.

STRUCTURES OF SOME TERTIARY AMINES

Names of Tertiary Amine	Structural Formula
trimethylamine	**CH_3** | **CH_3** – N – **CH_3** ○ From ammonia (NH_3), 3 hydrogen atoms are replaced by alkyl groups. ○ The 3 alkyl groups are all methyl (CH_3). ○ The name is **trimethylamine**.
triethylamine	**$CH_2 - CH_3$** | **$CH_3 - CH_2$** – N – **$CH_2 - CH_3$** ○ From ammonia (NH_3), 3 hydrogen atoms are replaced by alkyl groups. ○ The 3 alkyl groups are all ethyl (CH_2CH_3). ○ The name is **triethylamine**.

diethylpropylamine	 ○ From ammonia (NH_3), 3 hydrogen atoms are replaced by alkyl groups. ○ The 3 alkyl groups are all 2 ethyl (CH_2CH_3) and 1 propyl ($CH_2CH_2CH_3$). ○ The name is **diethypropylamine**.
Tripropylamin e	 ○ From ammonia (NH_3), 3 hydrogen atoms are replaced by alkyl groups. ○ The 3 alkyl groups are all propyl ($CH_2CH_2CH_3$). ○ The name is **tripropylamine**.

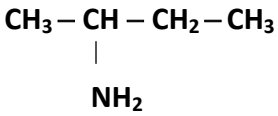
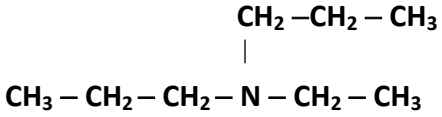
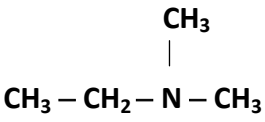
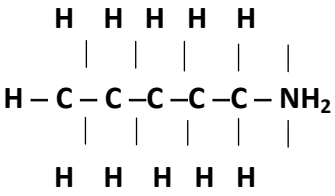
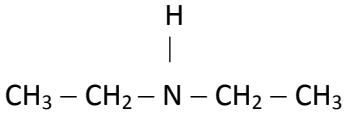
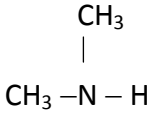
Now, check what you have just learnt by trying out the learning activity below!

Learning Activity 13

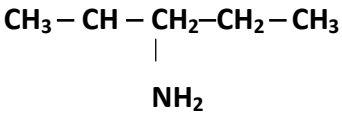
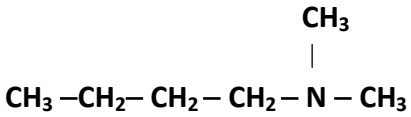
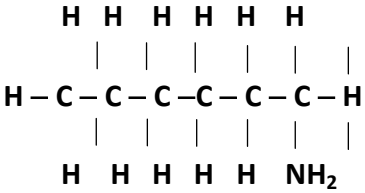
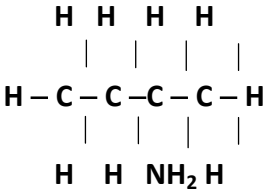
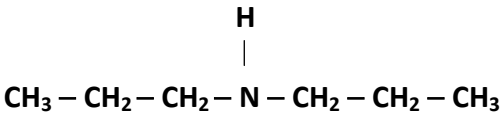
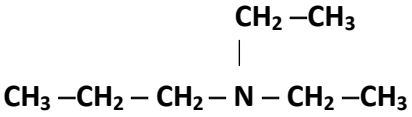
30 minutes

Answer the following questions.

1. Classify the following organic compounds as primary, secondary or tertiary amine.

a. 	**b.**  .....
c. 	**d.**  .....
e. 	f.  .....

2. Name the following amines below:

a.  …….	**b.**  …….
c.  …….	**d.**  …….
e.  …….	**f.**  …….

Thank you for completing your learning activity 13. Check your work. Answers are at the end of this module.

REVISE WELL USING THE MAIN POINTS ON THE NEXT PAGE.

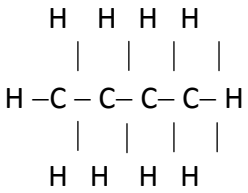
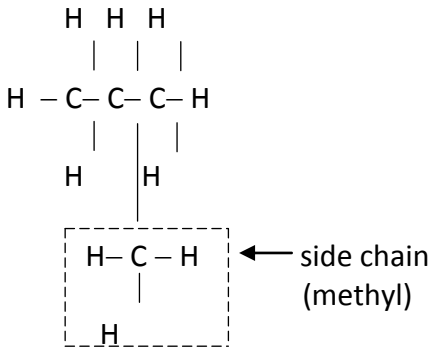
Summary

You will now revise this module before doing Assessment 5. Here are the main points to help you revise. Refer to the module topic if you need more information.

- **Organic compounds** contain carbon and often contain hydrogen, oxygen, and nitrogen as well.

- A **hydrocarbon** is an organic compound containing only hydrogen and carbon. It has two types:
  - **Aliphatic hydrocarbons** are also known as **non-aromatic compounds**. Their carbon atoms can be joined in straight chains, branched chains, or non- aromatic rings. Alkanes, alkenes, and alkynes belong to aliphatic compounds. Methane is the simplest aliphatic compound.
  - **Aromatic hydrocarbons** are also called **arene**. They have alternating double and single bonds between carbon atoms forming rings. Benzene is the simplest example of aromatic hydrocarbon.

- **Structural formula** is the formula which shows how atoms are arranged in a molecule.
- **Full structural formula** shows all the bonds between atoms and molecules.
- **Isomers** are compounds that have the same molecular formula, but different structural formula.
  For example:

Butane (C_4H_{10})	2 – methyl propane (iso –butane)
	

- A **homologous series** is a family of organic compounds that can be represented by a general formula. It has the same functional group or similar structures, and exhibits similar chemical properties. The examples of homologous series are **alkanes, alkenes, alcohols, and carboxylic acids.**

-

- The name of organic compound is divided into two parts. The **prefix** indicates the number of carbon atoms in each molecule and the **suffix** identifies the homologous series.

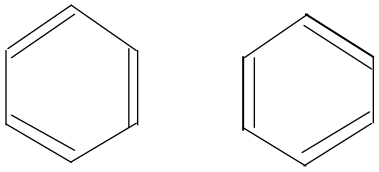
- The **alkanes** are a homologous series with the following characteristics:
  - They have the general formula $\mathbf{C_nH_{2n+2}}$.
  - heir names end in **-ane.**
  - The carbon atoms are joined by **single covalent bonds.**
  - They are saturated.
  - Each member of the alkane homologous series differs by a $–CH_2$ unit.

- **Cycloalkanes** are saturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n}}$**.**
- The **alkenes** are a family of hydrocarbons which have the following characteristics:
  - They have general formula $\mathbf{C_nH_{2n}}$.
  - Their names end in **-ene.**
  - There is a carbon to carbon **double bond** in a molecule as their functional group.
  - They are unsaturated as the double bond can open up and other atoms can be added to the molecule.
  - They can exist as branched or unbranched hydrocarbons.

- **Cycloalkenes** are unsaturated hydrocarbons with the general molecular formula $\mathbf{C_nH_{2n-4}}$.They form a close ring.

- The **alkynes** are another family of hydrocarbons with the following characteristics:
  - They have the general formula $\mathbf{C_nH_{2n-2}}$.
  - Their names end with **-yne.**
  - There is a carbon to carbon **triple bond** (its functional group) present in a molecule.
  - They are said to be unsaturated as other atoms can be added to the molecule, when the carbon to carbon triple bond opens up.

- **Benzene** is an organic aromatic compound that contains a benzene ring. It is a cyclic hydrocarbon that has the chemical formula $\mathbf{C_6H_6}$. The two ways of drawing the structure of benzene is:



- The characteristics of benzene are:
  - colourless liquid hydrocarbon
  - highly inflammable
  - cancer-causing (carcinogenic)
  - simplest aromatic compound

- less reactive than alkenes making them useful industrial solvents
- characterize by a sooty yellow flame due to high ratio of carbon to hydrogen

- The differences of saturated and unsaturated hydrocarbons are:

Saturated hydrocarbons	Unsaturated hydrocarbons
• They are compounds of carbon and hydrogen where adjacent (end to end) carbon atoms contain only one carbon – carbon bond. • The carbon hydrogen bonds are single covalent bonds. • The four bonds of carbon atoms are fully utilized and no more hydrogen or other atoms are attached to it. • They can undergo only substitution reaction. • They are representative of open –chain aliphatic hydrocarbon called alkanes.	• They are compounds of carbon and hydrogen that contain one double covalent bond between carbon atoms or a triple covalent bond between carbon atoms. • All the bonds of carbon are fully utilized by hydrogen atoms and more of these can be attached to them. • They undergo addition reaction (add on hydrogen), as they have two or more hydrogen atoms less than alkanes (saturated hydrocarbons) • They are divided into alkenes and alkynes, depending on the presence of double and triple bonds.

- The properties of saturated and unsaturated hydrocarbons are:

Saturated hydrocarbons	Unsaturated hydrocarbons
• They contain single carbon –carbon covalent bonds. • These compounds are less reactive due to the presence of all single covalent bonds. • Saturated compounds undergo substitution reactions. Example: methane + chlorine → chloromethane + hydrogen chloride $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ • The number of hydrogen atoms is more, when compared to its corresponding unsaturated hydrocarbons.	• They contain at least one double or triple covalent bonds. • These compounds are more reactive due to the presence of double or triple covalent bonds. • Unsaturated compounds undergo addition reactions. Example: ethene + chlorine → 1,2-dichloroethane $C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$ • The number of hydrogen atoms is less when compared to its corresponding saturated hydrocarbons.

- **Complete combustion** needs plentiful supply of air, so that elements in the fuel react fully with oxygen.

hydrocarbon + oxygen → carbon dioxide + water

- **Incomplete combustion** occurs when the supply of air or oxygen is poor.

  hydrocarbon + oxygen → carbon monoxide + water

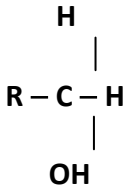
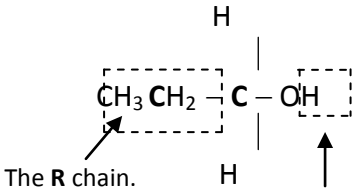
- **Polyunsaturated oils** are made up of molecules with two or more carbon to carbon double bonds. They are liquids at room temperature, and are better for health. Examples are sunflower oil, olive oil, and soya oil.

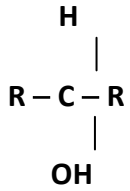
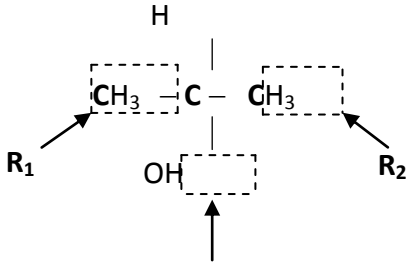
- **Saturated oils and fats** do not contain carbon to carbon double bonds. They are solid at room temperature and are unhealthy in the diet. Examples are fats, butter, and cream.

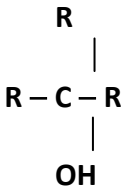
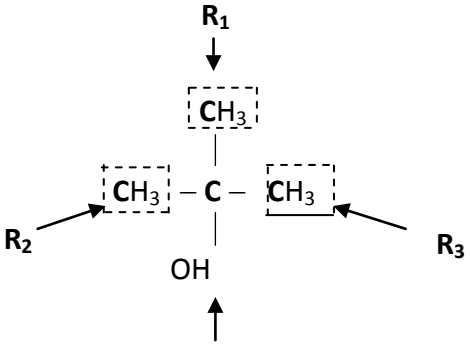
- The **alcohol** homologous series has the following features.
  - They have the general formula **$C_nH_{2n+1}OH$**.
  - They have hydroxyl functional group, **-OH**.
  - Their names end in **-ol**.

- The most important alcohol is **ethanol (C_2H_5OH)** which is a colourless liquid. It is used in alcoholic drinks, as a solvent and as a fuel.

- The types of alcohol are:

Types of Alcohols	Examples
Primary alcohol is one in which the carbon atom with the –OH group is attached to one other carbon atom. Its general formula is **RCH_2OH** . ***R*** is a chain of hydrocarbon. **General structural formula:**  	**Propan-1-ol ($CH_3CH_2CH_2OH$)** is a primary alcohol, since the – OH group is attached to a carbon atom which itself is attached to only one carbon atom. The –OH group is at the **end of the chain.** 
Secondary alcohol is one in which the carbon atom with the –OH group is attached to two other carbon atoms. Its general formula is **R_2CHOH** or **RCHOHR** .***R*** is a chain of hydrocarbons.	**Propan-2-ol ($CH_3CH(OH)CH_3$)** is a secondary alcohol, since the –OH group is attached to a carbon atom which itself is attached to two carbon atoms.

<table>
<tr>
<td>General structural formula:
  </td>
<td> 
–OH group is attached to a carbon atom which itself is attached to two carbon atoms.</td>
</tr>
<tr>
<td>Tertiary alcohol is one in which the carbon atom with the –OH group is attached to three other carbon atoms. Its general formula is R_3COH or R is a chain of hydrocarbon.

General structural formula:
  </td>
<td>Methylpropan-2-ol ($CH_3C(CH_3)OHCH_3$) is a tertiary alcohol, since the –OH group is attached to a carbon atom which itself is attached to three carbon atoms.
 
–OH group is attached to a carbon atom which itself is attached to three carbon atoms.</td>
</tr>
</table>

- **Aldehydes** are also called **alkanals** with the following characteristics:
  - They have the general molecular formula of **RCHO.**
  - Their names end in **-al.**
  - The functional group is carbon double bond with oxygen called **carbonyl group.**
  - The carbonyl group must always be attached to the **first or last carbon atom** in the chain of hydrocarbon.

- **Methanal** is the simplest aldehyde.

- **Ketones** are also called **alkanones** with the following characteristics:
  - They also have a carbonyl group like aldehydes that is attached in the **middle carbon of the hydrocarbon chain.**
  - Their names end in **-one**.
  - Their general formula is **RCOR**.

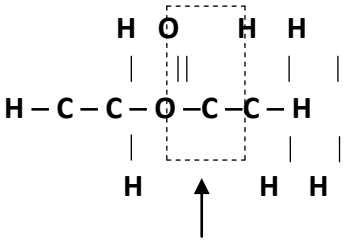
- The **carboxylic acid (alkanoic acid)** homologous series has the following characteristics:

- They have the general formula **RCOOH.**
- They have an acid functional group, **-COOH.**
- Their names end with **-oic.**

- **Esterification** is a process when a carboxylic group reacts with an alcohol.

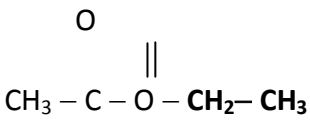
- **Esters** are derived from carboxylic acids. They formed when a carboxylic acid is reacted with an alcohol. A carboxylic acid contains the –COOH group and in ester the hydrogen in this group is replaced by a hydrocarbon group.

  - The functional group of an ester is:

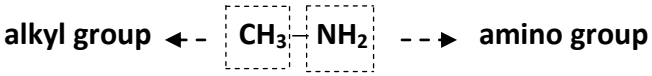


functional group of an ester

  - The common ester is called **ethyl ethanoate** and has the structural formula as:

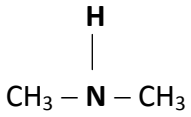
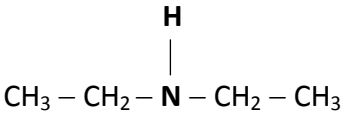


- **Amines** are derivative of ammonia. The three classes of amines are:
  - **Primary amines**
    In primary amines, **only one of the hydrogen atoms in the ammonia molecule** (NH_3) has been replaced. That means that the formula of the primary amine will be **RNH_2** where **"R"** is an alkyl group.



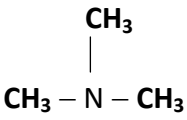
  - **Secondary amines**
    In a secondary amine, **two of the hydrogen atoms in an ammonia molecule (NH_3)** have been replaced by hydrocarbon groups.

    For example:

 dimethylamine	 diethylamine

- **Tertiary amines**
  In tertiary amine, **all of the hydrogen atoms in ammonia molecule (NH_3)** have been replaced by hydrocarbon groups. The naming is similar to secondary amines.

  For example:

   This is called **trimethylamine.**

Answers to Learning Activities 1-13

Learning Activity 1

1. Organic compounds contain the element carbon. They may also contain hydrogen and other elements such as oxygen and nitrogen.

2. (i) alkane
   (ii) alkenes
   (iii) alcohols
   (iv) carboxylic acids

3. a. Alkene is C = C or carbon to carbon double bond.
   b. Alcohol is –OH or hydroxyl group.
   c. Carboxylic acid is – COOH or carboxylic group.

4. a. Alkane is C_nH_{2n+2}.
   b. Alkene is C_nH_{2n}.
   c. Alcohol is $C_nH_{2n+1}OH$. Accept: RCH_2OH, R_2CHOH or R_3COH
   d. Carboxylic acid is $C_nH_{2n+1}COOH$ Accept: RCOOH.

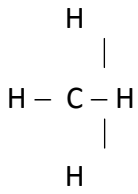
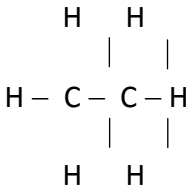
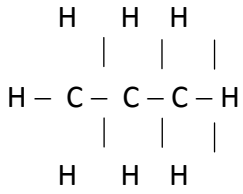
5. a. aliphatic
   b. aromatic

Learning Activity 2

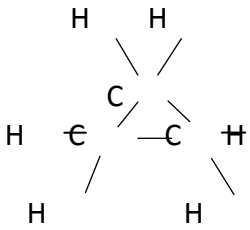
1. (i) They have the general formula C_nH_{2n+2}.
   (ii) Their names end with "– ane ".
   (iii) The carbon atoms are joined by single covalent bonds.
   (iv) They are said to be saturated, as no other atoms can be added to the carbon atoms, without first removing some other atoms.

2. a. methane - CH_4
   b. ethane - C_2H_6
   c. propane - C_3H_8
   d. butane - C_4H_{10}

3.

Name	Molecular Formula	Condensed Structural Formula	Full Structural Formula
Methane	CH_4	CH_4	
Ethane	C_2H_6	CH_3CH_3	
Propane	C_3H_8	$CH_3CH_2CH_3$	

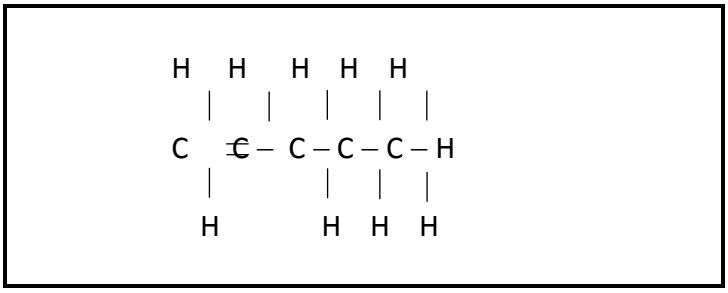
4.

Name	Molecular Formula	Full Structural formula
Cyclopropane	C_3H_6	

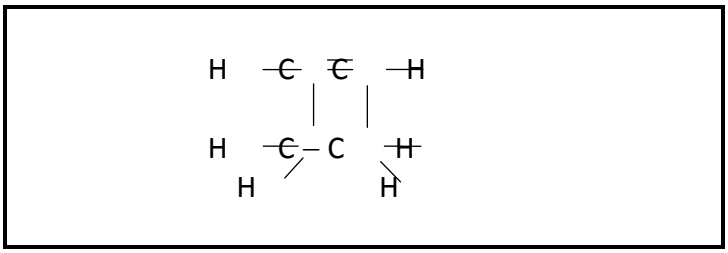
5. 2- methyl butane.

Learning Activity 3

1. 1- pentene or pent-1-ene



2. cyclobutene



3. a. pent-2-ene or 2-pentene
   b. pent-1-ene or 1-pentene

4. C_8H_{14} Cyclooctene

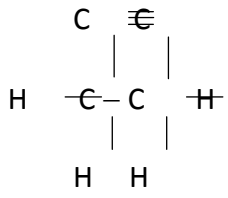
5. 5-methyl 1-hexene or 5 methyl hex-1-ene.

Learning Activity 4

1. a. C_4H_6
   b. C_6H_{10}
   c. $C_{10}H_{18}$

2. a. ethyne
   b. propyne
   c. 4-bromo,4-methylpent-2-yne

3. cyclobutyne



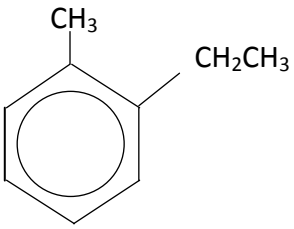
C_4H_4

Learning Activity 5

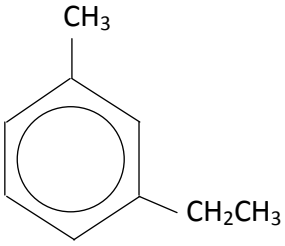
1. a. 1,2-dichlorobenzene
   b. 1,4-dichlorobenzene
   c. 4-ethyl-1,2-dimethylbenzene
   d. 1-ethyl-4-propylbenzene
   e. 1-methyl-4-propylbenzene
   f. 1,3-dinitrobenzene

2.

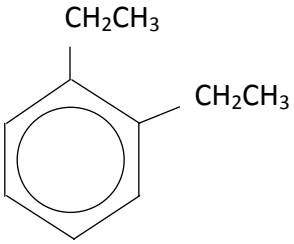
a. 1-ethyl-2-methylbenzene



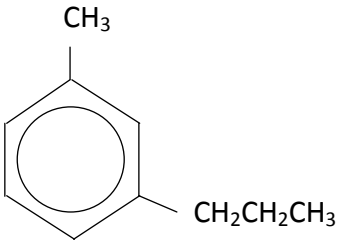
b. 1-ethyl-3-methylbenzene

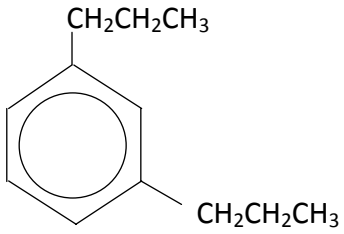
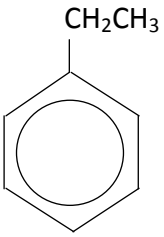


c. 1,2-diethylbenzene



d. 1-methyl-3-propylbenzene



e. 1,3-dipropylbenzene 	f. ethylbenzene 

3. Any 2 answers are correct:
   - colourless liquid
   - highly flammable
   - cancer causing(carcinogenic)
   - simplest aromatic compound
   - characterize by a sooty flame

Learning Activity 6

1. (i) A saturated compound is a compound of carbon and hydrogen where adjacent carbon atoms contain only one carbon – carbon bond.

   (ii) An unsaturated compound is a compound of carbon and hydrogen that contains one double covalent bond between carbon atoms, or a triple covalent bond between carbon atoms.

2. (i) saturated
   (ii) unsaturated
   (iii) unsaturated
   (iv) saturated
   (v) unsaturated
   (vi) unsaturated

3.

Saturated hydrocarbon	Unsaturated hydrocarbon
(i) They contain single carbon to carbon covalent bonds.	(i) They contain at least one double or triple covalent bonds.
(ii) These compounds are less reactive due to the presence of all single covalent bonds.	(ii) These compounds are more reactive due to the presence of double or triple covalent bonds.
(iii) Saturated compounds undergo substitution reactions.	(iii) Unsaturated compounds undergo addition reactions.
(iv) The number of hydrogen atoms is more, when compared to its corresponding unsaturated hydrocarbons.	(iv) The number of hydrogen atoms is less, when compared to its corresponding saturated hydrocarbons.

4. a. cyclobutene
   b. propane
   c. cyclopentane
   d. butyne

Learning Activity 7

1. a. Complete combustion needs a plentiful supply of air so that elements in the fuel react fully with oxygen forming carbon dioxide and water.

   b. Incomplete combustion occurs when the supply of air or oxygen is poor producing carbon monoxide and water.

2. (i) Alkane is used for fuels.
   (ii) Alkene is used in the manufacture of plastics.

3. pentane + oxygen → carbon dioxide + water
   C_2H_{12} + $8O_2$ → $5CO_2$ + $6H_2O$

4. pentane + oxygen → carbon monoxide + water
   $2C_5H_{12}$ + $11O_2$ → $10CO$ + $12H_2O$

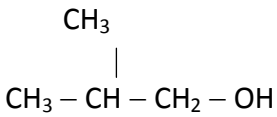
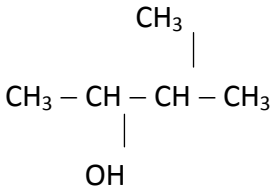
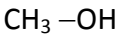
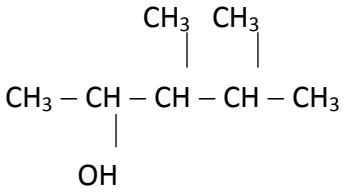
5. octane + oxygen → carbon dioxide + water
   $2C_8H_{18}$ + $22O_2$ → $16CO_2$ + $18H_2O$

6. decane + oxygen → carbon monoxide + water
   $2C_{10}H_{22}$ + $21O_2$ → $20CO$ + $22H_2O$

Learning Activity 8

1. a. ethanol
   b. butan-2-ol
   c. propan-2-ol
   d. butan-1-ol
   e. pentan-2-ol
   f. 2,2-dimethylbutan-1-ol

2.

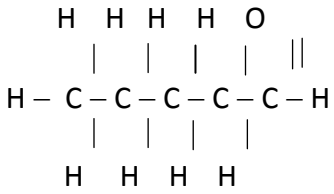
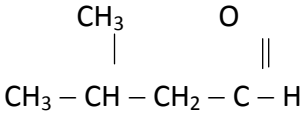
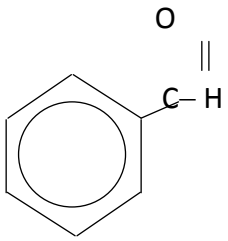
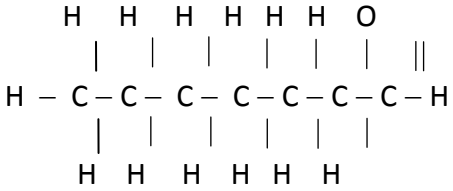
a. 	b 
c. 	d. 

3. a. primary
   b. secondary
   c. secondary
   d. tertiary

Learning Activity 9

1. a. 4-methylpentanal
   b. butanal
   c. propanal
   d. 3-chlorobenzaldehyde
   e. 2-methylbutanal
   f. hexanal

2.

a. pentanal 	b. 3-methylbutanal 
c. benzaldehyde 	d. heptanal 

3. carbonyl group

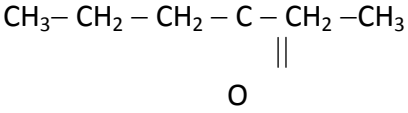
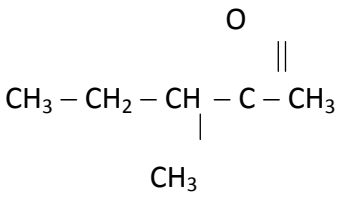
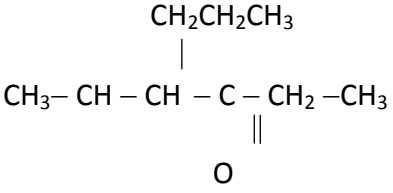
4. alkanal

5. 1st carbon atom

Learning Activity 10

1. a. 5-methyl-3-hexanone
   b. 3-pentanone
   c. 5-methyl-3-heptanone
   d. 2-propanone
   e. 2-butanone
   f. 3-heptanone

2.

a. 	b. 
c. 	d. 

3. carbonyl group

4. alkanone

5. in the middle

Learning Activity 11

1. carboxyl group
   –COOH

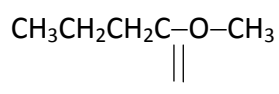
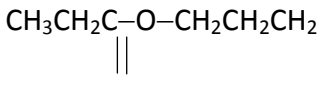
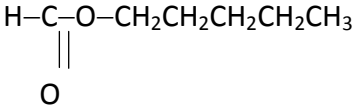
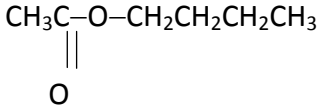
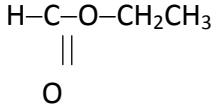
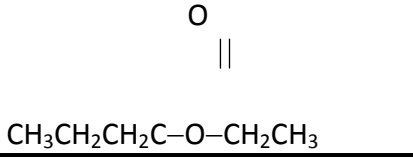
2. pentanoic acid

3. a. heptanoic acid
   b. butanoic acid
   c. pentanoic acid
   d. ethanoic acid
   e. hexanoic acid
   f. methanoic acid

Learning Activity 12

1. An ester is formed when a carboxylic acid reacts with alcohol.

2.

a. methyl butanoate 	b. propyl propanoate 
c. pentyl methanoate 	d. butyl ethanoate 
e. ethyl methanoate 	f. ethyl butanoate 

Learning Activity 13

1. a. primary amine
   b. tertiary amine
   c. tertiary amine
   d. primary amine
   e. secondary amine
   f. secondary amine

2. a. 3-aminopentane
   b. butyldimethylamine
   c. 1-aminohexane or hexylamine or hexanamine
   d. 2-aminobutane
   e. diethylamine
   f. diethylpropylamine

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FODE PROVINCIAL CENTRES CONTACTS

PC NO.	FODE PROVINCIAL CENTRE	ADDRESS	PHONE/FAX	CUG PHONE (COORDINATOR)	CUG PHONE (SENIOR CLERK)
1	ALOTAU	P. O. Box 822, Alotau	6411343/6419195	72228130	72229051
2	BUKA	P. O. Box 154, Buka	9739838	72228108	72229073
3	CENTRAL	C/- FODE HQ	3419228	72228110	72229050
4	DARU	P. O. Box 68, Daru	6459033	72228146	72229047
5	GOROKA	P. O. Box 990, Goroka	5322085/5322321	72228116	72229054
6	HELA	P. O. Box 63, Tari	73197115	72228141	72229083
7	JIWAKA	c/- FODE Hagen		72228143	72229085
8	KAVIENG	P. O. Box 284, Kavieng	9842183	72228136	72229069
9	KEREMA	P. O. Box 86, Kerema	6481303	72228124	72229049
10	KIMBE	P. O. Box 328, Kimbe	9835110	72228150	72229065
11	KUNDIAWA	P. O. Box 95, Kundiawa	5351612	72228144	72229056
12	LAE	P. O. Box 4969, Lae	4725508/4721162	72228132	72229064
13	MADANG	P. O. Box 2071, Madang	4222418	72228126	72229063
14	MANUS	P. O. Box 41, Lorengau	9709251	72228128	72229080
15	MENDI	P. O. Box 237, Mendi	5491264/72895095	72228142	72229053
16	MT HAGEN	P. O. Box 418, Mt. Hagen	5421194/5423332	72228148	72229057
17	NCD	C/- FODE HQ	3230299 ext 26	72228134	72229081
18	POPONDETTA	P. O. Box 71, Popondetta	6297160/6297678	72228138	72229052
19	RABAUL	P. O. Box 83, Kokopo	9400314	72228118	72229067
20	VANIMO	P. O. Box 38, Vanimo	4571175/4571438	72228140	72229060
21	WABAG	P. O. Box 259, Wabag	5471114	72228120	72229082
22	WEWAK	P. O. Box 583, Wewak	4562231/4561114	72228122	72229062

FODE SUBJECTS AND COURSE PROGRAMMES

GRADE LEVELS	SUBJECTS/COURSES
Grades 7 and 8	1. English
	2. Mathematics
	3. Personal Development
	4. Social Science
	5. Science
	6. Making a Living
Grades 9 and 10	1. English
	2. Mathematics
	3. Personal Development
	4. Science
	5. Social Science
	6. Business Studies
	7. Design and Technology- Computing
Grades 11 and 12	1. English – Applied English/Language& Literature
	2. Mathematics – General / Advance
	3. Science – Biology/Chemistry/Physics
	4. Social Science – History/Geography/Economics
	5. Personal Development
	6. Business Studies
	7. Information & Communication Technology

REMEMBER:

- For Grades 7 and 8, you are required to do all six (6) subjects.
- For Grades 9 and 10, you must complete five (5) subjects and one (1) optional to be certified. Business Studies and Design & Technology – Computing are optional.
- For Grades 11 and 12, you are required to complete seven (7) out of thirteen (13) subjects to be certified.

Your Provincial Coordinator or Supervisor will give you more information regarding each subject and course.

Notes: You must seek advice from your Provincial Coordinator regarding the recommended courses in each stream. Options should be discussed carefully before choosing the stream when enrolling into Grade 11. FODE will certify for the successful completion of seven subjects in Grade 12.

GRADES 11 & 12 COURSE PROGRAMMES			
No	**Science**	**Humanities**	**Business**
1	Applied English	Language & Literature	Language & Literature/Applied English
2	General / Advance Mathematics	General / Advance Mathematics	General / Advance Mathematics
3	Personal Development	Personal Development	Personal Development
4	Biology	Biology/Physics/Chemistry	Biology/Physics/Chemistry
5	Chemistry/ Physics	Geography	Economics/Geography/History
6	Geography/History/Economics	History / Economics	Business Studies
7	ICT	ICT	ICT

CERTIFICATE IN MATRICULATION STUDIES		
No	**Compulsory Courses**	**Optional Courses**
1	English 1	**Science Stream:** Biology, Chemistry and Physics
2	English 2	**Social Science Stream:** Geography, Intro to Economics and Asia and the Modern World
3	Mathematics 1	
4	Mathematics 2	
5	History of Science & Technology	

REMEMBER:

You must successfully complete 8 courses: 5 compulsory and 3 optional.