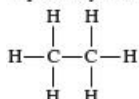


UNIT 7

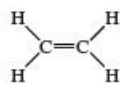
INTRODUCTION TO ORGANIC CHEMISTRY

Student version

aliphatic hydrocarbons



alkane

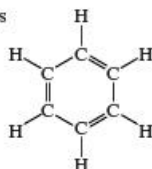


alkene



alkyne

aromatic hydrocarbons



Contents

- Introducing Organic Molecules
- Isomerism
- Crude Oil
- The Combustion of Alkanes
- Preparation and Chemical Reactions of Alkanes, Alkenes and Alkynes
- Benzene and Aromatic Compounds

Key words: unbranched, branched, aliphatic, alicyclic, alkane, alkene, alkyne, haloalkane, alkanol, homologous series, structural isomerism, geometrical isomerism, stereoisomerism, petroleum, fractional distillation, cracking, reforming, combustion, fuel, petrochemical, octane number, addition, substitution, elimination, hydroxyoxidation, saturated, unsaturated, aromatic, resonance

Units which must be completed before this unit can be attempted:

Unit 1 – Atoms and the Periodic Table

Unit 2 – Particles, Structure and Bonding

Unit 3 – Amount of Substance

Unit 4 – Introduction to Physical Chemistry

Unit 5 – Acids, Bases and Salts

Unit 6 – Redox Reactions

Estimated Teaching Time: 11 hours

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

UNIT 7 SUMMARY AND SYLLABUS REFERENCE

Lesson	Title and Syllabus Reference
1	Classification of Organic Compounds <i>CA11ai classification (broad classification into straight chain, branched chain and alicyclic compounds), CA11aii classification – functional groups, CAei alkanes (structure), CAfi alkenes (structure), CA11g alkynes (structure), CC6g alkanols, ISA13 organic compounds (hydrocarbons, alkanols, functional groups); ISA13.1 classification of compounds as inorganic or organic (differences between inorganic and organic compounds)</i>
2	Drawing and Representing Organic Compounds <i>ISA13 organic compounds (hydrocarbons (first four members in each group), alkanols (methanol, ethanol, propanol), functional groups); CC6g alkanols (recognition of the structures of mono-, di- and triols)</i>
3	Nomenclature of Organic Compounds I <i>CA11ai nomenclature – root names; CA11aii nomenclature – functional groups (systematic nomenclature of the following compounds: alkanes, alkenes, alkynes and alkanols); CA11ei alkanes (nomenclature); CA11fi alkenes (nomenclature); CA11g alkynes (nomenclature); CC6g alkanols; CA11i.i alkanols – nomenclature and structure; ISA4.3 ionic and covalent compounds (IUPAC names of common compounds); ISA13 organic and inorganic compounds (hydrocarbons (first four members in each group), alkanols (methanol, ethanol, propanol), functional groups)</i>
4	Nomenclature of Organic Compounds II; Homologous Series <i>CA3 van der Waal's forces (variation of the melting points and boiling points of alkanes in a homologous series explained in term of van der Waal's forces); CA11ai nomenclature – root names; CA11aii nomenclature – functional groups (systematic nomenclature of the following compounds: alkanes, alkenes, alkynes and alkanols); CA11di general properties – homologous series (gradation in physical properties, effects on the physical properties by introduction of active groups into the inert alkane); CA11ei alkanes (nomenclature); CA11fi alkenes (nomenclature); CA11g alkynes (nomenclature); CC6g alkanols (recognition of the structures of mono-, di- and triols); ISA4.3 ionic and covalent compounds (IUPAC names of common compounds)</i>
5	Isomerism (Structural) <i>CA11dii general properties – isomerism (examples should be limited to compounds having maximum of five carbon atoms)</i>
6	Isomerism (Geometric) <i>CA11dii general properties – isomerism (examples should be limited to compounds having maximum of five carbon atoms, differences between structural and geometric/stereo isomerism)</i>
7	Crude Oil <i>CA11ei alkanes – sources and properties (industrial preparations and other sources, cracking of large alkane molecules); CA11eii alkanes – uses (importance as fuels, as starting materials for synthesis); CA11eiii petroleum (composition, fractional distillation and major products, cracking and reforming, petrochemicals: starting materials of organic synthesis); ISA13 organic and inorganic compounds (hydrocarbons, properties and uses of organic compounds); ISA13.1 classification of chemicals as organic and inorganic (Importance of organic chemistry in industrialization); ISA13.3 petrochemicals (sources of petrochemicals, the refinery of crude oil)</i>

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Lesson	Title and Syllabus Reference
8	<p>Alkanes as Fuels CA11ei alkanes – properties (combustion); CA11eii alkanes – uses (importance as fuels, pollution effects); CA11eiii petroleum (quality of petrol, meaning of octane number); ISA13 organic and inorganic compounds (hydrocarbons, properties and uses of organic compounds); ISA13.1 classification of chemicals as organic and inorganic (importance of organic chemistry in industrialization); ISA13.3 petrochemicals (application and effects of petrochemicals on the environment); ISE2.2 human activities and their effects on the atmosphere (effects of human activities on the atmosphere: air transport, industrialization); ISE2.4 atmospheric pollutants (sources and effects of the following major pollutants: oxides of nitrogen and sulphur); ISE2.5 greenhouse effect (explanation of ‘greenhouse’ and its effect: global warming and climate change, greenhouse gases eg carbon (IV) oxide); ISE2.6 acid rain (identification of acidic pollutants which cause acid rain, the effects of acid rain on the environment (damage to buildings, paints forests etc))</p>
9	<p>Chemical Properties of Alkanes, Alkenes and Alkynes CA11ei alkanes – sources and properties (laboratory preparation, substitution reactions); CA11eii alkanes – uses (uses of haloalkanes and pollution effects); CA11fi alkenes – sources and properties (laboratory preparation, addition reactions with halogens, bromine water, hydrogen halides, oxidation: hydroxylation with aqueous KMnO_4); CA11fii alkenes – laboratory detection (use of reaction with Br_2/CCl_4 and $\text{KMnO}_4(\text{aq})$ as means of characterising alkenes); CA11g alkynes – sources and uses (industrial production of ethyne, uses of ethyne); CA13cv characteristic test tube reactions of the functional groups in the following simple organic compounds: alkenes; CC6e alkynes – chemical properties (tests to distinguish between alkanes, alkenes and alkynes); ISA13 organic and inorganic compounds (hydrocarbons (first four members in each group), functional groups, properties and uses of organic compounds); ISE2.5 ozone layer (sources and effects of CFCs on the ozone layer)</p>
10	<p>Benzene and Aromatic Compounds CA11ai classification (broad classification into straight chain, branched chain, aromatic and alicyclic compounds); CA11hi benzene - structure and physical properties; CA11hii benzene – chemical properties (resonance in benzene, stability leading to substitution reactions, halogenations (mechanism not required), addition reactions: hydrogenation and halogenation, compare reactions with those of alkenes); CC6f benzene – uses</p>
11	Unit 7 Revision and Summary

The Periodic Table of the Elements

1	2	3	4	5	6	7	0										
(1) 6.9 Li lithium 3	(2) 9.0 Be beryllium 4	(3) 45.0 Sc scandium 21	(4) 47.9 Ti titanium 22	(5) 50.9 V vanadium 23	(6) 52.0 Cr chromium 24	(7) 54.9 Mn manganese 25	(8) 55.8 Fe iron 26	(9) 58.9 Co cobalt 27	(10) 58.7 Ni nickel 28	(11) 63.5 Cu copper 29	(12) 65.4 Zn zinc 30	(13) 10.8 B boron 5	(14) 12.0 C carbon 6	(15) 14.0 N nitrogen 7	(16) 16.0 O oxygen 8	(17) 19.0 F fluorine 9	(18) 4.0 He helium 2
23.0 Na sodium 11	24.3 Mg magnesium 12	39.1 K potassium 19	40.1 Ca calcium 20	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	96.0 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac† actinium 89	[267] Rf rutherfordium 104	[268] Db dubnium 105	[271] Sg seaborgium 106	[272] Bh bohrium 107	[270] Hs hassium 108	[276] Mt meitnerium 109	[281] Ds darmstadtium 110	[280] Rg roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						
												162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.1 Yb ytterbium 70	175.0 Lu lutetium 71
												[251] Cf californium 98	[252] Es einsteinium 99	[257] Fm fermium 100	[258] Md mendelevium 101	[259] No nobelium 102	[262] Lr lawrencium 103

* 58 – 71 Lanthanides

† 90 – 103 Actinides

Lesson 1 – What are organic molecules?

a) Introducing Organic Molecules

(i) Overview

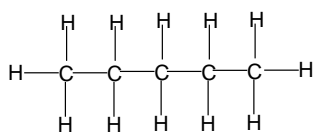
- Organic chemistry is the chemistry of carbon compounds; carbon forms a vast number of compounds because it can form strong covalent bonds with itself; this enables it to form long chains (up to 5000 in length) of carbon atoms, and hence an almost infinite variety of carbon compounds are possible
- An organic compound is a substance containing at least one carbon atom and usually containing at least one C-H covalent bond; generally all compounds involving carbon are described as organic except for carbon dioxide and carbonates; a compound not classified as an organic compound is an inorganic compound; inorganic chemistry is the chemistry of all elements and compounds which are not organic
- Most living organisms are composed largely of organic molecules; organic Chemistry thus forms the basis for Biochemistry – the Chemistry of Living Organisms
- All organic compounds contain carbon; most contain hydrogen and some contain oxygen
- In every molecule, each carbon atom always forms four covalent bonds; each hydrogen atom always forms one covalent bond and each oxygen atom always forms two covalent bonds

(ii) Describing and classifying organic molecules

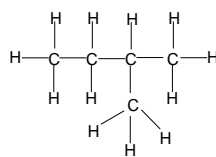
When describing an organic molecule, there are two main things to consider:

- the number and arrangement of carbon atoms in the molecule**
 - the total number of carbon atoms in a molecule can vary from 1 to more than 1,000,000
 - in many cases, all the carbon atoms are arranged in an **unbranched** chain; often, however, molecules contain shorter chains of carbon atoms branching off a longer chain; these are known as **branched** molecules

Eg



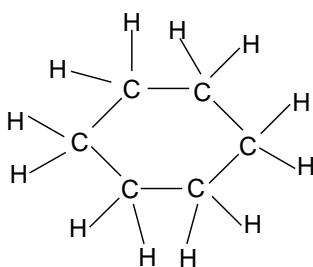
Unbranched molecule



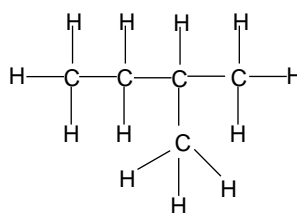
Branched molecule

- carbon atoms can also be arranged to form rings; these are known as **alicyclic** molecules; the most common number of carbon atoms in a ring is 6; molecules which do not contain a ring are known as **aliphatic** molecules

Eg



Alicyclic molecule



Aliphatic molecule

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- **the functional groups in the molecule**
- **a functional group is a specific atom or group of atoms which confer certain physical and chemical properties onto the molecule**
- organic molecules are classified by the dominant functional group on the molecule
- the most common functional groups found on organic molecules:

Type of compound	Description of functional group	Diagram of functional group
Alkane	C-C and C-H single bonds only (ie no functional group)	$\begin{array}{c} \\ \text{--- C ---} \\ \end{array}$
Alkene	C=C double bond	$\begin{array}{c} \diagup \quad \diagdown \\ \text{C} = \text{C} \\ \diagdown \quad \diagup \end{array}$
Alkyne	C≡C triple bond	-C≡C-
Haloalkane -Chloroalkane -Bromoalkane -Iodoalkane	Cl, Br or I atom attached to a carbon atom	$\begin{array}{c} \\ \text{--- C --- X} \\ \end{array}$
Alcohol	O atom in between a C atom and an H atom	$\begin{array}{c} \\ \text{--- C --- O --- H} \\ \end{array}$

- **molecules which contain carbon and hydrogen only** are known as **hydrocarbons**; alkanes, alkenes and alkynes are examples of hydrocarbons; haloalkanes and alcohols are not hydrocarbons
- an alicyclic alkane is called a cycloalkane; an alicyclic alcohol is called a cycloalcohol, etc

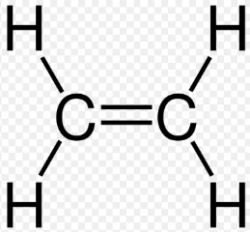
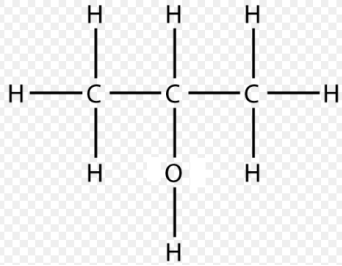
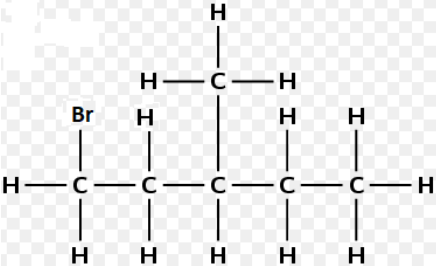
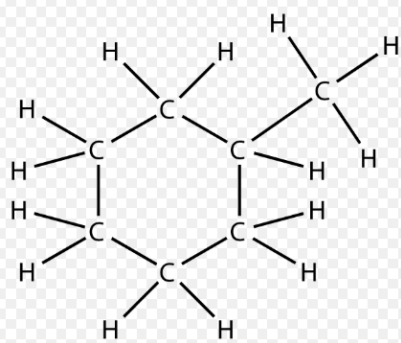
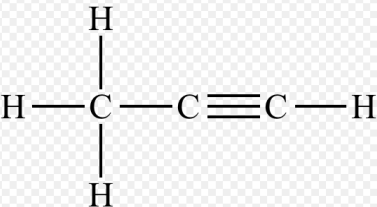
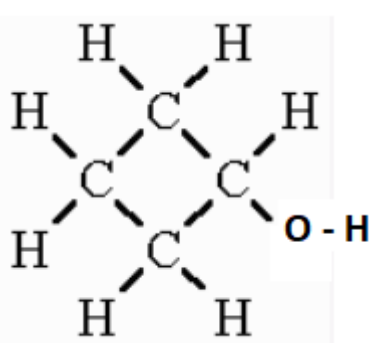
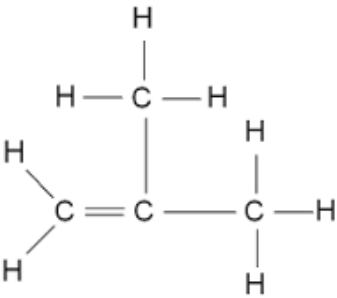
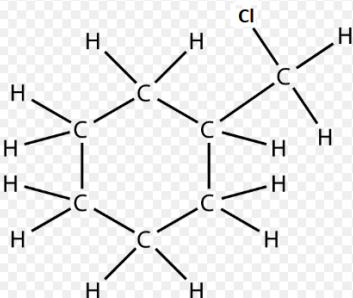
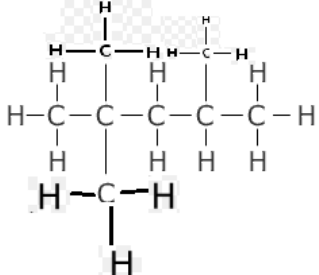
UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY



Test your knowledge 1.1: Classifying simple organic molecules

For each of the molecules below:

- identify the functional group
- indicate whether the molecule is branched or unbranched
- Indicate whether the molecule is aliphatic or alicyclic
- Indicate whether or not the molecule is a hydrocarbon

<p>(i)</p> 	<p>(ii)</p> 	<p>(iii)</p> 
<p>(iv)</p> 	<p>(v)</p> 	<p>(vi)</p> 
<p>(vii)</p> 	<p>(viii)</p> 	<p>(ix)</p> 

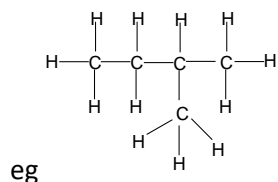
UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Lesson 2 – How can we draw and write organic molecules?

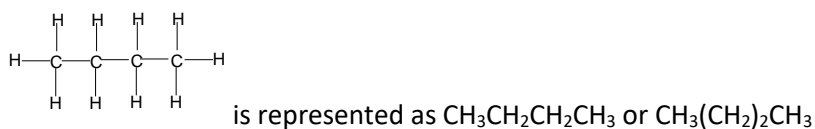
(iii) Drawing and writing organic molecules

Organic compounds can be represented in a number of ways:

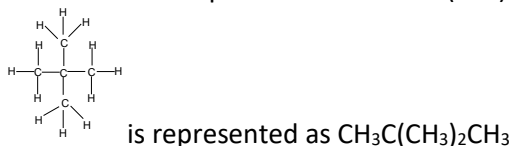
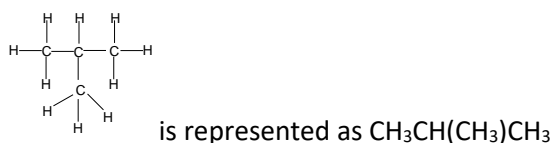
- **Displayed formula, showing all covalent bonds;** this is also known as the **graphical formula**; all covalent and ionic bonds between all atoms are shown:



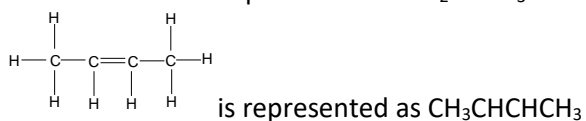
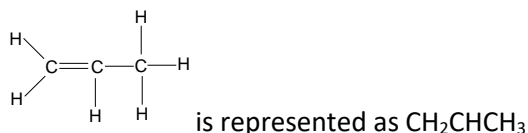
- **Structural formula, not showing covalent bonds;** enough information is shown to make the structure clear, but the actual covalent bonds are omitted
Unbranched alkanes are shown as follows:



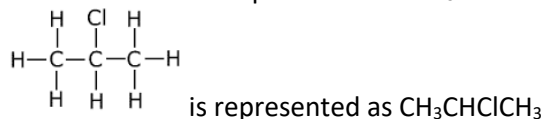
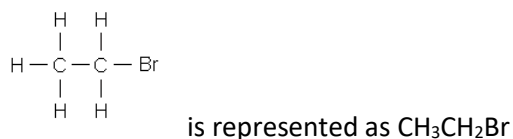
Branched alkanes are shown as follows:



Alkenes are shown as follows:

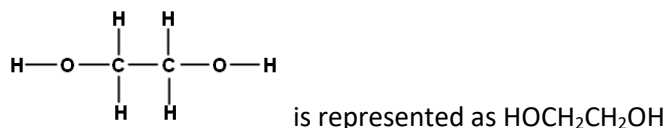
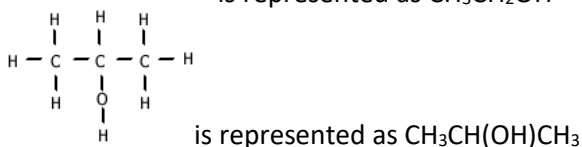
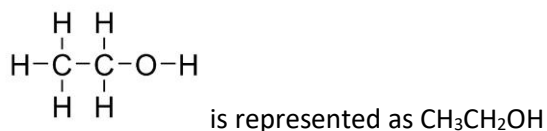


Haloalkanes are represented as follows:


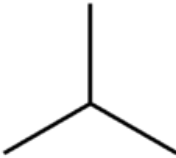
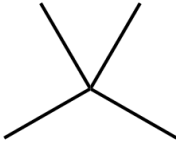
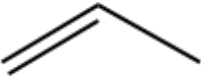

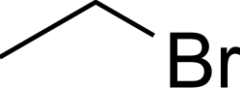
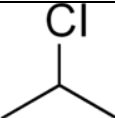


UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

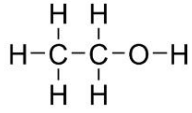
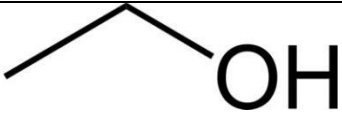
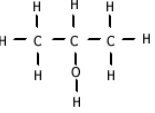
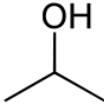
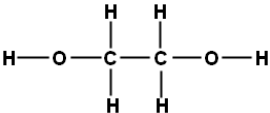
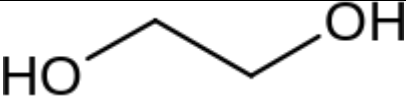
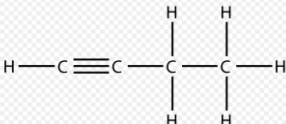
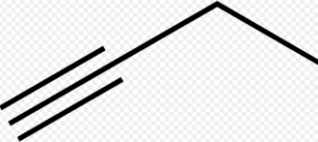
Alcohols are represented as follows:



- **Skeletal formula, not showing carbon atoms;** skeletal formulae are a useful simplified way of drawing organic molecules:
 - carbon atoms are not drawn – they are represented by a dot
 - hydrogen atoms are not drawn if they are bonded to carbon atoms
 - covalent bonds are represented by a line if they do not involve hydrogen
 - covalent bonds involving hydrogen are omitted
 - the angle between the bonds must be correct (109° if tetrahedral, 120° if planar) (see Unit 2 – Particles, Bonding and Structure)

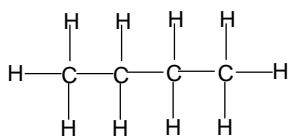
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$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \\ \quad \\ \quad \text{H} \end{array} $	is represented as	
$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \\ \quad \\ \quad \text{H} \end{array} $	is represented as	
$ \begin{array}{c} \text{H} \quad \quad \quad \text{H} \\ \diagdown \quad \diagup \quad \quad \quad \\ \text{C}=\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \quad \quad \text{H} \end{array} $	is represented as	
$ \begin{array}{c} \text{H} \quad \quad \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}=\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} $	is represented as	
$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{Br} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	is represented as	
$ \begin{array}{c} \text{H} \quad \text{Cl} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array} $	is represented as	

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

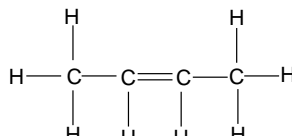
	is represented as	
	is represented as	
	is represented as	
	is represented as	

Note: it is common to see structures drawn as a combination of displayed, structural and skeletal formulae

- Molecular formula;** this shows the number of each atom in one molecule of the compound (see Unit 2 – Particles, Bonding and Structure); it does not show unequivocally the structure of the molecule, so different molecules can have the same molecular formula; **molecules with the same molecular formula but different structures** are known as **isomers**



is written C_4H_{10}



is written C_4H_8

Alkanes have the general molecular formula C_nH_{2n+2} (eg C_3H_8 or C_5H_{12})

Alkenes have the general molecular formula C_nH_{2n} (eg C_3H_6 or C_6H_{12})

Haloalkanes have the general molecular formula $C_nH_{2n+1}X$ (eg C_4H_9Cl or C_4H_9Br)

Alcohols have the general molecular formula $C_nH_{2n+2}O$ (eg $C_4H_{10}O$ or $C_6H_{14}O$)

- Empirical formula;** this the simplest whole number ratio of the number of atoms of each element in a substance (see unit 2 – Particles, Bonding and Structure)



Test your knowledge 2.1: Drawing simple organic molecules

- Using displayed or structural formulae, draw a compound with four carbon atoms which is:
 - an unbranched alkane
 - an unbranched alicyclic alcohol (cycloalcohol)
 - a branched alkene
 - an unbranched alkyne
 - a branched bromoalkane
- Give the molecular and empirical formula of the five compounds you have drawn in (a)
- Draw the displayed, structural, skeletal and molecular formula of a branched aliphatic alcohol with five carbon atoms
- Deduce the general molecular formula of:
 - aliphatic alkynes
 - alicyclic alcohols

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Lesson 3 – How do we name organic compounds?

- Most organic compounds can be named systematically by the IUPAC method; in order to describe completely an organic molecule, three features must be described:
 - the longest unbranched carbon chain or ring on the molecule
 - the nature and position of any functional groups on the molecule
 - the length and position of any branches on the molecule

(iv) Naming Unbranched Aliphatic Molecules

- **The longest unbranched chain on the molecule** is indicated by one of the following prefixes:

Number of carbon atoms in the chain	Prefix
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-

- **The functional group on the molecule** is usually shown with a suffix at the end of the name:
 - Alkanes end with -ane
 - Alkenes end with -ene
 - Alkynes end with -yne
 - Alcohols end with – anol
 - Haloalkanes, however are named using a prefix (chloro-, bromo- or iodo-)
- The number of carbon atoms in the longest unbranched chain is combined with the functional group to give the name of the molecule:

Molecule	Name	Reason
$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array} $	Methane	meth-: longest unbranched carbon chain = 1 -ane: it is an alkane (ie it has no functional group)
$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	Ethane	eth-: longest unbranched carbon chain = 2 -ane: it is an alkane (ie it has no functional group)
$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array} $	Propane	prop-: longest unbranched carbon chain = 3 -ane: it is an alkane (ie it has no functional group)
$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} $	Butane	but-: longest unbranched carbon chain = 4 -ane: it is an alkane (ie it has no functional group)
$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} $	Pentane	pent-: longest unbranched carbon chain = 5 -ane: it is an alkane (ie it has no functional group)

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Molecule	Name	Reason
$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} & \\ & / & \diagdown \\ \text{H} & & \text{H} \end{array}$	Ethene	eth-: longest unbranched carbon chain = 2 -ene: it is an alkene
$\begin{array}{c} & \text{H} & \text{H} \\ & & \\ \text{H} & -\text{C}=\text{C}- & \text{C}-\text{H} \\ & & \\ & \text{H} & \text{H} \end{array}$	Propene	prop-: longest unbranched carbon chain = 3 -ene: it is an alkene
$\text{H}-\text{C}\equiv\text{C}-\text{H}$	Ethyne	eth-: longest unbranched carbon chain = 2 -yne: it is an alkyne
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{C}\equiv\text{C}-\text{H} \\ \\ \text{H} \end{array}$	Propyne	prop-: longest unbranched carbon chain = 3 -yne: it is an alkyne
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	Methanol	meth-: longest unbranched carbon chain = 1 -anol: it is an alcohol
$\begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & / \\ \text{H}-\text{C}- & \text{C}- & \text{O} \\ & & \\ \text{H} & \text{H} & \end{array}$	Ethanol	eth-: longest unbranched carbon chain = 2 -anol: it is an alcohol
$\begin{array}{c} \text{H} \\ \\ \text{Br}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$	bromomethane	-meth-: longest unbranched carbon chain = 1 bromo- -ane: it is a bromoalkane
$\begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C}- & \text{C}-\text{Cl} \\ & \\ \text{H} & \text{H} \end{array}$	Chloroethane	-eth-: longest unbranched carbon chain = 2 chloro- -ane: it is a chloroalkane

- In haloalkanes and alcohols containing 3 or more carbon atoms, and in alkenes or alkynes containing 4 or more carbon atoms, the functional group can exist in more than one different position on the molecule; in such cases the position of the functional group must be specified as follows:
 - the carbon atoms on the unbranched chain must be numbered, starting with the end closest to the functional group
 - the lowest-numbered carbon atom involved in the functional group is indicated just before the part of the name which describes the functional group:

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Molecule	Name	Reason
	But-1-ene	but-: longest unbranched carbon chain = 4 -ene: it is an alkene -1-: the lowest numbered C atom involved in the C=C bond is 1
	But-2-ene	but-: longest unbranched carbon chain = 4 -ene: it is an alkene -2-: the lowest numbered C atom involved in the C=C bond is 2
	Pent-1-yne	pent-: longest unbranched carbon chain = 5 -yne: it is an alkyne -1-: the lowest numbered C atom involved in the C≡C bond is 1
	Pent-2-yne	pent-: longest unbranched carbon chain = 5 -yne: it is an alkyne -2-: the lowest numbered C atom involved in the C≡C bond is 2
	Propan-1-ol	prop-: longest unbranched carbon chain = 3 -an-ol: it is an alcohol -1-: the C atom attached to the O is No. 1
	Propan-2-ol	prop-: longest unbranched carbon chain = 3 -an-ol: it is an alcohol -2-: the C atom attached to the O is No. 2
	2-bromopropane	-prop-: longest unbranched carbon chain = 3 -bromo-ane: it is a bromoalkane -2-: the C atom attached to the Br is No. 2
	1-iodopentane	-pent-: longest unbranched carbon chain = 5 -iodo-ane: it is an iodoalkane -1-: the C atom attached to the I is No. 1

- Note that but-1-ene and but-2-ene have the same molecular formula, but different structures; this means that they are **isomers** of each other; pent-1-yne and pent-2-yne are also isomers of each other, as are propan-1-ol and propan-2-ol

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY


Test your knowledge 3.1: Naming simple organic molecules

(a) Name the following molecules:

(i)		(ii)		(iii)	
(iv)		(v)		(vi)	
(b) Draw the structures of the following molecules:					
(i)	Butane	(ii)	Propyne	(iii)	butan-2-ol
(iv)	2-chloropentane	(v)	Iodomethane	(vi)	propan-1-ol

Lesson 4 – How do we name more complex organic compounds?

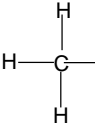
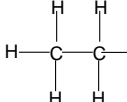
- Many molecules have more than one functional group; the only such molecules which will be discussed in this section are **dihaloalkanes** (organic molecules which contain two halogen atoms) and **diols** (organic molecules which contain two -OH groups)
 - When naming dihaloalkanes and diols, the position of both functional groups must be specified unless there is only one carbon atom in the molecule; if there is more than one of the same type of functional group on the molecule, the di (two) prefix should be used:

Molecule	Name	Reason
	1,1-dichloroethane	-eth-: longest unbranched carbon chain = 2 -dichloro-ane: it is a dichloroalkane (ie there are two Cl atoms on the molecule) 1,1-: both Cl atoms are on C No. 1
	1,2-dichloroethane	-eth-: longest unbranched carbon chain = 2 -dichloro-ane: it is a dichloroalkane (ie there are two Cl atoms on the molecule) 1,2-: one Cl atom is on C No. 1 and the other is on C No. 2
	1-bromo,2-chloropropane	-prop-: longest unbranched carbon chain = 3 -chloro-ane: it is a chloroalkane -bromo-ane: it is also a bromoalkane 1-: the Br is on C No. 1 2-: the Cl is on C No. 2
	pentan-2,3-diol	-pent-: longest unbranched carbon chain = 5 -diol: it is a diol -2,3-: the -OH groups are attached to the 2 nd and 3 rd C atoms

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

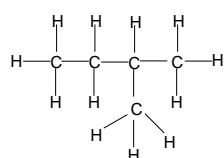
(v) Naming branched Aliphatic Molecules

- Many carbon chains are branched. The presence of a branch is indicated one of the following prefixes:

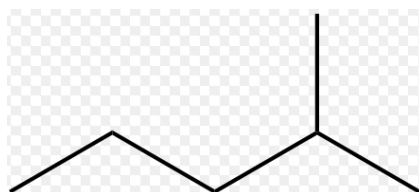
Branch	Prefix
	Methyl
	Ethyl

- Usually, there is more than one place in which the branch can be attached; in such cases, the position of the branch must be specified according to the number of the carbon on the straight chain to which it is attached; the carbon atoms should be numbered as follows:
 - the carbon atoms are numbered from the carbon at the end of the chain closest to the functional group
 - if there is no functional group, the carbons are numbered from the carbon at the end of the chain closest to the branch.

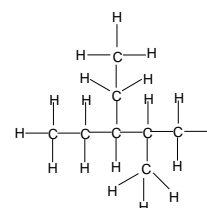
Eg



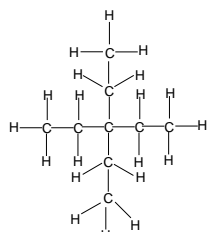
methylbutane



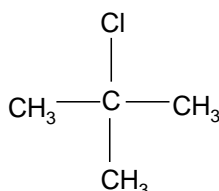
2-methylpentane



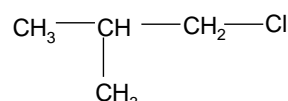
2-methyl,3-ethylpentane



diethylpentane



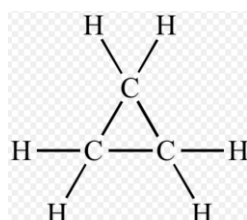
2-chloromethylpropane



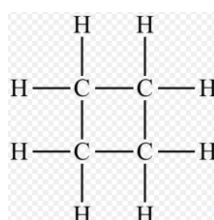
1-chloromethylpropane

(vi) Naming Alicyclic Molecules

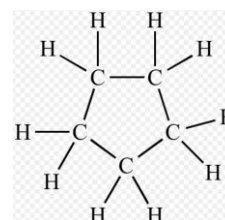
- Cyclic molecules are named using the prefix "cyclo-" to indicate the number of unbranched carbon atoms in the ring:



cyclopropane



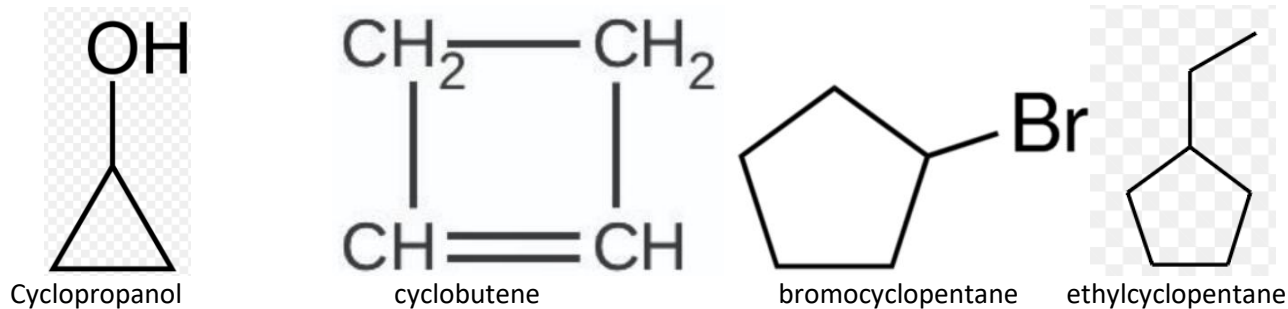
cyclobutane



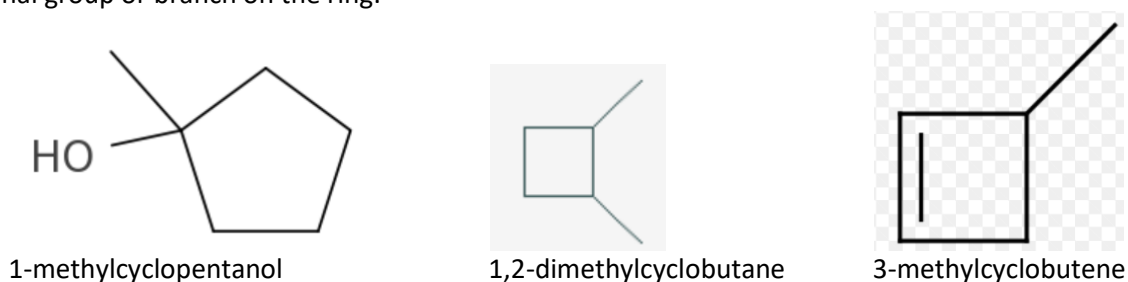
cyclopentane

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- If the ring also contains functional groups or is branched, the naming rules are the same as for aliphatic molecules:

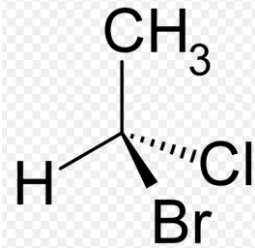
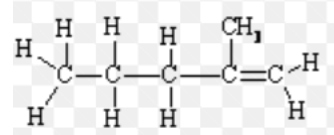
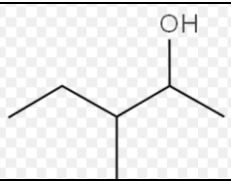
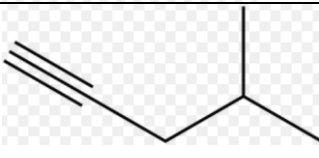
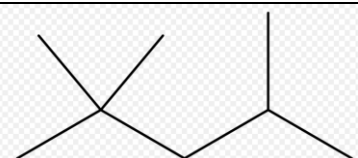
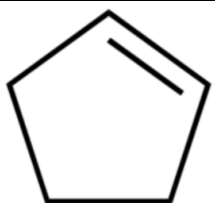
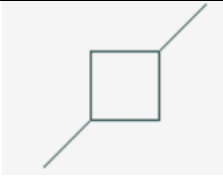
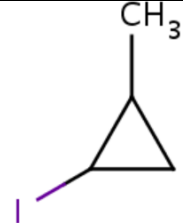


- As all the carbon atoms on the ring are identical, numbering is only necessary when there is more than one functional group or branch on the ring:



Test your knowledge 4.1: Naming more complex organic molecules

(a) Name the following molecules:

(i)	HOCH ₂ CH ₂ CH ₂ OH	(ii)		(iii)	
(iv)		(v)		(vi)	
(vii)		(viii)		(ix)	

(b) Draw the structures of the following molecules:

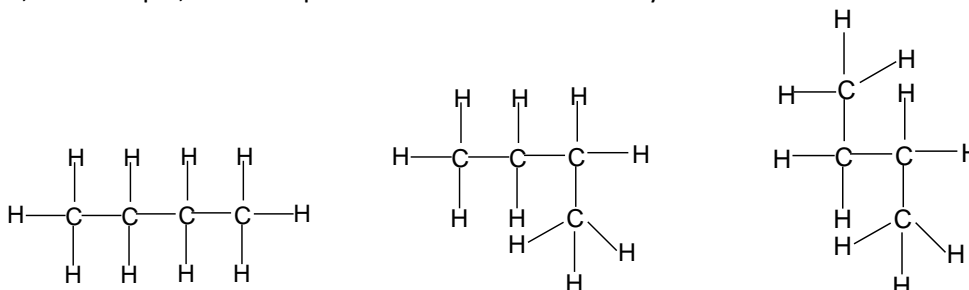
(i) ethan-1,2-diol	(ii) 1,2-dibromopropane	(iii) 2-methylpentan-3-ol
(iv) 3-methylbutan-1-ol	(v) 2-methylbut-1-ene	(vi) propan-1,2,3-triol
(vii) cyclobutanol	(viii) 1,1-dichlorocyclopropane	(ix) 4-methylcyclopentene

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

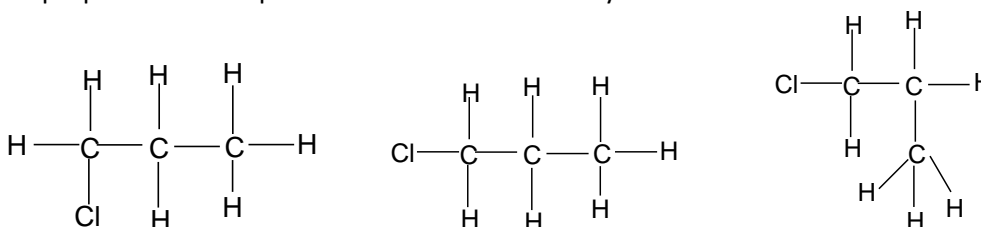
(vii) Recognising Identical Organic Molecules

- Many organic compounds which appear to be different are in fact the same; they appear to be different because different notations are used, or because some of the bonds are simply rotated; note that all single bonds are able to rotate freely

Eg Butane, for example, can be represented in a number of ways:



Eg 1-chloropropane can be represented in a number of ways:



- All molecules which are identical must have the same name and all molecules with the same name must be identical; non-identical molecules cannot have the same name and molecules with different names must be non-identical

(viii) Homologous series

- Organic compounds with the same functional group, but a different number of carbon atoms, are said to belong to the same **homologous series**; every time a carbon atom is added to the chain, two hydrogen atoms are also added; **a homologous series is a series of organic compounds which have the same functional group, but in which the formula of each successive member increases by $-CH_2-$**

Eg Homologous series of unbranched alkanes:

CH_4 , CH_3CH_3 , $CH_3CH_2CH_3$, $CH_3CH_2CH_2CH_3$, $CH_3(CH_2)_3CH_3$, $CH_3(CH_2)_4CH_3$ etc

Eg Homologous series of alcohols:

CH_3OH , CH_3CH_2OH , $CH_3CH_2CH_2OH$ etc

- As a homologous series is ascended, the size of the molecule increases; therefore the Van der Waal's forces between the molecules become stronger and the boiling point increases
 - Eg propan-1-ol has a higher boiling point than ethanol
 - Eg butane has a higher boiling point than propane
- Members of the same homologous series tend to have similar chemical properties; the chemical properties of an organic molecule depend mainly on the functional group; the functional group can also alter the physical properties of the molecule – for example ethanol, ethene and ethane will have different physical and chemical properties

Lesson 5 – How can we predict, recognise and classify isomers?

b) Isomerism

- Isomers are molecules which have the same molecular formula but different structures

**Summary Activity 5.1: What are isomers?**

- How many different molecules can you draw with the molecular formula C_3H_7Cl ? Can you name them? How are their structures different?
- How many different molecules can you draw with the molecular formula C_4H_8 ? Can you name them? How are their structures different?

- Isomerism can be classified either as **structural isomerism** or **stereoisomerism**

(i) Structural Isomerism

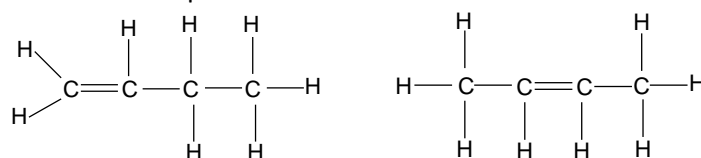
- Structural isomers are molecules which have the same molecular formula but a different arrangement of covalent bonds**

The different arrangement of covalent bonds can result from:

- The functional group being in different positions (**positional isomerism**)
- A different arrangement of the carbon skeleton (**chain isomerism**)
- A different functional group (**functional isomerism**)

- Positional isomers are molecules with the same molecular formula and the same carbon skeleton but which have the functional group on different positions in the molecule**

- alkanes do not show positional isomerism as they have no functional group
- alkenes with four or more carbon atoms show positional isomerism:
Eg but-1-ene and but-2-ene are positional isomers



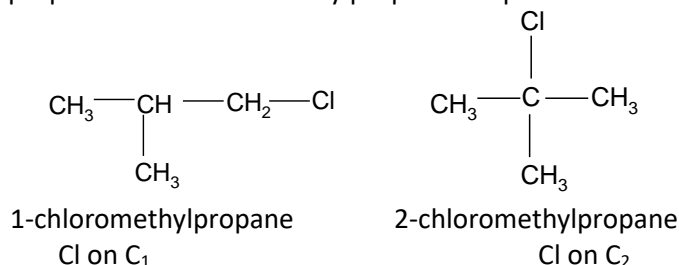
but-1-ene

C=C between C_1 and C_2

but-2-ene

C=C between C_2 and C_3

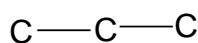
- halogenoalkanes and alcohols with three or more carbon atoms show positional isomerism:
Eg 1-chloromethylpropane and 2-chloromethylpropane are positional isomers



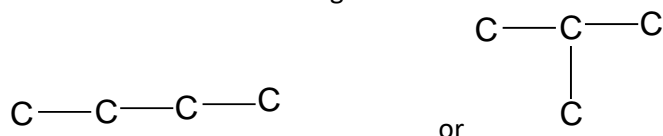
UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- **Chain isomers are molecules with the same molecular formula and the same functional group but a different arrangement of carbon atoms** (ie a different carbon skeleton)

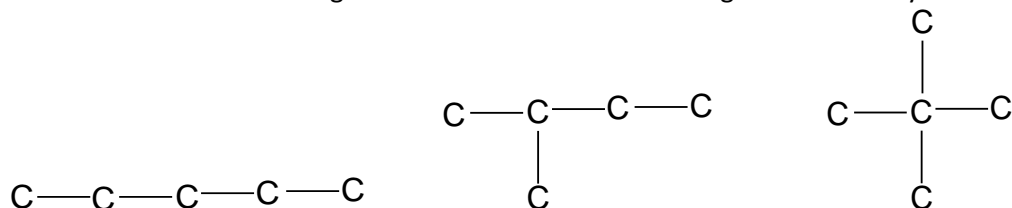
- Carbon skeletons containing up to three carbon atoms can only be arranged in one way – i.e. a straight chain with no branching:



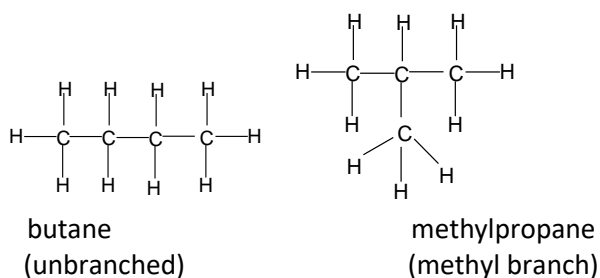
- Carbon skeletons containing four carbon atoms can be arranged in two ways:



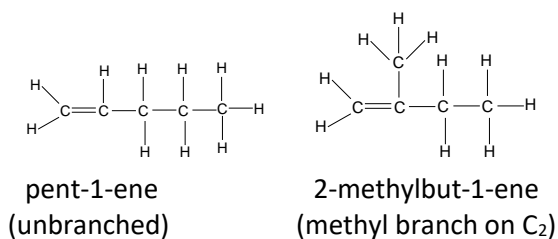
- Carbon skeletons containing five carbon atoms can be arranged in three ways:



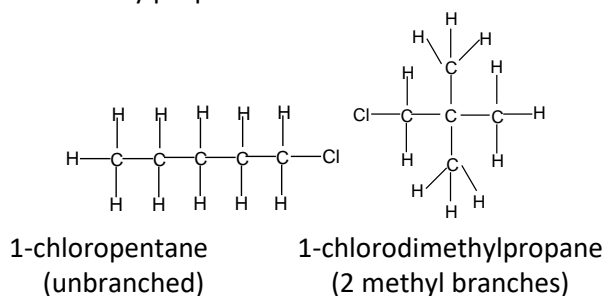
- All molecules containing four or more carbon atoms can thus show chain isomerism:
Eg butane and methylpropane are chain isomers:



- Eg pent-1-ene and 2-methylbut-1-ene are chain isomers:



- Eg 1-chloropentane and 1-chlorodimethylpropane are chain isomers:



UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

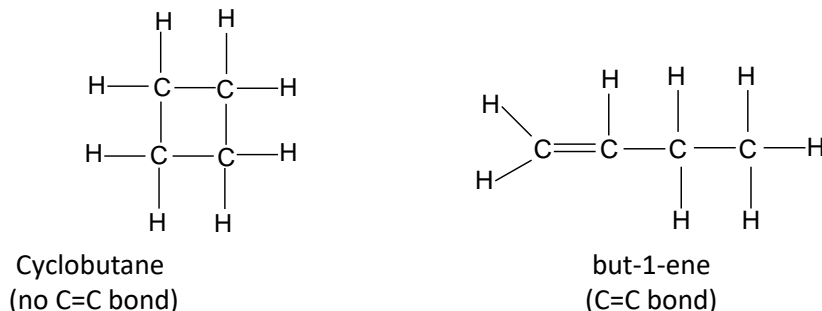
- **Functional isomers are molecules with the same molecular formula but different functional groups**

This is most commonly found when one of the molecules is alicyclic and the other is aliphatic:

- alicyclic alkanes have the general formula C_nH_{2n}
- aliphatic alkenes also have the same general formula C_nH_{2n}

A cycloalkane and an alkene with the same number of carbon atoms will therefore be functional isomers of each other:

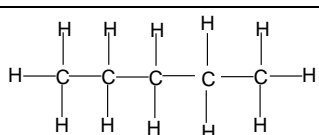
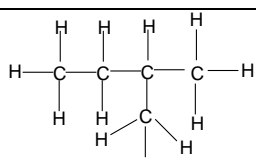
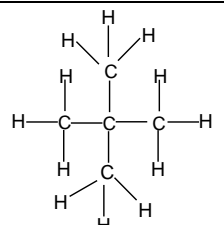
Eg cyclobutane and but-1-ene



- **Isomers have slightly different melting and boiling points**

- molecules with no branching tend to have higher boiling points than isomers with more branching; this is because they have a higher surface area, so they pack together better and so the van der Waal's forces are stronger

Eg isomers of pentane, C_5H_{12} :

Isomer	Structure	Boiling point/ $^{\circ}C$
Pentane		36
Methylbutane		28
dimethylpropane		10



Test your knowledge 5.2: Recognising structural isomerism

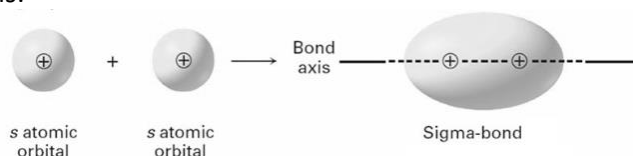
- Draw and name two different molecules with the molecular formula $C_2H_4Cl_2$; state the type of isomerism occurring
- show the structure of pent-1-ene
 - draw and name a positional isomer of pent-1-ene
 - draw and name a chain isomer of pent-1-ene
 - draw and name a functional isomer of pent-1-ene
- How many different alcohols are there with the molecular formula $C_4H_{10}O$? Draw and name them.
- State, with a reason, which of butane and methylpropane is likely to have the higher boiling point


Extension 5.3: Further structural isomerism

- (a) Draw and name all of the alkenes with the molecular formula C_5H_{10}
 (b) Draw and name all of the alcohols with the molecular formula $C_5H_{12}O$

Lesson 6 – What are stereoisomers?
(ii) Stereoisomerism

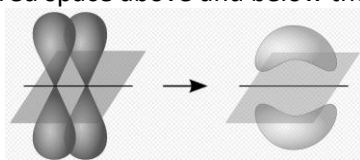
- It is possible for two molecules to contain the same atoms bonded to each other but to be different from each other due to a different spatial arrangement; this is known as stereoisomerism; the only type of stereoisomerism required for this course is **geometrical isomerism**
- Stereoisomers are molecules with the same structural formula but a different spatial arrangement of atoms**
- To understand geometrical isomerism, it is first necessary to understand more about the difference between single and double covalent bonds:
 - Covalent bonds are formed when atomic orbitals on different atoms (usually each containing one electron) overlap, so that both electrons occupy the same region of space
 - In single bonds, the orbitals overlap head-on to create a bond directly in between the nuclei of the two atoms:



(www.slideplayer.com)

This is known as a σ -bond; all single covalent bonds are σ -bonds

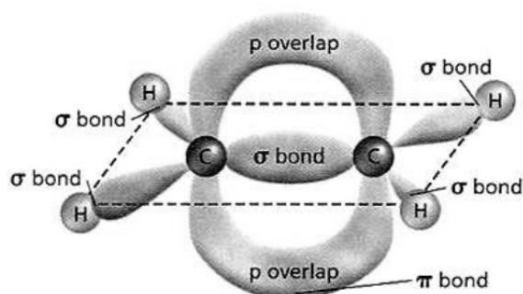
- In double bonds, the orbitals cannot overlap in the same way because the space directly in between the atoms is already occupied by the first covalent bond; instead, two p-orbitals overlap side-on to create a shared space above and below the σ -bond:



(www.wikipedia.org)

This is known as a π -bond; all double covalent bonds consist of one σ -bond and one π -bond:

Eg orbital structure of ethene showing σ -bond and one π -bond:



(www.slideshare.net)

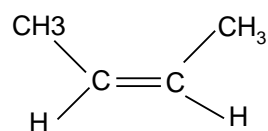
- Since π -orbitals overlap in two places, it is not possible to rotate a π -bond about its axis without breaking the bond; there is thus **restricted rotation** about the double bond


Activity 6.1: Why can single bonds rotate and why can double bonds not rotate?

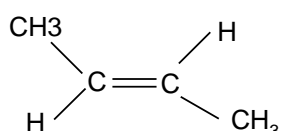
- Take two pieces of scrap paper; draw a small dot in the middle of each; then force a sharp pencil through both dots so the pencil passes through both sheets of paper; place the pieces of paper around 10 cm apart, still connected by the pencil; **can you rotate one piece of paper without rotating the other one?**
- Take two more pieces of scrap paper; draw two dots on each piece of paper, around 5 cm apart; then force a sharp pencil through one dot on each piece of paper so that the pencil passes through both sheets of paper; then force another sharp pencil through the second dot on each piece of paper; place the pieces of paper around 10 cm apart, still connected by two pencils; **can you rotate one piece of paper without rotating the other one?**

- Geometrical isomers are stereoisomers with different spatial orientations around the carbon-carbon double bond - it is caused by the restricted rotation about a carbon-carbon double bond, and it arises when the carbon atoms on both sides of the bond are attached to two different groups:

Eg but-2-ene has a C=C double bond; the left-hand carbon is attached to two different groups (CH₃ and H) and the right-hand carbon is also attached to two different groups (CH₃ and H); the two CH₃ groups can either be adjacent to each other or opposite each other:



CH₃ groups adjacent
cis but-2-ene

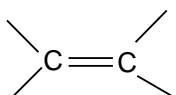


CH₃ groups opposite
trans but-2-ene

These two isomers cannot be interconverted without breaking the π-bond; they have the same structural formula but different spatial orientations and are therefore stereoisomers; if the groups on the left hand side are the same as those on the right hand side, the molecule can be named “cis” if the same groups are adjacent, or “trans” if the same groups are opposite

Note that molecules which show geometrical isomerism always have two specific structural features:

- there is a carbon-carbon double bond
 - both the carbon atoms are attached to two different groups
- Geometrical isomers should always be drawn using **crab notation**; crab notation shows the C=C bond as a planar centre with the 4 groups shown as follows:



UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Using crab notation, it is easy to predict whether geometrical isomerism will exist in molecules:

Ethene		No geometrical isomerism	
Propene		No geometrical isomerism	
But-1-ene		No geometrical isomerism	
But-2-ene		Geometrical isomerism	 cis but-2-ene trans but-2-ene
Methylpropene		No geometrical isomerism	
Pent-1-ene		No geometrical isomerism	
Pent-2-ene		Geometrical isomerism	 Trans pent-2-ene cis pent-2-ene
2-methylbut-1-ene		No geometrical isomerism	
2-methylbut-2-ene		No geometrical isomerism	



Test your knowledge 6.2: Geometrical isomerism

- (a) Molecules A, B, C, D, E and F are all isomers with the molecular formula C_5H_{10} . A and B are alicyclic. C is a branched alkene. D is an unbranched alkene. E and F are geometrical isomers of each other. Suggest names for all six molecules.
- (b) Draw and name the two geometrical isomers of 1,2-dichloroethene. Explain why 1,1-dichloroethene does not show geometrical isomerism. Explain why 1,2-dichloroethane does not show geometrical isomerism

Lesson 7 – What is crude oil and why is it useful?

c) Crude Oil

- The vast majority of carbon-containing compounds used in the world have been made from **crude oil**; crude oil is also known as **petroleum**; it is found naturally underground, where it has formed from plant and animal matter over millions of years
- Crude oil is a mixture of alkanes, most of which are unbranched and contain 20+ carbon atoms; each of the hydrocarbons present in crude oil has a slightly different use; mixed together, they are of no use at all; it is necessary, therefore, to separate them before they can be used productively; crude oil is separated into its different components by a process called **fractional distillation**
- The products of fractional distillation are often converted into other, even more useful hydrocarbons by a process called **cracking**
- The discovery of crude oil and the development of techniques allowing it to be converted into fuels and other useful products (known as **petrochemicals**) is considered to be one of the major driving forces behind industrialisation

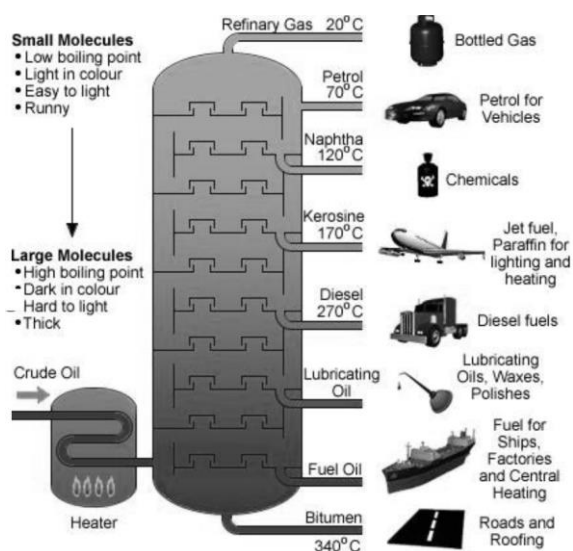
**Summary Activity 7.1: Why do different hydrocarbons have different boiling points?**

- What type of forces exist in between all molecules?
- How and why do these forces change as the molecules get larger?
- How and why do boiling points change as you ascend the homologous series of alkanes (ie from methane to ethane to propane etc)?
- Why do branched alkanes have lower boiling points than unbranched alkanes with the same number of carbon atoms?

(i) Fractional distillation

- The different hydrocarbons in crude oil have different boiling points; this is because the chain length varies; the longer the chain length, the stronger the Van der Waal's forces and the higher the boiling point; the difference in boiling points of the different hydrocarbons in crude oil is used to separate them from each other
- The crude oil is passed into a tall tower called a **fractionating column**:
 - this is very hot near the base but much cooler near the top
 - when the crude oil is passed into the tower, near the bottom, most of the mixture boils and the gaseous molecules start to rise up the tower
 - as they rise up the tower, they start to cool down and will gradually condense back into liquid form; they are then tapped off
 - the larger hydrocarbons, with higher boiling points, will condense first and be tapped off near the base of the column
 - the smaller hydrocarbons, with smaller boiling points, will condense later and be tapped off near the top of the column
 - thus the separation is achieved
 - note that the process involves breaking **intermolecular forces** only; the molecules themselves are unaffected by this process

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY



www.researchgate.net

- This process does not actually separate the crude oil mixture into pure hydrocarbon components, but into mixtures called **fractions**; **fractions are mixtures of hydrocarbons with similar boiling points**; in many cases these fractions can be used directly, but sometimes further separation is required into purer components; the most important fractions and their main uses are summarised as follows:

Fractions from crude oil

Name of fraction	Boiling range / °C	Number of hydrocarbons	Uses
Liquefied petroleum gas	Less than 25	1 – 4	Gas for camping/ cooking
Petrol or gasoline			Fuel for cars etc
Naphtha			Petrochemicals
Kerosine or paraffin			Plane fuel, petrochemicals
Diesel or gas oil			lorry, central heating fuel
Mineral/lubricating oil			Lubrication, petrochemicals
Fuel oil			Ship fuel, power stations
Wax and grease			Candles, grease, polish
Bitumen or tar	Above 450	More than 50	Road surfaces, roofing

- The term **petrochemical** means a useful chemical such as a solvent or paint, which is derived from crude oil

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

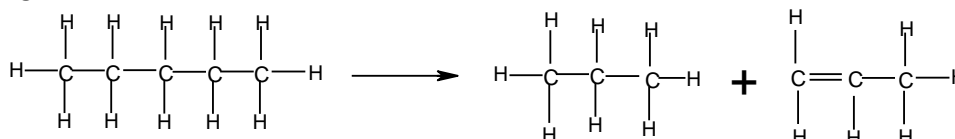
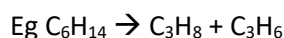
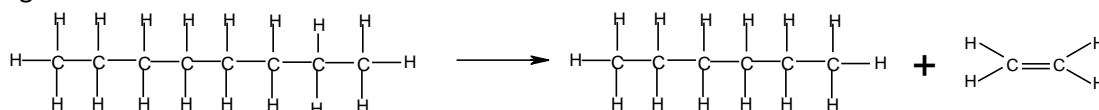
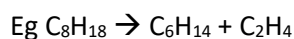
(ii) Cracking

- Some of the fractions from crude oil are produced in greater quantities than needed, whilst others are not produced in sufficient quantities; the table below gives an example of the difference between the supply and demand of some important fractions:

Supply and demand for fractions

Fraction	Approximate supply/%	Approximate demand/%
Liquefied petroleum gases	2	4
Petrol and naphtha	16	27
Kerosine	13	8
Gas oil	19	23
Fuel oil and bitumen	50	38

- This disparity can be corrected by breaking up some larger hydrocarbons in fuel oil into the smaller ones found in gas oil, or by breaking up some hydrocarbons in kerosene into the smaller ones found in petrol, naphtha or the liquefied petroleum gases; in other words the larger fractions (for which supply exceeds demand) can be broken up into smaller fractions (for which demand exceeds supply); the process by which this is carried out is called **cracking**
- Cracking has the added advantage of producing other useful hydrocarbons not naturally present in crude oil, such as **alkenes** (widely used as petrochemicals), **cycloalkanes** and **branched alkanes** (widely used in motor fuels); cracking is therefore important for two reasons:
 - it converts low-demand fractions into higher demand fractions
 - it makes other useful hydrocarbons not naturally found in crude oil
- Cracking involves the breaking of C-C bonds to form smaller molecules; C-C bonds are weaker than C-H bonds and so break more easily when heated; the conditions required for cracking are a **high temperature** and a **catalyst**

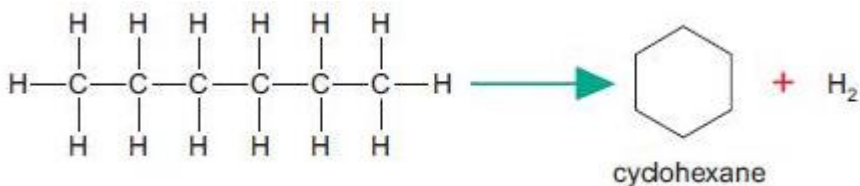


- Cracking always produces one shorter alkane molecule and at least one alkene
 - if there are two products, one will be an alkane and the other will be an alkene
 - if there are three products, one will be an alkane and two will be alkenes
 - if there are four products, one will be an alkane and three will be alkenes etc

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

(iii) Reforming

- Cracking produces shorter, more useful alkanes, but most of the products of cracking are aliphatic unbranched alkanes or alkenes; alicyclic alkanes tend to make better fuels, and so it is commercially useful to convert unbranched alkanes into alicyclic alkanes; this is carried out by a process called reforming:



Eg

- Reforming also produces **hydrogen** gas, which can be used to make ammonia and various other important petrochemicals



Test your knowledge 7.2: Processing crude oil

- Crude oil is separated into its fractions by fractional distillation
 - What are fractions?
 - Explain how a fractionating column works in five key points
 - Write down the names of five fractions, in order of increasing boiling point, and give a use for each
- Many of the fractions are then subjected to processes called cracking and reforming
 - Write two different equations to show the cracking of decane (C₁₀H₂₂) into two products
 - Write an equation to show the cracking of dodecane (C₁₂H₂₆) into three different products
 - Write an equation to show the reforming of hexane (C₆H₁₄)
- Explain why cracking and reforming are important

Lesson 8 – why are alkanes useful?

d) Combustion of Alkanes



Summary Activity 8.1: Exothermic reactions

- What is an exothermic reaction?
- Why are exothermic reactions useful?
- Why do some exothermic reactions not take place until heat or a spark is applied?
- What do you understand by the terms “fuel” and “combustion”?

(i) Alkanes as fuels

- Many of the fractions produced from crude oil are used as fuels; these fractions include:

Fraction	Uses
Liquefied petroleum gases	Camping gas, cooking gas
Petrol	Fuel for cars, motorbikes and machines
Kerosine	Fuel for aeroplanes, lamps, ovens
Diesel	Fuel for lorries, and central heating systems
Fuel oil	Fuel for ships, power stations
Wax	Fuel for candles

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- A **fuel** is something that can be converted into useful energy; hydrocarbons, and especially alkanes, will react with oxygen in the air to give carbon dioxide and water; a reaction with oxygen is known as **combustion**; as alkanes are unreactive, the reaction usually needs heat or a spark to get going

Once started, these reactions are very **exothermic**, which means that heat energy is released; this heat energy can be used for direct heating (eg camping gas, central heating, candles); it can also be converted into mechanical energy (eg cars, lorries, ships), or electrical energy (eg power stations); the release of large quantities of heat energy during these combustion reactions results in their widespread use as fuels; typical examples of combustion reactions include:

Reaction	Enthalpy change/ kJmol ⁻¹
$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$	-890
$\text{C}_4\text{H}_{10} + 6\frac{1}{2}\text{O}_2 \rightarrow 4\text{CO}_2 + 5\text{H}_2\text{O}$	-2877
$\text{C}_8\text{H}_{18} + 12\frac{1}{2}\text{O}_2 \rightarrow 8\text{CO}_2 + 9\text{H}_2\text{O}$	-5470

(ii) Environmental problems associated with burning hydrocarbons

- **carbon dioxide**: although carbon dioxide is not poisonous and is naturally removed from the atmosphere by plants, the enormous quantities of hydrocarbons burned over the last century has caused carbon dioxide levels to rise significantly; carbon dioxide, along with various other compounds, prevents the earth's heat from escaping into space and is resulting in an increase in the earth's temperature; this is known as **global warming**; it also causes a significant change in the weather patterns on earth; this is known as climate change; gases which contribute towards global warming are known as **greenhouse gases**
- **water vapour** is also produced in large quantities as a result of combustion of hydrocarbons and is also a **greenhouse gas**
- **carbon monoxide and carbon**: the combustion of hydrocarbons to produce carbon dioxide and water is called **complete combustion**, and it requires a lot of oxygen; if oxygen is not present in sufficiently large quantities, carbon monoxide or carbon is produced instead of carbon dioxide; this is called **incomplete combustion**; examples of incomplete combustion reactions are:

$\text{C}_4\text{H}_{10} + 4\frac{1}{2}\text{O}_2 \rightarrow 4\text{CO} + 5\text{H}_2\text{O}$
$\text{C}_4\text{H}_{10} + 2\frac{1}{2}\text{O}_2 \rightarrow 4\text{C} + 5\text{H}_2\text{O}$
$\text{C}_8\text{H}_{18} + 10\frac{1}{2}\text{O}_2 \rightarrow 8\text{CO} + 9\text{H}_2\text{O}$
$\text{C}_8\text{H}_{18} + 8\frac{1}{2}\text{O}_2 \rightarrow 8\text{C} + 9\text{H}_2\text{O}$

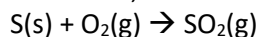
The less oxygen that is available, the more likely it is that incomplete combustion will occur; this is a particular problem in internal combustion engines where the air supply is limited; incomplete combustion is a problem for three reasons:

- less energy is released by incomplete combustion than by complete combustion
- carbon monoxide is a pollutant – it is absorbed by the blood in place of oxygen, and hence reduces the ability of the blood to carry oxygen causing suffocation and eventually death
- carbon particles can cause breathing difficulties and cancer

It is therefore desirable to ensure that the air supply is as good as possible when burning hydrocarbon fuels. Occasionally incomplete combustion is desirable – such as with a Bunsen burner; closing the air hole produces a yellow flame (the yellow colour results from hot carbon particles) and this makes the flame more visible and causes a more gentle heat; usually, however, complete combustion is more desirable

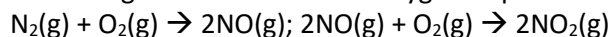
UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- **sulphur dioxide:** most crude oil deposits contain sulphur as an impurity; oil refineries are increasingly treating the petrol fractions to lower the sulphur content, but some sulphur is still present in most hydrocarbon fuels; when the fuel is burned, the sulphur also burns, producing sulphur dioxide:



This gas dissolves in rainwater forming a very acidic solution, known as **acid rain**; this causes various problems, including erosion of buildings and statues, killing of plants and trees, and killing of fish through contamination of lakes

- **oxides of nitrogen:** most fuels are not burned in pure oxygen but in air, which contains 80% nitrogen; although nitrogen is not a reactive gas, the high temperatures and the spark in combustion engines cause some of the nitrogen to react with the oxygen to produce nitric oxide and nitrogen dioxide:

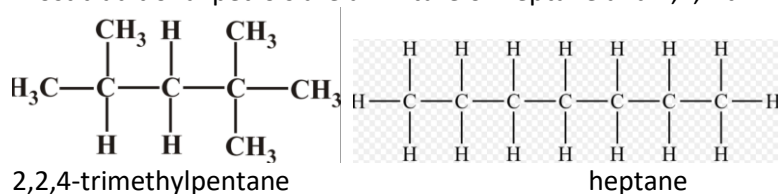


Nitrogen dioxide (NO_2) also dissolves in rainwater to form an acidic solution and contributes to the problem of **acid rain**

- **unburned hydrocarbons:** some of the hydrocarbon fuel is vaporised in the engine but escapes before it is burned; these unburned hydrocarbons cause various problems; they are toxic and can cause cancer if breathed in

(iii) Quality of Petrol

- In most internal combustion engines, petrol is first compressed and then ignited; it is important that the fuel does not self-ignite before it has been fully compressed, as this has an adverse effect on the performance of the engine; the self-ignition of a fuel before it has been fully compressed is known as **knocking**
- Petrochemical companies are constantly trying to reduce knocking by changing the composition of the petrol; the ability of a fuel to resist knocking is known as its **octane number**
- Most traditional petrols are a mixture of heptane and 2,2,4-trimethylpentane:



- 2,2,4-trimethylpentane is resistant to knocking and is given an octane number of 100
- Heptane is susceptible to knocking and is given an octane number of 0
- all other fuels are allocated an octane number based on their resistance to knocking compared to 2,2,4-trimethylpentane and heptane
- a fuel with an octane number of 95, for example, is slightly less resistant to knocking than 2,2,4-trimethylpentane but much more resistant to knocking than heptane



Test your knowledge 8.2: Alkanes as fuels

- Write equations to show:
 - the complete combustion of heptane (C_7H_{16})
 - the incomplete combustion of butane to make carbon monoxide
 - the incomplete combustion of hexane (C_6H_{14}) to make carbon
- Identify three pollutants produced during the combustion of alkanes and explain how each pollutant is formed
- Explain the meaning of the term “octane number”

Lesson 9 – What are the typical reactions of alkanes, alkenes and alkynes?

e) Preparation and Chemical Reactions of Alkanes, Haloalkanes, Alkenes and Alkynes

(i) Alkanes and Haloalkanes

- Methane is the main component in natural gas; most other alkanes are obtained industrially by the fractional distillation, cracking and reforming of crude oil
- Alkanes can be made in the laboratory by:
 - the addition of hydrogen to an alkene; eg $C_2H_4 + H_2 \rightarrow C_2H_6$
 - the addition of hydrogen to a haloalkane; eg $C_2H_5I + H_2 \rightarrow C_2H_6 + HI$
- Alkanes are mainly used as fuels for transport, domestic heating and electricity production
- Alkanes are also used as the starting point in the manufacture of a wide variety of organic products; the use of alkanes to manufacture other useful chemicals is known as the petrochemical industry
- The first step in the conversion of alkanes into other products is usually to convert alkanes into haloalkanes; one or more hydrogen atoms on the alkane are replaced by halogen atoms in presence of UV light:

Eg $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$
 $CH_4 + 2Cl_2 \rightarrow CH_2Cl_2 + 2HCl$
 $C_3H_8 + Br_2 \rightarrow C_3H_7Br + HBr$
 $C_3H_8 + 2Br_2 \rightarrow C_3H_6Br_2 + 2HBr$

These reactions are called **substitution** reactions because they involve the replacement of a hydrogen by a halogen on the organic molecule

These reactions tend to produce a wide variety of different haloalkanes because:

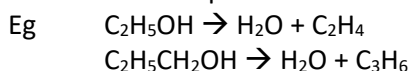
- The number of halogen atoms replacing hydrogen atoms on each hydrocarbon can vary; reacting CH_4 and Cl_2 will result in a mixture of CH_3Cl , CH_2Cl_2 , $CHCl_3$ or CCl_4
- The position of the halogen atoms on the carbon skeleton can vary; reacting C_3H_8 with Br_2 will result in a mixture of 1-bromopropane and 2-bromopropane, as well as a number of dibromoalkanes, tribromoalkanes etc
- Haloalkanes can be used to make a wide range of useful organic products, including plastics and pesticides; they can also be converted into a wide variety of other useful products, making them useful raw materials in the petrochemicals industry
- Haloalkanes in which all of the hydrogens have been replaced by halogen atoms (eg CCl_4 , C_2F_6 , $C_2Cl_2F_4$) are known as **halons**; they are used in refrigerators, air conditioning units and aerosols; however they are also known to damage the ozone layer (see Unit 13 – Chemistry in the World)
- Alkanes contain single bonds only and it is not possible to add additional atoms to alkanes without first removing another atom; for this reason alkanes are said to be **saturated**

(ii) Alkenes

- Alkenes are usually prepared industrially by the cracking of alkanes

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

- Alkenes are usually prepared in the laboratory by the dehydration of alcohols; the alcohol is heated using concentrated sulphuric acid as the dehydrating agent:



These reactions are called elimination reactions because they result in the loss of atoms from the organic molecule without replacement

- Alkenes can also be used as the starting point in the manufacture of a wide variety of petrochemicals
- The C=C double bond in alkenes can be easily broken and other atoms can be added to the carbon skeleton
 - the reactions are known as **addition** reactions because atoms are added to the carbon skeleton but no atoms are removed
 - the atoms being added must join the skeleton on the two carbon atoms where the double bond used to be
 - this means that the products are much easier to predict and control – only one or two products will ever be formed
 - with halogens (X₂), only one product is formed:
Eg $\text{C}_3\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_3\text{H}_6\text{Br}_2$ (1,2-dibromopropane only)
 - with hydrogen halides (HX) and water, two products are formed if the alkene is unsymmetrical around the double bond (eg propene, but-1-ene); one product is formed if the alkene is symmetrical around the double bond (eg ethene, but-2-ene):
Eg $\text{CH}_3\text{CH}=\text{CHCH}_3 + \text{HCl} \rightarrow \text{CH}_3\text{CHClCH}_2\text{CH}_3$ (2-chlorobutane only)
Eg $\text{CH}_3\text{CH}=\text{CHCH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$ (butan-2-ol only)
Eg $\text{CH}_2=\text{CH}_2 + \text{HBr} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ (1-bromopropane)
- Alkenes can also be converted to diols using KMnO₄ in alkaline solution; two -OH groups are added across the double bond to give a single organic product:
Eg $\text{C}_3\text{H}_6 + [\text{O}] + \text{H}_2\text{O} \rightarrow \text{HOCH}_2\text{CH}(\text{OH})\text{CH}_3$ (propan-1,2-diol only)
This reaction is known as **hydroxyoxidation** because oxygen is added in the form of two -OH (hydroxy) groups
- It is possible to test for alkenes in the laboratory; there are two common tests:
 - Br₂/CCl₄; when bromine is shaken with an alkene in the presence of an inert organic solvent such as CCl₄, the mixture turns from orange to colourless (ie it decolorises); this is because the orange bromine is involved in an addition reaction with the alkene; when the bromine reacts, its colour disappears
Eg $\text{C}_4\text{H}_8 + \text{Br}_2 \rightarrow \text{C}_4\text{H}_8\text{Br}_2$
 - KMnO₄; when potassium manganate (VII) is shaken with an alkene in aqueous conditions, the mixture turns from purple to colourless (ie it decolorises); this is because the purple manganate (VII) ion is involved in a hydroxyoxidation reaction with the alkene; when the manganate (VII) ion reacts, its colour disappears
 $\text{C}_3\text{H}_6 + [\text{O}] + \text{H}_2\text{O} \rightarrow \text{HOCH}_2\text{CH}(\text{OH})\text{CH}_3$
 - Note that alkynes also give the same reactions, so these tests cannot distinguish between alkenes and alkynes
- Alkenes are said to be **unsaturated** as it is possible to add additional atoms to alkenes without first removing any

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

(iii) Alkynes

- Ethyne is manufactured by adding water to calcium carbide (CaC_2):
$$\text{CaC}_2 + 2\text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_2 + \text{Ca(OH)}_2$$
- Ethyne is also a by-product of some cracking reactions
- The most important use of ethyne is to manufacture ethanal: $\text{C}_2\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CHO}$; ethanal will be studied later in the course
- Ethyne is also used to make chloroethene, which is in turn used to make polychloroethene:
$$\text{C}_2\text{H}_2 + \text{HCl} \rightarrow \text{CH}_2=\text{CHCl}$$

This is an example of an **addition** reaction
- Alkynes show many of the characteristic reactions of alkenes; alkynes decolorise both bromine (addition) and KMnO_4 (hydroxyoxidation); it is difficult to distinguish alkenes from alkynes in the laboratory
- Ethyne can be distinguished from alkenes and alkanes because it will give a yellow-white precipitate (of Ag_2C_2) when bubbled through an aqueous ammoniacal solution of $\text{AgNO}_3(\text{aq})$; this happens because ethyne is weakly acidic, dissociating very slightly in aqueous solution to form H^+ ions, especially in the presence of an alkali such as ammonia:
$$\text{C}_2\text{H}_2(\text{aq}) \rightleftharpoons 2\text{H}^+(\text{aq}) + \text{C}_2^{2-}(\text{aq})$$

The resulting carbide (C^{2-}) ion will react with Ag^+ ions to give a yellow-white precipitate of Ag_2C_2 :
$$\text{Ag}^+(\text{aq}) + \text{C}^{2-}(\text{aq}) \rightarrow \text{Ag}_2\text{C}_2(\text{s})$$

Neither ethane nor ethene are acidic; they therefore do not give this reaction
- Like alkenes, alkynes are said to be **unsaturated** as it is possible to add additional atoms to alkenes without first removing any



Test your knowledge 9.1: Simple reactions of hydrocarbons

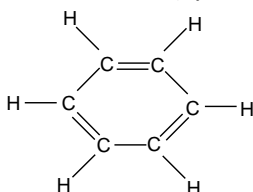
- Describe a simple laboratory preparation of each of ethane, ethene and ethyne
- Explain the difference between addition reactions, substitution reactions and elimination reactions and give one simple example of each in organic chemistry
- Describe a simple chemical test to distinguish between ethane and ethene
- Describe a simple chemical test to distinguish between ethene and ethyne
- Give the structure(s) of the organic product or products formed when:
 - Ethane reacts with chlorine in the presence of UV light
 - Propene reacts with hydrogen bromide
 - But-1-ene reacts with KMnO_4
 - Ethyne reacts with hydrogen chlorideState the type of reaction occurring in each case

Lesson 10 – What are aromatic compounds?

f) Benzene and Aromatic Compounds

(i) Structure

- Benzene is a cyclic hydrocarbon containing six carbon atoms and six hydrogen atoms (C_6H_6); it was originally thought to contain alternate single and double bonds (cyclohex-1,3,5-triene) as follows:



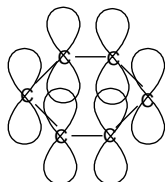
- It is usually represented as its skeletal formula:



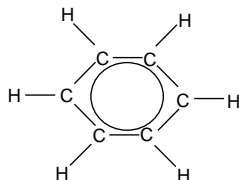
- This structure is often known as the Kekulé structure of benzene; it is now known that this is not the correct structure of benzene, although the molecule is often drawn in this way
- If this structure were correct, the sides of the hexagon with double bonds would be shorter than the sides with single bonds; this is because $C=C$ bonds are shorter than $C-C$ bonds, as the extra π -orbital overlap brings the atoms closer together:

Bond	Length/nm
C-C	0.154
C=C	0.134

- Analysis of the molecule, however, shows that all bonds have a length of 0.142 nm, intermediate between single and double; it is therefore believed that that the structure did not in fact contain alternate single and double bonds but contained delocalized electrons in six overlapping orbitals:



- The delocalized electrons can be represented as a circle within the hexagonal ring:



- Benzene is usually represented by its skeletal formula:



- All six $C-C$ bonds have the same length, the angle between the bonds 120° and the molecule is planar
- This delocalisation of electrons is known as **resonance**
- Any molecule containing the benzene ring can be described as **aromatic** (as distinct from aliphatic or alicyclic)

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

(ii) Stability and Reactions

- The delocalization (resonance) of the electrons in benzene makes the molecule more stable than expected for a molecule with three double bonds; as benzene contains carbon-carbon double bonds, it might be expected to behave like alkenes; i.e. react readily with bromine and hydrogen to undergo addition reactions, but this is not the case; benzene will not decolorise bromine water and will not readily undergo any other addition reactions
- Addition reactions break up the delocalized system and are therefore not favoured; benzene thus tends to undergo substitution, rather than addition reactions; in this respect the reactivity of benzene is more similar to alkanes than to alkenes
- In the presence of a catalyst such as AlCl_3 or FeBr_3 , benzene can undergo a substitution reaction with a halogen: $\text{C}_6\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_6\text{H}_5\text{Br} + \text{HBr}$
- In more extreme conditions (high pressure, high temperature and UV light), benzene can be persuaded to undergo an addition reaction with a halogen: $\text{C}_6\text{H}_6 + 3\text{Cl}_2 \rightarrow \text{C}_6\text{H}_6\text{Cl}_6$ or hydrogen: $\text{C}_6\text{H}_6 + 3\text{H}_2 \rightarrow \text{C}_6\text{H}_{12}$

(iii) Uses of benzene

- Benzene is used to make ethylbenzene, which is in turn used to make polystyrene.
- Benzene is also added to petrol to improve its octane number
- Benzene is used as the starting point in the manufacture of a variety of petrochemicals, including pharmaceutical products and dyes



Test your knowledge 10.1: Benzene

- Describe the structure and bonding in benzene
- Write an equation to show benzene reacting with chlorine:
 - in an addition reaction
 - in a substitution reaction
- Explain why benzene undergoes substitution reactions more readily than it undergoes addition reactions
- Give two uses of benzene
- Explain the meaning of the term “aromatic”

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY

Lesson 11 – What have I learned about Organic Chemistry?

11.1 END-OF-TOPIC QUIZ

UNIT 7 – INTRODUCTION TO ORGANIC CHEMISTRY



1. Draw the structure of: (i) a saturated branched aliphatic hydrocarbon; (ii) an unsaturated unbranched aliphatic hydrocarbon; (iii) a saturated unbranched alicyclic hydrocarbon; (iv) an aromatic hydrocarbon
2. Show the structures of the following molecules: (i) methylbutane; (ii) pent-2-ene; (iii) 3-methylbutan-1-ol; (iv) 1,2-dibromopropane; (v) cyclobutanol
3. Name the following molecules:



; (ii) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$; (iii) $(\text{CH}_3)_2\text{C}=\text{CHCH}_3$; (iv) $(\text{CH}_3)_3\text{CBr}$; (v)

4. Draw and name all the alcohols with the molecular formula $\text{C}_3\text{H}_8\text{O}$
5. Draw two molecules with the molecular formula C_5H_{10} which are:
(i) positional isomers; (ii) functional isomers; (iii) chain isomers; (iv) geometrical isomers
6. Name the first three molecules in the homologous series of alkanes and state and explain their trend in boiling points
7. Describe briefly how crude oil is separated into its fractions
8. Write a possible equation to show the cracking of octane (C_8H_{18})
9. Write a possible equation to show the reforming of hexane (C_6H_{14})
10. Name three fractions produced from crude oil and state their main use
11. Write an equation for: (i) the complete combustion of pentane; (ii) the incomplete combustion of methane
12. Explain how sulphur dioxide is produced during combustion and explain why it is a pollutant
13. Describe a simple test to distinguish cyclopentane from pent-1-ene
14. Draw both products formed when pent-1-ene reacts with HBr
15. Explain why benzene tends to undergo substitution rather than addition reactions