Cambridge (CIE) A Level Chemistry

Your notes

Formulas, Functional Groups & the Naming of Organic Compounds

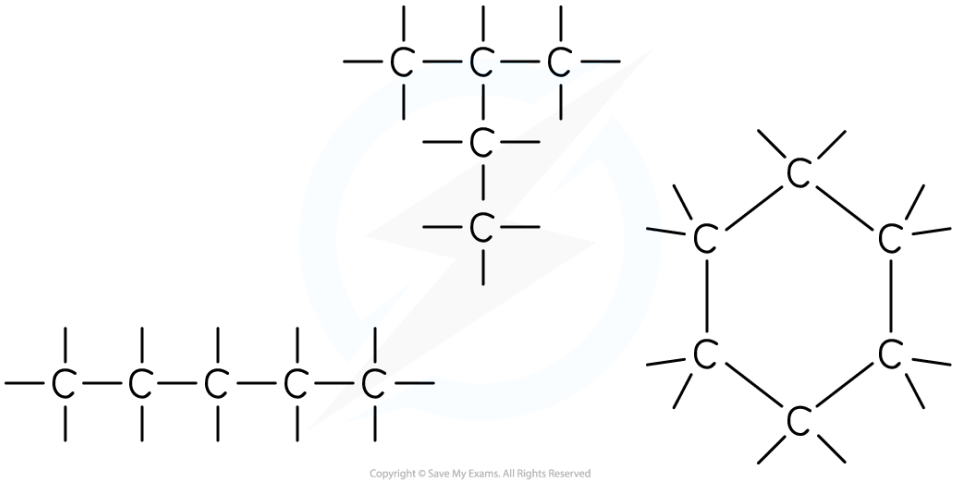
Contents

Your notes

Hydrocarbons

- **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 of carbon atoms, branched chains or cycles, and hence an almost infinite variety of carbon compounds are known
- Carbon always forms four covalent bonds which can be single, double or triple bonds

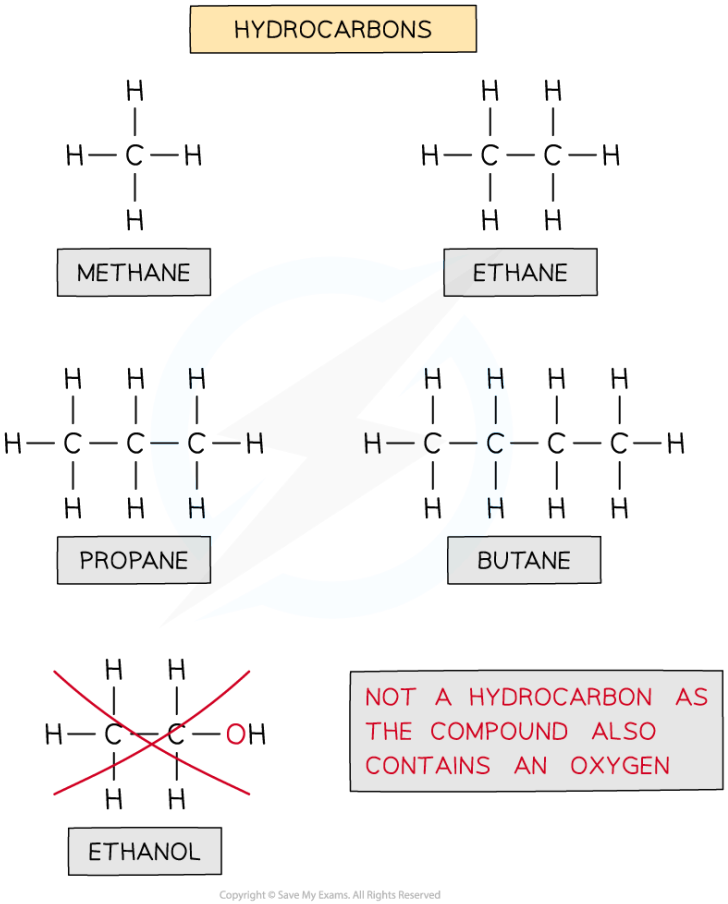
Examples of carbon structures



There is an almost infinite variety of chains, branches and rings able to form

- 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
- Organic compounds with the same functional group, but with each successive member different by CH_2 are called a **homologous series**
  - Every time a carbon atom is added to the chain, two hydrogen atoms are also added, which is why the successive members differ by CH_2
- Hydrocarbons are compounds that are made up of carbon and hydrogen atoms **ONLY**

Examples of hydrocarbons



Ethanol is NOT a hydrocarbon as the molecule also contains an oxygen atom and is not solely made up of carbon and hydrogen

Examiner Tips and Tricks

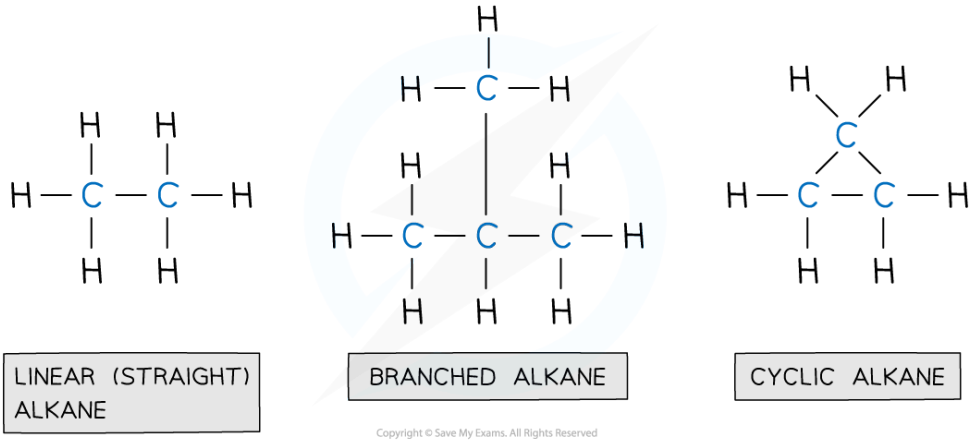
You must state that hydrocarbons are '**only**' made up of C and H atoms if defining this term in an exam

Alkanes

- A **functional group** is an atom or a group of atoms in an organic molecule, which determines the physical and chemical properties of the molecule
- **Alkanes** are the simplest hydrocarbons with no functional group
- They are made up of carbon and hydrogen atoms bonded to each other with single covalent bonds

Different types of alkanes

Your notes



Alkanes are compounds made up of carbon and hydrogen atoms only and contain no functional group

Homologous series of alkanes table

Name of alkane	Number of carbons	Chemical formula	Boiling point in °C	State at room temperature	Melting point in °C
Methane	1	CH_4	-162	gas	-183
Ethane	2	C_2H_6	-89	gas	-172
Propane	3	C_3H_8	-42	gas	-188
Butane	4	C_4H_{10}	0	gas	-138
Pentane	5	C_5H_{12}	36	liquid	-130

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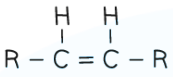
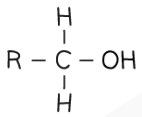
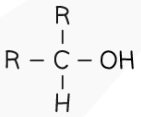
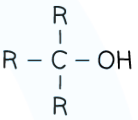
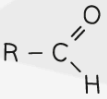
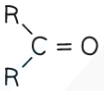
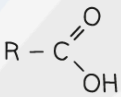
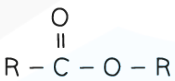
Functional Groups of Organic Compounds

- Functional groups determine the physical and chemical properties of molecules
- The table below shows a summary of common functional groups found in compounds
- R is any other atom or group of atoms (except for hydrogen)

Functional groups found in compounds table

Family	Functional Group
Alkene	
Halogenoalkane	R – X Where X = F, Cl Br and I
Alcohol	 Primary alcohol  Secondary alcohol  Tertiary alcohol
Aldehydes	
Ketone	
Carboxylic Acid	
Ester	
Primary Amine	$R-NH_2$
Nitrile	R – C ≡ N

Formulae of Organic Compounds

- The **general formula** is a formula that represents a **homologous series** of compounds using letters and numbers
  - Eg. the general formula of alkanes is C_nH_{2n+2}
  - A homologous series is a group of organic compounds that have the same functional group, the same general formula and the same chemical properties
- The **structural formula** is a formula that shows how the atoms are bonded to each carbon atom in a molecule
- The **displayed formula** is a 2D representation of an organic molecule showing **all** its atoms (by their **symbols**) and their bonds (by single, double or triple bonds)
- The **skeletal formula** is a simplified displayed formula with all the carbon and hydrogen (C-H) bonds removed

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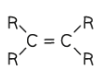
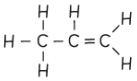
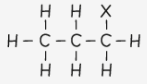
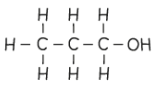
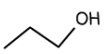
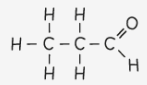
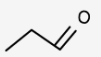
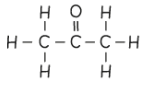
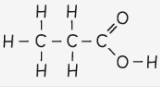
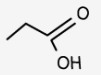
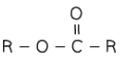
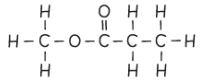
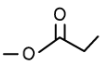
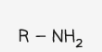
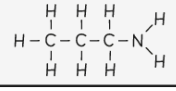
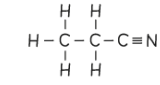
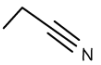
Overview of the formulae of organic compounds table

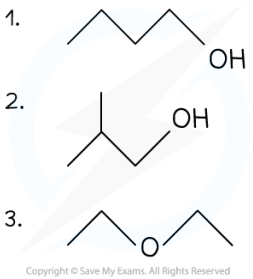
Family	General Formula	Structural Formula	Displayed Formula	Skeletal Formula	Name
Alkene	C_nH_{2n}				propene
Halogenoalkane	$C_nH_{2n+1}X$				halogenopropane
Alcohol	$C_nH_{2n+1}OH$				propan−1−ol
Aldehydes	$C_nH_{2n+1}CHO$				propanal
Ketone	$C_nH_{2n+1}COC_mH_{2m+1}$				propanone
Carboxylic Acid	$C_nH_{2n+1}COOH$				propanoic acid
Ester	$C_nH_{2n+1}COOC_mH_{2m+1}$				methyl propanoate
Amine	$C_nH_{2n+1}NH_2$				propylamine
Nitrile	$C_nH_{2n+1}CN$				propanitrile

Worked Example

Draw the skeletal formula of the following molecules:

1. $CH_3(CH_2)_3OH$
2. $(CH_3)_2CHCH_2OH$
3. $CH_3CH_2OCH_2CH_3$

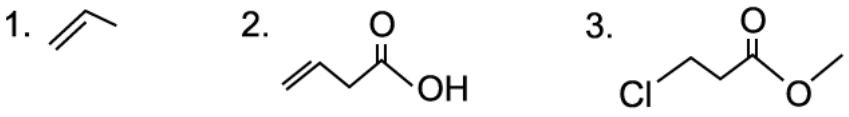
Answer:



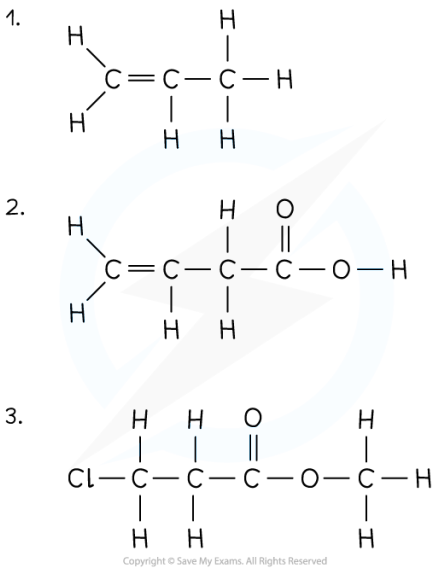
Your notes

Worked Example

Draw the fully displayed formula of the following molecules:



Answer:



Your notes

Nomenclature of Aliphatic Compounds

- **Systematic nomenclature** can be used to name organic compounds and therefore make it easier to refer to them
- The **alkanes** provide the basis of the naming system and the **stem** of each name indicates how many carbon atoms are in the **longest chain** in one molecule of the compound

Nomenclature of organic compounds table

Number of C atoms	Molecular formula of straight-chain alkane	Name of alkane	Stem used in naming
1	CH_4	methane	meth-
2	C_2H_6	ethane	eth-
3	C_3H_8	propane	prop-
4	C_4H_{10}	butane	but-
5	C_5H_{12}	pentane	pent-
6	C_6H_{14}	hexane	hex-
7	C_7H_{16}	heptane	hept-
8	C_8H_{18}	octane	oct-
9	C_9H_{20}	nonane	non-
10	$C_{10}H_{22}$	decane	dec-

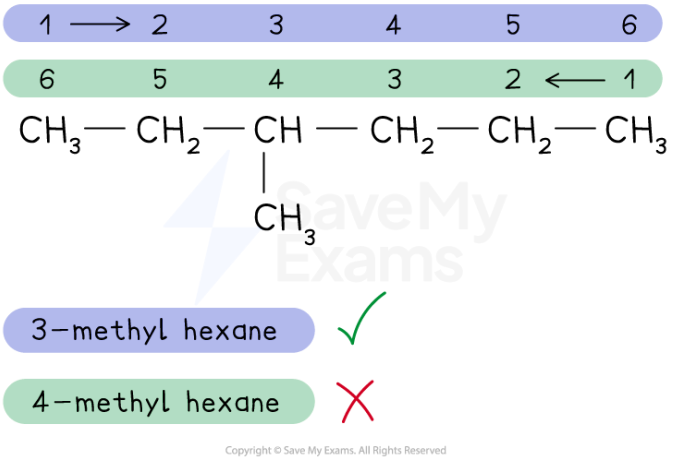
Side chains

- When naming compounds with side chains or functional groups, number the carbon atoms in the longest chain, starting from the end that gives the lowest possible numbers to the substituents
- In structural formulas, a side chain is often shown in brackets.
  - E.g. $CH_3CH(CH_3)CH_2CH_3$

- Side chains are named by changing the **-ane** ending of the parent alkane to **-yl**
- These groups are known as alkyl groups

Your notes

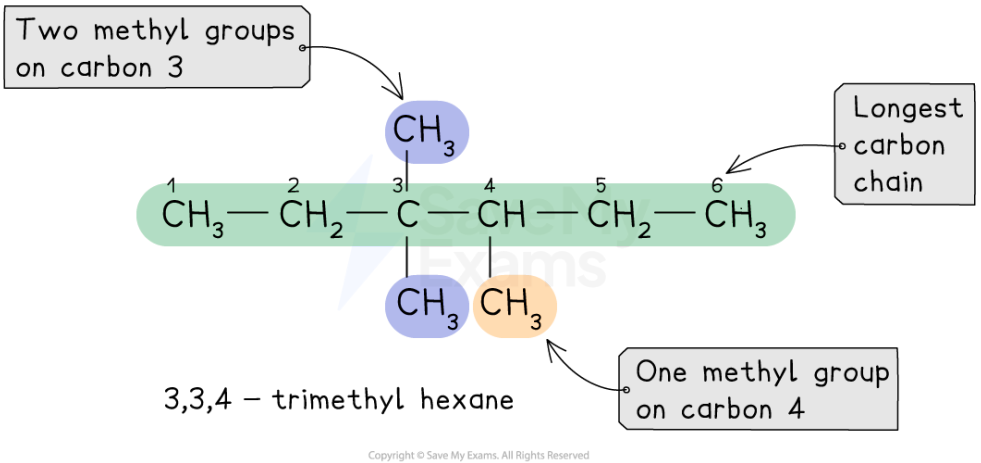
Naming organic compounds with one alkyl side chain



The longest chain provides the main name and the side chain is shown as a numbered alkyl prefix

- If there are more than one of the same alkyl side chain or functional groups, **di-** (for two), **tri-** (for three) or **tetra-** (for four) is added in front of its name
- The adjacent **numbers** have a comma between them
- **Numbers** are separated from **words** by a hyphen

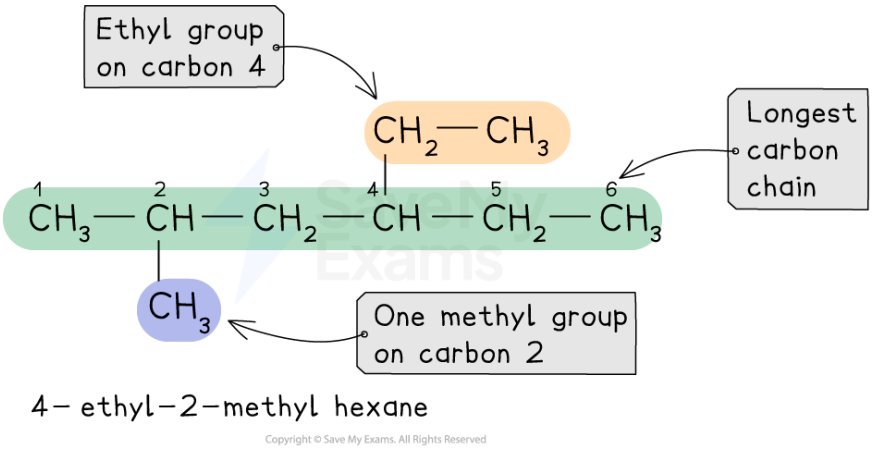
Naming organic compounds with multiple, identical side chains



The longest chain still provides the main name and the side chains are shown as numbered alkyl prefixes

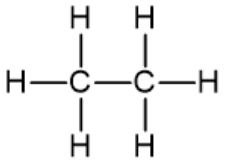
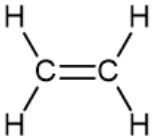
- If there is more than one type of alkyl side chain, the same numbering system applies but the different side chains are listed in alphabetic order

Naming organic compounds with multiple, different side chains



The longest chain still provides the main name and the side chains are still shown as numbered alkyl prefixes but in alphabetical order

Functional groups & their nomenclature table

Class	IUAC prefix– or –suffix	Example
alkane	–ane	 ethane
alkene	–ene	 ethene

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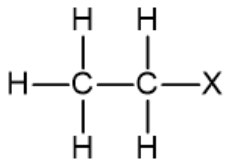
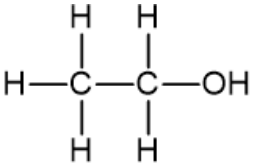
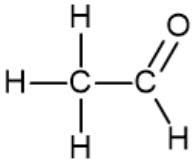
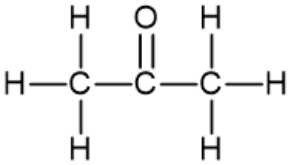
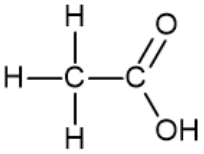
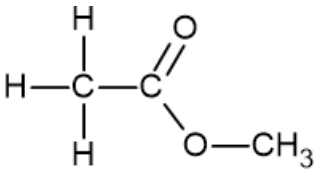
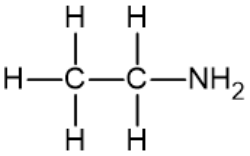
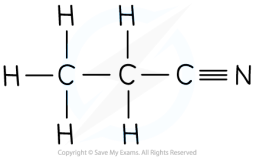
halogenoalkane	fluoro– chloro– bromo– iodo–	 if X = F, fluoroethane
alcohol	hydroxy– –ol	 ethanol
aldehyde	–al	 ethanal
ketone	–one	 propanone
carboxylic acid	–oic acid	 ethanoic acid

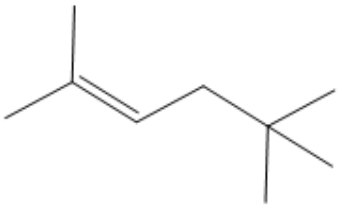
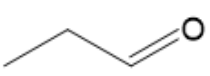
Your notes

ester	-oate	 methyl ethanoate
amine	-amine	 ethanamine
nitrile	-nitrile	 ethanenitrile

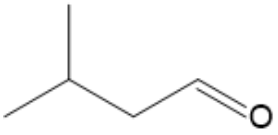
Your notes

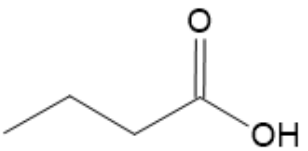
Worked Example

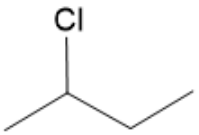
Name the following molecules using correct systematic nomenclature:

1. 
2. 
3.

Your notes

4. 

5. 



Answers:

1. The chemical name is 2,5,5–trimethylhex-2–ene
    - The longest carbon chain is six carbons long
    - There is an alkene / double carbon-carbon bond on carbon-2
    - There are 3 methyl groups on carbons 2, 5 and 5
2. The chemical name is propanal
    - The longest carbon chain is 3 carbons long with only single carbon-carbon bonds
    - There is an aldehyde group which is fixed as carbon-1
3. The chemical name is 2–methylbutanal
    - The longest carbon chain is 4 carbons long with only single carbon-carbon bonds
    - There is a methyl group on carbon-2
    - There is an aldehyde group which is fixed as carbon-1
4. The chemical name is butanoic acid
    - The longest carbon chain is 4 carbons long with only single carbon-carbon bonds
    - There is a carboxylic acid group which is fixed as carbon-1
5. The chemical name is 2–chlorobutane
    - The longest carbon chain is 4 carbons long with only single carbon-carbon bonds
    - There is a chlorine atom attached to carbon-2

Examiner Tips and Tricks

An **aliphatic** compound is **straight** or **branched-chain** and also includes **cyclic** organic compounds that do not contain a **benzene** ring.

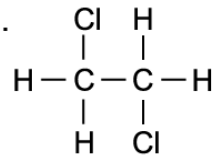
Your notes

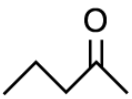
Molecular & Empirical Formulae of Organic Compounds

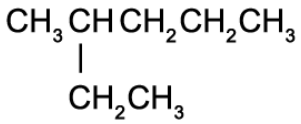
- The **molecular formula** shows the number and type of each atom in a molecule
  - E.g. the molecular formula of ethanoic acid is $C_2H_4O_2$
- The **empirical formula** shows the simplest whole number ratio of the elements present in one molecule of the compound
  - E.g. the empirical formula of ethanol is CH_2O

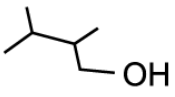
Worked Example

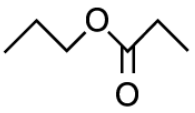
Deduce the molecular and empirical formula of the following compounds:

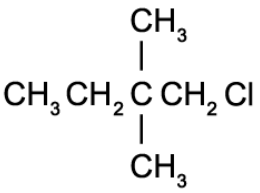
1. 

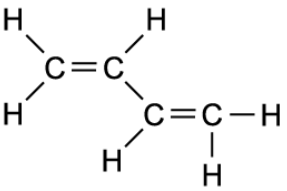
2. 

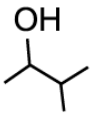
3. 

4. 

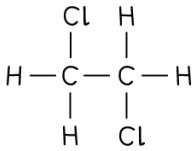
5. 

6. 

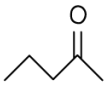
7. 

8. 

Answers:

1. 

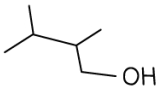
$C_2H_4Cl_2$
CH_2Cl

2. 

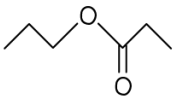
$C_5H_{10}O$
$C_5H_{10}O$

3. $CH_3CHCH_2CH_2CH_3$
CH_2CH_3

C_7H_{16}
C_7H_{16}

4. 

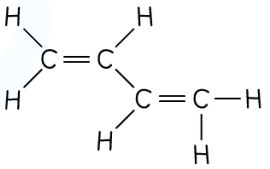
$C_6H_{14}O$
$C_6H_{14}O$

5. 

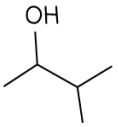
$C_6H_{12}O_2$
C_3H_6O

6. $CH_3CH_2CCH_2Cl$
CH_3 CH_3

$C_6H_{13}Cl$
$C_6H_{13}Cl$

7. 

C_4H_6
C_2H_3

8. 

$C_5H_{12}O$
$C_5H_{12}O$

MOLECULAR FORMULA
EMPIRICAL FORMULA

Your notes