Hydrocarbons

Definition: A hydrocarbon is an organic compound which consists entirely of hydrogen and carbon.

It is important to note that carbon atoms have 4 free bonds and that hydrogen has 1 free bond. Hydrogen is very reactive as all atoms want to achieve noble gas state. This means that hydrogen and carbon have the ability to form long chains known as hydrocarbons.

When a hydrocarbon only has single bonds between carbon atoms it is called an alkane. Its general formula is \( C_n H_{2n+2} \). The first ten are as follows:

<table>
<thead>
<tr>
<th>Alkane</th>
<th>General Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>( CH_4 )</td>
</tr>
<tr>
<td>Ethane</td>
<td>( C_2H_6 )</td>
</tr>
<tr>
<td>Propane</td>
<td>( C_3H_8 )</td>
</tr>
<tr>
<td>Butane</td>
<td>( C_4H_{10} )</td>
</tr>
<tr>
<td>Pentane</td>
<td>( C_5H_{12} )</td>
</tr>
<tr>
<td>Hexane</td>
<td>( C_6H_{14} )</td>
</tr>
<tr>
<td>Heptane</td>
<td>( C_7H_{16} )</td>
</tr>
<tr>
<td>Octane</td>
<td>( C_8H_{18} )</td>
</tr>
<tr>
<td>Nonane</td>
<td>( C_9H_{20} )</td>
</tr>
<tr>
<td>Decane</td>
<td>( C_{10}H_{22} )</td>
</tr>
</tbody>
</table>

Two important terms to understand are saturated and unsaturated hydrocarbons. A saturated hydrocarbon has a single bond between carbon atoms:

- \( \text{C} = \text{C} \)

A unsaturated hydrocarbon has either a double or triple bond between carbon atoms:

- \( \text{C} = \text{C} \)  -  \( \text{C} \equiv \text{C} \)

Classification of hydrocarbons:

Hydrocarbons

- Saturated
- Unsaturated

  - Alkanes
  - Alkenes
  - Alkynes

- Haloalkanes
- Alcohols
- Ketones
- Aldehydes
- Carboxylic acids
- Esters
- Amines*
- Amides*

*Not included in the table on page 4
Alkanes (C – C)
Alkanes have low boiling points and are insoluble in water as they contain no polar groups. Alkanes are quite unreactive, but they do burn in oxygen and react with halogens and nitric acid.

Use of Alkanes
Alkanes are used in the form of fuel in cars and paraffin in cooking stoves. They are used in the process of catalytic cracking in the Petroleum industry, as well as in Chemical industry to manufacture plastics, ammonia, higher alkanes, aldehydes and ketones.

Reactions of alkanes
There are three types of reactions that alkanes undergo:

1. Oxidation reactions
Carbon dioxide and water are formed.

\[ C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \]

A large amount of heat energy is given off.

2. Substitution reactions
Hydrogen is formed as a by-product.

\[ C_2H_6 + Br_2 \rightarrow C_2H_4Br_2 + H_2 \]

In this reaction ethane, when reacted with bromine, becomes 1,2-dibromoethane.

3. Elimination reactions
Elimination reactions are when two atoms are removed from a molecule of a saturated compound, resulting in the formation of a carbon-carbon double bond.

A strong base, for example NaOH, reacts with a saturated compound to form a double bond. The NaOH serves to take up the H atom leaving the saturated compound to form water.

Alkenes (C=C)
Alkenes are unsaturated hydrocarbons having one double bond between two carbon atoms. Their names are derived from the alkane having the same number of carbon atoms, however, all alkenes end in the suffix –ene. Examples of alkenes are methene, ethene and propene. Alkenes have the general formula: \( C_nH_{2n} \).

Alkenes are unsaturated and are therefore more reactive than alkanes. A lot of the reactions involving alkenes involve the double bond between the two carbon atoms ‘breaking’ to form other bonds.

Use of Alkenes
Alkenes, specifically ethene, are used to make polythene, the plastic used for plastic bags, wrapping and Tupperware. It is also as a general anaesthetic. Other alkenes are good solvents of grease, while others are used in the dry-cleaning industry.
Reactions of Alkenes

1. Addition reactions
   Addition reactions convert a double bond into a single bond. It forms a saturated compound from an unsaturated compound.

   **Types of addition:**
   - **Hydrogenation**
     \[ C_2H_4 + H_2 \rightarrow C_2H_6 \]
     Ethene is reacted with hydrogen gas, causing the double carbon-carbon bond to break and allow the two hydrogen atoms to bond with the carbons.
   - **Bromination**
     \[ C_2H_4 + Br_2 \rightarrow C_2H_4Br_2 \]
     The bromine molecule causes the double bond in the ethene to break and convert it to a saturated form, and thus becomes 1,2 – dibromoethane
   - **Chlorination**
     \[ C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2 \]
     The chlorine molecule causes the double bond in the ethene to break and convert it to a saturated form, and thus becomes 1,2 – dichloroethane

2. Polymerisation
   Unsaturated compounds can react with other unsaturated compounds to form long hydrocarbon chains called polymers. The original molecules, from which the polymer is derived, are called monomers. This process is called polymerisation.

   Monomer + monomer = Polymer

Alkynes (C ≡ C)
Alkynes are also unsaturated hydrocarbons, they have the general formula: \( C_nH_{2n-2} \). They have a triple bond between two carbon atoms.

Use of Alkynes
Ethyne reacting with oxygen is used for welding. Alkynes are also used for the preparation of a large number of addition compounds.

Reactions of Alkynes

1. Oxidation reactions
   \[ 2C_2H_2 + 5O_2 \rightarrow 4CO_2 + H_2O \]
   A large amount of heat energy is released.
2. Addition reactions
Just like alkenes, alkyne addition reactions reduce the degree of unsaturation. The only difference is that alkynes go from having a triple bond to having a double bond.

\[ C_2H_2 + H_2 \rightarrow C_2H_4 \]

The hydrogen atoms react with the ethyne and convert the triple bond to a double bond, allowing the hydrogen atoms to bond to the carbon atoms.

Functional Groups
Functional groups are a group of compounds with similar structures and properties. Each one has a particular structure of atoms which determines its properties.

<table>
<thead>
<tr>
<th>Series</th>
<th>Functional group</th>
<th>Series</th>
<th>Functional group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkane</td>
<td>C – C</td>
<td>Ester</td>
<td>( R^1OR^2 )</td>
</tr>
<tr>
<td>Alkene</td>
<td>C = C</td>
<td>Aldehyde</td>
<td>( R\text{=O} )</td>
</tr>
<tr>
<td>Alkyne</td>
<td>C ≡ C</td>
<td>Ketone</td>
<td>( R\text{=C=O} )</td>
</tr>
<tr>
<td>Haloalkane</td>
<td>R – X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carboxylic acid</td>
<td>( R\text{=O} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Haloalkanes (Alkyl Halides)
Haloalkanes are a functional group with the structure \( R – X \), where the \( R \) is a hydrocarbon and the \( X \) is a halogen. The haloalkanes form a homologous series\(^1\) with a general formula: \( C_nH_{2n+1}X \)

Haloalkanes, also known as alkyl halides, are used in hospitals as general anaesthetic. They are also solvents which dissolve oil and grease (tetrachloromethane). Some are used in the dry-cleaning industry (tetrachloroethene).

Due to the presence of halogens in haloalkanes they are more reactive than regular alkanes and react with alkalis, alkali metals, silver oxide, silver salts, hydrogen and magnesium.

Alcohols (Alkanols)
Alcohols have the structure \( R – OH \). Alcohols’ names all end in the suffix –ol. An example of an alcohol is Ethanol \( (C_2H_5OH) \). The alcohols form a homologous series with the general formula: \( C_nH_{2n+1}OH \).

Alcohols are slightly polar as a result of the electronegative oxygen atom in the hydroxide (OH). It is therefore soluble in water. The oxygen atom, being more electronegative, pulls the shared electron pair away from the hydrogen atom. This leaves the oxygen atom with a slightly negative charge, and the

\(^1\) A series of compounds that have the same functional group and can be represented by the same general formula

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The hydrogen atom with a slightly positive charge. This means the molecule is polar. Therefore it can dissolve in water, which is also a polar molecule.

**Uses of Alcohols**
Methanol is used as a solvent for gums and resins. Ethanol is used in alcoholic beverages, also as a solvent for paints and varnishes. Ethanol is used in preparation of medicines, as a fuel, and as a preparation of other organic compounds as we shall see in the reactions below.

**Reactions involving alcohol**

1. **Oxidation of Alcohols (Preparation of carboxylic acids)**
   Alcohol + oxidising agent → carboxylic acid
   
   Ethanol + $K_2Cr_2O_7$ → $Cr^{3+}$ + ethanoic acid

2. **Preparation of Esters**
   Alcohol + carboxylic acid → an ester + water

We will take a look at this reaction in more detail under “Esters.”

**Carboxylic acids**
Carboxylic acids are the organic acids that are found in everyday substances, such as vinegar and lemon juice. Their structure is:

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R' \underline{\text{O}}H
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The condensed functional group is R – COOH. Their names end in –oic acid.

**Uses of Carboxylic acids**
Vinegar is used in cooking, garnishing salads and preserving food. They also play a role in the preparation of esters.

**Properties of Carboxylic acids**

1. **Acid Properties**
   They are weak acids, as they do not dissociate completely into hydrogen ions. As acids they can neutralise bases, recall the acid/base reaction: $\text{Acid} + \text{Base} \rightarrow \text{a Salt} + \text{Water}$.

2. **Solubility in water**
   Carboxylic acids are soluble in water as they are polar and form hydrogen bonds with polar water molecules. See Alcohols on pg. 4 for full explanation.

**Esters**
Esters are organic compounds with pleasant smells and flavours. Their functional group is: Their names have two words, the first ending in –yl, and the second ending with –oate.

**Uses of Esters**
Esters are used in the food industry to produce synthetic flavours and aromas. The lighter esters are fragrant liquids, while the heavier esters are fats, vegetable oils and waxes.
Preparation of Esters
Esters are formed when an alcohol reacts with a carboxylic acid.

A small amount of concentrated sulphuric acid ($H_2SO_4$) is added. The sulphuric acid is a dehydrating agent. Note: In the process of dehydration, water is given off. Therefore this reaction is classified as a dehydration or elimination reaction.

Alcohol + Carboxylic acid → Ester + Water

For example, suppose methanol reacts with ethanoic acid in the presence of sulphuric acid.

$$CH_3OH + C_2H_3COOH \rightarrow C_2H_5CO + H_2O$$

The sulphuric acid forces the H atom of the methanol to join up with the HO of the ethanoic acid, to form water. The remaining parts of the alcohol and acid link together to form the ester, methyl ethanoate.

Ketones
Ketones are organic compounds that have characteristic smells and tastes. The functional group is:
Their name end with the suffix –one.

Uses of Ketones
Ketones are used in food flavourings and solvent. Ketones are found in peppermint, caraway and camphor.

Aldehydes
Aldehydes are also found in various fragrances and tastes, such as vanilla, nuts and cinnamon. The functional group is:

Uses of Aldehydes
Aldehydes are also used in the food industry for synthetic flavourings and aromas. Glucose is an aldehyde. They are used in solvents, as well as preserving laboratory biological specimens (formaldehyde).

Preparation of Aldehyde
Aldehydes are created when alcohols are oxidised:

Alcohol + oxidising agent → Aldehyde

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