BioMedical Admissions Test (BMAT)

Section 2: Chemistry

Topic C13: Carbon/Organic Chemistry

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General Concepts

Hydrocarbons

Hydrocarbons are **organic compounds** consisting only of **carbon and hydrogen**.
The carbon atoms form the "framework"; they have the ability to **form double and triple bonds** between themselves, as well as forming structures such as **rings** (known as an **alicyclic compound**). The hydrogen atoms attach to this framework in different configurations.

The ability of carbon atoms to form double/triple bonds gives rise to the following two categories of hydrocarbon:

- ➔ **Saturated**: contain only **single bonds** between the carbon atoms, so each is bonded to as many hydrogen atoms as possible.
- ➔ **Unsaturated**: have **double/triple bonds** between adjacent carbon atoms (i.e. more hydrogen atoms could be added to the hydrocarbon to saturate it).

These two types will behave differently, reacting via different mechanisms and having different properties.

Another way that hydrocarbons may differ is the **size/length of the chain**.

- ➔ **Smaller molecules** will have **weaker intermolecular forces** as they have less surface contact and electrons to interact in the induced dipole-dipole interactions holding them together.
- ➔ This means it takes **less energy** for these interactions to be overcome, and they therefore have **lower boiling points**.

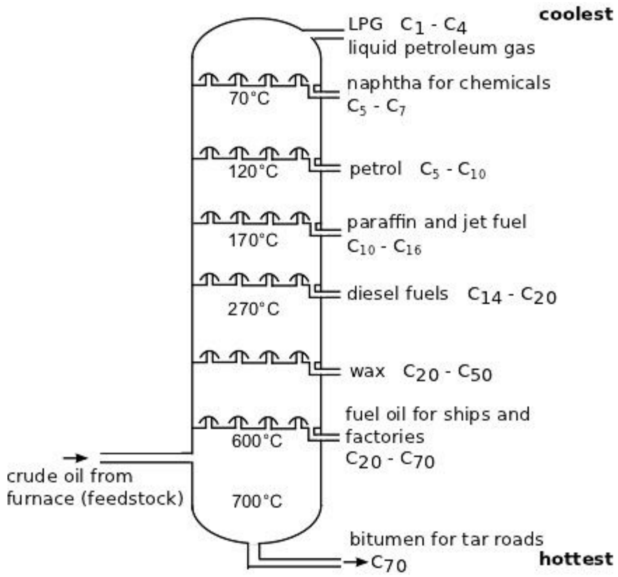
This actually comes into play in their production.

Crude Oil

Crude oil is a dark, viscous liquid found in the Earth's crust, formed from the remains of organisms that died millions of years ago. It is a **finite** resource, and our main source of hydrocarbons. However, crude oil must be **refined** in order to extract useful (and simpler) components as it is a complex mixture of many different hydrocarbons.

The first step of refining crude oil is **Fractional Distillation**: this is the separation of crude oil into simpler mixtures which is possible due to differing boiling points of different hydrocarbons

1. Crude oil enters the fractionating column; a tall subdivided chamber which is hot at the bottom and becomes cooler upwards.
2. The oil vaporises, rising through the column.
3. These vapours condense when they reach the point in the chamber where it is colder than their boiling point.
4. Liquid is led out of the column.



By Duncan Watson, 14 February 2015
https://www.flickr.com/photos/121935927@N06/15821230683

Fractional distillation separates the mixture into smaller ones: **fractions**. The hydrocarbons in each have similar:

- No. of hydrogen/carbon atoms
- Boiling points
- Viscosity
- Ease of ignition

In the image above, C_1 - C_4 shows the **amount of carbon molecules** in the hydrocarbons found in each fraction.

The fractions containing smaller molecules are therefore generally more useful, e.g. making better fuels. This is as they...

- are very volatile (easily evaporated at normal temperatures)
- have lower viscosity, i.e. flow more easily
- are more flammable.

One method of remembering the fractions and their uses is
Lazy **P**enguins **N**aughtily **K**eep **D**rinking **H**ot **B**eer:

- Liquefied petroleum gases: domestic heating/cooking fuel
- Petrol (gasoline): car fuel
- Naphtha: chemicals (diluting heavy fuel, cleaning metal, etc.)
- Kerosene: aircraft fuel
- Diesel: train, lorry, bus fuel
- Heavy fuel oil: for ships/power stations
- Bitumen (residue): roads/roofs

* cool; around 25°C, hot: around 350°C

(modified from BBC Bitesize)

The next stage in refining is called **catalytic cracking**. This allows for more shorter chain molecules to be produced.

- The longer chain molecules are passed over a **heated catalyst**; breaking down into shorter chain molecules by means of random events.
  - The large hydrocarbon molecules are often sources from the naphtha/gas oil fraction from the column.
- The liquids obtained are **re-vaporised** before being **cracked**.
- There are no specific mechanisms by which the molecules are broken down, and these hydrocarbons produced can contain carbon-to-carbon double bonds (characteristic of alkenes- of a different homologous series to alkanes).

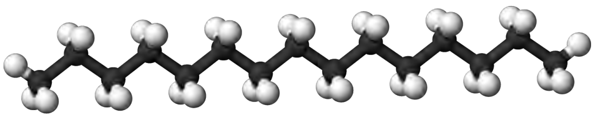
The presence of a **catalyst** means that lower temperatures and pressures can be used.

One reaction that might occur in this stage would be:

$$C_{15}H_{32} \rightarrow 2C_2H_4 + C_3H_6 + C_8H_{18}$$

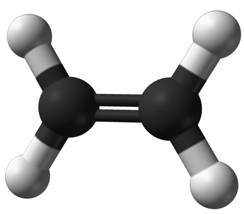
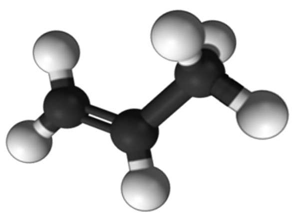
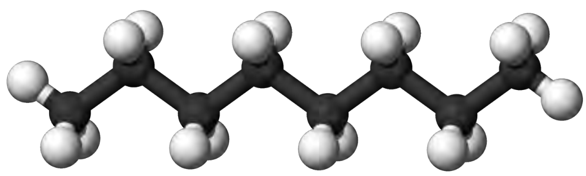
pentadecane → **ethene** + **propene** + octane

To demonstrate the changes in bonding in a 3D model:



By Jynto and Ben Mills, 8 January 2011
https://commons.wikimedia.org/wiki/File:Pentadecane-3D-balls.png

pentadecane

 Ethene an alkene; note double bond *By Ben Mills, 27 April 2009* https://commons.wikimedia.org/wiki/File:Ethylene-CRC-MW-3D-balls.png	 Propene also an alkene; note one double bond and one single *By Claudio Pistilli, 21 January 2019* https://commons.wikimedia.org/wiki/File:Propene3D.png	 Octane alkane; only single bonds *By Jynto and Ben Mills, 8 January 2011* https://commons.wikimedia.org/wiki/File:Pentadecane-3D-balls.png

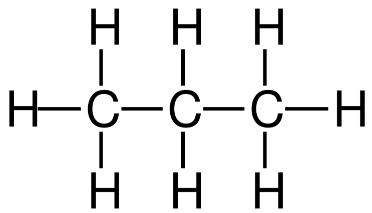
Molecular Formula

Molecular formula = chemical formula for a compound that exists as discrete molecules, giving the **total number of atoms of each element in the molecule**.

➔ For example, the molecular formula of ethane is C_2H_6.

This is not sufficient however to describe organic compounds as they have molecules composed of many atoms. The arrangement of these atoms must be explained to identify the compound. This can be done by giving the **structural formula**. This can be referred to as 'displayed structure.'

For example, this is the structural formula of **propane**.



By Jü, 10 July 2018
https://commons.wikimedia.org/wiki/File:Propane_Structural_Formula_B_V1.svg

The structural formula can also be shown in a more compact way as a 'condensed' structural formula, for example for C_5H_{12} it can be:

$CH_3CH_2CH_2CH_2CH_3$ pentane (not branched),

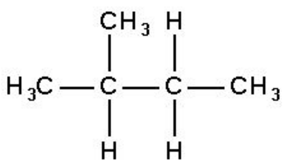
$CH_3CH(CH_3)CH_2CH_3$ when 2-methylbutane.

Note: in condensed structural formula, display any carbon-to-carbon double bonds (as C=C).

Structural Isomerism

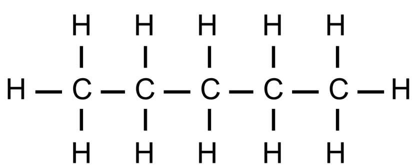
Isomerism is the existence of more than one compound with the same molecular formula but a different arrangement of the atoms, i.e. different structural formulas.

The molecules above are an example of structural isomerism.



2-methylbutane

From rozeta, 2004
https://commons.wikimedia.org/wiki/File:2-methylbutane.png



pentane

By User:Bangin, 27 April 2007
https://commons.wikimedia.org/wiki/File:Pentane.svg

Combustion of hydrocarbons

Many hydrocarbons ignite easily, releasing significant amounts of energy when combusted. This makes the combustion of hydrocarbons a vital reaction.

The **complete combustion** of hydrocarbons requires a **plentiful supply of oxygen** - i.e. an excess. The only **products** of this reaction are **carbon dioxide** and **water**.

The equation for the complete combustion of **heptane** is:

$$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$$

Equation Method: What order to balance in

1. Write the molecular formula of hydrocarbon.
2. Number of CO_2 molecules can be found by halving the number of carbon molecules in the hydrocarbon.
3. Number of H_2O molecules can be found by halving the number of hydrogen molecules in the hydrocarbon.
4. Find the number of oxygen molecules by counting the total on the right hand side. Half this number to find the amount of O_2 molecules.

In the case of an insufficient supply of oxygen, the hydrocarbons will be **incompletely combusted**. As a result, while some of the carbon atoms will still form carbon dioxide, some or all of the carbon atoms will form carbon monoxide or be left as carbon atoms.

So for the **incomplete combustion** of **heptane**, the equation may be:

$$C_7H_{16} + 9/2O_2 \rightarrow 4CO_2 + 3CO + 8H_2O$$

Nomenclature

Nomenclature is the name given to the **naming system** for organic compounds. It follows specific guidelines set by the IUPAC (International Union of Pure and Applied Chemistry). The system regarding the number of carbon molecules present in the hydrocarbon follows these steps:

No. carbon atoms	prefix
one	meth-
two	eth-
three	prop-
four	but-
five	pent-
six	hex-
seven	hept-
eight	oct-

In a molecule, count the **longest straight chain of carbons** to find which prefix should be given.

There are additional rules concerning the families of different compounds i.e. homologous series. The suffix to the name will indicate the **homologous series** the compound belongs to:
- For alkanes, **-ane**
- For alkenes, **-ene**

For a **straight chain hydrocarbon**:
For example, **octane**:
- ➔ oct means 8 carbon atoms
- ➔ ane means it is an alkane.

For example, **ethene**:
- ➔ eth means 2 carbon atoms
- ➔ ene means it is an alkene, so contains carbon-carbon double bonds.

For a **branched chain**, the following rules will apply:
1. Carbon atoms in the longest straight are **numbered** so the positions of the branches have the lowest numbers possible (and total).
2. Branches are named following the first rules mentioned, i.e. a branch with one carbon atom will be called **methyl**.
3. These branches are named in an **alphabetical order**, and numbered as a prefix.