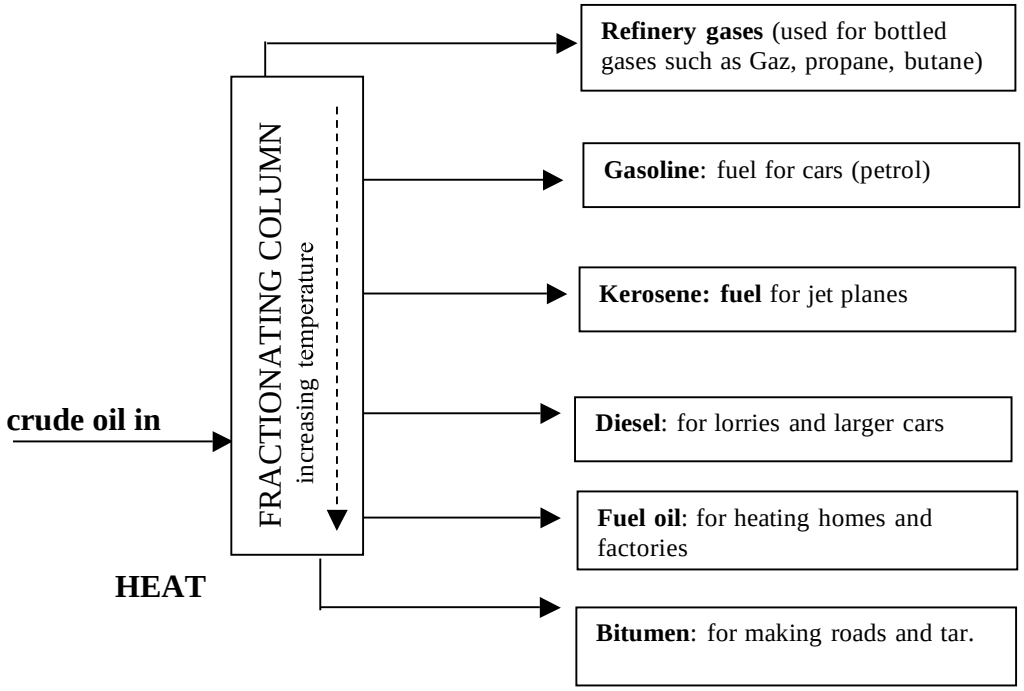
# Organic Chemistry

Crude oil is a complex mixture of hydrocarbons (compounds containing hydrogen and carbon only).
It forms a valuable resource, both as the origin of many types of fuel, and as the starting point for *petrochemicals* (plastics, detergents, solvents etc).
However, it must first be separated into mixtures with a much narrower *boiling range.*
In industry, crude oil is separated by **FRACTIONAL DISTILLATION** in a *continuous* process, taking off the samples at *different levels* from the fractionating column. The dissolved gases come out of the top, and the boiling points rise as one goes down the column. Note that the process does not produce single substances, but less complex mixtures than in crude oil. A simplified diagram is shown below:




- The Crude oil is initially heated and evaporated.
- The small molecules have a low boiling point and rise to the top of the tower.
- As the tower is descended the molecules get longer and have a higher boiling point and so condense at higher temperatures.

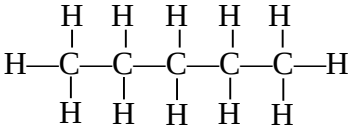
There is a problem with the fractional distillation of crude oil;

- it produces too many of the less useful long chained fractions.

The products obtained from oil are invaluable to society, providing transportation fuels (cars, planes), plastics, pesticides, detergents — a huge range of *petrochemicals*.
There is an environmental cost to this. Extraction of oil may pollute the environment (e.g. in Alaska). Transport of oil by pipeline (leaks in Siberia) and tanker (routine spillages, major accidents from *Torrey Canyon* to *Esso Valdez*) is hazardous, and is bound to result in problems.
Some substances obtained from oil have their own environmental problems:
**Petrol, diesel**: greenhouse effect, air pollution (nitrogen oxides, carbon monoxide, unburnt hydrocarbons, particulates)
**Plastics:** most are not biodegradable (not broken down by bacteria in the environment), and so last for very long periods in landfill sites. When burnt some give toxic fumes, so safe disposal, especially of packaging, is difficult.

# Carbon compounds

Carbon always forms four bonds and hydrogen forms one bond. For example:



Pentane

The simplest carbon compounds are the **hydrocarbons** (defined as compounds which contain carbon and hydrogen **only**).

The **molecular formula** of a compound shows how many of each type of atom there are in a molecule. For pentane (above) this is $C_5H_{12}$.

The **displayed formula** of a compound shows all the bonds between the atoms in a molecule (as shown for pentane and cyclobutane above).

## ALKANES

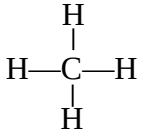
Most of the hydrocarbons present in crude oil are alkanes.

The alkanes are said to form a **homologous series**, that is a series of organic compounds with the same general formula and similar chemical properties.
**The general formula for alkanes is $C_nH_{2n+2}$.**

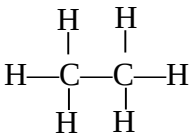
Each member (after the first) differs from the one before by addition of a $–CH_2–$ group.

The physical properties of a homologous series usually show a regular *trend*.
For example, their boiling points increase steadily along the series; this is because, as the molecules get larger, the attractions between molecules increase and so take more energy to break.

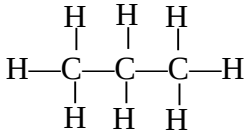
The alkanes may be defined as hydrocarbons of general formula $C_nH_{2n+2}$.
You should learn the names and structures of the first five members:



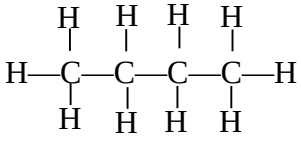
methane $CH_4$



ethane $C_2H_6$



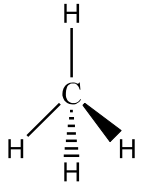
propane $C_3H_8$



butane $C_4H_{10}$

Pentane, $C_5H_{12}$, is shown at the top of this page.

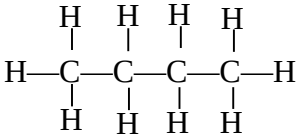
In alkanes the four bonds on each carbon are directed to the corners of a tetrahedron.



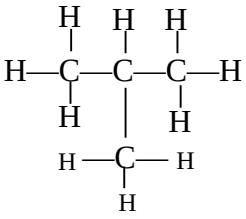
## Isomers

Alkanes with four or more C atoms can show *isomerism.*

**Isomerism**: when two or more different compounds have the same molecular formula but different structural formula, they are called **isomers.** For example there are two compounds of formula $C_4H_{10}$:



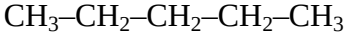
butane



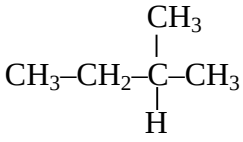
methylpropane

The one on the right is a *branched-chain* compound (i.e. the carbon atoms are not all in a row).

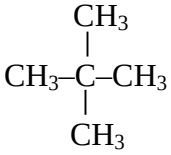
For $C_5H_{12}$ there are three isomers, two of which are branched:



pentane



methylbutane



dimethylbutane

## Reactions of Alkanes

Alkanes are widely used as **fuels**.
When they burn in air they form waste gas (carbon dioxide and water vapour), and the reaction gives out heat to the surroundings (**exothermic**).

e.g. $CH_4 + 2\ O_2 \rightarrow CO_2 + 2H_2O$ (combustion of natural gas)
$C_5H_{12} + 8\ O_2 \rightarrow 5CO_2 + 6H_2O$
$C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$

In a restricted supply of air, **carbon monoxide** is formed: this is highly toxic (and particularly dangerous since it has no colour or smell). Carbon monoxide is poisonous because it reduces the capacity of blood to carry oxygen by bonding to haemoglobin.

During the combustion of fuels such as petrol and diesel, sulphur dioxide and nitrogen oxides may also be formed. These gases are pollutants which contribute to acid rain.

Apart from combustion, alkanes are very unreactive.

They will however react with chlorine and bromine in the presence of sunlight.

$$\mathbf{CH_4 + Cl_2 \rightarrow CH_3Cl + HCl}$$
$$\mathbf{C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr}$$

## Catalytic Cracking

**Cracking**: this is an example of a **thermal decomposition** (a reaction in which a substance is heated until it breaks down into other substances).
When an alkane is cracked, by passing its hot vapour over a catalyst, it splits into a shorter-chain alkane and an alkene:

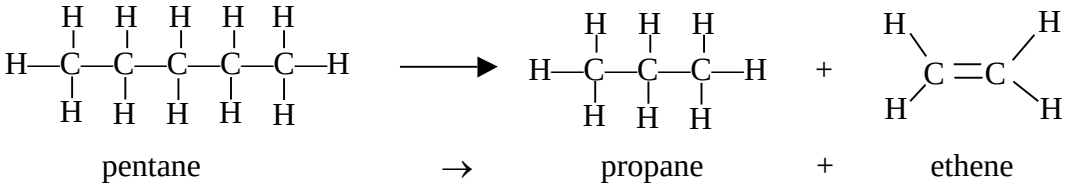
| | long-chain alkane | → | shorter-chain alkane | + | alkene (or hydrogen) |
|---|---|---|---|---|---|
| e.g. | $C_{10}H_{22}$ | → | $C_8H_{18}$ | + | $C_2H_4$ |
| or | $C_3H_8$ | → | $C_3H_6$ | + | $H_2$ |

**Conditions for Catalytic Cracking** – Temperature 600-700 $^oC$
Catalyst $SiO_2$ or $Al_2O_3$

## Importance of Catalytic Cracking

Cracking is important because;
(a) it produces valuable alkenes, which are the starting point for petrochemicals;
(b) it also gives shorter alkanes, which are more useful as fuels.

We can illustrate this using displayed formulae, for cracking pentane, the fifth alkane:



pentane → propane + ethene