

Fuels Notes

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At some point you will have taken a bus, car or plane journey, or perhaps all. All of these means of transport use fuels to work. Even if you yourself don't use fossil fuels, think about how your food gets to the supermarkets. Large trucks, which burn fuels. Burning fuels can cause some problems that we will look at in this booklet. We'll look at the fuels themselves first.

A fuel: a substance that releases energy. Some fuels (for example uranium) release energy from nuclear reactions. Many are hydrocarbons which release their energy by reacting with oxygen in the air.

Hydrocarbons: are substances which are made of hydrogen and carbon atoms only.

Crude oil is the source of most of our hydrocarbon fuels, it is a finite (non-renewable) resource because it forms extremely slowly over millions of years and cannot quickly be replaced.

Crude oil is a complex mixture of lots of different kinds of hydrocarbons like petrol, diesel and jet fuel. These need to be separated from crude oil to be used. You would cause a big problem if you put crude oil into a petrol cars fuel tank, or a small problem if you don't mind buying a new car.

However, crude oil is an important source of: fuels and feedstock for the petrochemical industry.

A feedstock: raw material used to provide reactants for an industrial reaction.

A petrochemical: a substance made from crude oil using chemical reactions.

For example, ethene is produced from crude oil. It is used as feedstock to make poly(ethene), a polymer used to make plastic shopping bags.

Fractional distillation

Fractional distillation: a method of separating a mixture of liquids with different boiling points into individual components (fractions).

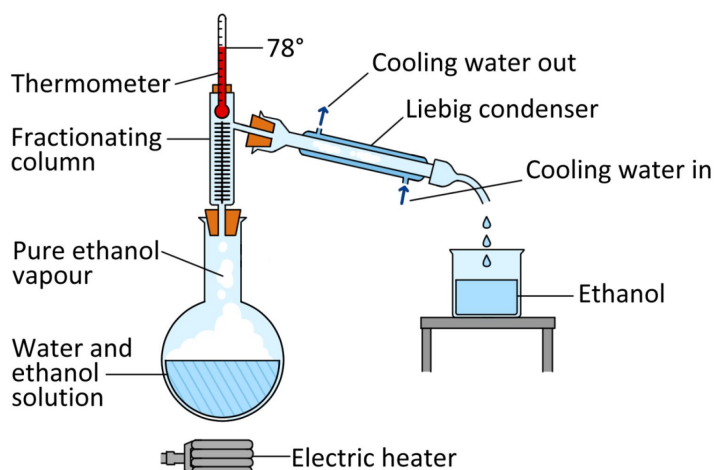
Where is it used?

It is useful for separating ethanol from a mixture of ethanol and water and for separating crude oil into its different fractions e.g. gasoline and kerosene.

How does it work?

Fractional distillation works by separating the different liquids based on their different boiling points. When the mixture is heated:

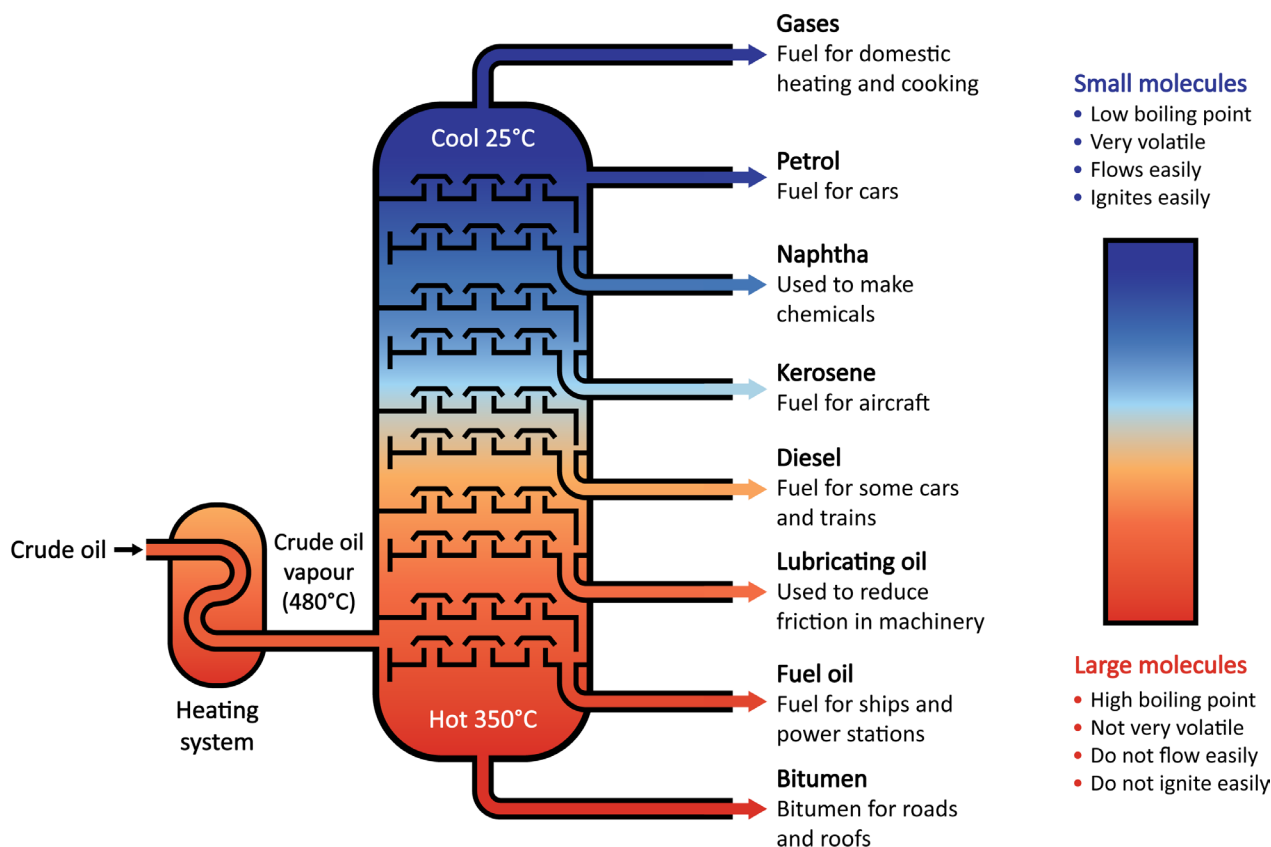
1. The vapours rise through a column which is hotter at the bottom, and cooler at the top.
2. The vapours condense when they reach a part of the column that is below the temperature of their boiling point.
3. Each liquid is then removed from the column.



The figure shows the set up for a fractional distillation

Questions in exam papers tend to ask questions about fractional distillation in the form of fractionating columns dealing mostly with separating crude oil into its various fractions.

The diagram below gives a rough guide to the fractional distillation of crude oil. Please be aware of roughly where each fraction comes off and a use of each fraction.



Exam hint: many questions about fractional distillation also have aspects of organic chemistry, alkanes and alkenes, in them. Questions on these will be on paper 2 but questions on fractional distillation can come up on both paper 1 and paper 2.

Properties of the Fractions

Each crude oil fraction contains a mixture of hydrocarbons. The hydrocarbons in a fraction are mostly hydrocarbons called Alkanes.

The alkanes in each fraction have similar:

- Numbers of hydrogen and carbon atoms in their molecules.
- Boiling points.
- Ease of ignition – how easily they are set on fire.
- Viscosity – is a measure of how well they flow.

Take for example, the gases fraction. It contains hydrocarbon chains that are between one to four carbon atoms long. These have low boiling points that are below room temperature. They are very flammable and have a low viscosity – so flow very easily.

In comparison the bitumen fraction contains hydrocarbon chains with more than 35 carbon atoms. These have boiling points well above room temperature. They are very difficult to ignite and have a high viscosity – so flow quite slowly.

The simplest organic compounds are hydrocarbons which contain only single bonds (ordinary covalent bonds where two electrons are shared). These are called **alkanes**.

Alkanes

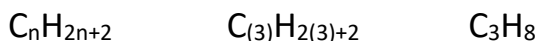
An Alkane: is a saturated hydrocarbon. This means that all the covalent bonds between atoms in an alkane molecule are single bonds. All alkanes have names that end in –ane.

The general formula of an alkane is C_nH_{2n+2} . Please do learn this. It mostly tends to come up as a multiple-choice question.

How do we use the general formula of an alkane? Just like we would use an n^{th} term in maths. Substitute in the number of carbon atoms instead of n to find the formula. Let's have a look at one of these.

Example 1: Let's say that want to find the molecular formula of an alkane with 3 carbons in it.

We substitute in 3 instead of 'n' and complete the expression.



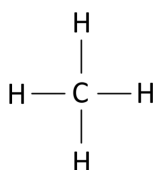
This is the molecular formula for the alkane with 3 carbon atoms in it. It's called Propane 😊.

Alkanes are a homologous series. But what is a homologous series? Excellent question!

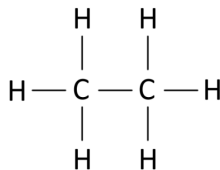
A homologous series – is a group of compounds with the same general formula, that have similar chemical properties meaning that they react the same way as each other and that they show a gradual variation in their physical properties.

For example, the boiling point (which is a physical property) of a molecule will increase as the carbon chain gets longer. This makes sense as the longer the chain is the more bonds that there are in the molecule. Therefore we need to break more bonds and this takes more energy. Let's look at the first 5 alkanes.

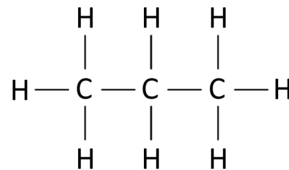
1. Methane, CH_4



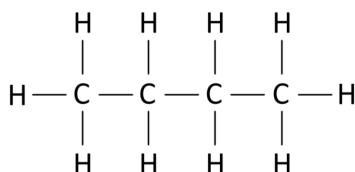
2. Ethane, C_2H_6



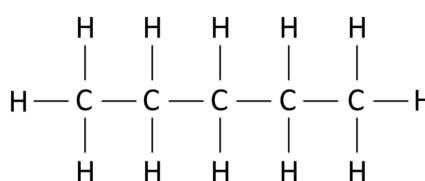
3. Propane, C_3H_8



4. Butane, C_4H_{10}



5. Pentane, C_5H_{12}



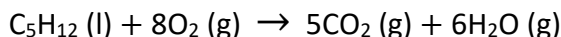
Reactions of Alkanes

We need to know about two typical reactions that alkanes undergo. Those are combustion and cracking. Cracking is sometimes called thermal cracking but its exactly the same reaction.

Combustion

Like all hydrocarbons, alkanes burn to give CO_2 and H_2O . Take the example of the combustion of pentane below:

Pentane + Oxygen $\rightarrow$ Carbon dioxide + Water



This is complete combustion. There are two types of combustion, **complete combustion** and **incomplete combustion**.

Complete combustion – occurs when a fuel fully reacts with a sufficient supply of oxygen. It results in the formation of two main products, carbon dioxide, CO_2 and water, H_2O .

Incomplete combustion – occurs when a fuel burns in an insufficient supply of oxygen. As a result, the fuel is not fully oxidised. This leads to the formation of harmful products, such as carbon monoxide, CO (g) and soot (carbon particles), in addition to water, H₂O. The equation below shows the incomplete combustion of hexane:

Hexane + oxygen → carbon monoxide + carbon + water



Carbon monoxide, CO (g) is a toxic gas. It is taken in by the lungs and binds with the haemoglobin in the red blood cells. This reduces the capacity of the blood to carry oxygen. This can be fatal if the exposure is high for a long time.

Carbon solid – soot. The carbon from incomplete combustion is released as fine black particles.

Soot can cause breathing problems for people with asthma and it can blacken buildings.

Catalytic Cracking

What is it catalytic cracking? It's a process of strongly heating a large alkane over a catalyst in the absence of O₂, this can crack any hydrocarbon. The word equation below shows this reaction.

Large alkane → smaller alkane + alkene

Cracking will produce a mixture of alkanes and alkenes and these can be separated by fractional distillation.

What are the conditions used for cracking?

High temperature.

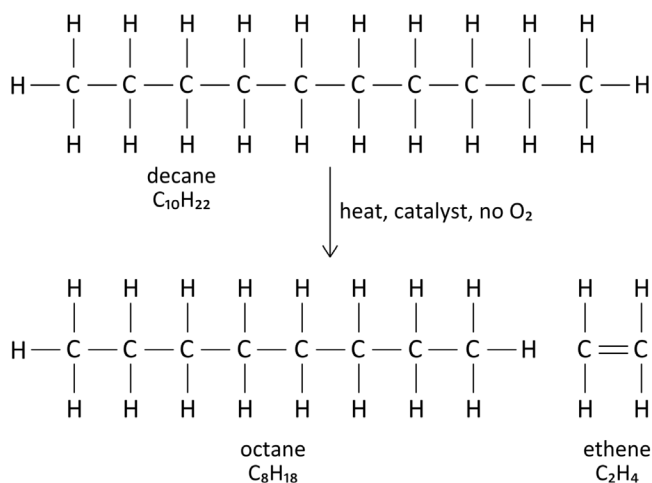
Catalyst – which is zeolite.

No oxygen.

Why is cracking done? Cracking is carried out because large alkanes are less useful as fuels so there is less demand for them. Smaller alkanes are much more useful as fuels as they burn quickly, for example gasoline for cars.

The alkenes that are produced in this reaction can be used to make polymers and other useful chemicals.

The figure below shows the cracking of decane, C₁₀H₂₂ into octane C₈H₁₈ and ethene, C₂H₄.



Steam Cracking

Is another type of cracking that can be used instead of catalytic cracking.

How does it work? Hydrocarbons are mixed with steam and heated rapidly. The heat breaks down the hydrocarbon molecules into smaller ones

What are the conditions?

High temperature

Steam

No catalyst

What is it used for? Used to make lots of alkenes mostly.

Physical Properties of Alkanes

State: Methane, ethane, propane and butane are all colourless gases at room temperature. The other alkanes are all clear colourless liquids at room temperature.

Boiling and melting points: increase as the number of carbon atoms increases (due to stronger intermolecular forces).

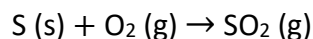
Solubility: Alkanes are insoluble in water.

Density: All of the alkanes float on top because they are less dense than water.

Sulfur Impurities

Many hydrocarbon fuels naturally contain sulfur impurities. When the fuels are burned, the sulfur oxidises to form sulfur dioxide gas:

sulfur + oxygen → sulfur dioxide



The sulfur dioxide produced in combustion can react with water vapour in clouds to form acid rain.

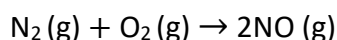
Acid rain can damage all environments. For example, it:

- Damages plants and trees, damaging their leaves which reduces their ability to photosynthesise.
- Reacts with metals and rocks such as limestone, damaging buildings and eroding statues.
- Can cause rivers and lakes to become too acidic for some aquatic life.

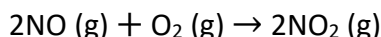
Oxides of Nitrogen

High temperatures are reached when fuels are burned in engines. At these high temperatures, nitrogen and oxygen from the air can react together to produce oxides of nitrogen. For example:

Nitrogen + oxygen → nitrogen monoxide



Nitrogen monoxide gas can be oxidised further in air to produce nitrogen dioxide gas, NO₂.



Nitrogen monoxide and nitrogen dioxide can react in sunlight with other substances to produce a hazy, harmful smog. Nitrogen dioxide is toxic. It can cause bronchitis and other lung diseases. It also dissolves in water in the clouds, forming an acidic solution that contributes to acid rain.

Comparing Petrol and Hydrogen

We could be asked to evaluate the advantages and disadvantages of using hydrogen rather than petrol, as a fuel in cars. First let's look at what they are and how each is made.

Petrol: is a non-renewable fossil fuel. It is extracted from crude oil, a finite resource. Some of the substances found in petrol are made by cracking crude oil fractions, a process which uses large amounts of energy.

Hydrogen: is a gas. We can get hydrogen in a number of different ways. These are:

- Reacting methane with steam.
- Cracking of crude oil fractions (hydrogen is a by-product of this process).
- Electrolysis of water.

	Petrol	Hydrogen
Products of combustion	CO ₂ , CO & H ₂ O	H ₂ O
Uses fossil fuels to be manufactured	✓	✓
Energy released (MJ)	46	142
Ease of ignition	Ignites easily	Ignites easily
State at room temperature and pressure	Liquid	Gas

There are a few small issues with hydrogen though. The pressurised cylinders that hydrogen is stored in can be dangerous in the event of a crash and storing these cylinders can have it's own problems such as having enough space and the risk of fire.