WJEC Wales Chemistry GCSE

2.5: Crude oil, fuels and organic chemistry

Detailed notes

Crude oil

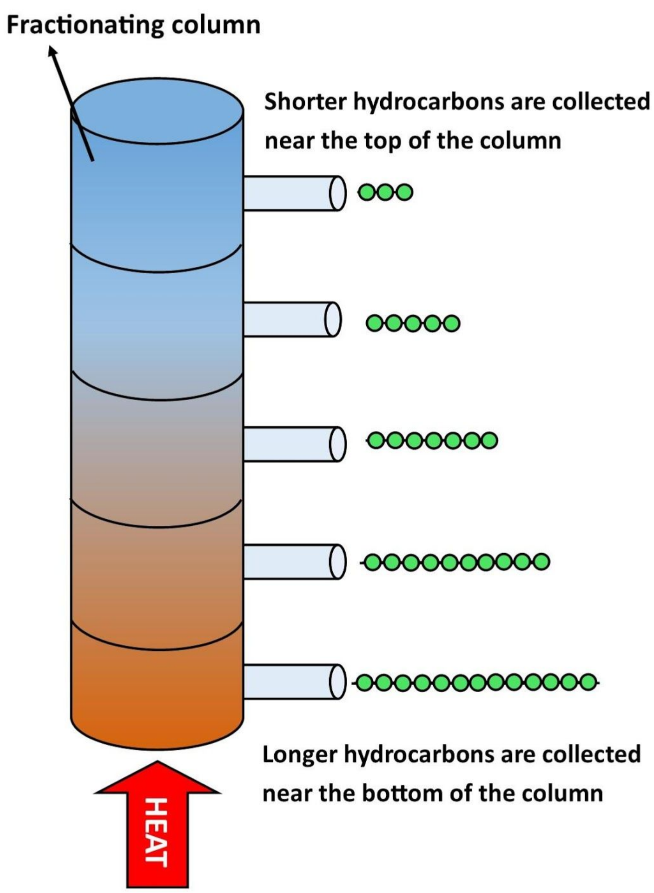
What is crude oil?

- Crude oil is a finite resource found in rocks, formed over millions of years from the remains of an ancient biomass consisting mainly of plankton that was buried in mud
- It contains a complex mixture of hydrocarbons
  - Hydrocarbons are compounds that contain hydrogen and carbon atoms only
  - Mixture: 2 or more elements/compounds that are not chemically combined
- Crude oil is a feedstock for the petrochemical industry
- It is possible to separate the substances in crude oil by physical methods including fractional distillation

Fractional distillation

Crude oil contains many hydrocarbons which differ in the length of their carbon chain. This gives them different boiling points which allows them to be separated by fractional distillation. Method:

1. The crude mixture is put in the bottom of the fractionating column and heated
2. The hydrocarbons evaporate and rise up the column
3. The further up the column, the cooler it is, so as hydrocarbons rise they eventually reach a fraction which is cool enough to cause them to condense back to a liquid. Each fraction contains hydrocarbons of a similar chain length and can be tapped off.
4. The mixture left at the bottom of the fractionating column which does not evaporate at all is called bitumen.



- The longer the hydrocarbon, the more intermolecular forces it can form so the lower its boiling point.
    - Therefore, longer hydrocarbons are collected nearer the bottom of the column and shorter hydrocarbons are collected nearer the top.
- The shorter chains are generally in higher demand and are more useful fuels.
- As chain length increases:
    - Boiling point and melting point increases
    - Viscosity increases
    - Flammability decreases
    - Volatility decreases (harder to evaporate)
    - Their colour darkens

Cracking

- Some long chain hydrocarbons can be broken down into shorter chains, which are more useful. This process is known as cracking.
- Cracking involves heating the hydrocarbons to vaporise them. The vapours are either:
    - Passed over a hot catalyst of silica or alumina
    - Mixed with steam and heated to a very high temperature so that thermal decomposition reactions can occur
        - This thermal decomposition causes covalent bonds to break, splitting long hydrocarbons into multiple smaller ones.
- The products of cracking include alkanes and unsaturated hydrocarbons called alkenes.
    - Alkenes have the general formula C_nH_{2n}
    - Alkenes are monomers that are used to make plastics
- An example is the cracking of decane into propene and heptane:
  Decane → Propene + Heptane
  $C_{10}H_{22} \rightarrow C_3H_6 + C_7H_{16}$

The impact of the oil industry

- Economic importance -
    - Oil companies set the price of oil so have an influence globally on the economy. It can become hard for poorer countries to buy oil.
    - Wars or internal crisis within a country that produces oil can affect the flow of oil to other countries they sell to.
- Political importance -
    - Countries that are large producers of oil can essentially cut off oil supplies to other countries; this is used as a political tool.
- Social impact -
    - The oil industry supplies jobs and money for the economy.
- Environmental impact -
    - Burning fossil fuels releases large amounts of carbon dioxide, a greenhouse gas, into the atmosphere, contributing towards global warming and climate change.
    - The building of power stations and the process of drilling for oil causes damage to the landscape and loss of habitats.
    - Oil spillages in the ocean result in the deaths of marine life and birds and are often dealt with by setting them alight.

Combustion

Combustion of hydrocarbons

Hydrocarbons can react in oxygen to produce large amounts of useful heat energy.

- When the fuel burns in plenty of oxygen it will combust as follows:
  Hydrocarbon + oxygen → carbon dioxide + water
  - For instance, the complete combustion reaction for propane, which has 3 carbon atoms, is:
  - $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
- When there is insufficient oxygen the fuel will undergo incomplete combustion and as a result form carbon monoxide or carbon and water.
- Ethanol, an alcohol, also undergoes combustion:
  $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Combustion of hydrogen

- Hydrogen burns in oxygen and forms water:
  $2H_2 + O_2 \rightarrow 2H_2O$
- Hydrogen is used as a fuel in rockets and some cars.

There are many pros and cons to using hydrogen as a fuel:

Advantages	Disadvantages
• No greenhouse gases are produced in the combustion of hydrogen • An alternative fuel option in a world where the current fuels are running out	• Hydrogen is extremely flammable • Most of the hydrogen produced comes from fossil fuels or electrolysis so it still has a negative impact on the environment • Hard fuel to store and transport. Hydrogen must be cooled to very low temperatures so it liquifies and can be stored and transported. This is hard to do and the container must be very strong to withstand the high pressure inside it; it could potentially explode.

The fire triangle

- The fire triangle is a symbol that contains the 3 things that are needed for a fire to burn:
  - Oxygen
  - Fuel
  - Heat
- Removing any of these will cause the fire to stop burning, so knowledge of the fire triangle can be used to prevent and put out fires.
- Removal of oxygen -

- Fire extinguishers contain carbon dioxide that, when sprayed on the fire, push the oxygen away
- Fire blankets prevent new oxygen reaching the fire so it will eventually run out of oxygen and die out

- Removal of the fuel -
  - Fuel resistant materials can ensure any fires that start will quickly stop due to lack of fuel
- Removal of heat -
  - Water can be used to remove the heat in fires - however water can't be used on electrical fires or oil fires

Calorimetry

Calorimetry is an experimental technique used to work out the energy released when burning a fuel.

Method:

1. A known volume of water is added to a calorimeter (a kind of copper beaker) and a thermometer is used to measure and record the start temperature.
2. A known mass of fuel is then burnt beneath the calorimeter so the heat given off heats the water.
3. The maximum temperature the water reaches is recorded and the final mass of the fuel is found so the mass of fuel that was burned can be calculated.
4. The energy per gram of fuel can then be calculated:
   - Energy released (in Joules) = mass of water in grams x 4.2 x temperature change
   - The total energy released can then be divided by the mass of fuel burned to calculate the energy per gram of fuel.

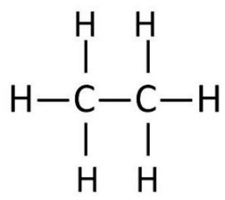
Example calculation: The start mass of a fuel was 7.2g and at the end 3.4g was left. The starting temperature of 100g of water was 24℃ and the maximum temperature reached was 79 °C. Calculate the energy per gram of the fuel.

- Mass of fuel burned = 7.2 - 3.4 = 3.8g
- Temperature change = 79 - 24 = 55℃
- Total energy change = 100 x 4.2 x 55 = 23,100 J = 23.1 kJ
- Energy per gram of fuel = 23.1 ÷ 3.8
  = 6.08 kJ/g (3 sig. fig.)

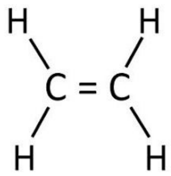
Alkanes and alkenes

Hydrocarbons

- Contain hydrogen and carbon atoms only
- Can be saturated (no double bonds); these are called alkanes and have the general formula C_nH_{2n+2}
  The structure of the alkane ethane is shown:



- Can be unsaturated (have at least one double bond); these are called alkenes and have the general formula C_nH_{2n}
  The structure of the alkene ethene is shown:



Naming compounds

- Prefixes (beginning of the name) give the number of carbon atoms in the longest chain of carbon atoms in the molecule
  - The first 4 prefixes can be remembered using the mnemonic Monkeys Eat Peanut Butter:
  - Meth- (1C)
  - Eth- (2C)
  - Prop- (3C)
  - But- (4C)
  - Pent- (5C)
  - Hex- (6C)
  - Etc,
- The suffix of any compound refers to the functional group
  - Alkanes – ane (C-C) e.g. ethane
  - Alkenes – ene (C=C) e.g. ethene
  - Alcohols – ol (OH) e.g. ethanol
  - Carboxylic acids – anoic acid (-COOH) e.g. ethanoic acid

Representing compounds

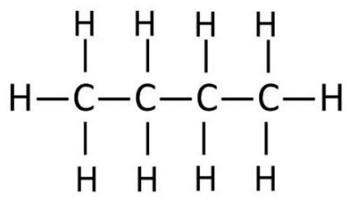
In organic chemistry, compounds can be represented by a number of ways:

- IUPAC name - the formal name of the compound
- Molecular formula - gives the number and type of each type of atom, e.g. C_4H_{10} for butane
- Structural formula - gives the number and type of each type of atom and their arrangement in the molecule, e.g. $CH_3CH_2CH_2CH_3$ for butane

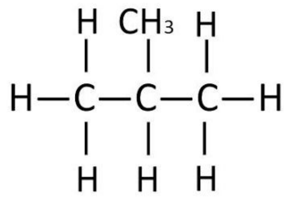
HIGHER TIER ONLY - Isomerism in complex alkanes and alkenes

- **Isomerism exists when 2 compounds have the same molecular formula (same number and type of each atom) but their structures differ in some way.**
- **Some examples of isomerism include:**
  - **Chain - the main carbon chain differs in length**

For instance, both butane and 2-methylpropane have the molecular formula C_4H_{10} but butane has a main chain length of 4 carbons whereas 2-methylpropane has a main chain length of 3 carbons and a methyl group on the second carbon in the chain.

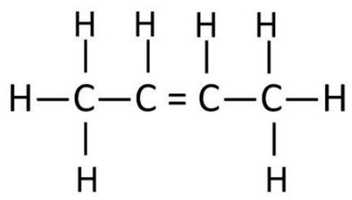


Butane

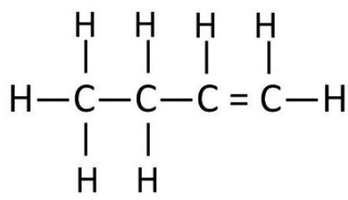


2-methylpropane

- Position - in alkenes the position of double bond(s) in the molecules can differ



But-2-ene



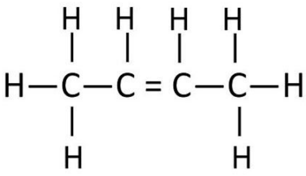
But-1-ene

HIGHER TIER ONLY - Naming complex alkenes and alkanes

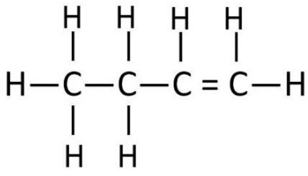
Rules:

- Locate the longest unbroken chain of carbon atoms (they may not be in a straight line!)
- Number the carbon atoms from the end closest to a functional group or branch point.
- Alphabetically list the functional groups attached to the carbon chain and state the carbon number the group is attached to.
- For double bonds, count the position of the double bond by counting BONDS not carbon ATOMS.
- If there are multiple groups of the same functional groups the prefixes di-, tri-, tetra-, penta- etc are used.

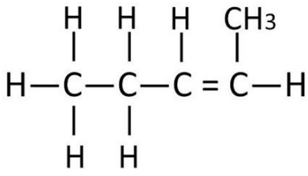
Examples:



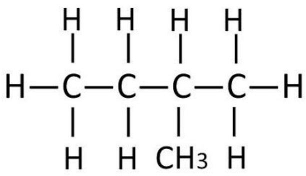
But-2-ene



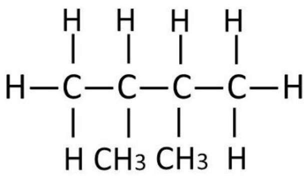
But-1-ene



Pent-2-ene



2-methylbutane



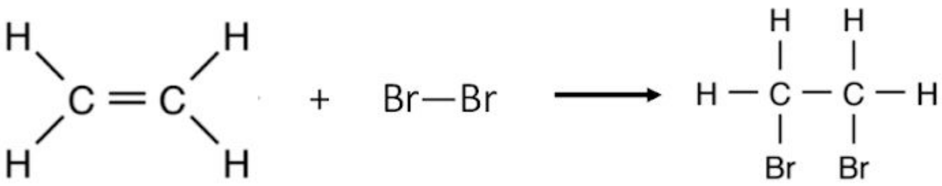
2,3-dimethylbutane

Reactions of alkenes

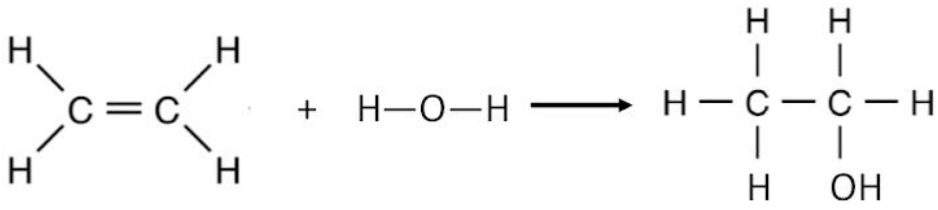
Addition reactions

Addition reactions are reactions in which two or more molecules combine to form a larger one with no other products.

- Alkenes have a double bond which makes them more reactive than alkanes
- Alkenes undergo addition reactions with hydrogen and bromine
- When alkenes are reacted with hydrogen, the double bonds open up and bond to hydrogen, forming an alkane.
  Example: $CH_2CH_2 + H_2 \rightarrow CH_3CH_3$
- Alkenes react in the same way with bromine
  - This is used as a test for the presence of alkenes
  - Bromine water is an orange solution. When shaken with an alkene the bromine water will decolorise as the bromine reacts with the alkene to form substituted alkanes.
  - An example reaction occurring is: $CH_2CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$

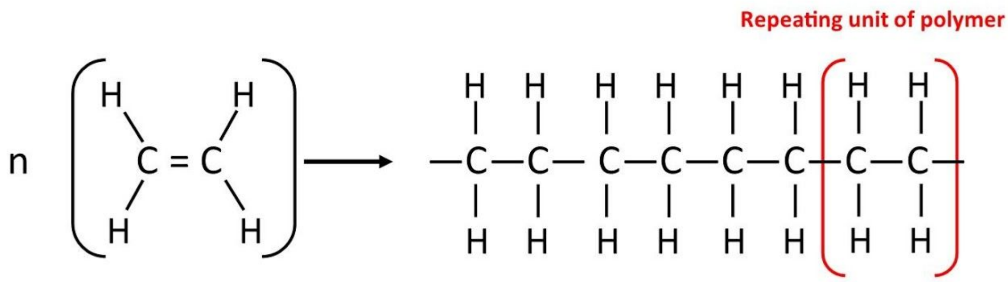


  - Conversely, if alkanes are shaken with bromine water, the solution will remain orange as the bromine does not react.
- Alkenes can react with steam to form alcohols:
  $CH_2CH_2 + H_2O \rightarrow CH_3CH_2OH$



Addition polymerisation

- Alkenes can be used to make polymers
- Polymers are large molecules made up of many repeating units called monomers
- Alkenes can be monomers because they have double bonds that open up to connect to other alkene monomers in a chain

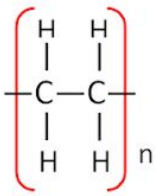


Ethene —> polyethene

(Monomers —> Polymer)

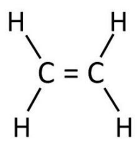
Drawing polymers

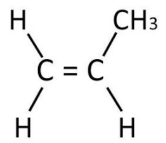
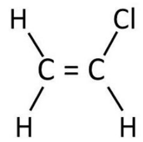
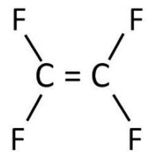
- When drawing out a polymer you have to to draw the bonds coming out the brackets from the outermost carbon atoms and subscript ‘n’ (means there are large numbers of these molecules joined together)



Uses of polymers

This table shows the monomers needed to make various polymers and the uses of these polymers.

Name	**Monomer**	**Polymer uses**
Polyethene	Ethene, C_2H_4 	• Bin liners • Plastic bottles • Hoses and tubes • Plastic bags
Polypropylene	Propene, C_3H_6	• Plastic parts for cars

		• Packaging • Textiles
Polyvinylchloride (PVC)	Chloroethene, CH_2CHCl 	• Water pipes • Electrical wires • Window panes • Medical tubing and IV bags
Polytetrafluoroethene (PTFE or Teflon)	Tetrafluoroethene, CF_2CF_2 	• Coating non-stick pans • Nail polishes • Coating hair straighteners and curlers

Properties of polymers

The properties of polymers depend on their monomers and the way they are made. Some differences include:

- Thermosetting vs thermosoftening polymers
  - Thermosoftening polymers melt when heated and can be remoulded and reshaped
  - Thermosetting polymers do not melt when heated
- High-density vs low-density polymers
  - High-density polymers tend to be harder and stronger than low-density polymers.

Environmental impact of polymers

- Polymers are made from alkene monomers which come from crude oil, a fossil fuel which is bad for the environment
- Disposal of plastics:
  - Puts pressure on landfill
  - Can be burned (incineration disposal); however, this releases carbon dioxide, a greenhouse gas
  - Recycling - this manages the other issues of disposal, provides jobs and helps preserve the non-renewable resource of crude oil.

Alcohols

Overview

- Alcohols have the general formula $C_nH_{2n+1}OH$
- They have a hydroxyl, OH, functional group
- Their names end in -ol
- Short chain alcohols are used as solvents and fuels

Production of ethanol

- Ethanol is an alcohol with the structural formula CH_3CH_2OH

- Ethanol can be made by fermentation of sugar; the enzymes in yeast catalyse the reaction:
  Glucose → ethanol + carbon dioxide
  $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- The conditions required are: 30 °C and yeast

Uses of ethanol

In alcoholic drinks -

- Social impact -
  - Alcohol is bad for your health and causes a number of illnesses including liver disease, different cancers and cardiovascular problems. After smoking and obesity it is the biggest lifestyle risk factor.
  - Alcohol can increase the number of violent fights and other crimes.
- Economic impact -
  - Taxation of alcoholic drinks, employment thanks to the alcohol industry and alcohol export to outside of the UK all bring money into the economy.
  - However, alcohol also costs the economy due to healthcare and police costs from alcohol-related issues.

As a solvent -

- Ethanol is a good solvent, meaning it dissolves a large number of other substances easily

As a fuel -

- Ethanol can be used as a fuel called bioethanol. There are many pros and cons to this biofuel.

Advantages	**Disadvantages**
• A carbon neutral fuel - the carbon dioxide released when ethanol is combusted is equal to the carbon dioxide removed from the atmosphere as sugar cane grows. So, there is no net addition of carbon dioxide to the atmosphere, which is good for the environment. • Good fuel alternative to countries without their own crude oil supply • Is a renewable resource	• The ethanol can only build up to around 15% concentration before it begins to kill the yeast at which point it must be distilled to obtain pure ○ Distillation is a high energy and cost process • Engines must be altered before they can use bioethanol as a fuel • Can cause deforestation to provide land for growing sugar cane • Some areas of the world are not hot enough and don't have enough light hours in the day to be able to completely switch to biofuel • Using food as fuel could increase food prices • Energy is needed in the growing, distillation and transportation of ethanol which would require the burning of fossil fuels so would still cause global

	warming

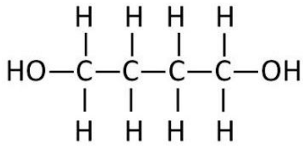
Test for alcohol

Method:

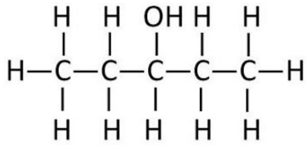
1. Add a few drops of sulfuric acid and potassium dichromate solution to the sample being tested
2. Gently heat
3. If alcohol is present the solution will change from orange to green. If no alcohol is present, the solution will remain orange.

The structure of alcohols

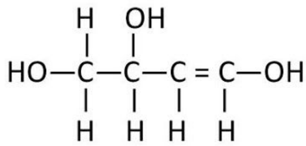
- When naming alcohols:
    - The suffix is -ol which is preceded by the number of the carbon the hydroxyl (OH) functional group is on
    - If there are multiple alcohol functional groups the suffix becomes -diol, -triol, tetrol etc
    - Examples:



Butan-1,4-diol

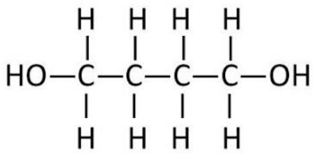


Pentan-3-ol

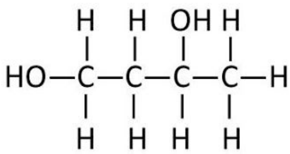


1-Buten-1,3,4-triol

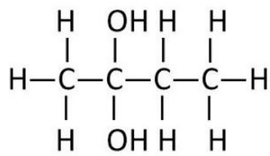
- **HIGHER TIER ONLY: Positional isomers-these are compounds which have the same molecular formula but their structures differ in the position of their functional group(s)**
    - **Example: The 3 compounds below all have the molecular formula $C_4H_{10}O_2$ but their structures differ in the positions of the -OH groups.**



Butan-1,4-diol



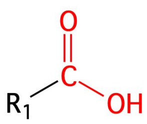
Butan-1,3-diol



Butan-2,2-diol

The microbial oxidation of ethanol

- When ethanol is oxidised it forms ethanoic acid, CH_3COOH, a carboxylic acid which has the functional group -COOH



- This oxidation can be carried out by microbes
- Other alcohols can undergo this oxidation to a carboxylic acid
- An oxygen atom is gained and hydrogen atoms are reduced

Higher tier only - Infrared spectroscopy

What is infrared spectroscopy?

- Infrared spectroscopy is an experimental technique that can be used in combination with other techniques to work out the structure of a compound or molecule
- When infrared light is shone at a compound, its bonds absorb some of the infrared
- Different bonds absorb at different frequencies of infrared light
- An infrared spectrum is produced which contains peaks which correspond to specific bond types, such as a C-H bond and O-H bond.
- By working out the bonds a structure contains you can predict the functional groups that are present

Bond absorptions

The table shows where on a spectrum certain bonds will have a peak:

Bond	Absorption frequency region
C-H	2900 - 2700
O-H	3650 - 3590
C=C	1600 - 1500
C-O	1250 - 1000
C=O	1750 - 1600