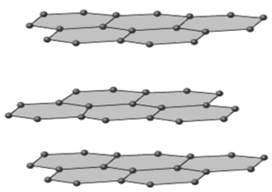
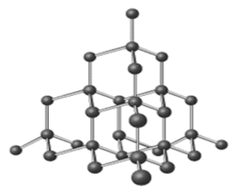
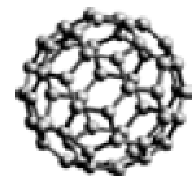
Chemistry AS90648
Describe properties & reactions of carbon & its compounds

Properties & reactions of carbon

Forms of pure carbon include: Diamond, Graphite and C-60 (Buckminster fullerene or Bucky balls) – all solids at room temperature. Different forms of elements in the same state are called allotropes. Impure forms include charcoal and coke.

		
Graphite is a 2D layer structure, formed by carbon atoms strongly bonded in hexagonal layers, with weak forces *between* the layers and delocalised electrons. It is slippery (can use as a lubricant) as layers slide over each other (weak forces *between* the layers). Graphite can be used as pencil "lead" as the layers easily slide over one another, off onto the paper. Graphite electricity due to the presence of "delocalised electrons" (electrons that are able to move and carry a charge) between the layers – can be used as electrodes. Graphite has a high melting point because of the strong covalent bonds between the C atoms in the layers.	Diamond is a 3D network structure (giant covalent lattice), with each carbon atom bonded covalently to four other carbon atoms forming a strong rigid structure. Diamond is hard, strong & has a high melting point due to Diamond has strong bonding (covalent) between its atoms in three dimensions. Due to the strong rigid structure of diamond it can be used for drill and saw blades. Diamond has no mobile / delocalised electrons so is unable to carry a charge and would be a non-conductor.	C-60 would have a melting point lower than graphite or diamond because only weak forces *between* the C-60 molecules. In C-60 the covalent bonding is limited to small molecules of 60 carbon atoms unlike the continuous covalent bonding is in 3D diamond and 2D graphite layers. Not as hard as others (it would be greasy/powdery) as the molecules separate easily. It has no mobile / delocalised electrons so is unable to carry a charge and would be a non-conductor.

Combustion (oxidation)
Reaction then heated in air with oxygen carbon burns to form carbon monoxide & carbon dioxide

$$2C + O_2 \rightarrow 2CO \qquad C + O_2 \rightarrow CO_2$$

Carbon monoxide burns with a blue flame to form CO_2. $2CO + O_2 \rightarrow 2CO_2$

Properties of carbon dioxide

Density – it is denser than air (which is why it can be collected by "downward delivery" method.) This property makes it useful in fire extinguishers to smother fires (along with the fact that CO_2 does not "support combustion" (won't let things burn in it).

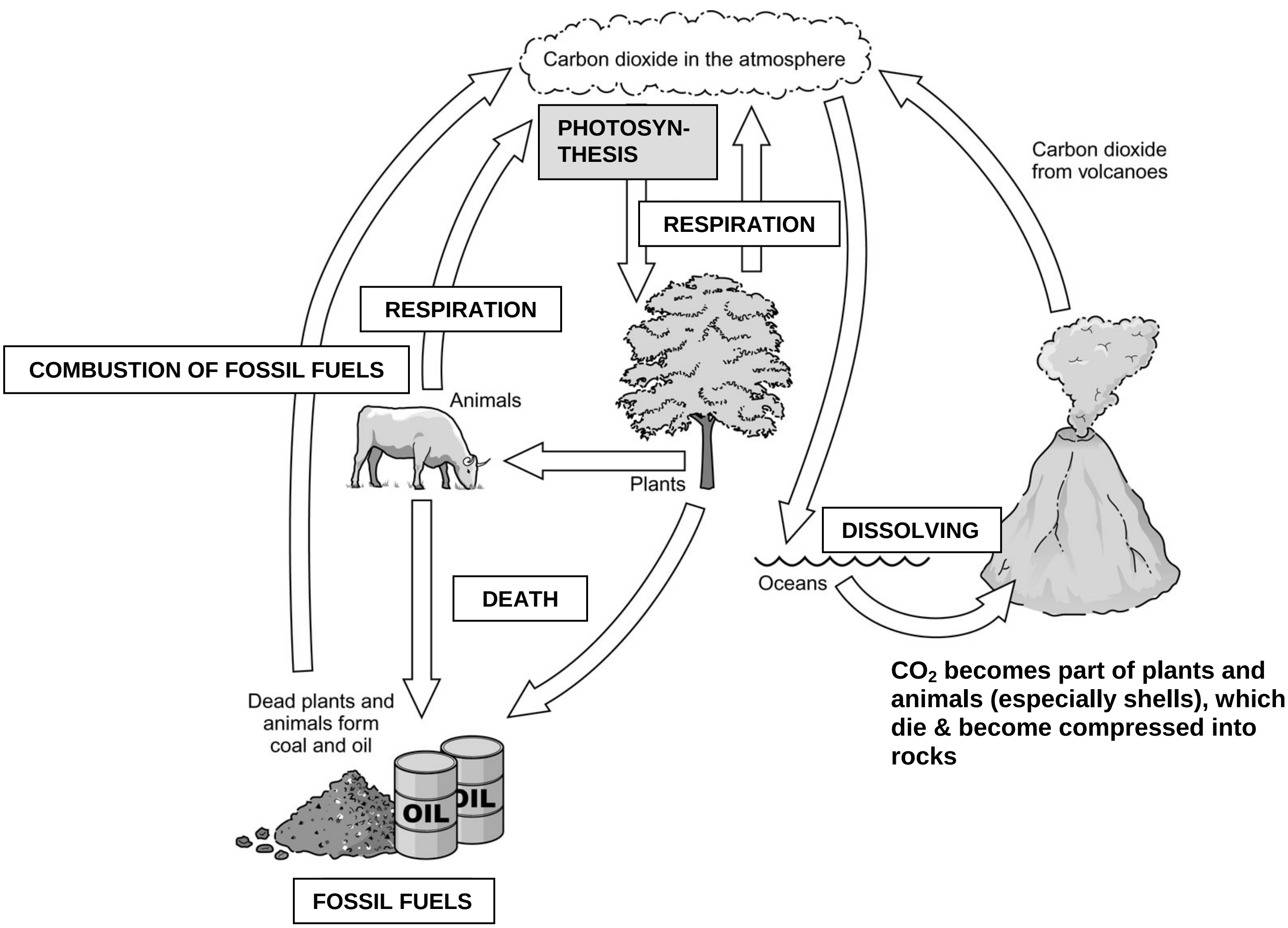
Solubility in water – is only slightly soluble in water (which is why it can be collected by displacement of water" method.) It is more soluble under pressure. When making a drink like lemonade, CO_2 is dissolved under pressure and as the soft-drink bottle lid comes off, the pressure is decreased, allowing the gas to escape. When making a drink like ginger beer in sealed plastic bottles, the CO_2 gas produced dissolves in the water as the ginger beer ferments, making it naturally fizzy. Again the pressure is released upon opening, the CO_2 gas is released causing 'bubbles' in the drink.

A solution of CO_2 in water (aqueous solution) is weakly acidic. $H_2O + CO_2 \rightarrow H_2CO_3$ (carbonic acid). It will turn damp litmus red, & UI paper/solution orange-red.

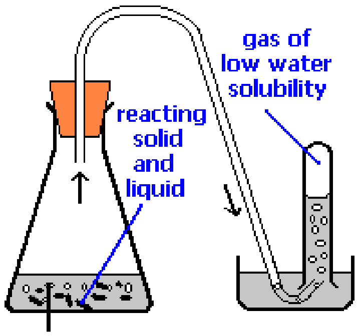
Its reaction with lime water is used as a test for CO_2. Collect a sample of the gas in a teat pipette from just above the reaction mixture. Bubble the gas sample into calcium hydroxide solution (limewater) and a milky white confirms the gas is carbon dioxide. Lime water is calcium hydroxide solution, $Ca(OH)_2$.
$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$. Since $CaCO_3$ is insoluble, small white specks of solid form in the solution giving it the "milky" or "cloudy" appearance. If CO_2 continues to be bubbled through, the solution eventually goes clear again, as soluble calcium hydrogen carbonate, $Ca(HCO_3)_2$, is formed. $CaCO_3(s) + H_2O(l) + CO_2(g) \rightarrow 2Ca(HCO_3)_2(aq)$

Other uses: Refrigeration: dry ice keeps items cold without wetting them because it sublimes. 'Foggy effect' for concert and stage productions.

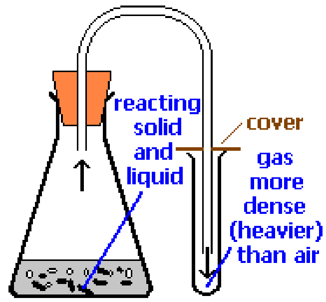
Carbon cycle (photosynthesis, combustion, respiration, formation of fossil fuels)



Laboratory preparation of CO_2. It is usually prepared from hydrochloric acid HCl & calcium carbonate $CaCO_3$ (marble chips). The gas is collected by the displacement of water or by downward delivery. $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O$.



CaCO₃ and dilute HCl



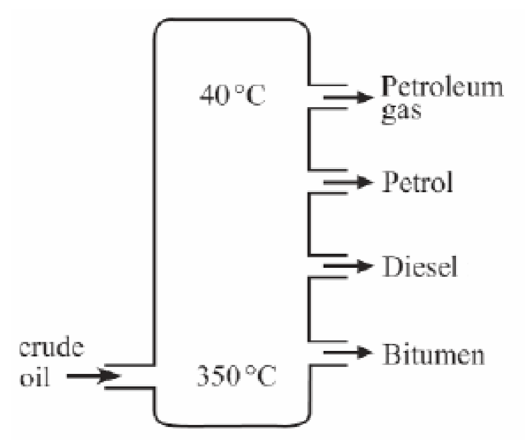
The problem with the downward delivery method is that CO_2 is a colourless gas and so it is hard to tell when the tube is full / all the air has been displaced. If a lit splint held just inside the top of the test tube goes out, the test tube is full.

Hydrocarbons & other related organic chemicals

Organic chemistry, chemistry of living/once living things. Includes fossil fuels - coal, oil & gas. Carbon atoms join to other atoms by covalent bonds. Each line in a structural formula is a covalent bond. Carbon always forms 4 bonds. Hydrocarbons are compounds containing carbon & hydrogen atoms only. Two main families - alkanes & alkenes

Distillation of Crude Oil

Crude oil (petroleum) is a complicated mixture of many hydrocarbons. It is processed into useful substances at an oil refinery. The crude oil is first desulfurised (S removed) & then distilled. Distillation occurs in a fractionating tower where the oil is 'boiled'.

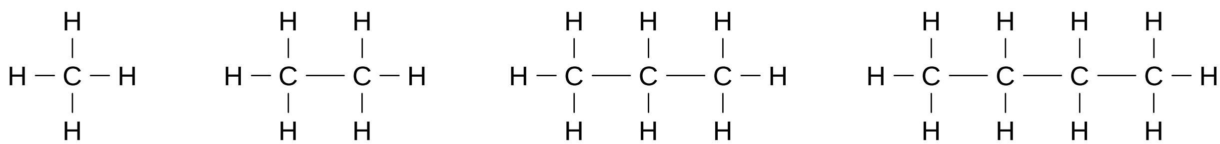


- Hydrocarbons have different boiling points depending on the length of the chain, the shorter the chain the lower the boiling point.
- The diagram is a fractionating column where crude oil is pumped in, heated & the molecules separate.
- Heavy molecules condense & are drawn off, lighter molecules rise to the top of the fractioning column before being condensed off.
- Fractional distillation allows for a mixture of substances in this case hydrocarbons to be separated depending on the different boiling points

The larger a molecule is (the more carbon atoms it has); the higher its boiling point; the less volatile it is; the less easily it flows (the more viscous it is); & the less easily it ignites (the less flammable it is). This limits the use of large hydrocarbon molecules (such as bitumen) as fuels. So, large hydrocarbon molecules are broken down using a process called cracking. This produces smaller, more useful molecules. Some of these smaller molecules are useful as fuels.

In **cracking**, heavier fractions are heated & mixed with steam & catalyst. Carbon-carbon bonds break inside the molecule, & big molecules split up into smaller, lighter molecules. Cracking also makes molecules with carbon-carbon double bonds, C=C. These unsaturated molecules are important as the starting points of many plastics & organic chemicals, plastics (polymers) such as poly(ethene) & poly(vinyl chloride) (PVC).

Alkanes
General formula C_nH_{2n+2} ("Take the number of C atoms, multiply by 2 & add 2 to find the number of H atoms"). Alkanes contain only single bonds C-C between carbon atoms. Each C atom is bonded to the maximum number of other atoms (4) & they are called SATURATED.
As number of carbon atoms increase their melting points & boiling points increase in a regular way because the weak attractive forces between the molecules get bigger. At room temperature C1-C4 are gases.



- methane, CH_4 - occurs in natural gas, marsh gas from stagnant water & from either end of cows!! Compressed it is CNG - fuel. CH_4 is a "green house gas", contributing to the "green house effect"/ global warming).
- ethane, C_2H_6
- propane, C_3H_8 Propane & butane together make up most of LPG (liquid petroleum gas - liquefied by high pressure)
- butane, C_4H_{10} fuel in cigarette lighters
- pentane, C_5H_{12}, hexane, C_6H_{14} etc…

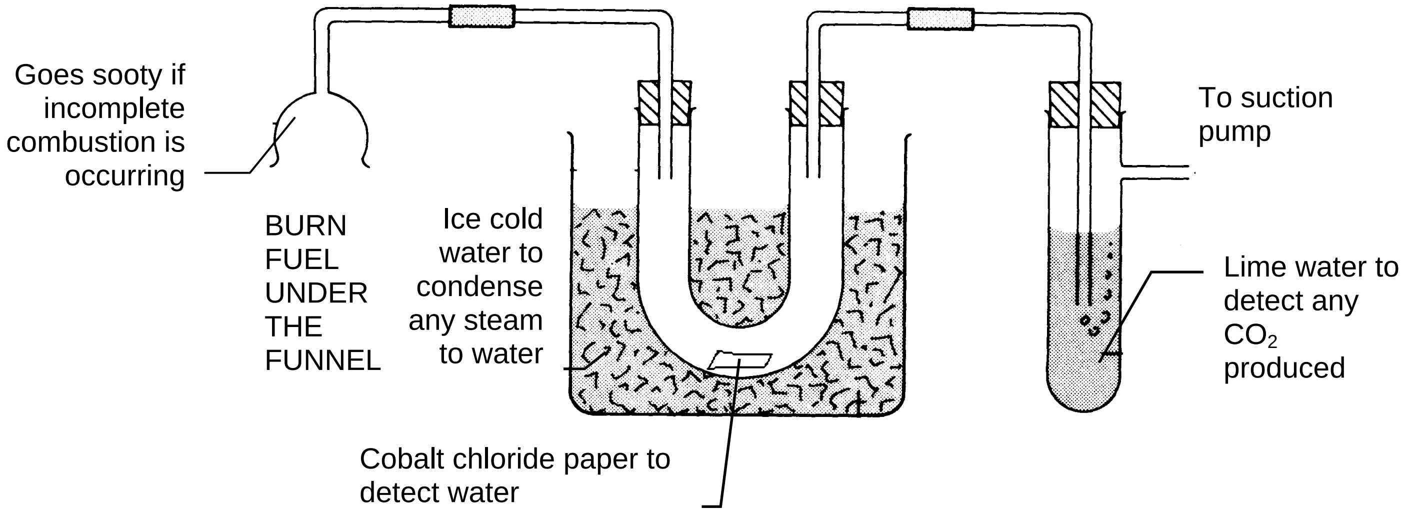
Combustion
Alkanes make good fuels. Eg petrol is mostly octane C_8H_{18}

In plentiful oxygen, *complete* combustion occurs;
alkane + plentiful O_2 → CO_2 + H_2O + much energy
Eg propane $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$.

In limited oxygen, *incomplete* combustion occurs, eg in a car engine, when a Bunsen burns with the air hole closed, a candle burning, a fire burning in a room with poor ventilation.
alkane + limited O_2 → C + CO (+ a little CO_2) + H_2O + less energy
CO is carbon monoxide. CO can cause decrease in oxygen in blood, leading to possible brain damage & death (due to binding with haemoglobin in red blood cells, so carbon monoxide rather than oxygen is carried around the body). It is particularly dangerous as the gas is colourless & has no smell. C is carbon (soot) - makes things dirty. Soot can cause irritation of the lungs – respiratory problems (bronchitis, asthma etc).
Incomplete combustion occurs in engines or boilers that have not been serviced regularly. Less than maximum potential amount of energy is released which also wastes fuel / money.

Products of combustion experiment
(see next page for apparatus)
Can be carried out to demonstrate the products of the combustion of a hydrocarbon or an alcohol. The suction pump pulls the **products of combustion** through the apparatus.

Blue cobalt chloride paper	turns pink if water is produced
Lime water (clear at start)	turns cloudy if carbon dioxide is produced

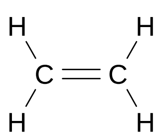


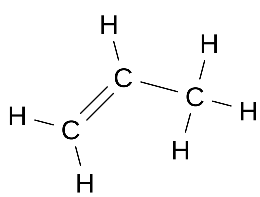
Physical properties of alkanes: All insoluble in water. Melting & boiling points increase as the molar mass increases (due to increased forces of attraction between molecules).

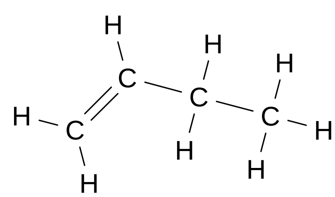
Alkenes - ethene & propene

Alkenes are also hydrocarbons. General formula C_nH_{2n}. Each one has one C=C in it. C=C is called a double (covalent) bond. Each C is NOT bonded to 4 other atoms so they are called unsaturated.

ethene C_2H_4 propene C_3H_6 butene C_4H_8 (2 different forms)







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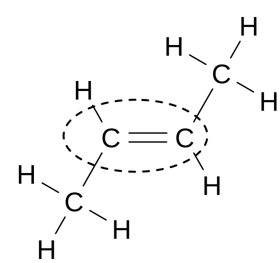
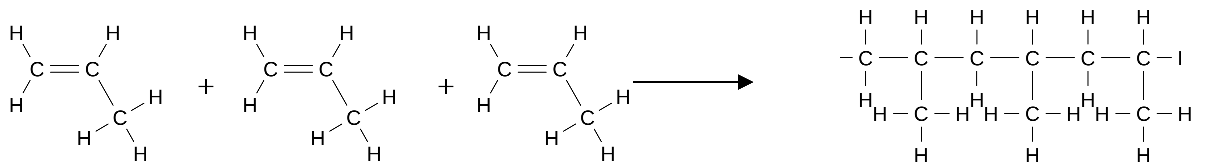


Alkenes burn like the alkanes (but there tends to be more incomplete combustion occurring). They are NOT used as fuels because they are much more reactive & therefore more valuable - can be used to make plastics (polymerisation – see below). Alkenes undergo *addition reactions* in which one bond of the double bond breaks & other atoms or groups of atoms are added on. The product contains single C-C bonds

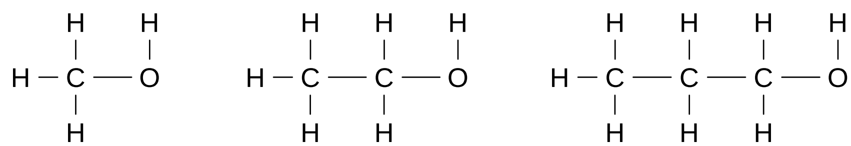
Polymerisation

A polymer is a long molecule made up of many repeating units (monomers).
Eg ethene is polymerised to give polyethene (polythene),
eg. nC_2H_4 ---> $-(CH_2-CH_2)-_n$ (where n is a very large number).
Ethene is the simplest type of monomer (building block). Often one or more of the hydrogen atoms is replaced by another element &/or group, e.g. -Cl or $-CH_3$. If a hydrogen atom is replaced by chlorine, the monomer, monochloroethene, is built up into the polymer (giant molecule) polyvinylchloride (PVC). If the monomer is propene, the polymer is polypropene. The process requires heat, pressure & use of a catalyst.



3 propene monomers | short section of polypropene

Alcohols - methanol, ethanol etc
Methanol CH_3OH, ethanol C_2H_5OH, propanol C_3H_7OH. (They contain O as well as C & H & are NOT hydrocarbons). ETHANOL is C_2H_5OH, a colourless liquid with a characteristic odour.

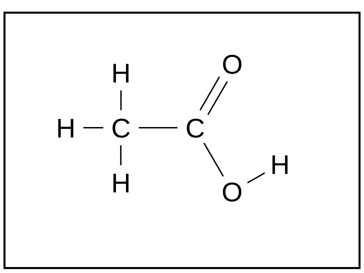


Ethanol is used as a solvent; fuel; & present in alcoholic drinks.
Burn well as fuels - mostly complete combustion. Eg ethanol $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Ethanol can be formed from **fermentation** of any plant material containing sugar. This process uses yeast, & doesn't need oxygen & so is called **anaerobic respiration**.
$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$ Occurs best between 25-40^{o}C since yeast is a living organism. (High temperatures denature (destroy) the enzymes (biological catalysts) in the yeast & so kill the yeast. Crops can be used to make alcohol for fuels for cars (specially adapted engines).

Alcohols have much higher melting points & boiling points than the corresponding alkanes. The first few members are soluble in water.

Carboxylic acids
The acids that we find in fruits & in vinegar (ethanoic acid, CH_3COOH) belong to a family called carboxylic acids. They have the functional group -COOH.



Ethanoic acid is formed from ethanol by the process of oxidation (details of oxidants & balanced equations not included).

$$C_2H_5OH \xrightarrow{[O]} CH_3COOH$$

Impact of carbon & its combustion products on human health & the environment
Increased levels of CO_2 gas have been linked to enhancing the greenhouse effect & global warming. Increasing levels of CO_2 increase the ability of the atmospheric layer to retain heat. Consequences include: ice cap melting, sea levels rising, droughts etc. A rise in atmospheric temperature will impact on health, agriculture, & weather patterns. (Don't confuse this with the "hole in the ozone layer").
Incomplete combustion produces carbon monoxide and soot as products. See above for effects of C and CO on health & environment.