St. Ninian's High School

National 4 and 5 Chemistry

Unit 2

Nature's Chemistry

2A: Fuels and Hydrocarbons

Name:________________________ **Class:** __________

Teacher:_____________________________

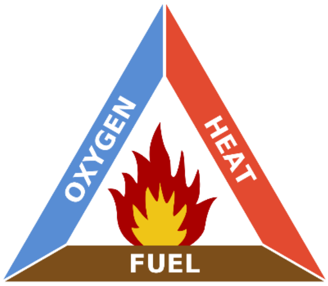
Unit 2: Nature's Chemistry

Key Area: Fuels

A fuel is a substance that has stored energy and burns to release energy.

Fuels store energy in chemical bonds, through processes such as photosynthesis. Wood, petrol, coal, peat are examples of fuels that have energy-rich chemical bonds created using the energy from the Sun. A good fuel will burn slowly releasing a lot of energy without producing a lot of pollution.

In order for a fuel to burn there must be oxygen and a source of heat. We can represent the **three things** required for burning using the **fire triangle.** Removing any one side of the fuel triangle would extinguish a fire.



If we remove at least one of the things from the fire triangle then the fire will go out e.g. putting water on the fire removes the HEAT and putting carbon dioxide on the fire removes the OXYGEN.

A reaction/ process which gives out heat energy is called an **exothermic** reaction. **Combustion is the reaction of burning a fuel in oxygen** (a form of oxidation). Combustion is an exothermic reaction. Respiration is another example of an exothermic reaction.

Reactions/ processes which take in heat energy are called **endothermic** reactions.

Fossil Fuels

Coal, **oil** and **natural gas** are all examples of **fossil fuels**, they supply around 90% of the world's energy. Fossil fuels are a useful reserve of fuels and are therefore used extensively to satisfy the demands of an energy-dependent world.

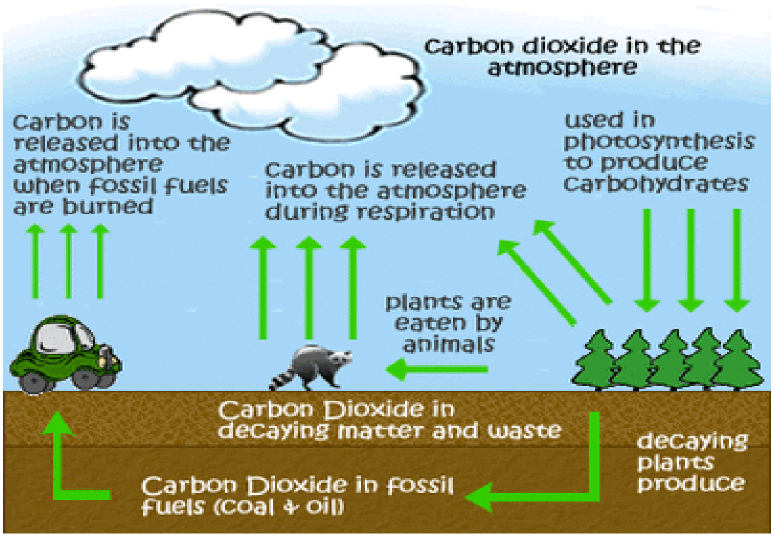
Fossil fuels are formed from the decayed and fossilised remains of plants and animals that lived millions of years ago. Natural gas is a **Hydrocarbon.**

Hydrocarbons are compounds which contain the elements **carbon and hydrogen only.**

Fossil Fuels and the Environment

Fossil fuels are a **finite** energy source. This means they will run out one day. Fossil fuels are being used up far faster than they can be formed.

The burning of fossil fuels impacts on the environment and contributes to the carbon cycle. The levels of carbon dioxide and other greenhouse gases in the earth's atmosphere is becoming unsustainable. Carbon is **released** into the atmosphere by **respiration** and **combustion of fossil fuels**. Carbon is **removed** from the atmosphere by **photosynthesis.**



We can reduce the impact of the burning of fossil fuels by reducing the energy we require for everyday activities.

Ways to reduce carbon emissions include:

- Walk/ cycle/ take public transport instead of driving
- Switch off lights and other electrical items when they are not being used
- Put on a jumper instead of the heating
- Recycle
- Catalytic converters in engines can be used to minimise the output of carbon monoxide
  - Carbon capture Carbon capture is the process of capturing waste carbon dioxide released from industry, before it enters the atmosphere and transporting it to a storage site, normally underground.

Alternative Energy Sources

Instead of using fossil fuels, there are alternative energy sources:

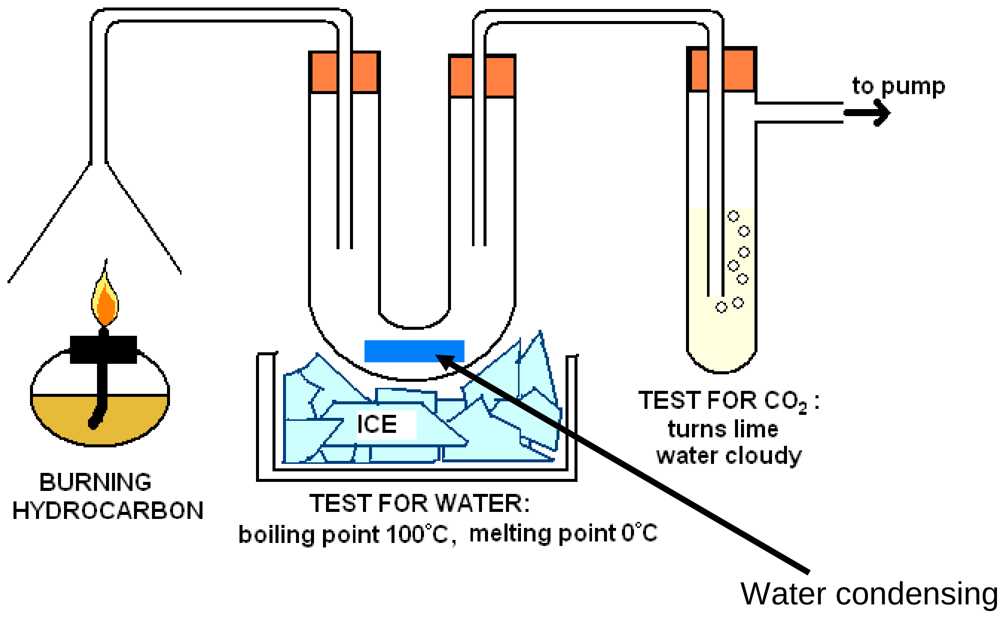
- Wind power
- Solar power
- Wave and tidal
- Geothermal
- **Biomass** is energy that comes from living things, such as **trees and plants**. The energy from biomass is natural and renewable as the plants, or other organisms, absorb energy from the sun. The biomass is then **burned** releasing this natural energy.

- Instead of burning biomass it can be converted into **biofuels (methane gas, ethanol, biodiesel)**. Biomass, a source of biofuels, is plant-based material which can be burned to release energy.

Combustion of Hydrocarbons

Combustion is the burning of a substance in oxygen to release energy. **Complete** combustion of a hydrocarbon takes places when there is a good supply of oxygen gas present.

The apparatus below will help us identify the products of complete combustion of a hydrocarbon:



hydrocarbon + oxygen → water + carbon dioxide

e.g. methane + oxygen → water + carbon dioxide

The burning of a hydrocarbon in a plentiful supply of oxygen always produces **water (H_2O) and carbon dioxide (CO_2).**

Incomplete combustion occurs when **insufficient oxygen** is present. Carbon (soot) and carbon monoxide (CO), a poisonous gas, are formed when a hydrocarbon burns in a limited supply of oxygen. All cars are now fitted with catalytic converters which minimise the output of carbon monoxide.

Balancing equations

All chemical equations need to be balanced – all the elements present as reactants and products must be equal on both sides of the equation.

- You always **balance from left to right** and when balancing the equations
- **Numbers can only be placed IN FRONT of formulae**, not in the middle or at the end.
- Always balance the carbon atoms, then hydrogen atoms and finally, balance the oxygen atoms.

A worked example is shown below:

$$C_7H_{16} + O_2 \longrightarrow CO_2 + H_2O$$

There are 7 carbon atoms on the LHS of the equation, and only 1 on the RHS. So you need to multiply the carbon dioxide molecule by 7 to balance the carbon atoms.

There are 16 hydrogen atoms on the LHS of the equation, and only 2 on the RHS. So you need to multiply the water molecule by 8 to balance the oxygen atoms.

There are 2 oxygen atoms on the LHS of the equation. After balancing the carbon and hydrogen atoms in the carbon dioxide and water, there is now a total of 22 oxygen atoms on the RHS of the equation. So the LHS side needs to be multiplied by 11 to balance the oxygen.

C = 7 → C = 1 x 7 = 7

H =16 → H = 2 x 8 = 16

O =2 x 11 = 22 ← O = (2x7) + (1x8) = 22

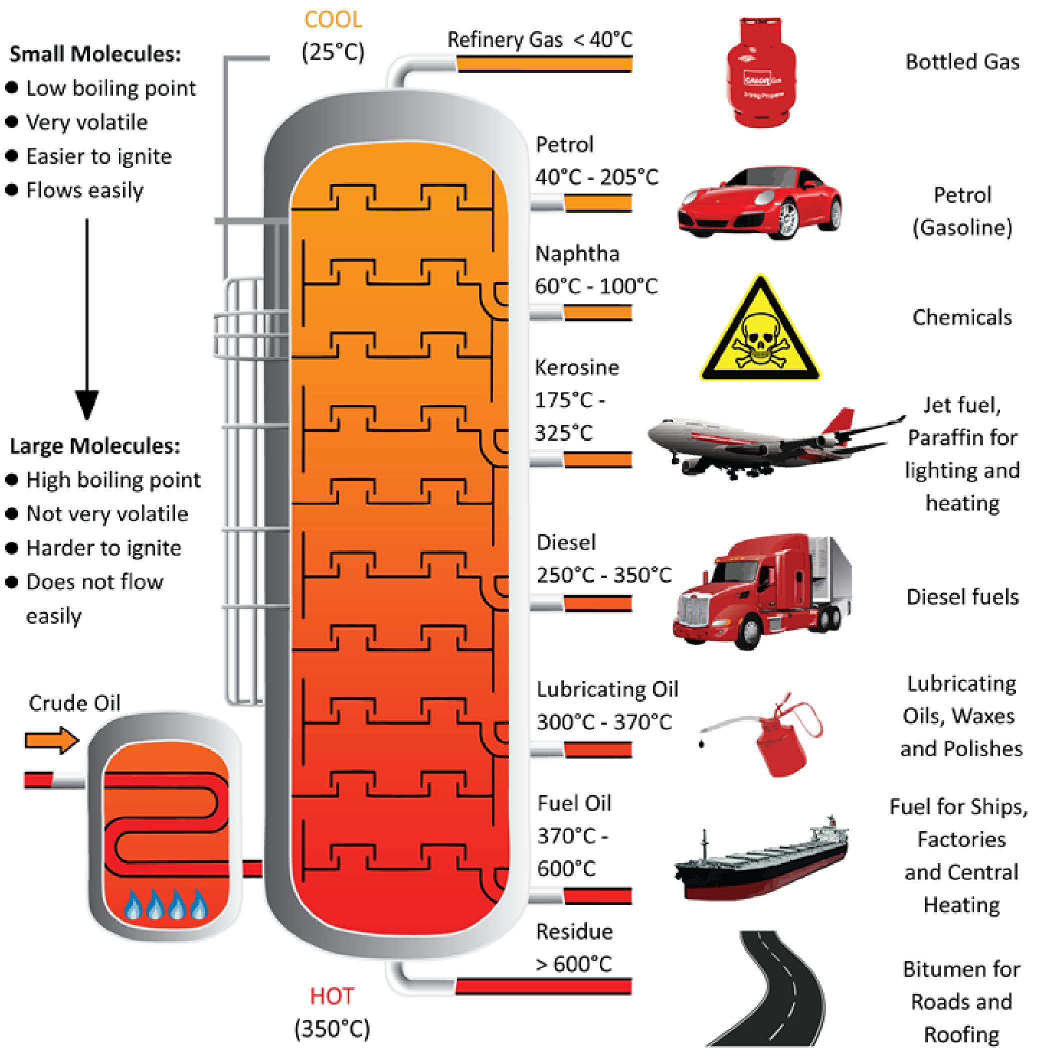
The final balanced equation is shown below:

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

Crude Oil and Hydrocarbons

Crude oil is a mixture of many different hydrocarbons. In its raw state crude oil is of no use. It has to be treated in an oil refinery to produce many useful fuels and other chemicals.

Crude oil is separated into useful mixtures using the process called **fractional distillation**. The useful mixtures are called **fractions**. A fraction is a group of hydrocarbons with **boiling points within a given range**.



As the hydrocarbons molecules get larger their boiling points increase.This is due to the increasing strength intermolecular forces of attraction between the molecules.,

Homologous Series

A homologous series is a group of chemicals with the **same general formula** and **similar chemical properties.**

The name of the hydrocarbon depends on the number of carbon atoms in the molecule.

Number of carbon atoms in molecule	Name starts with
1	meth
2	eth
3	prop
4	but
5	pent
6	hex
7	hept
8	oct

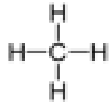
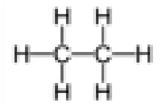
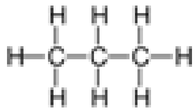
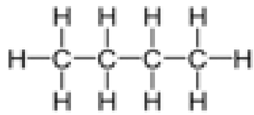
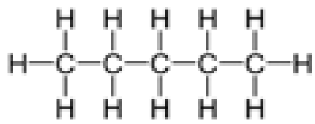
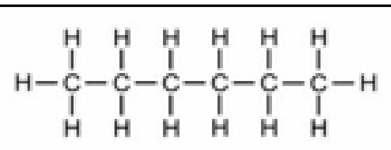
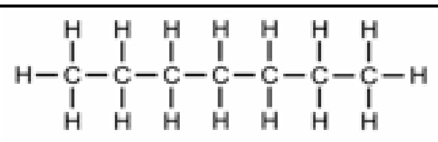
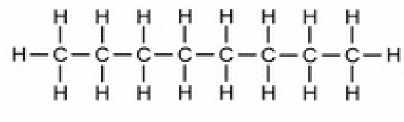
Alkanes

Alkanes are a subset of hydrocarbons and are identified from the **–ane** ending.

Alkanes:

- are a homologous series of **saturated** (carbon to carbon single bond) hydrocarbons.
- are commonly used as fuels.
- are insoluble in water.
- can be represented by the general formula $\mathbf{C_nH_{2n+2}}$.

Straight Chain Alkanes

Name	Molecular Formula	Full Structural Formula	Shortened Structural Formula
Methane	CH_4		CH_4
Ethane	C_2H_6		CH_3CH_3
Propane	C_3H_8		$CH_3CH_2CH_3$
Butane	C_4H_{10}		$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}		$CH_3CH_2CH_2CH_2CH_3$
Hexane	C_6H_{14}		$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	C_7H_{16}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	C8H18		CH3CH2CH2CH2CH2CH2CH2CH3

Formula mass

The Formula Mass of a substance is exactly what it says: it is the combined mass of all the atoms you can see in the formula for that substance. It can be done as follows:

1. Calculate the formula (this is sometimes given to you in the question)
2. Determine number of atoms of each element
3. Use Data Book to calculate the mass for each element present (number of atoms of each element x Relative Atomic Mass of the element)
4. Calculate total mass of substance

Worked Example: Butane C_4H_{10}

C_4H_{10}

→ 4 x C = 4 x 12 = 48

→ 10 x H = 10 x 1 = 10

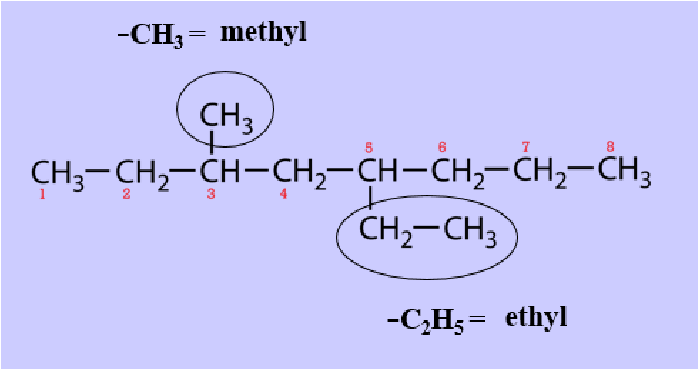
formula mass = 58 amu

Notice the units are amu (atomic mass units)

Branched Chain Alkanes

- Branched Chain Alkanes are alkanes in which the carbon atoms are not in a straight chain. They are also represented by the general formula C_nH_{2n+2}.

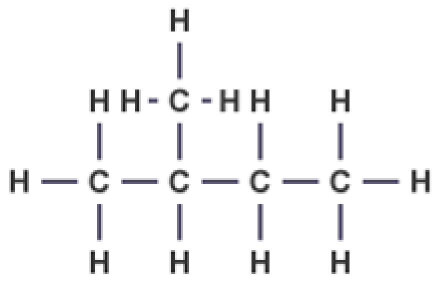
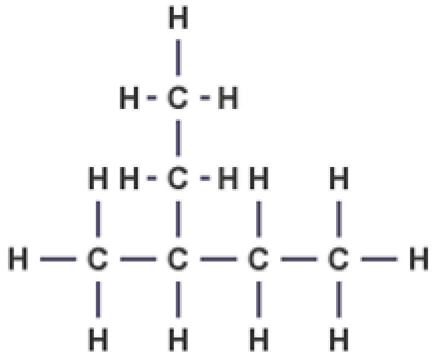
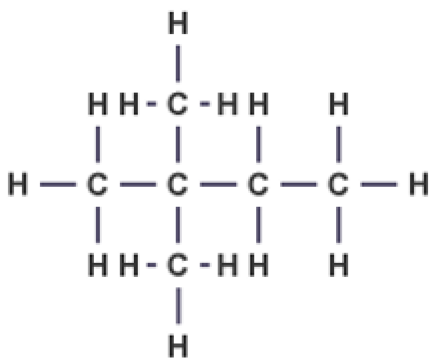
Name of Branches



Rules for Naming Branched Alkanes

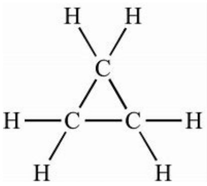
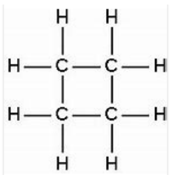
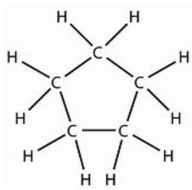
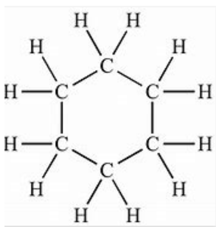
1. Identify the longest carbon chain which gives the name of the alkane.
2. Number the carbon atoms starting from the end nearest the branch.
3. Identify the type of branch
4. Number the position of the branch (what carbon is it bonded to)
5. Use prefixes if there are more than 1 of the same branch (di, tri)
6. If more than one side group is present, the names are in alphabetical order, thus ethyl is always placed in front of methyl.

Examples of Branched Chain Alkanes

Name	Molecular Formula	Full Structural Formula	Shortened Structural Formula (Note: branches are always shown in brackets)
2 -methyl butane	C_5H_{12}		$CH_3CH(CH_3)CH_2CH_3$
3 -methyl pentane	C_6H_{14}		$CH_3CH_2CH(CH_3)CH_2CH_3$
2,2 - dimethyl butane	C_6H_{14}		$CH_3C(CH_3)_2CH_2CH_3$

Cycloalkanes

The cycloalkanes are a homologous series of saturated, cyclic hydrocarbons. Their names all begin with CYCLO- and end in –ANE. They are used as fuels and solvents and are insoluble in water. They can be represented by the general formula $\mathbf{C_nH_{2n}}$.

Name	Molecular Formula	Full Structural Formula
Cyclopropane	C_3H_6	
Cyclobutane	C_4H_8	
Cyclopentane	C_5H_{10}	
Cyclohexane	C_6H_{12}	

Alkenes

The alkenes are homologous series of **unsaturated** hydrocarbons as they contain the **carbon to carbon double bond (C=C).**

The alkenes all end in **–ene** and they have the general formula $\mathbf{C_nH_{2n}}$.

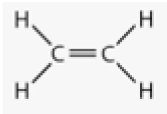
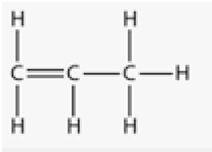
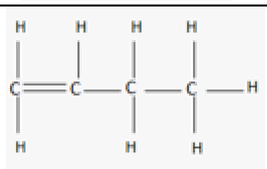
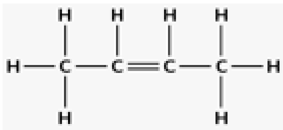
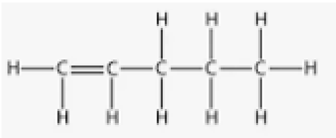
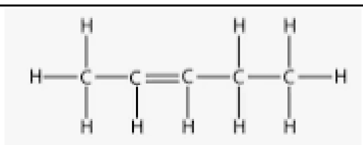
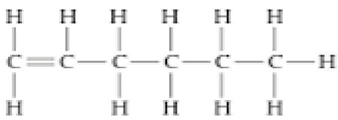
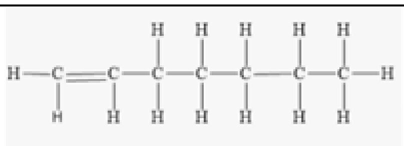
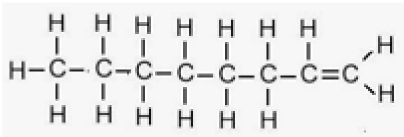
Alkenes are used to make polymers (see Unit 3) and alcohols (see Unit 2, Everyday Consumer Products). Alkenes are insoluble in water.

Naming alkenes has the same rules as alkanes. However, the position of the carbon to carbon double bond must be identified.

Naming Alkenes/Branched Chain Alkenes

1. **Identify the longest** carbon chain containing the double bond which gives the name of the alkene.
2. Number the carbon atoms in the chain (**starting from end closest to the carbon to carbon double bond**)
3. For chains of **4** or more the **position of the double bond** must be noted.
    a. e.g. hex-**2**-ene, pent-**1**-ene
4. Number the position of any branch (what carbon is it bonded to)
5. Use prefixes if there are more than 1 of the same branch (di, tri)

Alkenes

Name	Molecular Formula	Full Structural Formula	Shortened Structural Formula
Ethene	C_2H_4		CH_2CH_2
Propene	C_3H_6		CH_2CHCH_3
But-1-ene	C_4H_8		$CH_2CHCH_2CH_3$
But-1-ene	C_4H_8		$CH_3CHCHCH_3$
Pent-1-ene	C_5H_{10}		$CH_2CHCH_2CH_2CH_3$
Pent-2-ene	C_5H_{10}		$CH_3CHCHCH_2CH_3$
Hex-1-ene	C_6H_{12}		$CH_2CHCH_2CH_2CH_2CH_3$
Hept-1-ene	C_7H_{14}		$CH_2CHCH_2CH_2CH_2CH_2CH_3$
Oct-1-ene	C_8H_{16}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

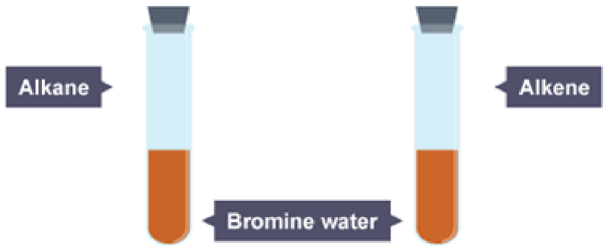
Saturated and Unsaturated Hydrocarbons

The alkenes are unsaturated. This means that they contain at least one carbon to carbon double bond. The alkanes are saturated because they only contain carbon to carbon single bonds.

An unsaturated hydrocarbon decolourises bromine water quickly. This is known as the test for unsaturation. The experiment shown below is an example of how to distinguish between alkanes and alkenes by adding bromine water.

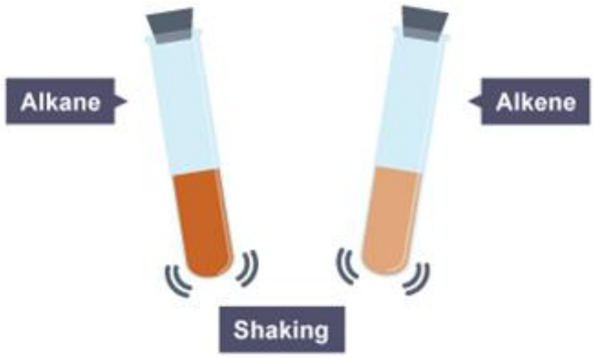
Step one

Two test tubes of bromine water. An alkane is added to one, an alkene to the other.



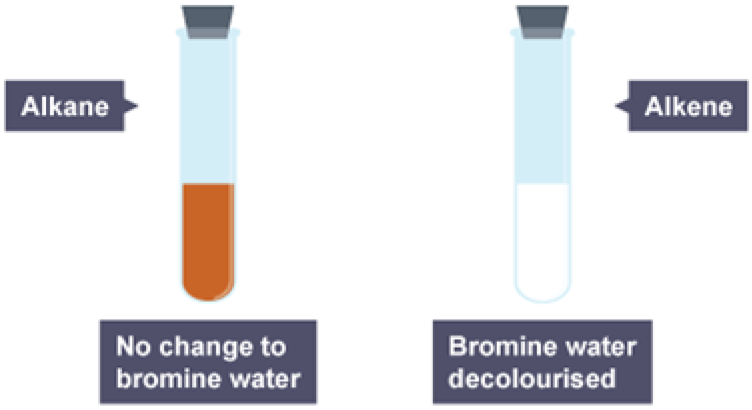
Step two

The test tubes are shaken



Step three

The alkane liquid remains orange-brown. The alkene liquid has turned colourless.



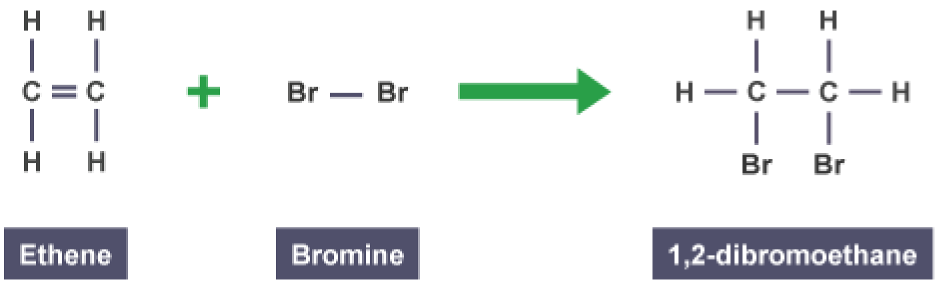
The addition of bromine to an alkene is called **bromination** and produces a **dihaloalkane.**

Addition reactions

Alkenes are more reactive than alkanes and cycloalkanes because they have a carbon to carbon double bond (-C=C-). While alkanes, alkenes and cycloalkanes undergo combustion reactions with oxygen, only alkenes can participate in addition reactions.

In an addition reaction, the double bond of the alkene partially breaks when the reactant molecule attacks and adds on across it.

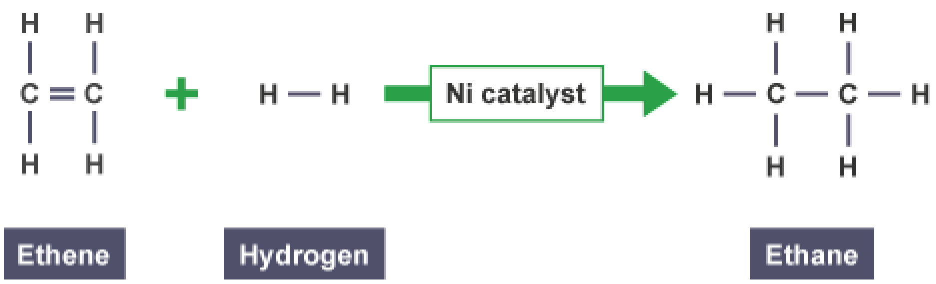
Example – addition of bromine (Br_2) to ethene



The addition of a **halogen** to an **alkene** forms a **dihaloalkane.** In this example, the addition of the halogen bromine is also known as **bromination.**

Other small molecules can be added across double bonds in alkenes. If hydrogen is added, then the corresponding alkane molecule is formed.

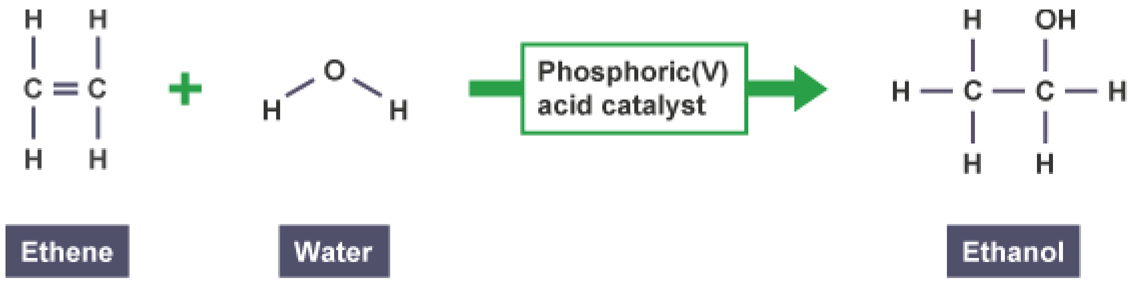
Example – addition of hydrogen (H_2) to ethene



The addition of **hydrogen** to an **alkene** is called **hydrogenation** and produces an **alkane**.

Example – addition of water (H_2O) to ethene

If water is added to an alkene, then an alcohol is produced.



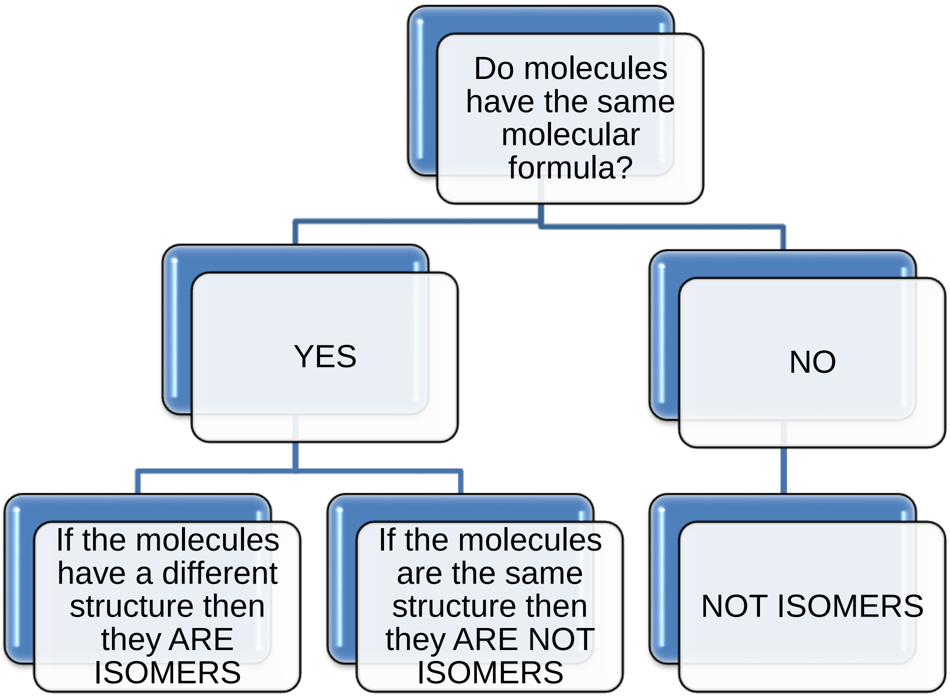
The addition of **water** to an **alkene** is called **hydration** and produces **an alcohol.**

Isomers

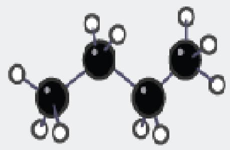
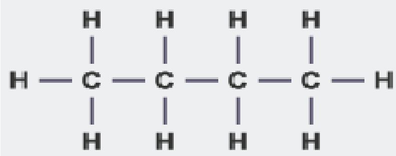
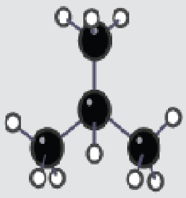
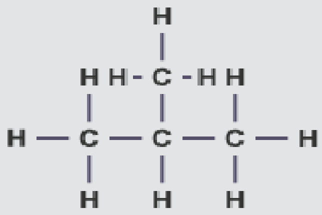
Isomers are compounds with <u>the **same molecular formulae but different structural formulae.**</u>

They have the same number of each type of atom but they may belong to different homologous series and have different physical and chemical properties.

The flow diagram below can be used to decide whether or not two compounds are isomers:



General Formula	Homologous Series
$C_n H_{2n}$	**Alkene and Cycloalkane**
$C_n H_{2n+2}$	**Alkane and Branched Chain Alkane**

Name	Formula	Chemical structure	Full structural formula
Butane	C_4H_{10}		
Methylpropane	C_4H_{10}		

Both have a molecular formula of C_4H_{10}. The structural formulae are different, so they are isomers of each other. (the alkene and cycloalkane homologous series are isomers of one another due to the fact both families of compounds fit the same general formula, C_nH_{2n})

Properties of the hydrocarbons

Chemical properties of compounds within the one homologous series are very similar.

Physical properties, e.g. boiling point, show a gradual change from one member to the next in a homologous series.

Page nine of the National 5 Chemistry data booklet provides information regarding the melting and boiling point of selected organic compounds i.e. hydrocarbons.

General trend:

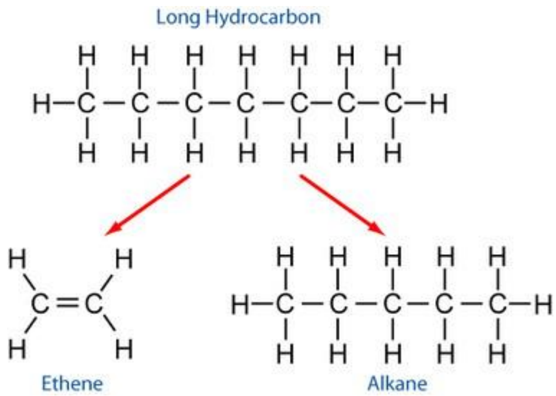
- as molecular size increases, the **boiling and melting points of the members in the series also increases**.

Explanation:

- **as the molecular size increases, the strength of the intermolecular forces also increases**.

Cracking

The problem with fractional distillation is that is produces a lot of hydrocarbons which have too many carbons in their chains to be useful in everyday life. Scientists have therefore had to come up with a method of breaking them up into smaller hydrocarbons, which are better suited for use in everyday life. This process is called cracking.



$$C_7H_{16} \longrightarrow C_2H_4 + C_5H_{12}$$