

Intensive note (Topic 5: Fossil fuels and carbon compounds)

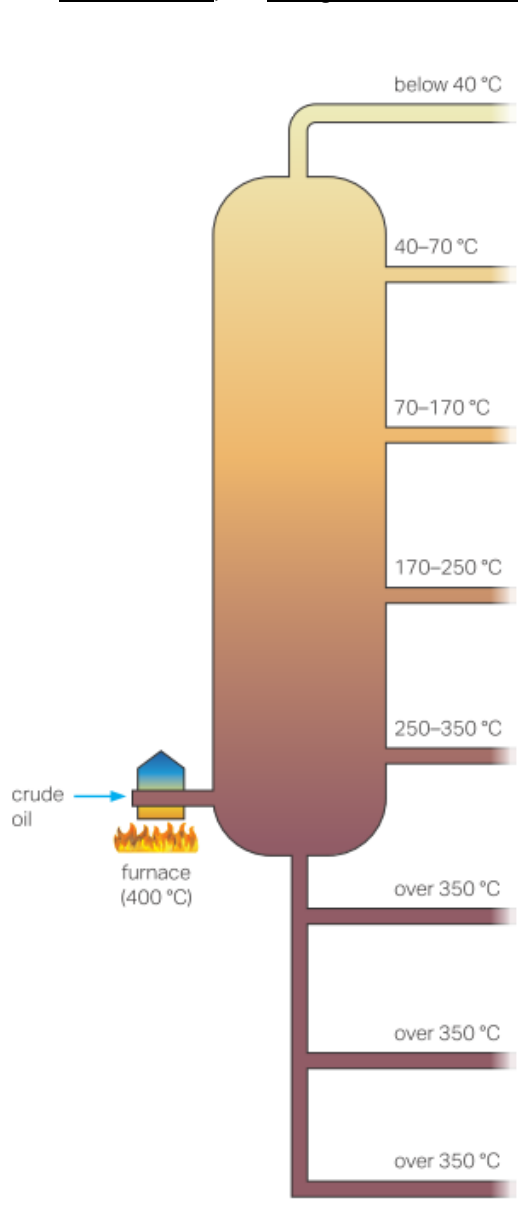
Fossil fuel as a source of hydrocarbons

Hydrocarbon: A compound made of hydrogen and carbon only

- **Petroleum** is formed from the remains of marine organisms (**coal**: remains of ancient plants) that are buried underneath sedimentary rock and subjected to intense heat and pressure for a long time

Fractional distillation of petroleum (crude oil)

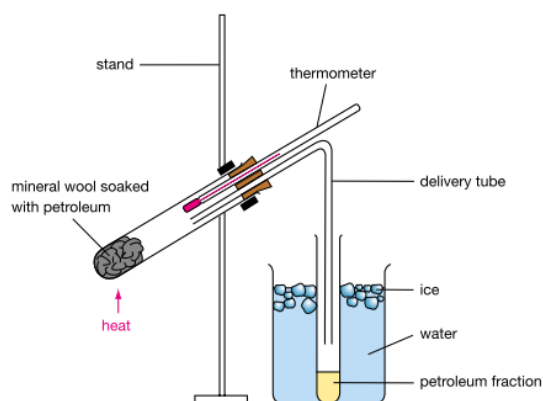
- Petroleum contains mainly aliphatic hydrocarbons (no benzene ring) and aromatic hydrocarbons (with benzene rings)
- Petroleum is not burnt directly as it may emit many pollutants. It has to be refined
- Different components in petroleum can be separated by fractional distillation. The longer the carbon chain, the larger the molecular size, the stronger the van der Waals' forces between molecules, the higher is the boiling point.



Fractions	Main uses
Refinery gas	<ol style="list-style-type: none"> 1. Domestic fuels / fuels for taxis, public light buses 2. Raw materials for producing other chemicals
Petrol (gasoline)	<ol style="list-style-type: none"> 1. Fuels for motor cars
Naphtha	<ol style="list-style-type: none"> 1. Raw materials for production of town gas 2. Raw materials for production of plastics
Kerosene	<ol style="list-style-type: none"> 1. Fuels for aeroplanes 2. Domestic fuels
Diesel oil	<ol style="list-style-type: none"> 1. Fuels for lorries and buses
Fuel oil	<ol style="list-style-type: none"> 1. Fuels for ships 2. Fuel for the generation of electricity
Lubricating oil and waxes	<ol style="list-style-type: none"> 1. Make lubricating oils and candles
Bitumen	<ol style="list-style-type: none"> 1. Material for covering roads

Intensive note (Topic 5: Fossil fuels and carbon compounds)

Fractional distillation of petroleum in the laboratory



Fraction	1	2	3	4
Color	Colorless	Pale yellow	Yellow	Brown
No. of C per molecule	★	★★	★★★	★★★★
Boiling point	★	★★	★★★	★★★★
Viscosity	★	★★	★★★	★★★★
Volatility	★★★★	★★★	★★	★
Flammability	★★★★	★★★	★★	★
Sootiness of flame	★	★★	★★★	★★★★
Color of flame	Yellow	Yellow	Orange	Orange

Combustion of hydrocarbons and air pollutants

Combustion is an exothermic reaction. Combustion of hydrocarbons can be complete or incomplete.

- When there is a plentiful supply of oxygen, hydrocarbons burn completely to give CO₂ and H₂O

General equation for the complete combustion of hydrocarbons: $C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$

- Incomplete combustion (due to insufficient oxygen supply or large carbon content of fuels) may give some pollutants.

Pollutant	Source	Harmful effects	Measures for reduction
Carbon monoxide (CO)	Incomplete combustion of fuel	- Toxic	- *Catalytic converter (in cars) $2CO + O_2 \rightarrow 2CO_2$ $2CO + 2NO \rightarrow 2CO_2 + N_2$
Sulphur dioxide (SO ₂)	Sulphur impurities react with oxygen $S + O_2 \rightarrow SO_2$	- Causes acid rain $SO_2 + H_2O \rightleftharpoons H_2SO_3$ - Causes respiratory disease	- Scrubber (in power plants) $SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$ - Use fuels of low sulphur content
Nitrogen oxides (NO, NO ₂)	High temperatures of car engines cause N ₂ in air to react with O ₂ $N_2 + O_2 \rightarrow 2NO$ $2NO + O_2 \rightarrow 2NO_2$	- Causes acid rain $4NO + 2H_2O + O_2 \rightarrow 4HNO_2$ $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ - Causes photochemical smog	- *Catalytic converter (in cars) $2CO + 2NO \rightarrow 2CO_2 + N_2$ $4CO + 2NO_2 \rightarrow 4CO_2 + N_2$
Unburnt hydrocarbon (C _x H _y)	Incomplete combustion of fuel	- Carcinogenic (cause cancer) - Causes photochemical smog	- *Catalytic converter (in cars) $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$
Particulates (Carbon particles, dust, soot)	Incomplete combustion of fuel	- Reduce visibility - Causes respiratory disease	- Electrostatic precipitator (in power plants) - Mechanical filtering

* Catalytic converters can work efficiently only on unleaded petrol. Otherwise lead compound in petrol will poison the catalysts (Pt, Rh) in the catalytic converter.

Intensive note (Topic 5: Fossil fuels and carbon compounds)

Systematic name

Table 1: Stem name:								
No. of C atoms	1	2	3	4	5	6	7	8
Stem name	Meth-	Eth-	Prop-	But-	Pent-	Hex-	Hept-	Oct-
Branch name	Methyl	Ethyl	Propyl	---	---	---	---	---

Table 2: Homologous series			Table 3: Some groups can only be named as prefixes.		
Formula (Group)	Prefix	Suffix	Group	Formula	Prefix
-COOH (Carboxyl)	---	-oic acid	Fluoride	-F	Fluoro-
-OH (Hydroxyl)	---	-ol	Chloride	-Cl	Chloro-
C=C double bond	-en-	-ene	Bromide	-Br	Bromo-
Saturated hydrocarbon	---	-ane	Iodide	-I	Iodo-

Alkane naming

$ \begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{ccc} & & \text{H} \\ & & \\ & & \text{H}-\text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{ccc} & & \text{H} \\ & & \\ & & \text{H}-\text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array} $
Butane	Butane	Methylpropane

$ \begin{array}{ccccc} & & \text{H} & & \\ & & & & \\ & & \text{H}-\text{C}-\text{H} & & \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{ccccc} & & \text{H} & & \\ & & & & \\ & & \text{H}-\text{C}-\text{H} & & \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{ccccc} & & & & \text{H} \\ & & & & \\ & & & & \text{H}-\text{C}-\text{H} \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array} $
2-methylpentane	3-methylpentane	2-methylpentane

$ \begin{array}{ccc} & & \text{F} \\ & & \\ \text{H} & & \text{H} \\ & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{H} \\ & & \\ \text{H} & & \text{H} \end{array} $	$ \begin{array}{ccc} & & \text{Cl} \\ & & \\ \text{H} & & \text{H} \\ & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array} $	$ \begin{array}{ccc} & & \text{Br} \\ & & \\ \text{H} & & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array} $
Fluoroethane	2-chloropropane	1-bromopropane

$ \begin{array}{cccc} & & \text{H} & \\ & & & \\ & & \text{H}-\text{C}-\text{H} & \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \text{H}-\text{C}-\text{H} \\ & & & \\ & & & \text{H} \end{array} $	$ \begin{array}{cccc} & & \text{Br} & \text{Cl} \\ & & & \\ \text{H} & & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & \\ \text{H} & & \text{H} & \text{H} \end{array} $	$ \begin{array}{cccc} & & \text{H} & \\ & & & \\ & & \text{H}-\text{C}-\text{H} & \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & - & \text{C} & - & \text{C} & - & \text{C}-\text{H} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \text{H}-\text{C}-\text{H} \\ & & & \\ & & & \text{F} \end{array} $
2,3-dimethylbutane	3-bromo-1-chlorobutane	1-fluoro-2,3-dimethylbutane

Intensive note (Topic 5: Fossil fuels and carbon compounds)

Alkene naming

$\begin{array}{c} \text{H} - \text{C} = \text{C} - \text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} = \text{C} - \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} - \text{C} = \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
Ethene	Propene	Propene

$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H} - \text{C} = \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} \quad \quad \text{H} \\ \quad \quad \\ \text{H} - \text{C} - \text{C} = \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H} - \text{C} - \text{C} - \text{C} = \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
But-1-ene	But-2-ene	But-1-ene

$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} - \text{H} \\ \\ \text{H} - \text{C} - \text{C} - \text{C} = \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{Cl} \\ \\ \text{H} - \text{C} - \text{C} = \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{H} - \text{C} = \text{C} - \text{C} = \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
3-methylbut-1-ene	3-chloropropene	Buta-1,3-diene

Alcohol naming

$\begin{array}{c} \text{OH} \\ \\ \text{H} - \text{C} - \text{C} - \text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{OH} \\ \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{OH} \\ \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
Ethanol	Propan-1-ol	Propan-2-ol

$\begin{array}{c} \text{Cl} \quad \quad \text{OH} \\ \quad \quad \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{OH} \quad \quad \text{OH} \\ \quad \quad \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{OH} \\ \\ \text{H} - \text{C} = \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
4-chlorobutan-2-ol	Butane-1,3-diol	But-3-en-2-ol

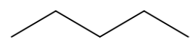
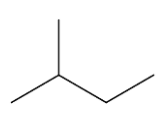

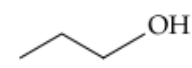
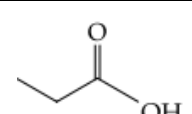
Intensive note (Topic 5: Fossil fuels and carbon compounds)

Carboxylic acid naming

$\begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}-\text{OH} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
Methanoic acid	Ethanoic acid	Pentanoic acid

$\begin{array}{c} \text{Cl} \quad \text{O} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\begin{array}{c} \text{O} \quad \text{O} \\ \quad \\ \text{HO}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}=\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
3-chloropropanoic acid	Propanedioic acid	But-3-enoic acid

Structural formula and skeletal formula

Compound	Molecular formula	Displayed structural formula	Condensed structural formula	Skeletal formula
Pentane	C ₅ H ₁₂	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH ₃ (CH ₂) ₃ CH ₃	
Methylbutane	C ₅ H ₁₂	$\begin{array}{c} \text{H} \\ \\ \text{H} \quad \text{H}-\text{C}-\text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	(CH ₃) ₂ CHCH ₂ CH ₃	
Propene	C ₃ H ₆	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}=\text{C}-\text{H} \\ \\ \text{H} \end{array}$	CH ₃ CH=CH ₂	
Propan-1-ol	C ₃ H ₈ O	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH ₃ CH ₂ CH ₂ OH	
Propanoic acid	C ₃ H ₆ O ₂	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{O} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	CH ₃ CH ₂ COOH	

Intensive note (Topic 5: Fossil fuels and carbon compounds)

Homologous series

- A homologous series is a series of carbon compounds that have the same general formula and each member differs from the next by a $-\text{CH}_2-$ unit.
- A functional group is an atom or a group of atoms responsible for most of the chemical properties of a compound.

Characteristics of members of a homologous series:

1. They can be represented by the same general formula

Alkane: $\text{C}_n\text{H}_{2n+2}$ Alkene: C_nH_{2n} Alkanol: $\text{C}_n\text{H}_{2n+1}\text{OH}$ Alkanoic acid: $\text{C}_n\text{H}_{2n+1}\text{COOH}$

2. Each of them differs from the next-one by a $-\text{CH}_2-$ unit.

Methane: CH_4 Ethane: C_2H_6 Propane: C_3H_8 Butane: C_4H_{10}

3. They have similar chemical properties

e.g. All alkenes can undergo addition reaction with Br_2 (in organic solvent)

4. There is a gradation in physical properties among them

	Methane	Ethane	Propane	Butane	Pentane
*Boiling point / °C	-161.5	-88.6	-42.1	-0.5	36.1

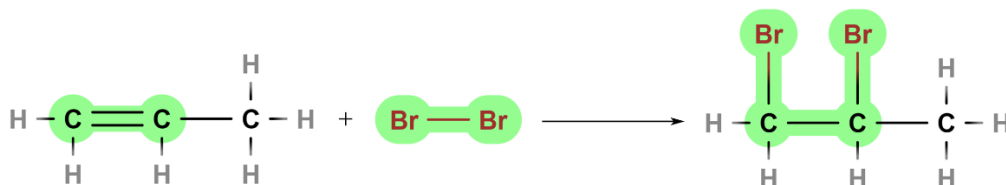
*The boiling point increase with molecular size.

Addition reaction of alkenes with halogens (Cl_2 , Br_2) and acidified $\text{KMnO}_4(\text{aq})$

Unsaturated compound is a compound that contains at least one carbon-carbon multiple bonds

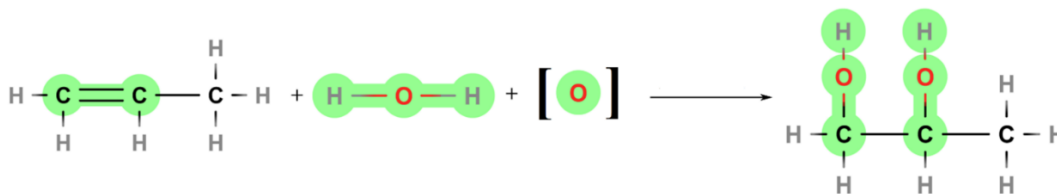
Unsaturated compounds (except benzene) often undergo addition reactions with halogens or acidified $\text{KMnO}_4(\text{aq})$

1. Addition of alkene with halogen (Cl_2 , Br_2)



- Observation for the reaction between Cl_2 (in organic solvent) and alkene: Solution turns from pale green to colorless rapidly
- Observation for the reaction between Br_2 (in organic solvent) and alkene: Solution turns from brown to colorless rapidly

2. Addition of alkene with cold acidified KMnO_4



- Observation: Purple solution turns colorless
- Cold, acidified KMnO_4 should be used. Otherwise, further oxidation of alcohol may occur
- Acidified $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})$ CANNOT be used in this reaction.

Suggest a chemical test to distinguish between hexane and hex-1-ene.

Add Br_2 (in organic solvent) to hexane and hex-1-ene in dark separately.

Hex-1-ene turns Br_2 (in organic solvent) from brown to colorless rapidly, but hexane does not.

Intensive note (Topic 5: Fossil fuels and carbon compounds)

Substitution reaction of alkanes with halogens (Cl₂, Br₂)

The overall equation for the reaction between Cl₂ and CH₄: $\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$

Alkanes react with Cl₂ and Br₂ in the presence of light or heat only

- Observation for the reaction between Cl₂ and alkane: Solution turns from pale green to colorless slowly, steamy fumes form
- Observation for the reaction between Br₂ and alkane: Solution turns from brown to colorless slowly, steamy fumes form

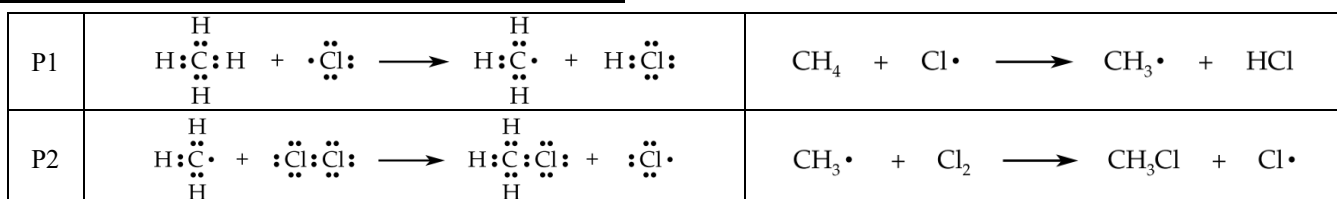
The replacement of a H atom in a CH₄ molecule by a Cl atom involves initiation, propagation and termination:

1. Initiation (Molecule → Radical)



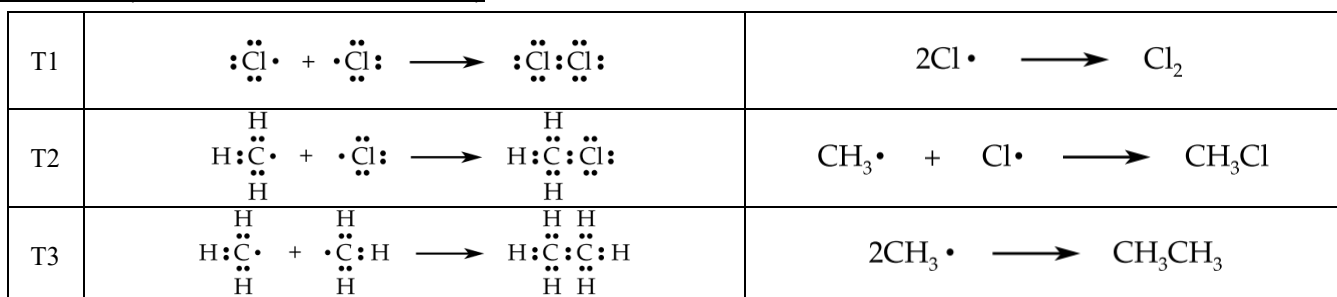
- The energy supplied light or heat breaks the Cl–Cl bonds in chlorine molecules to form chlorine free radicals

2. Propagation (Molecule + radical → Molecule' + radical')

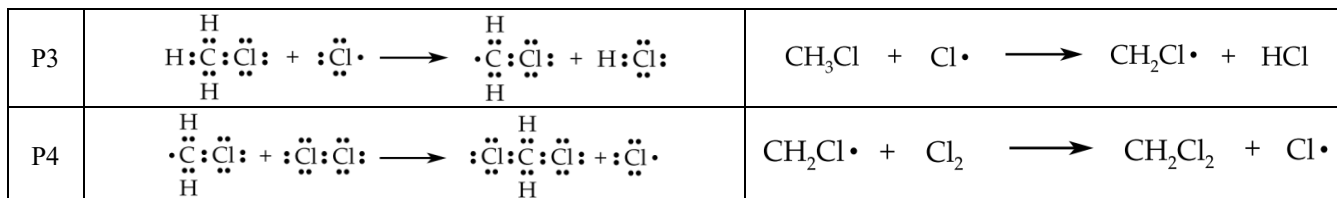


- Cl· radical and CH₃· radical are highly reactive as they do not have a stable noble gas electronic arrangement. They have at least one unpaired electrons

3. Termination (Radical + radical → Molecule)



- This is NOT a good method to prepare CH₃Cl. This is because CH₃Cl can further react with Cl₂ to give CH₂Cl₂, CHCl₃ and CCl₄ etc.



- To increase the yield of CH₃Cl, excess CH₄ should be used.
(Reaction P1 will occur more frequently than P3, CH₃Cl produced can be retained)
- To increase the yield of CCl₄, excess Cl₂ should be used

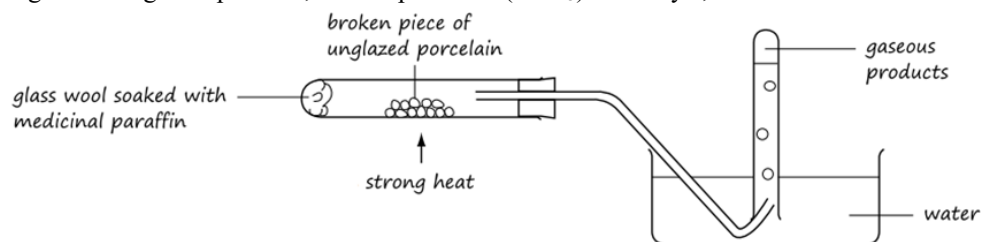
Intensive note (Topic 5: Fossil fuels and carbon compounds)

Cracking

Cracking is the breaking down of large molecules into smaller ones

Importance of cracking: Produce extra petrol and smaller alkenes as raw materials for making plastics

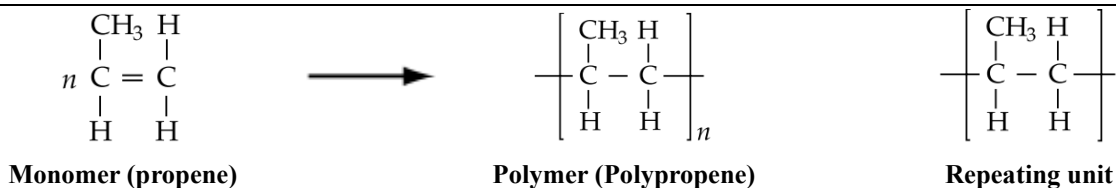
Conditions of cracking: High temperature, broken porcelain (Al_2O_3) as catalyst, absence of air



- Cracking occurs at the surface of porcelain, but NOT at glass wool.
- We should heat the porcelain strongly, but not the glass wool. Otherwise paraffin will vaporize too quickly and pass through the cold porcelain surface without cracking. Also paraffin may burn directly if we heat the glass wool strongly
- Safety precautions: Remove the delivery tube before removing heating source at the end of the experiment. Otherwise sucking back of cold water will occur which may crack the hot boiling tube

Addition polymer

Addition polymerization: Monomer molecules join together repeatedly to form polymer molecules without the elimination of small molecules



- Monomer should contain C=C bond
- Conditions of polymerization: High temperature, presence of suitable catalyst, high pressure
- Polypropene does NOT have a fixed relative molecular mass as polypropene is a mixture of polymer with different lengths.

	Polyethene	Polypropene	Polyvinyl chloride	Polystyrene	Perspex
Structure	$\left[\begin{array}{cc} \text{H} & \text{H} \\ & \\ \text{C} & - & \text{C} \\ & \\ \text{H} & \text{H} \end{array} \right]_n$	$\left[\begin{array}{cc} \text{H} & \text{CH}_3 \\ & \\ \text{C} & - & \text{C} \\ & \\ \text{H} & \text{H} \end{array} \right]_n$	$\left[\begin{array}{cc} \text{H} & \text{Cl} \\ & \\ \text{C} & - & \text{C} \\ & \\ \text{H} & \text{H} \end{array} \right]_n$	$\left[\begin{array}{cc} \text{H} & \text{C}_6\text{H}_5 \\ & \\ \text{C} & - & \text{C} \\ & \\ \text{H} & \text{H} \end{array} \right]_n$	$\left[\begin{array}{cc} \text{H} & \text{CH}_3 \\ & \\ \text{C} & - & \text{C} \\ & \\ \text{H} & \text{C} = \text{O} - \text{CH}_3 \end{array} \right]_n$
Properties	LDPE: Lightweight, flexible	Rigid, higher m.p. than PE, resistant to chemicals	Water resistant, electrical insulator,	Transparent Hard but brittle	Hard but rigid Transparent
	HDPE: Resistant to chemicals, rigid		With plasticizer: Flexible	Expanded: Light, rigid, heat insulator	
Uses	Plastic bags, flexible water pipes	Ropes, baskets, food container, luggage cases, packaging films, boxes	Drainage pipe, floor tiles	Disc cases Sample bottles	Aeroplane windows, car windows, optical fibres
	Bottles, boxes, buckets		Raincoats, covering for electric wires, tablecloths	Disposable food boxes, packaging materials	