Cambridge (CIE) IGCSE Chemistry

Your notes

Organic Families

Contents

- Fossil Fuels
- Alkanes
- Alkenes
- Addition Reactions
- Alcohols
- Carboxylic Acids
- Ethanoic Acid & Esterification Reactions

Common fossil fuels

- A fuel is a substance which when burned, releases heat energy
- This heat can be transferred into electricity, which we use in our daily lives
- Most common fossil fuels include **coal**, **natural gas** and **petroleum**
- **Methane,** CH_4, is the main constituent of natural gas and is a hydrocarbon
- **Hydrocarbons** are made from hydrogen and carbon atoms only

Petroleum & fractional distillation

Petroleum

- Petroleum is also called **crude oil** and is a mixture of hydrocarbons which also contains natural gas
- It is a thick, sticky, black liquid that is found under porous rock (under the ground and under the sea)

The location of crude oil

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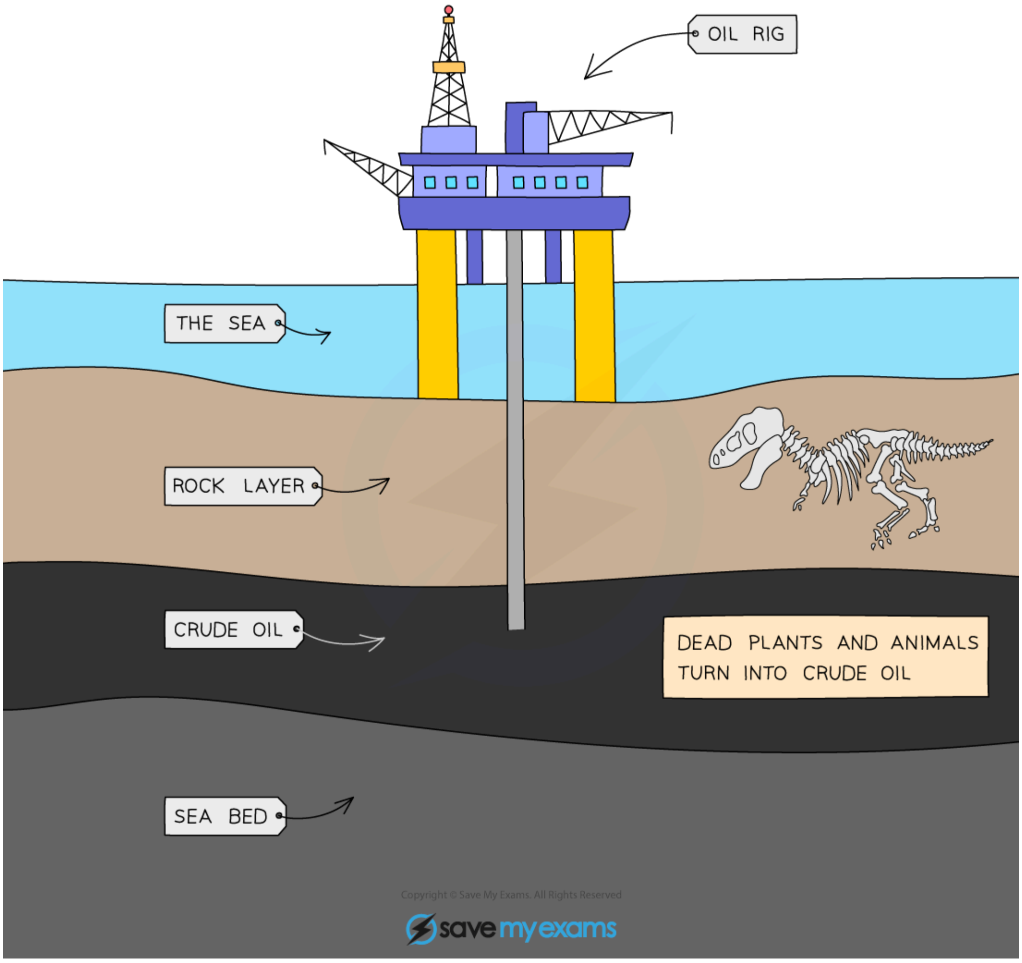


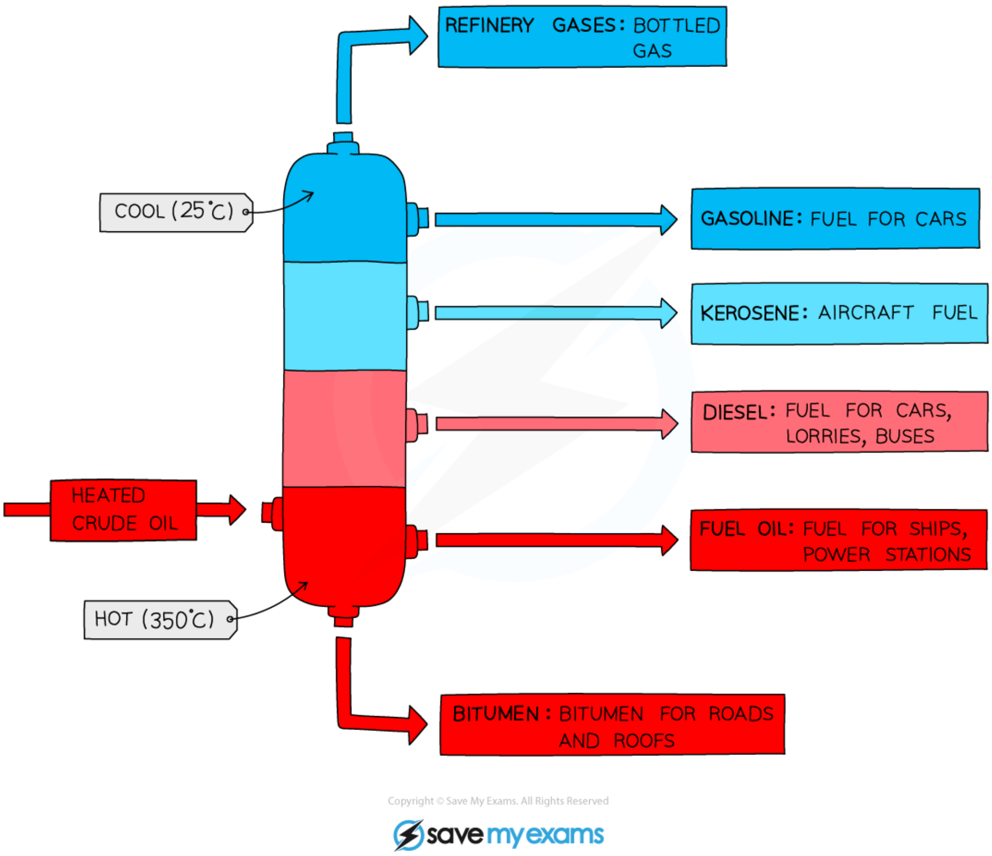
Crude oil is located under the sea

- Petroleum itself as a mixture isn't very useful but each component part of the mixture, called a **fraction**, is useful and each fraction has different applications

Fractional distillation

- Each fraction consists of groups of hydrocarbons of **similar** chain lengths
- The fractions in petroleum are separated from each other in a process called **fractional distillation**
- The molecules in each fraction have similar **properties** and **boiling points**, which depend on the number of carbon atoms in the chain
- The size of each molecule is directly related to how many carbon and hydrogen atoms the molecule contains
- Most fractions contain mainly **alkanes**, which are compounds of carbon and hydrogen with only **single** bonds between them

Diagram to show fractional distillation



The process separates the fractions according to their boiling point

- Fractional distillation is carried out in a **fractionating column** which has a temperature gradient
  - It is very hot at the bottom of the column and cooler at the top
- During the process of fractional distillation:
  - The crude oil is heated and **vapourises**
  - The vapours of hydrocarbons enter the column which has a **temperature gradient**
  - The vapours of hydrocarbons with high boiling points **condense** at the bottom of the column
  - The vapours of hydrocarbons with lower boiling points rise up the column and condense at the top

Properties of fractions

- **Viscosity**
  - This refers to the ease of flow of a liquid.
  - High viscosity liquids are thick and flow less easily.

- As the number of carbon atoms increases, the attraction between the hydrocarbon molecules also increases which results in the liquid becoming more viscous with the increasing length of the hydrocarbon chain.
  - Going down the column, the viscosity of the fractions increases
- **Melting point/boiling point**
  - As the molecules get larger, the intermolecular attraction becomes greater.
  - More heat is needed to separate the molecules.
  - Going down the column, the boiling points of the fractions increases
- **Volatility**
  - Volatility refers to the tendency of a substance to vaporise.
  - As the size of the hydrocarbon increases, the attraction between the molecules increases
  - Going down the column, the volatility of the fractions therefore decreases

Uses of Fractions

- Refinery gas: heating and cooking
- Gasoline: fuel for cars (petrol)
- Naphtha: raw product for producing chemicals
- Kerosene: for making jet fuel (paraffin)
- Diesel: fuel for diesel engines (gas oil)
- Fuel oil: fuel for ships and for home heating
- Lubricating oil: for lubricants, polishes, waxes
- Bitumen: for surfacing roads

Table to show the trends in properties

Fraction	Number of carbon atoms	Boiling point range / °C	Viscosity	Volatility
Refinery gas	1–4	Below 25	Viscosity increases going down the fractions	Volatility decreases going down the fractions
Gasoline / petrol	4–12	40–100		
Naptha	7–14	90–150		
Kerosene / paraffin	12–16	150–240		

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Diesel / gas oil	14–18	220–300		
Fuel oil	19–25	250–320		
Lubricating oil	20–40	300–350		
Bitumen	More than 70	More than 350		

Examiner Tips and Tricks

You **must** be able to recall a use for each fraction as well describe the trends in properties.

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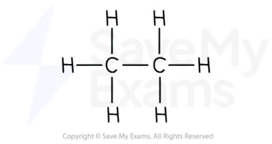
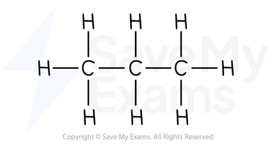
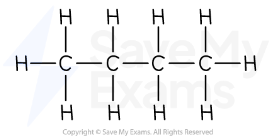
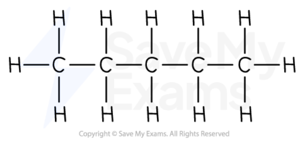
Alkanes: properties & bonding

What is an alkane?

- Alkanes are a group of **saturated** hydrocarbons
- The term saturated means that they only have single carbon-carbon bonds, there are no double bonds
- Alkanes have covalent bonds as they consist of non-metal atoms
- The general formula of the alkanes is $\mathbf{C_nH_{2n+2}}$

Table of alkanes

Displayed formula	Name	Molecular formula
	methane	CH_4
	ethane	C_2H_6
	propane	C_3H_8
	butane	C_4H_{10}

	pentane	C_5H_{12}

The first five members of the alkane homologous series

Your notes

Examiner Tips and Tricks

Co-ordinated students only need to be able to name and draw the displayed formula for methane and ethane but extended students should know the whole table.

- Alkanes are colourless compounds which have a gradual change in their physical properties as the number of carbon atoms in the chain increases
- They are generally unreactive compounds but they:
  - Undergo **combustion**
  - Can be **cracked** into smaller molecules
  - React with **halogens** in the presence of light in substitution reactions

Combustion of alkanes

- Alkanes undergo complete combustion to form carbon dioxide and water:

$$\text{Alkane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

- Combustion of methane:

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$$

- Combustion of ethane:

$$C_2H_6\,(g) + 3½O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(l)$$

- Combustion of propane:

$$C_3H_8\,(g) + 5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(l)$$

- Combustion of butane:

$$C_4H_{10}\,(g) + 6½O_2\,(g) \rightarrow 4CO_2\,(g) + 5H_2O\,(l)$$

Substitution reaction of alkanes with halogens

Extended tier only

- In a **substitution reaction**, one atom (or group of atoms) is swapped with another atom (or group of atoms)
- Alkanes undergo a substitution reaction with halogens in the presence of ultraviolet radiation (sunlight is a source of UV radiation)
- This is called a **photochemical** reaction
- The UV light provides the activation energy, E_a, for the reaction
- A hydrogen atom is replaced with the halogen atom
- More than one hydrogen atom can be substituted depending on the amount of ultraviolet radiation there is

In the presence of ultraviolet (UV) radiation, methane reacts with chlorine to form chloromethane and hydrogen chloride

Examiner Tips and Tricks

You need to be able to draw the displayed and structural formulae of the products formed when chlorine replaces one hydrogen atom (also known as monosubstitution)

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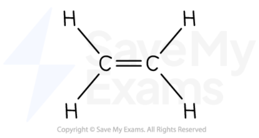
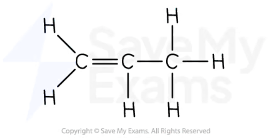
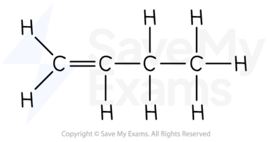
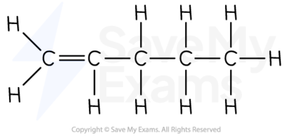
Catalytic cracking

- Alkenes are **unsaturated** hydrocarbons with carbon-carbon double bonds (C=C)
- They have **covalent** bonds
- Their general formula is $\mathbf{C_nH_{2n}}$
- The presence of the double bond, C=C, means they can **make more bonds** with other atoms by opening up the C=C bond and allowing incoming atoms to form another single bond with each carbon atom of the functional group
- Each of these carbon atoms now forms 4 single bonds instead of 1 double and 2 single bonds
- This makes them much more reactive than alkanes

Table of alkenes

Displayed formula	Name	Molecular formula
	ethene	C_2H_4
	propene	C_3H_6
	but-1-ene	C_4H_8

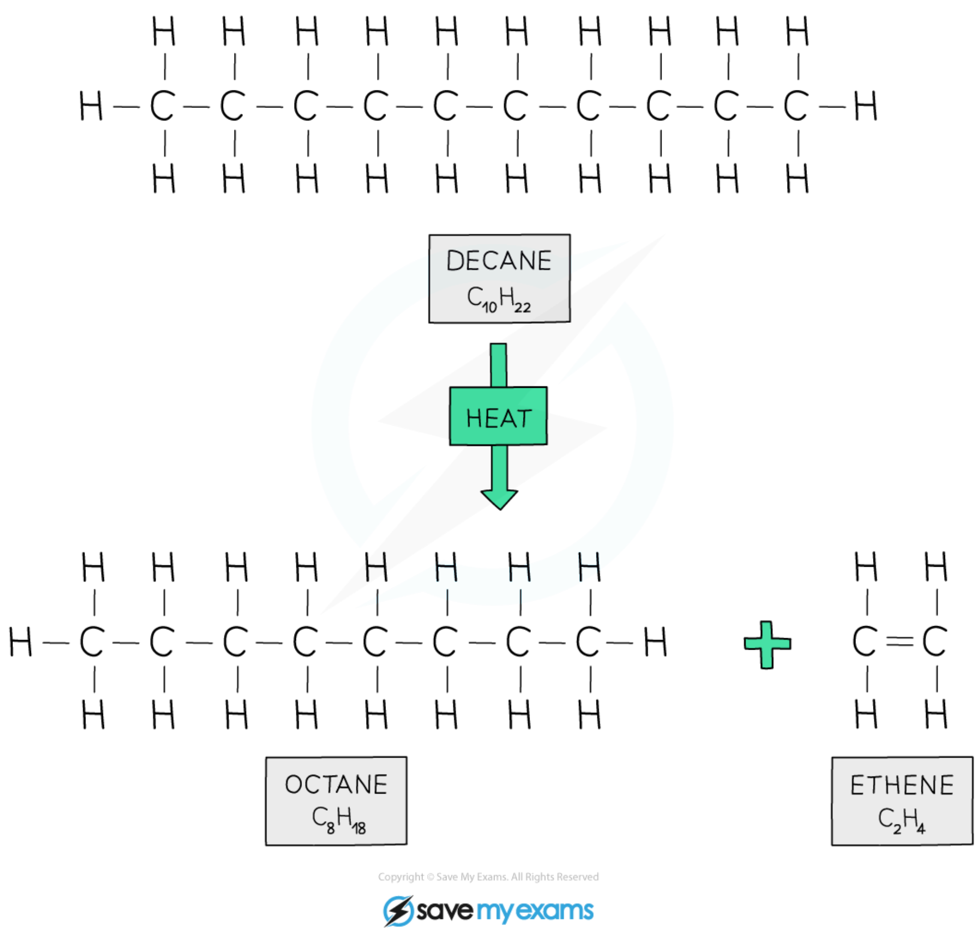
	pent-1-ene	C_5H_{10}

The first four members of the alkene homologous series

Manufacture of alkenes

- Although there is use for each fraction obtained from the fractional distillation of crude oil, the amount of longer chain hydrocarbons produced is far greater than needed
- These **long chain hydrocarbon** molecules are further processed to produce other products
- A process called **catalytic cracking** is used to convert longer-chain molecules into **short-chain** and more useful hydrocarbons
- Shorter chain alkanes, alkenes and hydrogen are produced from the cracking of longer chain alkanes
- Alkenes can be used to make polymers and the hydrogen used to make ammonia
- Kerosene and diesel oil are often cracked to produce petrol, other alkenes and hydrogen
- **Cracking** involves heating the hydrocarbon molecules to around 600 – 700°C to **vaporise** them
- The vapours then pass over a hot powdered **catalyst** of alumina or silica
- This process breaks covalent bonds in the molecules as they come into contact with the surface of the catalyst, causing **thermal decomposition** reactions
- The molecules are broken up in a random way which produces a mixture of smaller alkanes and alkenes
- Hydrogen and a higher proportion of alkenes are formed at higher temperatures and higher pressure

The cracking of decane



Decane is catalytically cracked to produce octane for petrol and ethene for ethanol

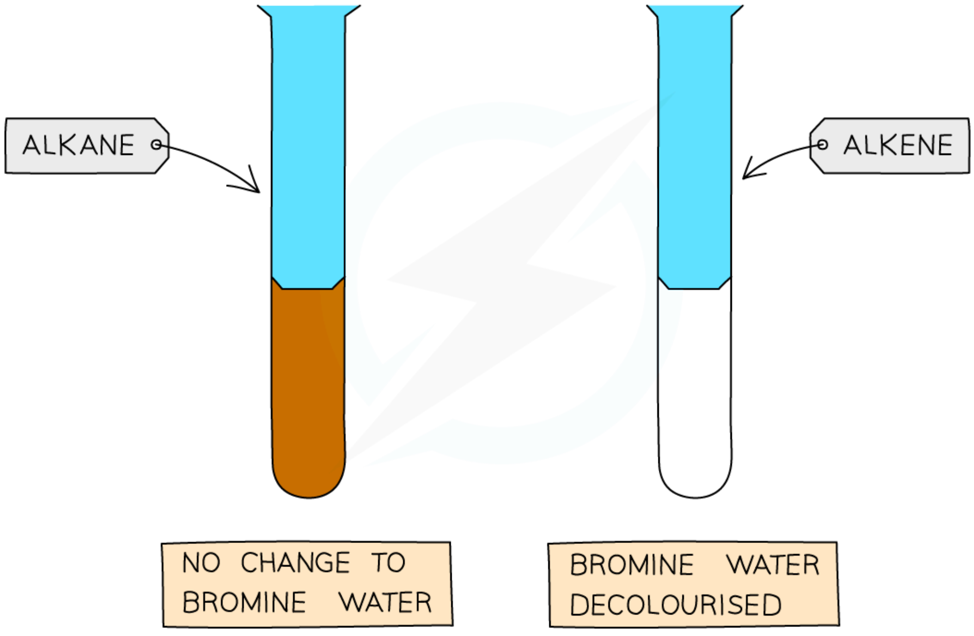
Distinguishing from alkanes

- The presence of the C=C double bond in an alkene but not an alkane allows us to distinguish between them
- To do this, **bromine water** is used
- Bromine water is an orange coloured solution
- When bromine water is shaken with an alkane the solution **remains orange**
- When bromine water is shaken with an alkene, the solution will go **colourless,** as the bromine can add across the double bond meaning it is no longer in solution

How to distinguish between alkanes and alkenes

Your notes

Your notes



Alkenes will decolourise bromine water

Examiner Tips and Tricks

When describing what happens to bromine water in an alkene ensure you say colourless, and not clear.

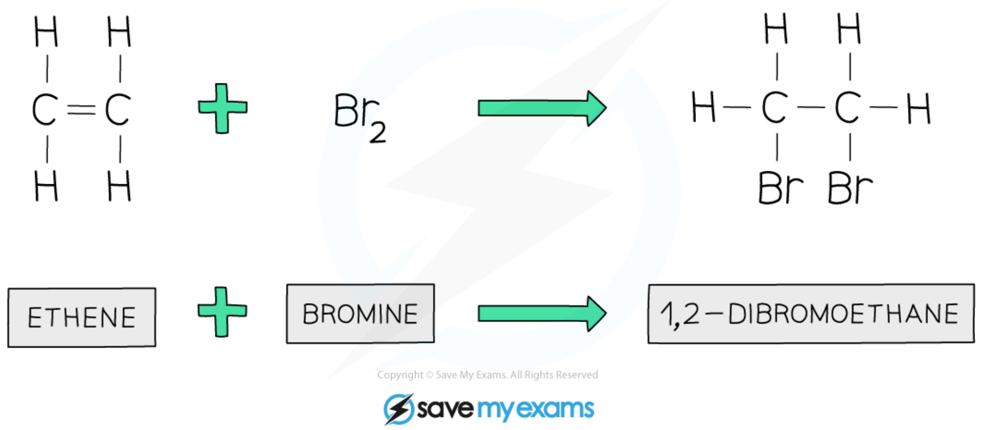
Addition reactions

Extended tier only

- Alkenes undergo **addition reactions** in which atoms of a simple molecule add across the C=C double bond
- In an addition reaction, only one product is formed

Alkenes and bromine

- The reaction between bromine and ethene is an example of an addition reaction
- The two bromine atoms add across the carbon-carbon double bond to form a saturated compound
- Bromine water is orange but would decolourise when added to an alkene

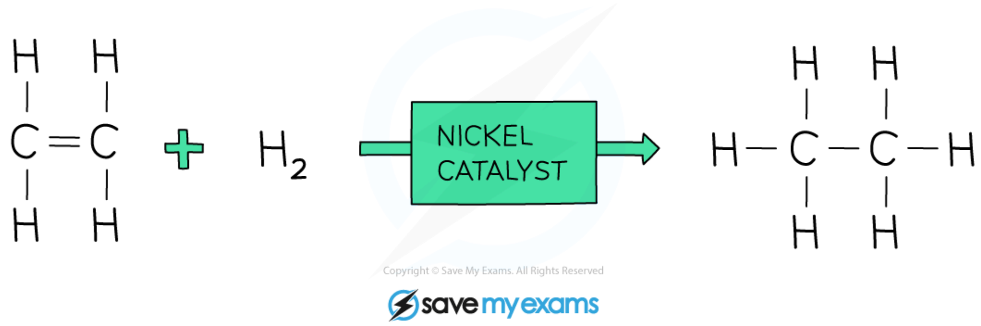


Bromine atoms add across the C=C in the addition reaction of ethene and bromine

Alkenes and hydrogen

- When alkenes undergo addition reactions with hydrogen, an **alkane** is formed
- This reaction requires a **nickel catalyst**
- The reaction between ethene and hydrogen would produce ethane, propene and hydrogen would form propane and so on

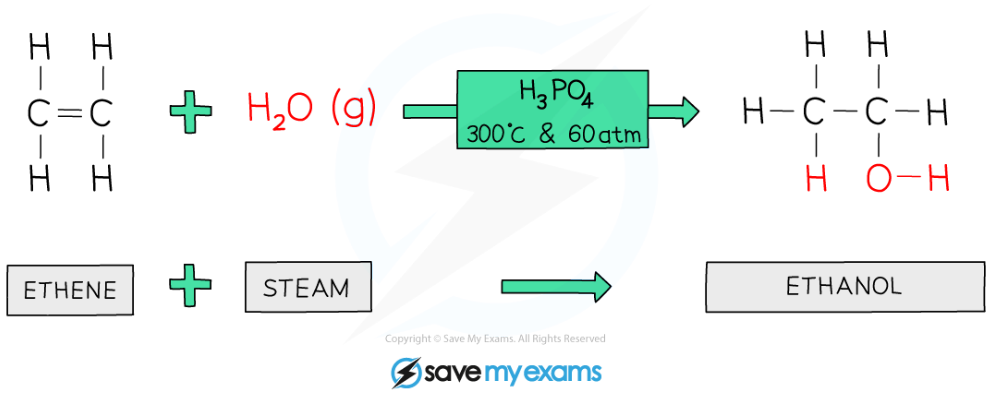
Your notes



The hydrogen adds across the carbon carbon-double bond

Alkenes and steam

- When alkenes undergo addition reactions with steam, an **alcohol** is formed.
- Since water is being added to the molecule it is also called a **hydration** reaction
- This reaction requires an **acid catalyst**
- Ethene would react with steam to produce ethanol, propene will react with steam to produce propanol and so on



A water molecule adds across the C=C in the hydration of ethene to produce ethanol

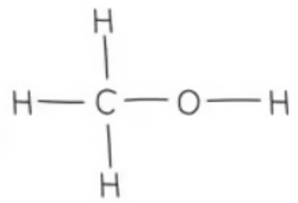
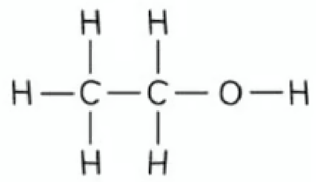
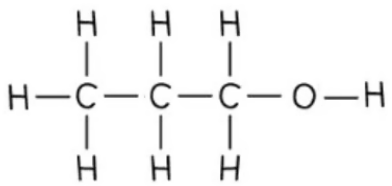
Examiner Tips and Tricks

You need to be able to draw the structural and displayed formulae of the products of alkenes with steam, hydrogen and bromine.

Alcohols

- All alcohols contain the hydroxyl (**–OH**) functional group which is the part of alcohol molecules that is responsible for their characteristic reactions
- Alcohols are a homologous series of compounds that have the general formula **$C_nH_{2n+1}OH$**
- They differ by one $-CH_2$ in the molecular formulae from one member to the next

Table showing the first three alcohols

Name	Formula	Displayed formula
Methanol	CH_3OH	
Ethanol	C_2H_5OH	
Propanol	C_3H_7OH	

- Ethanol (C_2H_5OH) is one of the most important alcohols
  - Ethanol can also be represented by its structural formula CH_3CH_2OH
- It is the type of alcohol found in **alcoholic drinks** such as wine and beer

- It is also used as **fuel** for cars and as a **solvent**
- Ethanol will undergo complete combustion and burn in excess oxygen to produce carbon dioxide and water

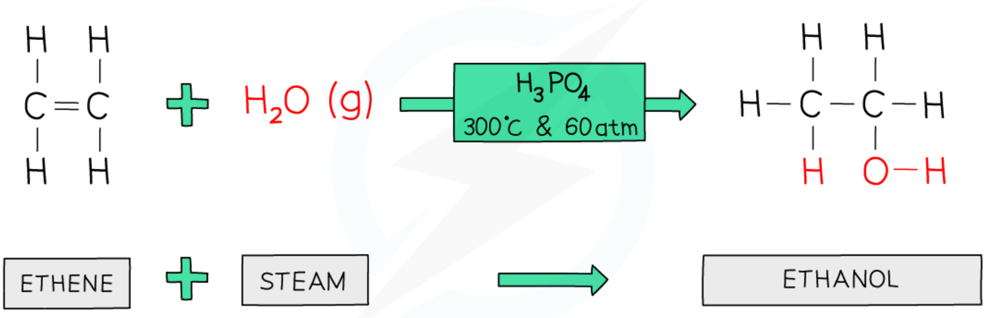
$$C_2H_5OH\ (l) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (l)$$

The manufacture of ethanol

- There are two methods used to manufacture ethanol:
  - The **hydration** of **ethene** with steam
  - The **fermentation** of glucose
- Both methods have advantages and disadvantages which are considered

Hydration of ethene

- A mixture of ethene and steam is passed over a hot catalyst of **phosphoric acid** at a temperature of approximately **300 °C**
- The pressure used is **60 atmospheres (6000kPa)**
- The gaseous ethanol is then condensed into a liquid for use



A water molecule adds across the C=C in the hydration of ethene to produce ethanol

Fermentation of glucose

- Sugar or starch is dissolved in water and yeast is added
- The mixture is then fermented between **25** and **35 °C** with the **absence of oxygen** for a few days
- Yeast contains **enzymes** that catalyse the break down of starch or sugar to glucose
- If the temperature is too **low** the reaction rate will be too slow and if it is too **high** the enzymes will become **denatured**
- The yeast respire anaerobically using the glucose to form ethanol and carbon dioxide:

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$$C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$$

- The yeast are killed off once the concentration of alcohol reaches around 15%, so the reaction vessel is emptied and the process is started again
- Ethanol production by fermentation is therefore a **batch** process

Examiner Tips and Tricks

Make sure you learn the conditions for both hydration and fermentation.

Comparing methods of ethanol production

Extended tier only

	Hydration of ethene	Fermentation
Equipment	complex set up required	simple equipment needed
Raw materials	uses non- renewable resources (crude oil)	uses renewable resources (sugar cane)
Type of process	continuous process- a steam of reactants is constantly passed over a catalyst	batch process- everything is mixed together in a reaction vessel and left for several days and the process repeated again
Rate of reaction	fast	very slow (several days)
Quality of product	produces pure ethanol	produces a dilute solution requiring further processing
Atmospheric effects	no greenhouse gases produced but pollutants are formed from the burning of fossil fuels to maintain high temperatures	carbon dioxide produced which is a greenhouse gas
Reaction conditions	high temperatures and pressures required increasing the energy input and cost	low temperatures required

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Carboxylic acids

- The carboxylic acids behave like other acids
- They react with:
  - **metals** to form a salt and hydrogen
  - **carbonates** to form a salt, water and carbon dioxide gas
  - **bases** to form a salt and water
- The salts formed by the reaction of carboxylic acids all end –**anoate**
- So methanoic acid forms a salt called methanoate, ethanoic a salt called ethanoate etc.
- In the reaction with metals, a metal salt and hydrogen gas are produced

Example reactions of carboxylic acids

- The reaction of ethanoic acid with **metals** such as magnesium forms the salt magnesium ethanoate and hydrogen gas:

$$2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$$

- The **neutralisation** reaction of a carboxylic acid with a **hydroxide** produces salt and water
- For example, the reaction between potassium hydroxide and ethanoic acid forms the salt potassium ethanoate and water:

$$CH_3COOH + KOH \rightarrow CH_3COOK + H_2O$$

- The reaction of a carboxylic acid with a **carbonate** produces a metal salt, water and carbon dioxide
- For example, in the reaction between potassium carbonate and ethanoic acid, the salt potassium ethanoate is formed with water and carbon dioxide

$$2CH_3COOH + K_2CO_3 \rightarrow 2CH_3COOK + H_2O + CO_2$$

Examiner Tips and Tricks

You need to be able to name and give the formulae of the salts produced in these reactions.

Your notes

Formation of ethanoic acid

Extended tier only

- Two methods used to make carboxylic acids are:
  - Oxidation by **fermentation**
  - Using **oxidising agents**
- The **microbial oxidation** (fermentation) of ethanol will produce a weak solution of vinegar (ethanoic acid)
- This occurs when a bottle of wine is opened as bacteria in the air (acetobacter) will use atmospheric oxygen from air to oxidise the ethanol in the wine

$$C_2H_5OH\ (aq) + O_2\ (g) \rightarrow CH_3COOH\ (aq) + H_2O\ (l)$$

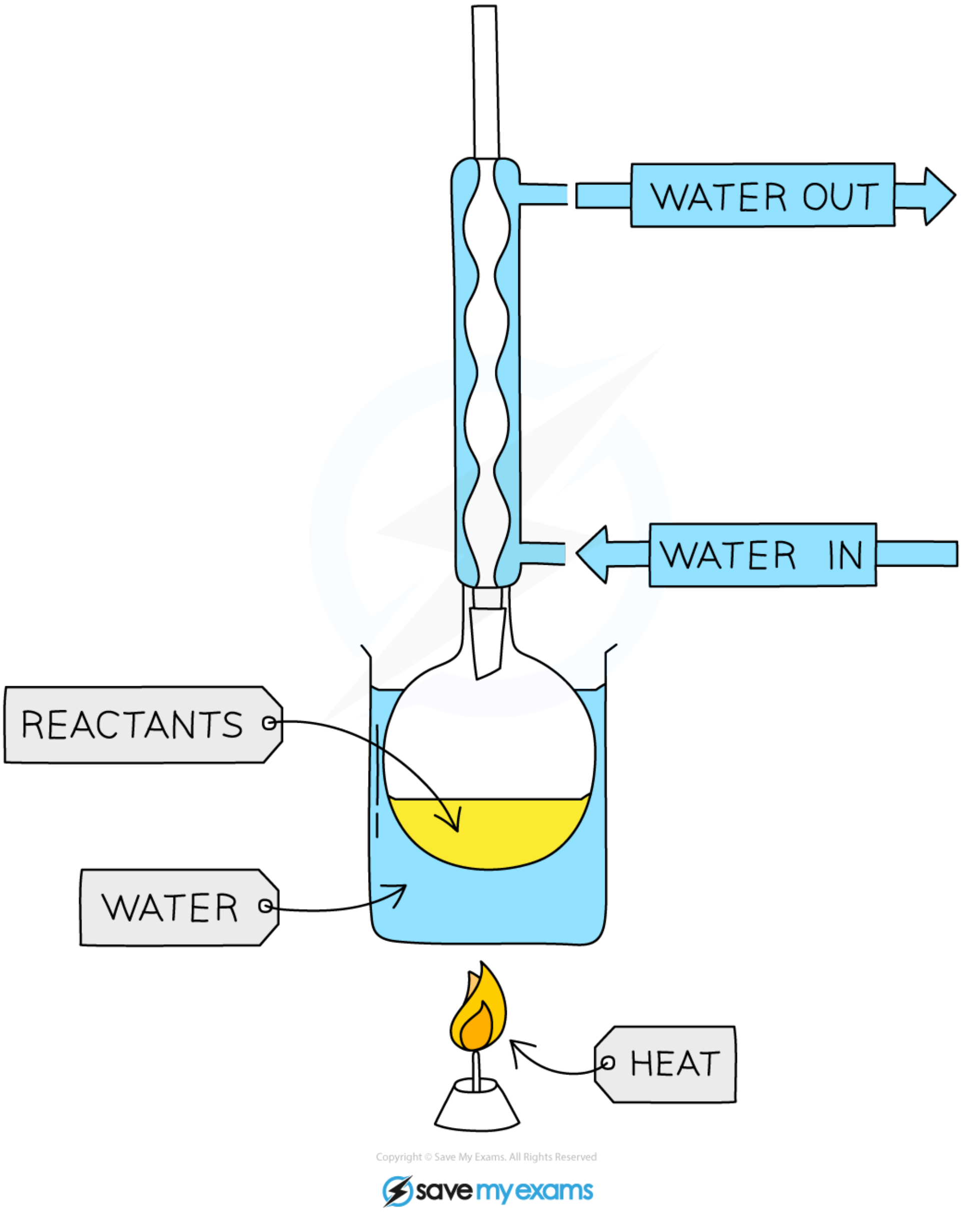
- The acidic, vinegary taste of wine which has been left open for several days is due to the presence of ethanoic acid
- Alternatively, oxidising agent **potassium manganate(VII)** can be used
- This involves heating ethanol with **acidified potassium manganate(VII)** in the presence of an acid
- The heating is performed under **reflux** which involves heating the reaction mixture in a vessel with a condenser attached to the top
- The condenser prevents the volatile alcohol from escaping the reaction vessel as alcohols have low boiling points
- The equation for the reaction is:

$$CH_3CH_2OH\ (aq) + 2[O] \rightarrow CH_3COOH\ (aq) + H_2O\ (l)$$

- The solution will change from purple to colourless
- The oxidising agent is represented by the symbol for oxygen in square brackets

Diagram showing the experimental setup for the oxidation with $KMnO_4$ using reflux apparatus

Your notes

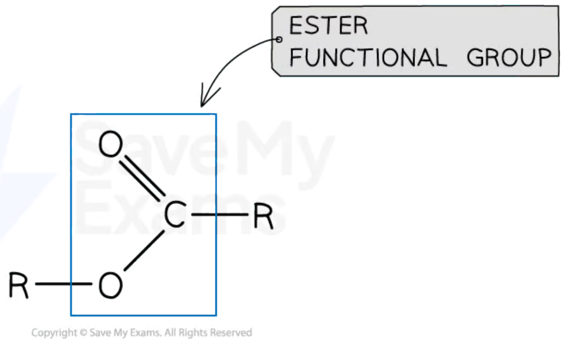


Ethanol is heated with acidified potassium manganate(VII) in the presence of an acid

Esterification

Extended tier only

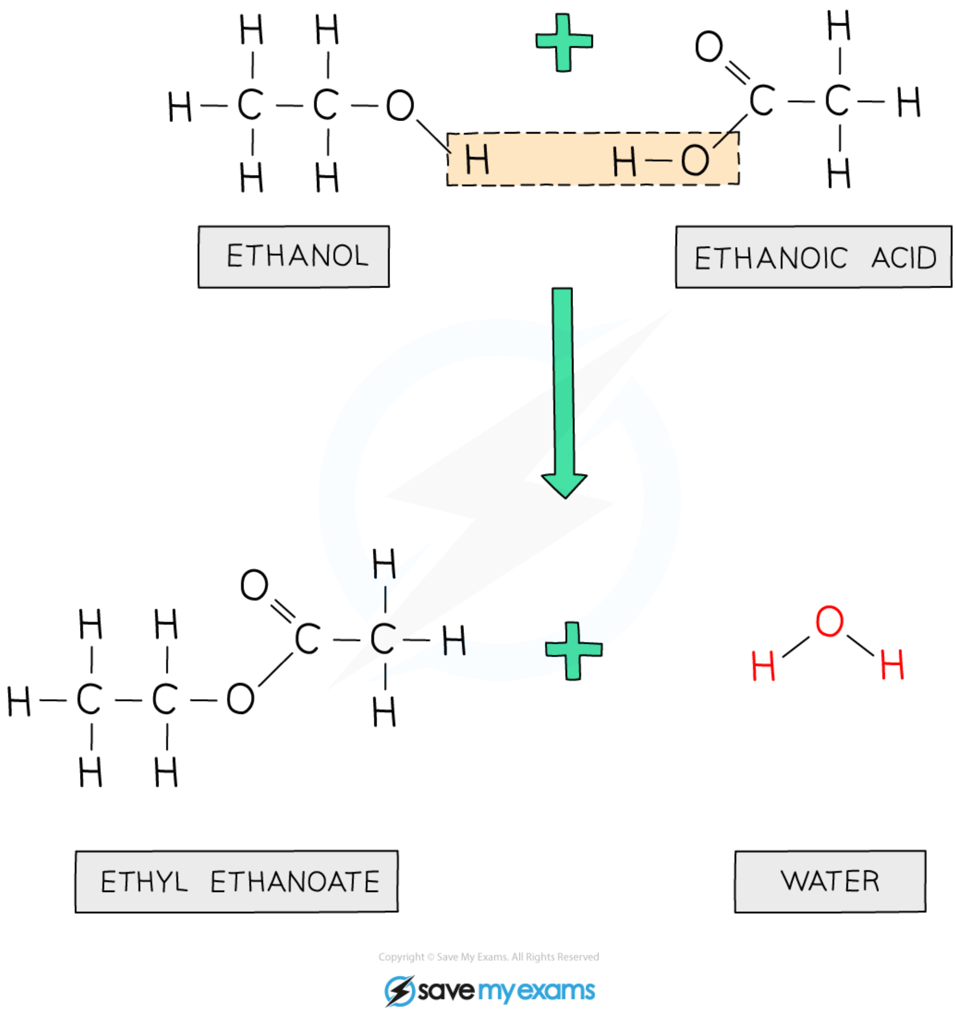
- Alcohols and carboxylic acids react to make esters in **esterification** reactions
- Esters are compounds with the functional group R-COO-R



- Esters are sweet-smelling oily liquids used in **food flavourings** and **perfumes**
- An acid catalyst is required for an esterification reaction
- Ethanoic acid will react with ethanol in the presence of concentrated sulfuric acid (catalyst) to form ethyl ethanoate:

$$CH_3COOH\,(aq) + C_2H_5OH\,(aq) \rightleftharpoons CH_3COOC_2H_5\,(aq) + H_2O\,(l)$$

Diagram showing the formation of ethyl ethanoate



During this esterification reaction, a molecule of water is also produced

Your notes

Naming Esters

- An ester is made from an alcohol and carboxylic acid
- The first part of the name indicates the length of the carbon chain in the alcohol, and it ends with the letters '- yl'
- The second part of the name indicates the length of the carbon chain in the carboxylic acid, and it ends with the letters '- oate'
  - E.g. the ester formed from **pent**anol and **butan**oic acid is called **pent**yl **butan**oate

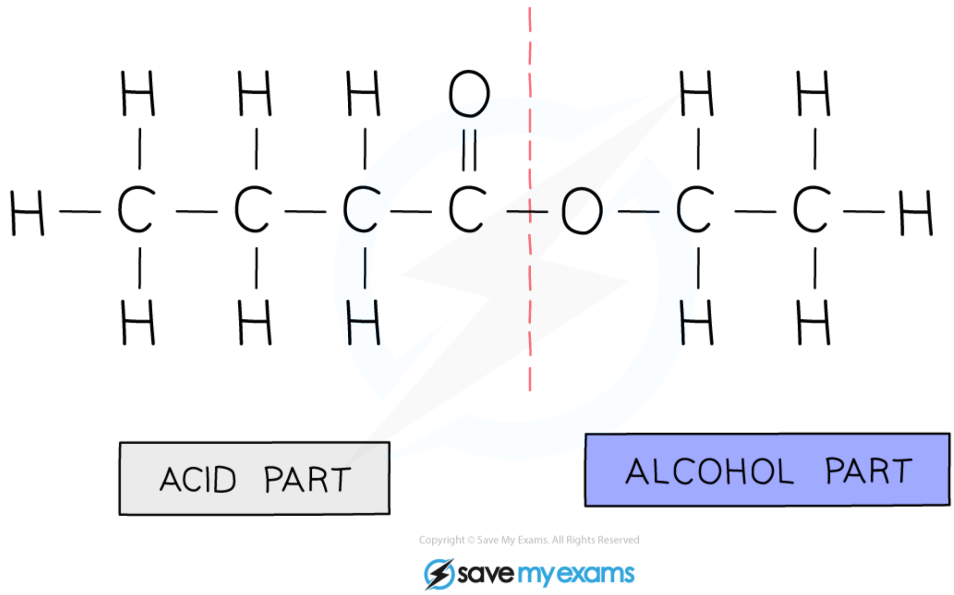


Diagram showing the origin of each carbon chain in ester; this ester is ethyl butanoate

Summary table of some esters and the compounds they are formed from

Name of ester	Alcohol and carboxylic acid it is formed from
propyl methanoate	propanol and methanoic acid
methyl butanoate	methanol and butanoic acid
ethyl propanoate	ethanol and propanoic acid