GCSE Chemistry

21st Century Science

C7: Chemistry for a sustainable world [Part 1]

Name: ______________

The Chemical industry

The chemical industry has a significant positive impact on our daily lives, producing substances that we use every day. However, scientists must ensure that the negative impact on the environment and society is minimised, through careful research into 'green chemistry'.

Bulk and fine chemicals

The chemical industry makes some chemicals in very large quantities. These chemicals are called **bulk chemicals**. Examples of these include:

[1] ammonia

[2] sulfuric acid

[3] sodium hydroxide

[4] phosphoric acid

Bulk chemicals are made at large chemical plants

Other chemicals are made in much smaller quantities, and are called **fine chemicals**. Examples of these include:

[1] drugs

[2] food additives

[3] fragrances

Research and development

A large proportion of the people employed in the chemical industries work in research and development.

Developing new chemical products or processes – such as new *catalysts* for industrial reactions - requires an extensive programme of research and development.

The government has a duty to protect people working in the chemical industry, and also to protect the consumers and the environment. It imposes **strict regulations** on the chemical industry to control the manufacturing processes as well as the storage and processing of chemicals.

Chemical Plants

Chemical plants manufacture chemicals. The centre of the plant is where reactions take place that convert reactants into products.

The chemical(s) fed into the process (known as the 'feedstock') may sometimes have to be heated, which takes energy. ***Synthesis*** then takes place inside the reactor often with the presence of a ***catalyst***.

A mixture of chemicals that needs to be separated then leaves the reactor. This separation of products isolates the desired product from by-products and unchanged starting materials. Unchanged starting materials may be recycled and fed back into the reactor to make the process more sustainable.

The sustainability of such a process can be determined using ideas described in the above section.

Question: Why do you think it is important for the chemical industry to employ:

[1] A technical team?

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[2] Maintenance workers?

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[3] Analytical chemists?

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What is green chemistry?

Green chemistry is a term that is used to describe a set of principles that can help to make the production of a chemical more sustainable.

The **sustainability** of a process depends on:

[1] Whether or not the raw materials needed are renewable

[2] The 'atom economy' (the total mass of the atoms in the desired product expressed as a percentage of the total mass of all the atoms in all of the reactants)

[3] Whether there are a lot of waste products (or by-products) and whether they can be recycled, used for something else, or are hazardous

[4] The amount of energy that is required by the process or released from the process

[5] The overall effect of the process on the environment

[6] Whether the process is hazardous for the workers

[7] The social and economic benefits

Renewable feedstocks

Plants can be grown year after year. They are a renewable resource. However, growing plants for chemicals takes up land that could be used to grow food. Energy is needed to make fertilisers and for harvesting crops.

DuPont has developed a way of making a new type of polyester by fermenting plant materials. The company calls this polymer Sorona. Manufacturers convert Sorona into fibres for clothing, upholstery, and carpets.

The production of Sorona uses 40% less energy than that required making the same amount of nylon. This reduces emissions of greenhouse gases and saves crude oil.

Manufacturers have to weigh up both sides of the argument and decide which is the most sustainable process.

Question: Classify these raw materials as 'renewable' or 'non-renewable'

[a] Salt [sodium chloride] _______________

[b] crude oil _____________

[c] wood chippings __________

[d] limestone _________

[e] sugar beet __________

Question: Why is the manufacture of Sorona an example of green chemistry?

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Calculating masses – Higher tier

A **balanced symbol equation** can be interpreted *quantitatively* as long as the*relative formula masses* (RFMs) have been calculated. It is then simply a question of manipulating a ratio.

For example, in the *thermal decomposition* of calcium carbonate, we can work out the mass of calcium oxide that can be produced when 300 tonnes of calcium carbonate is heated:

Balanced symbol equation	CaCO3 →	CaO +	CO_2
Relative formula mass	100	56	44
Reacting mass in g	100 g	56 g	44 g
Scale up into tonnes	100 T	56 T	
Now multiply by 3	300 T	168 T	

So the answer to the question is that **300 tonnes of $CaCO_3$** will thermally decompose to produce **168 tonnes of CaO**.

This method can also be used if the equation needs balancing - by multiplying the RFM by the large number in front of the formula. For example, what mass of iron can be produced from 32 g of iron(III) oxide in the thermite reaction?

Balanced symbol equation	Fe2O3 +	2AI →	2Fe +	Al_2O_3
Relative formula mass	160	2 x 27	2 x 56	102
Reacting mass in g	160 g		112 g	
Divide by 10	16 g		11.2 g	
Now multiply by 2	32 g		22.4 g	

So the answer to the question is that 32 g of iron(III) oxide will produce **22.4 g of iron** in the thermite reaction.

Percentage yield

In the above reaction it shows the **theoretical yield** of iron to be 22.4g. If this reaction was carried out the **actual yield** is likely to be below this. When the actual yield and theoretical yield are known, the **percentage yield** can be calculated:

Percentage yield = $^{\text{actual yield}}/_{\text{theoretical yield}}$ **x 100**

For example, using the theoretical yield calculated above and given the actual yield was found to be 15.2g, what is the percentage yield?

Percentage yield = $^{15.2\text{ g}}/_{22.4\text{ g}}$ **x 100 = 67.9%**

Atom economy

Atom economy is a useful tool in assessing the efficiency with which a reaction uses the *atoms* in the *reactants*. It is expressed as a percentage.

In a reaction that uses all reactants to make the desired product, the atom economy would be 100%. This is not usually the case. The atom economy of a reaction can be calculated using the following equation:

atom economy = $^{\text{mass of atoms in product}}/_{\text{mass of atoms in reactant}}$ x 100

For example, the *thermal decomposition* of copper carbonate, with the desired product being copper oxide and waste product being carbon dioxide is shown like this:

CuCO3 (s) + HEAT = CuO (s) + CO2 (g)

In the reactants there is one copper atom (1Cu), one carbon atom (1C) and three oxygen atoms (3O).

The *relative formula mass* is 63.5 + 12.0 + (3 x 16.0) = 123.5

The desired product is copper oxide (CuO) with a relative formula mass of 63.5 + 16 = 79.5

atom economy = $^{79.5}/_{123.5}$ x 100 = **64.4%**

Note that if you calculate a value greater than 100%, it is likely that you have put the mass of atoms in the product on the bottom of the equation instead of at the top.

At the very best for this thermal decomposition reaction, just over half of the mass of starting materials can end up as product. So this is not a green process.

This process does not take yield into account and does not allow for the fact that many real-world processes use a deliberate excess of reactants.
This can be demonstrated in the reaction between a base [e.g. black copper oxide] which is a powder added in excess to sulphuric acid, to make a salt.

Question: Write out a word equation for this reaction.

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Question: Explain how you would obtain the pure salt.

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Question: 16g of methane [CH_4] was burned in the air. 32g of carbon dioxide were collected during the reaction. During the reaction, some sooty deposits were noticed. The equation for the combustion of methane is:

CH_4 [g] + O_2 [g] = CO_2 [g] + $2H_2O$ [l]

Question continued:

[a] What was the percentage yield of carbon dioxide?

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[b] Why do you think the percentage yield was so low?

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[c] Calculate the atom economy for the reaction.

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Question: Heating with a catalyst converts cyclohexanol, $C_6H_{11}OH$, to cyclohexane, C_6H_{10}

[a] What is the percentage yield if 20g of cyclohexanol gives 14.5g of cyclohexene?

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[b] What is the atom economy, assuming that the catalyst is recovered and reused?

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Energy changes in reactions

When a chemical reaction occurs, energy is transferred to, or from, the surroundings - and there is often a temperature change. For example, when a bonfire burns it transfers heat energy to the surroundings. Objects near a bonfire become warmer. The temperature rise can be measured with a thermometer.

Exothermic reactions

These are reactions that **transfer energy to the surroundings**. The energy is usually transferred as heat energy, causing the reaction mixture and its surroundings to become hotter. The temperature increase can be detected using a thermometer. Some examples of exothermic reactions are:

[1] Burning
[2] Neutralisation reactions between acids and alkalis
[3] The reaction between water and calcium oxide

Endothermic reactions

These are reactions that **take in energy from the surroundings**. The energy is usually transferred as heat energy, causing the reaction mixture and its surroundings to get colder. The temperature decrease can also be detected using a thermometer. Some examples of endothermic reactions are:

[1] Electrolysis
[2] The reaction between ethanoic acid and sodium carbonate
[3] The *thermal decomposition* of calcium carbonate in a blast furnace

In industry it is important for scientists to be able to predict if a reaction is going to be endothermic or exothermic. The main reasons for this are:

As energy is given out in exothermic reactions it could be harnessed to be used elsewhere.

Endothermic reactions require energy, therefore fuel is needed which costs money.
An increase in temperature makes chemical reactions go faster. So, if the reaction is exothermic (giving out heat energy) the rate of reaction may increase to an unsafe point causing an explosion.

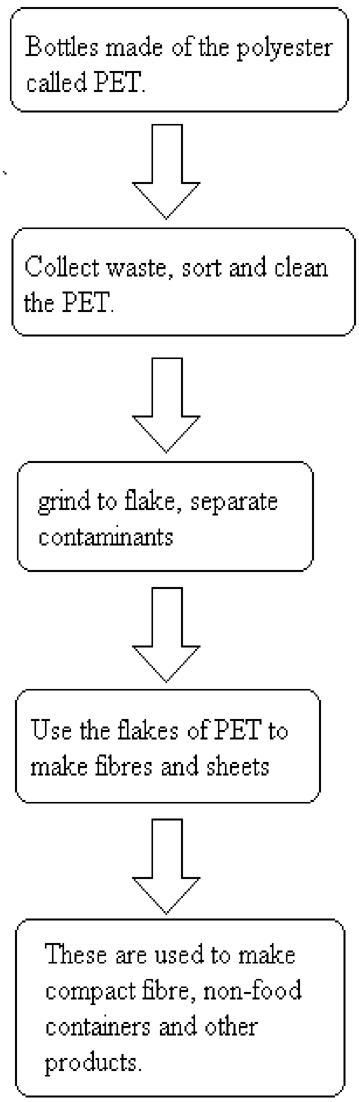
The development of catalysts has made a significant contribution. Chemical reactions can be speeded up without speeding up other reactions that produce un-wanted by-products. This reduces waste and reactions work at a lower temperature, saving energy.

In green chemistry we want to make chemicals with a lower energy demand. Catalysts such as enzymes produced by microorganisms operate within a limited temperature range. Above this they no longer work as they are denatured. Each enzyme also works within a limited pH range. This limits the conditions that can be used for enzyme-catalysed reactions.

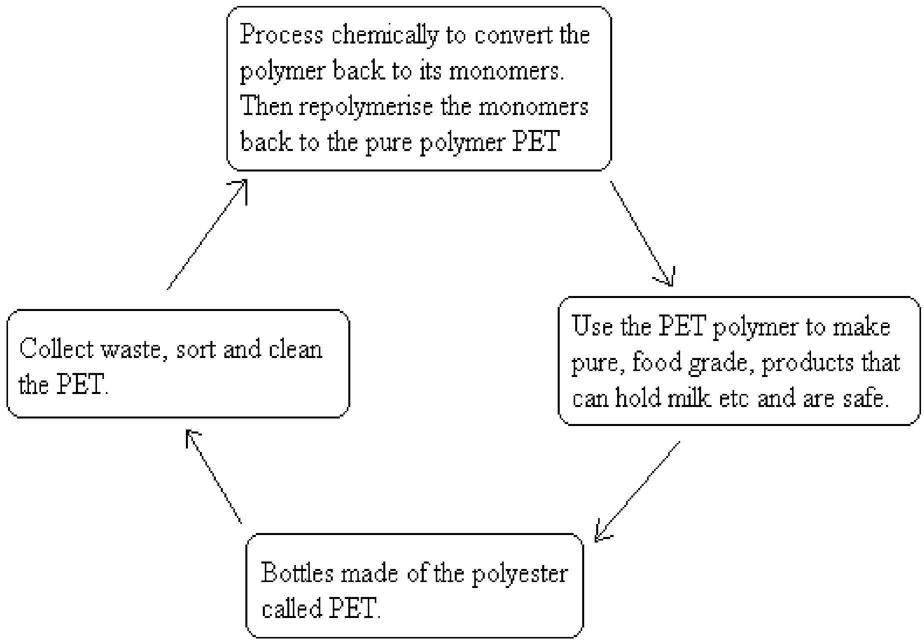
E.coli bacteria at 37C when added to glucose solution can make the flavouring agent called vanillin. Alternatively it can be made industrial from the benzene in crude oil at 260C.

Question: In terms of green chemistry which of the above two methods would be favoured? [Explain].

Open Looped Recycling



Closed - loop recycling



Open-loop recycling

During open – loop recycling green chemistry, waste from one product that is made can be recovered and used in the manufacture of another, lower quality product.

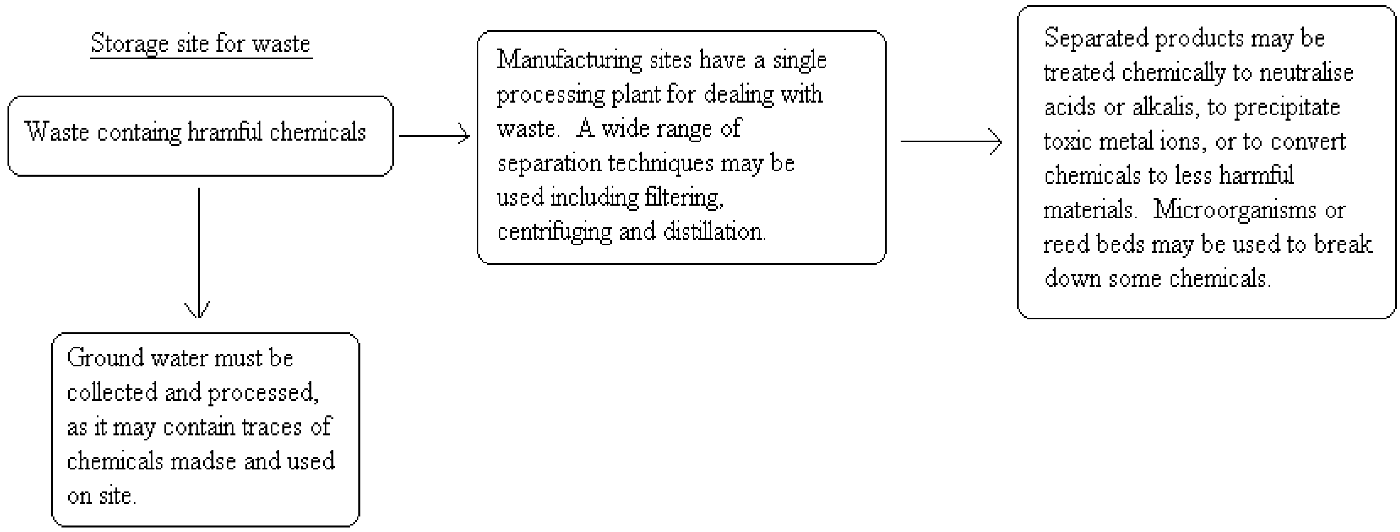
This can be seen in the previous diagram. The recovered PET is sold to manufacturers, who convert it into a variety of useful products, which are of a poorer, lower grade quality than the original PET. It cannot be used to hold food products, but can be used to make polyester carpets, fibre filling for pillows, quilts and jackets.

Closed-Loop recycling

Recycling is at its best when the waste material that is collected can be used to manufacture the same product with no loss in quality. This can be seen with the closed-loop recycling process in the previous diagram.

Question: Explain in a short paragraph the difference between open-loop and closed-loop recycling.
Suggest one possible advantage and one possible disadvantage of each of these approaches to recycling with reference to PET.

Cutting pollution by waste



Question: Why is it important to carefully control waste from industrial processes?

Organic chemistry

Crude oil is a mixture of compounds called hydrocarbons. Many useful materials can be produced from crude oil. It can be separated into different fractions using fractional distillation, and some of these can be used as fuels. Unfortunately, there are environmental consequences when fossil fuels such as crude oil and its products are used.

Designing new catalysts

Sustainable development is about how we organise our lives and work so that we don't destroy our planet. It is about meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Green chemistry is about the long-term sustainability of the planet and the short-term impacts of the chemical industry on our health and the environment. It is a way of thinking that can help chemists in research and production to make more eco-friendly and efficient products.

Catalysts are vital in green chemistry. They lower the temperature at which chemical process takes place.

When boots patented ibuprofen, there were six stages in the process of making the drug. The process had low atom economy. It needed 75 atoms for each ibuprofen molecule formed, so 42 of these atoms ended up as waste.

[Atoms in reactants to make one molecule of drug = 20C, 42H, N, 10 x O, Cl, Na].

Later, the Celanese Corporation, used recoverable and recycled catalysts to develop a more efficient three step process with less waste. The atoms in the reactants for this process were: 15C, 22H, and 40.

Question: Compare sustainable development and green chemistry. What is the difference?

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Question: what is the atom economy for making ibuprofen by:

[a] The boots process:

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[b] The Celanese process.

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Question: Calculate a new value for the Celanese process if the ethanoic acid [CH_3 COOH] formed as a by-product in one step is recycled and does not go to waste.

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Hydrocarbons and alkanes

Hydrocarbons

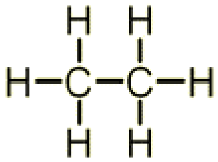
Most of the compounds in crude oil are hydrocarbons. This means that they only contain hydrogen and carbon atoms, joined together by chemical bonds. There are different types of hydrocarbon, but most of the ones in crude oil are alkanes.

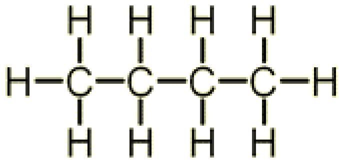
Alkanes

The alkanes are a family of hydrocarbons that share the same general formula. This is:

$$C_nH_{2n+2}$$

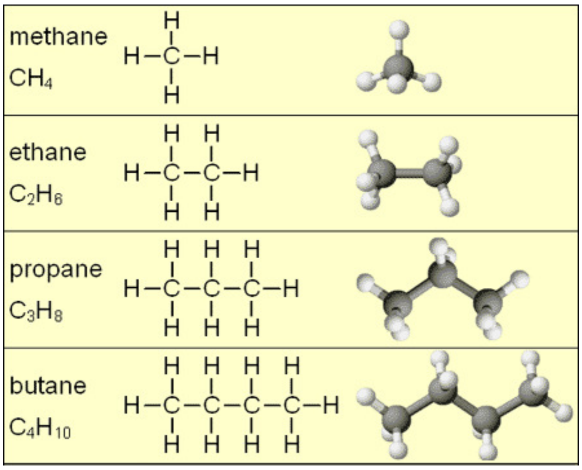
The general formula means that the number of hydrogen atoms in an alkane is double the number of carbon atoms, plus two. For example, methane is CH_4 and ethane is C_2H_6. Alkane molecules can be represented by displayed formulae in which each atom is shown as its symbol (**C or H**) and the chemical bonds between them by a straight line.





Notice that the molecular models on the right show that the bonds are not really at 90º.

Alkanes are saturated hydrocarbons. This means that their carbon atoms are joined to each other by single bonds. This makes them relatively unreactive, apart from their reaction with oxygen in the air, which we call **burning or combustion.**



Boiling point and state at room temperature

Hydrocarbons have different boiling points, and can be solid, liquid or gas at room temperature:

[1] Small hydrocarbons with only a few carbon atoms have low boiling points and are gases.
[2] Hydrocarbons with between five and 12 carbon atoms are usually liquids.
[3] Large hydrocarbons with many carbon atoms have high boiling points and are solids.

Question: [a] Draw a carbon atom in the space below using the periodic table to help you. In which group and period would you find this atom?

[b] Is carbon likely to form single ions? If you disagree and believe that it is more likely to form covalent bonds, explain why and how many.

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Question: Petrol contains octane molecules with the molecular formula $C_8 H_{18}$. Draw the structural formula of octane below:

Question: Write a word equation for propane burning in plenty of air. Write a balanced equation with state symbols for the same reaction.

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Question: Write a word equation for methane [1 carbon atom] burning in a limited supply of air to form carbon monoxide and steam. Write a balanced equation with state symbols for the same reaction.

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Question: Explain why the ethane molecule is more reactive than the ethane molecule.

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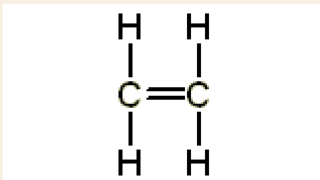
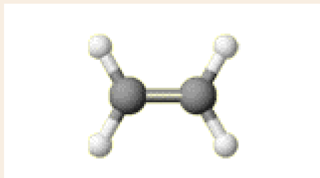
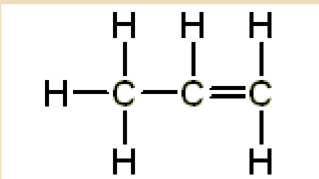
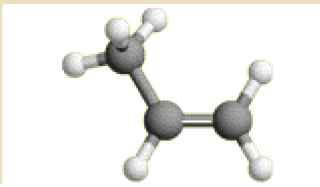
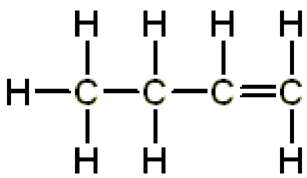
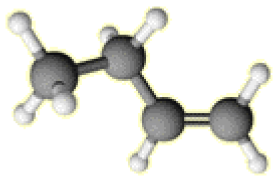
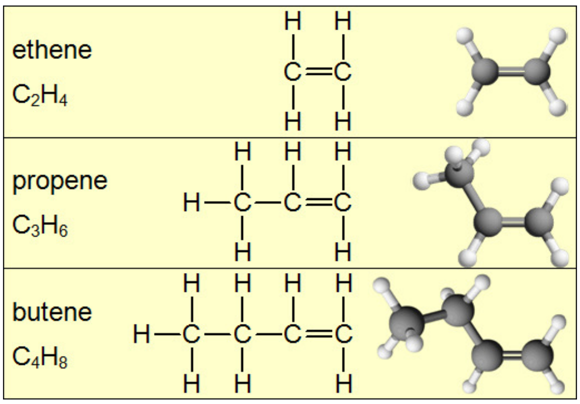
Alkenes

Alkenes are hydrocarbons that contain a carbon-carbon double bond. The number of hydrogen atoms in an alkene is double the number of carbon atoms. For example, the molecular formula of ethene is $\mathbf{C_2H_4}$**,** while for propene it is C_3H_6.

Structure of alkenes

ethene	C_2H_4		
propene	C_3H_6		
butene	C_4H_8		

Note the double bond between carbon atoms.



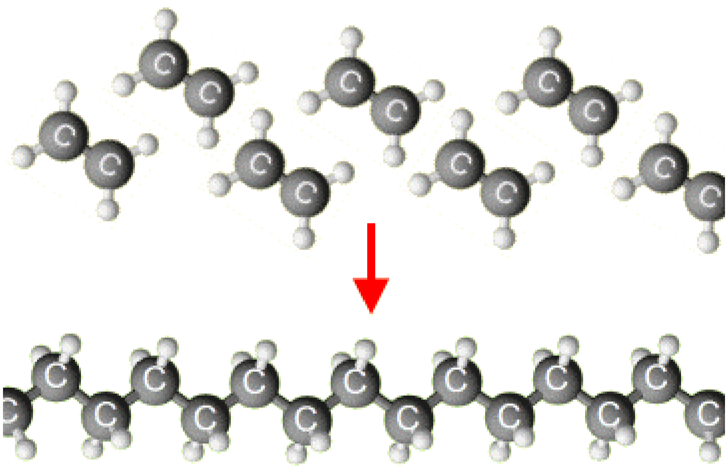
Alkenes are 'unsaturated' - meaning they contain a *double bond*. The presence of this double bond allows alkenes to react in ways that alkanes cannot. This allows us to distinguish alkenes from alkanes using a simple chemical test. Alkenes are examples of unsaturated hydrocarbons because not all their carbon bonds are single.

Question: Write both the molecular formula and structural formula for the 8 carbon alkene called Octene, in the space below:

Polymerisation

Some small molecules can join together to make very long molecules called **polymers**. This process is called polymerisation.

Many polymers are made from chemicals that are obtained from crude oil. For example, molecules of ethene join together to make poly (ethene), commonly known as polythene. It is the presence of the double bond that allows this to happen.



Ethene makes polyethene

By polymerising other small molecules, a wide variety of different polymers can be made. These synthetic materials have many uses.

Testing for alkenes

Bromine water is a dilute solution of bromine that is normally orange-brown in colour, but becomes colourless when shaken with an alkene. Alkenes can decolourise bromine water, while alkanes cannot.

Testing for unsaturation

Bromine water is orange. If you shake it with an unsaturated compound it loses its colour – its decolourised.

Question: Explain why propene will decolourise bromine water but propane will not.

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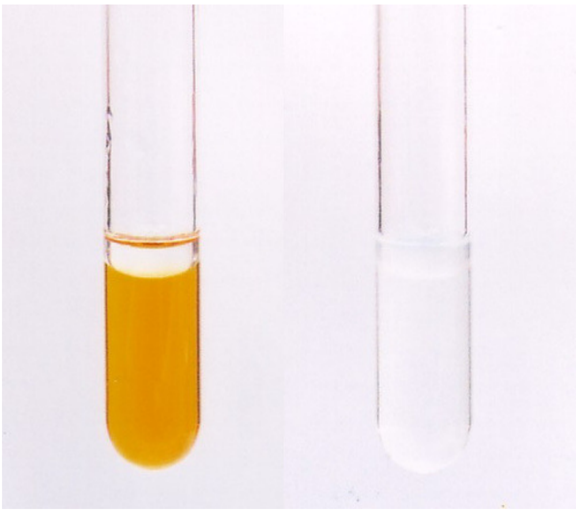
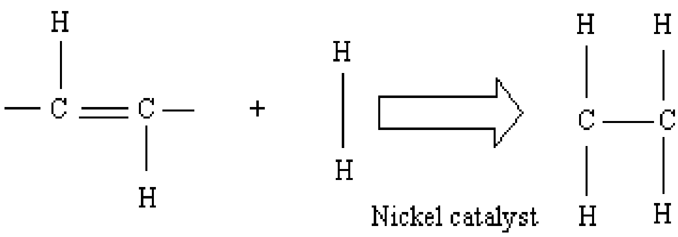
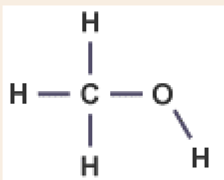
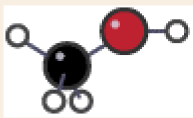
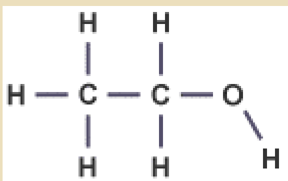
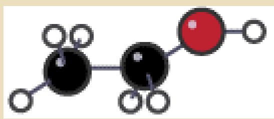


One industrial use of vegetable oils is to make margarine. Unfortunately vegetable oils are unsaturated, making most of them too runny. The first stage is to 'harden' them – to turn them into saturated compounds. Hydrogen is bubbled through the oil at about 200C using a nickel catalyst. The hydrogen reacts with the double bond and turns them into single bonds:



Alcohols

Structure of alcohol

Alcohol	Molecular formula	Structural formula	Ball-and-stick model
Methanol	CH_3OH		
Ethanol	C_2H_5OH		

Question: Using the table below, draw the different structural formula for the first four alcohol molecules in the space provided.

Alkanes + molecular formula	Alcohols + molecular formula
Methane (CH_4)	Methanol (CH_3OH)
Ethane (C_2H_6)	Ethanol (C_2H_5OH)
Propane (C_3H_8)	Propanol (C_3H_7OH)
Butane (C_4H_{10})	Butanol (C_4H_9OH)
Pentane (C_5H_{12})	Pentanol ($C_5H_{11}OH$)

Structural formula of the first four alcohols

Ethanol can be used as a ***solvent*** and as a fuel.

Physical properties of alcohols

Short-chain alcohols like methanol and ethanol have a low boiling point (ie lower than water) because they have weak ***intermolecular forces*** , which are easily overcome. Longer chain alcohols have higher boiling points.

Alcohols have higher boiling points than their corresponding alkane (eg ethanol has a higher boiling point than ethane) because the –OH group has the effect of strengthening the intermolecular forces.

Short chain alcohols are very ***soluble*** in water because of the effect of the –OH group that is strongly attracted to water molecules.

Longer chain alcohols are less soluble because they behave more like an alkane and tend to float on top of the water.

Alcohols as fuels

Alcohols are good fuels because of the presence of the ***hydrocarbon*** chain. They burn in a good air supply to produce carbon dioxide and water. For example:

Ethanol + oxygen = carbon dioxide + water

$C_2H_5OH + 3O_2 = 2CO_2 + 3H_2O$

Most ethanol is made using plants during fermentation. Plants are renewable, so this ethanol is a renewable fuel. During fermentation, yeast breaks down into sugars in plants to produce ethanol. Yeast does this in the absence of air (oxygen), so the fermenting is done in huge temperature-controlled tanks.

Question: Complete the following table using the words that follow:

What is needed for fermentation to produce ethanol	Reason for this

Possible words: Sugars from plants, water, temperature between 25C and 50C, absence of oxygen, enzymes from yeast, speed up conversion of sugar to alcohol, fermentation of sugar not aerobic respiration produces ethanol, substrate needed for fermentation, these temperatures are ideal for enzymes, solvent which dissolves sugar

Question: Give three uses of ethanol.

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Question: Why is ethanol considered as a renewable fuel?

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Question: What group of compounds does ethanol belong to?

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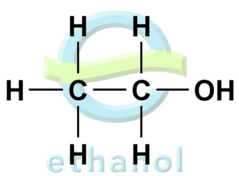
The formula of ethanol

The molecular formula for ethanol is C2H5OH and its structural formula is shown below:



Ethanol is an example of an alcohol molecule. These molecules all have the general formula of:

$$C_n H_{2n} OH$$

Fermentation conditions

The balanced chemical equation for fermentation is:

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

Fermentation is carried out under carefully controlled conditions:

- If the temperature is too cold the enzymes in yeast are inactive
- If the temperature is too hot the enzymes in yeast are denatured.

- If air is present there is a different reaction, producing ethanoic acid instead of ethanol.

Question: Use the general formula for alcohols and write below the molecular formula for (a) pentanol (5 carbons), hexanol (6 carbons), heptanol (7 carbons)

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Question: In the space provided below, draw the structural formula for these alcohols.

Question: What is a common feature of all alcohols?

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Question: What is the gas produced during fermentation of glucose? How can we test for it?

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Ethanol can be made by **fermentation**. In fermentation, sugars are used by *yeast* as a source of energy for *anaerobic respiration*. Ethanol and carbon dioxide are the products:

glucose → ethanol + carbon dioxide

Because this reaction is catalysed (sped up) by *enzymes* in the yeast, there are *optimum* conditions that are needed:

A temperature of approximately 37°C - any lower and the reaction is slow, but any higher and the enzymes are *denatured* - which changes the shape of the active site on the enzyme.

An optimum *pH* - significantly high or low pHs will also prevent the active site on the enzyme from working properly.

If the concentration of ethanol exceeds a certain level, it will start to kill the yeast. This means that there is a limit to the concentration of ethanol that can be achieved through fermentation.

However, the concentration of the ethanol can be further increased by *distillation*, which is how spirits like whiskey and brandy are made.

Making ethanol from ethene

Most of the world's ethanol is made from biomass, but there is another way: it can be made from ethene. The UK is the world's largest producer of ethanol in this way.

Ethene is made from crude oil or from natural gas. Fresh supplies of oil cannot be grown, so if ethanol is made from oil, the ethanol is non-renewable.

The ethanol is made by reacting ethene and water. The reaction is called a **hydration reaction.**

Ethanol can be used to make other compounds

Ethanol can be used to make other compounds, even the ethene from which it was originally made from!

In this reaction, the ethanol molecule breaks into two smaller parts, water and ethene. Water has been taken out of the ethanol molecule so it is called a **dehydration** reaction.

Question: Explain two ways of producing ethanol.

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Question: Explain two ways of making ethene.

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Question: One way of making ethanol is in a renewable manner. Another way is in a non-renewable manner. Explain what this means.

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Question: Write the word equation to show the formation of ethanol from ethene and water.

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Question: Why is this called a hydration reaction?

____

Question: Write the word equation to show the formation of ethene from ethanol.

____

Question: Why is this called a dehydration reaction?

____

Summary of the synthesis of ethanol

Ethanol can be made using crude oil as a raw material. There are several stages in the synthesis of ethanol:

1. Crude oil is processed by *fractional distillation*.
2. *Alkanes* (such as ethane) are '*cracked*' to produce *alkenes* - including ethene (C2H4).
3. Ethene is reacted with steam at high temperatures and in the presence of a phosphoric acid *catalyst*.
4. Any unreacted ethene and steam are recycled back into the process so that they are not wasted.

Making ethanol from ethene

ethene + steam (water) → (hot phosphoric acid catalyst) → ethanol (C_2H_5OH)

Ethanol can be produced as a fuel and burnt to release energy. As these crops grow they carry out photosynthesis and remove the CO2 that burning produces

+ oxygen ⇄ carbon dioxide + water

(photosynthesis)

glucose → (fermentation by microbes) → ethanol

crops
These are called cash crops e.g. sugar beet - could this land be better used growing food crops for the local population?

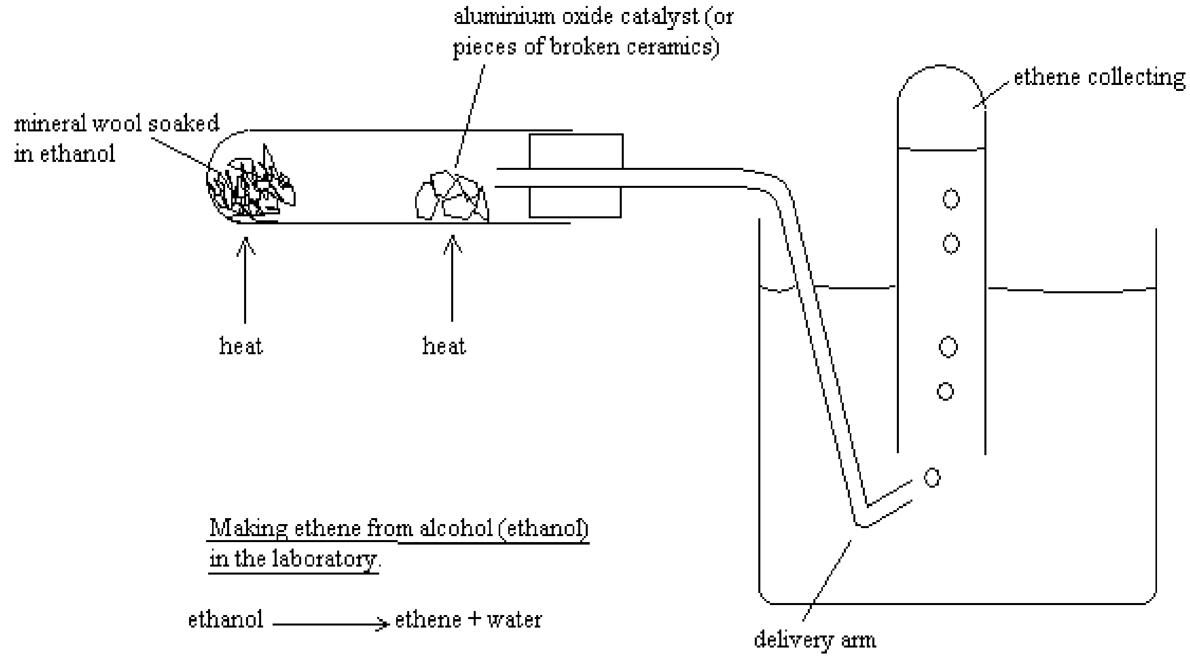
If we were sensible, we would use household waste which could be fermented to make ethanol. This would otherwise rot and produce methane which is a greenhouse gas. This also reduces the need for landfill sites.

Using massive amounts of ethanol, we can convert it back into ethene by pass ethanol over hot aluminium oxide catalyst

ethene + water
(C_2H_4 H_2O)

Used to make many chemicals including plastics

In UK, crude oil and natural gas are broken down (cracking) to make ethene which can then be used to make plastics. Cash crops for ethanol production are therefore not necessary



Making ethene from alcohol (ethanol) in the laboratory.

ethanol → ethene + water

Question: What catalyst is used during the hydration of ethene?

____

Advantages and disadvantages of ethanol production

Question: Give reasons why the fermentation of glucose to produce ethanol is useful for environmental reasons.

____

____

Disadvantages

(1) Using land for cash crops which can be used for fermentation and ethanol production, could be better used for growing food for the local population.

(2) Large areas of forest may be cut down to make room for the crops.

(3) It is not an efficient process using cash crops. There are high transport costs getting crops to the fermentation plants.

(4) There are energy costs in producing the fertilisers and pesticides that plants need to grow well.

Question: What are the advantages of ethene production in Britain compared to that in South America with the use of cash crops.

____

____

Question: Explain how the climate in the UK is not ideal for growing crops to make ethanol.

____

Question: Name the plastic that is made directly from ethene.

____

Synthesis or fermentation?

Fermentation can be done with very simple technology, so it allows people in the developing world to produce ethanol from crops. However, there is a limit to the concentration of the ethanol that can be produced, and it is expensive to use this process to make large quantities.

Fermentation is more likely to be *carbon neutral*. This is because the amount of carbon dioxide that is produced when the ethanol is burned is the same as the amount that was absorbed by *photosynthesis* when the plants that have been fermented were growing.

Direct synthesis of ethanol requires very expensive equipment, but the yield is very high (when the way in which unreacted ethene is recycled is taken into account). This means that large quantities of ethanol can be made very cheaply. However, this process is not *sustainable* because it relies on oil - which is a *fossil fuel*.

Reactions of alcohols

In addition to their reactions with oxygen when they are burned, alcohols react with sodium to produce a salt and hydrogen gas. For example:

Ethanol + sodium = sodium ethoxide + hydrogen

$2C_2H_5OH + Na = 2C_2H_5O\text{-}Na+ + H_2$

Because *alkanes* do not react with sodium it is unlikely to be the carbon chain in the alcohol that is causing this reaction to take place.

On the other hand, water reacts vigorously with sodium, suggesting that it is the –OH group in the alcohol, which is causing the reaction between an alcohol and sodium.

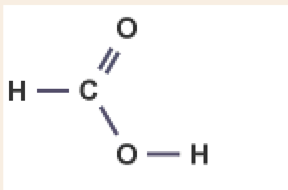
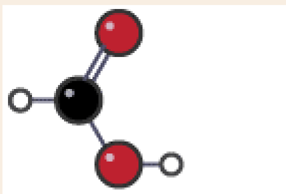
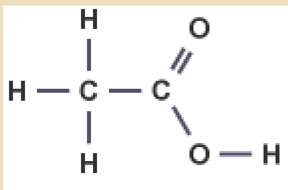
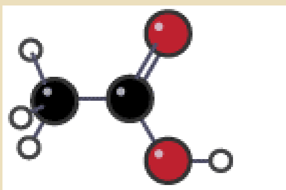
This is sodium reacting with ethanol. Note that the sodium sinks, whereas it floats on the surface of water

Carboxylic acids

Carboxylic acids all contain the **–COOH group** and this is generally responsible for their chemical properties and reactions.

They are named after their 'parent' *alkanes*, for example: methanoic acid (carboxylic acid) and methane ('parent' alkane), and ethanoic acid (carboxylic acid) and ethane ('parent' alkane).

Structure of carboxylic acids

Carboxylic acid	Molecular formula	Structural formula	Ball-and-stick model
Methanoic acid	HCOOH		
Ethanoic acid	CH_3COOH		

Vinegar is a dilute solution of ethanoic acid.

Properties and reactions of carboxylic acids

Many carboxylic acids have unpleasant smells and tastes. They are responsible for:

[1] The taste of vinegar

[2] The smell of sweaty socks

[3] The taste of rancid butter

Carboxylic acids are **weak acids**. This means that dilute solutions of carboxylic acids have higher *pHs* (ie are less acidic) than dilute solutions of strong acids such as hydrochloric acid, nitric acid and sulphuric acid.

Weak acids are less reactive than strong acids.

Carboxylic acids show the normal characteristic reactions of acids.

Reaction with metals

acid + metal = salt + hydrogen

For example:

ethanoic acid + magnesium = magnesium ethanoate + hydrogen

Reaction with alkali

acid + soluble hydroxide = salt + water

For example:

ethanoic acid + sodium hydroxide = sodium ethanoate + water

Reaction with carbonate

Acid + metal carbonate = salt + water + carbon dioxide

For example:

ethanoic acid + calcium carbonate = calcium ethanoate + water + carbon dioxide

Question: Complete the following table;

Carboxylic acid	Molecular formula	Structural formula
Methanoic acid		
Ethanoic acid		
Propanoic acid		
Butanoic acid		
Pentanoic acid		

Question: Write word equations and balanced symbol equations for the reactions of methanoic acid with:

[a] Magnesium

[b] Potassium hydroxide solution

[c] Copper carbonate [Cu CO_3].

Question: a good way of removing the disgusting smell of butanoic acid from vomit on a carpet is to sprinkle it with sodium hydrogen carbonate [$NaHCO_3$] powder. Write a word equation for the reaction that takes place [salt, water and carbon dioxide are produced]. Can you explain why the smell might disappear after this reaction?

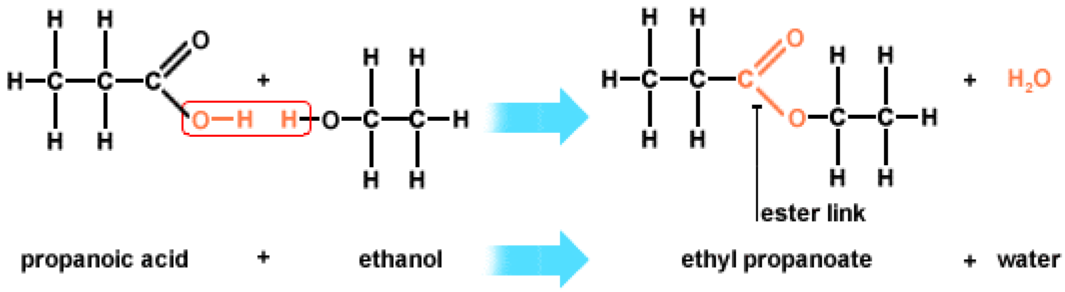
____
____
____

Esters

Esters are formed when a *carboxylic* acid reacts with an *alcohol*. The general word equation is:

carboxylic acid + alcohol → ester + water

For example, here is the reaction of propanoic acid with ethanol:



Esters have distinctive smells, which are often fruity. They are therefore used in the manufacture of perfumes and food additives.

Esters are also used in *solvents* and *plasticisers*.

Question: Why would ethanoic acid be an acid and yet ethyl propanoate is not?

____
____

Fats and oils

Fats and **oils** are naturally-occurring *esters* of three long *carboxylic acids* with a special type of *alcohol* called **glycerol**. Glycerol has three carbon atoms, each with an –OH group on.

Fats are solid at room temperature, whereas oils are liquids. Animals and plants produce oils and fats as an energy store.

Natural fats and oils

Natural fats and oils come from animals and plants. They were being used long before crude oil was discovered.

What is the difference between fats and oils?

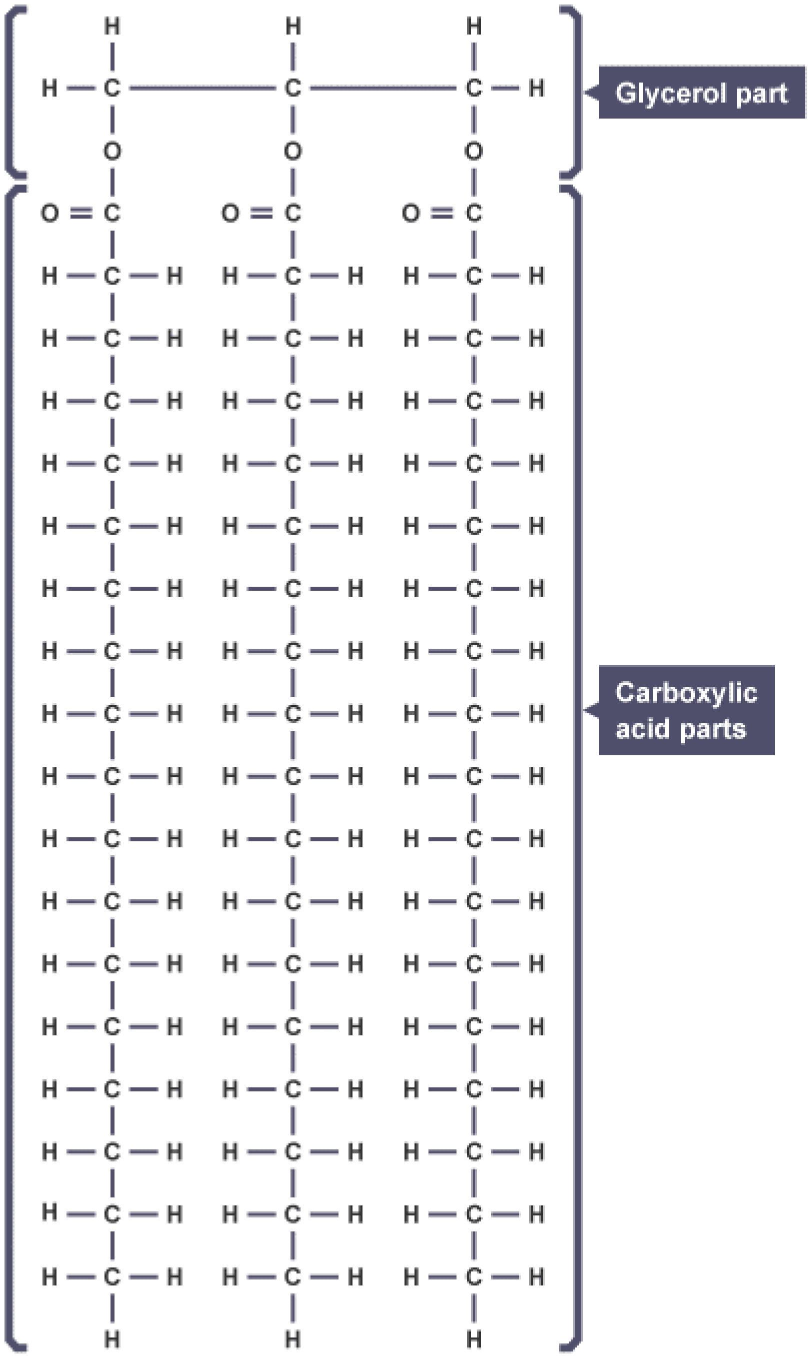
Fats and oils are the same type of chemical.

- Oils are liquid at room temperature.
- Fats are solid at room temperature.

Question: Bacon gives us lard and olives give us olive oil. Which is solid and which is liquid?
____
____

Saturated fats

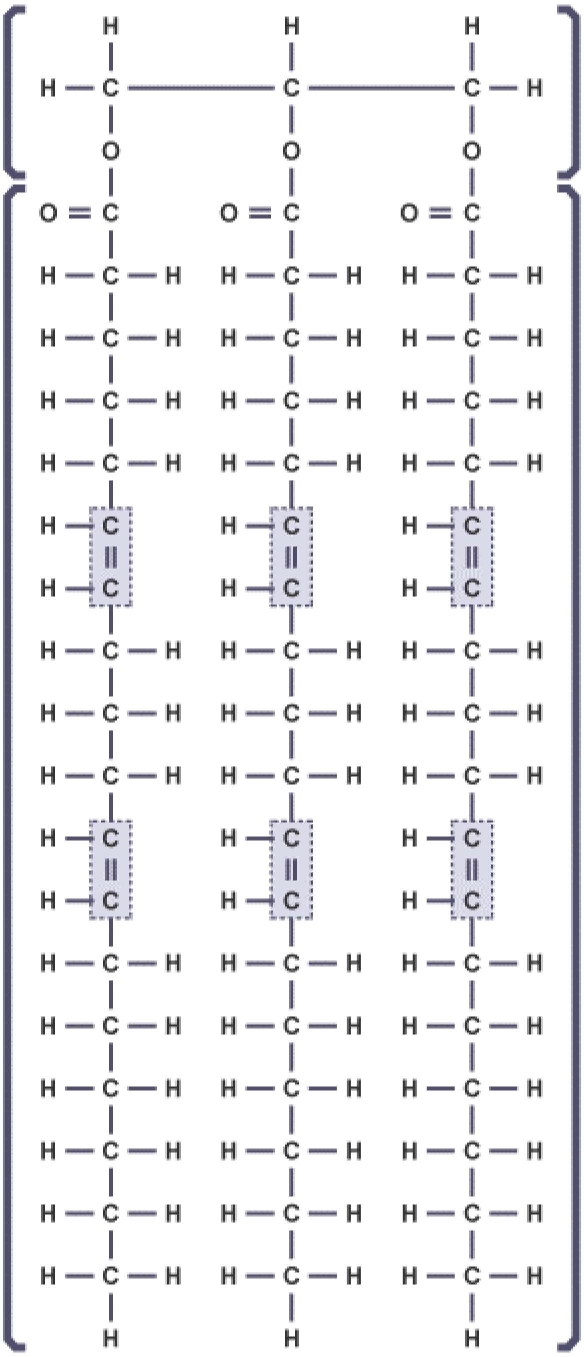
Animal fats (eg lard) usually contain a lot of **saturated** fats, which means that there are no C=C ***double bonds*** Fats [and oil molecules] are ester molecules linking three fatty acid molecules [carboxylic acids] to one glycerol molecule [alcohol].



This is a fat molecule and probably came from an animal cell. There are no double bonds in the fatty acids. This makes them very straight so that lots of fat molecules can be closely packed together – hence encouraging strong bonding and encouraging the fat to become solidified.

Unsaturated fats and oils

Vegetable oils and fats usually contain a higher proportion of unsaturated molecules, which means that they contain one or more C=C bonds.



This molecule is polyunsaturated fatty acids [more than one carbon – carbon double bond in each molecule]. This makes the fatty acids ‘kink’ or bend [not shown in diagram]. These fat molecules cannot come very close together as a result. They can move about and so they collectively produce a liquid and not a solid. They are called ‘oil’ molecules and usually we find them in plant cells.

Hydrolysis of fats and oils

Fats and oils contain ester links formed when glycerol has reacted with fatty acids. These ester links can be broken when they react with water, splitting the molecule back into an acid and an alcohol.

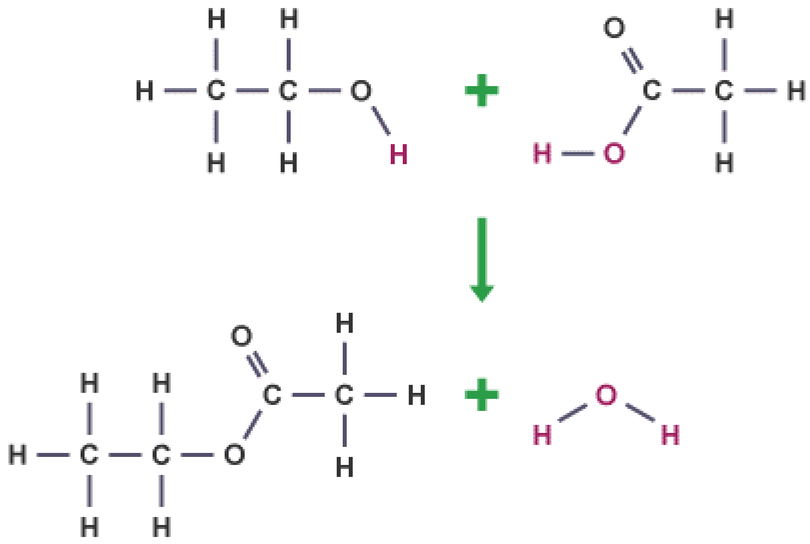
This process is known as **hydrolysis of an ester**. It can be described using the following word equation:

Ester + water = acid + alcohol

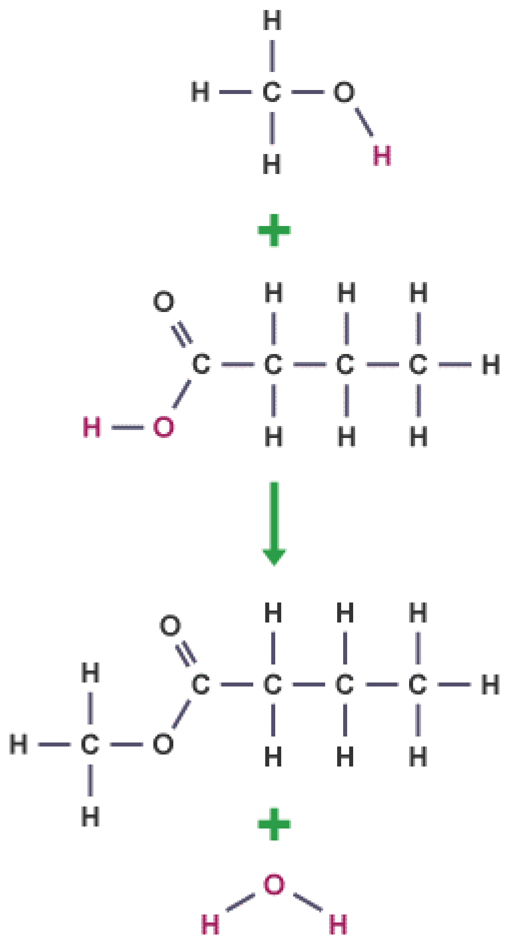
Making an ester

You can make a variety of *esters* by reacting different *carboxylic acids* with different *alcohols*.

For example: **ethanol + ethanoic acid → ethyl ethanoate + water**



Or methanol + butanoic acid → methyl butanoate + water

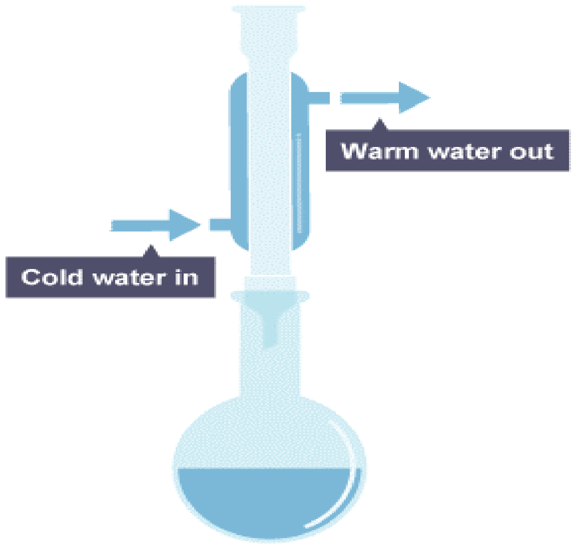


A *catalyst* is needed to speed up the reaction. Concentrated sulphuric acid is often used.

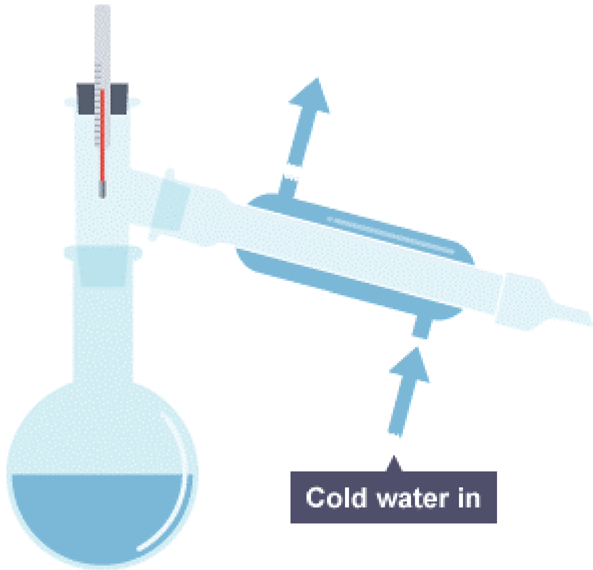
Steps in making an ester

[1] Add the correct carboxylic acid and alcohol to a flask, along with a few drops of concentrated sulphuric acid.

[2] Fit a condenser vertically to the flask and heat the mixture strongly. This is called 'heating under reflux' because the vapours that ***evaporate*** are cooled and ***condense*** back into the flask.

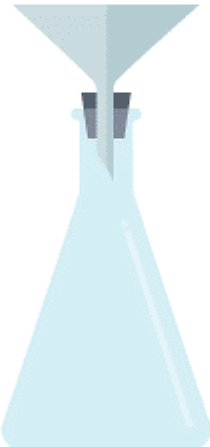


[3] The condenser is rearranged so that the mixture can be heated gently and the ester can then be ***distilled*** off from the remaining reactants and the water.



[4] The distillate is transferred to a separating funnel where aqueous sodium carbonate is added. This reacts with any remaining acid to ***neutralise*** it and remove it into the **aqueous layer**, which will be the lower (more dense) of the two liquids. The aqueous layer is then run off, leaving the ester in the upper (less dense) **organic layer**

[5] The organic layer is then transferred to a flask and solid ***anhydrous*** calcium chloride is added to remove any remaining water. The calcium chloride is removed by ***filtration***. A final distillation is then performed to obtain the pure ester.



Question: Calculate the percentage yield if the yield of ethyl ethanoate is 50g from a preparation starting from 42g thanol and 52g ethanoic acid.

Fats and oils are used for much more than cooking

Natural fats and oils are important raw materials in the chemical industry. They are used to make margarine and soap. They can also be turned into alternative fuels, such as biodiesel, that could become very useful when crude oil runs out.

If all the carbon atoms in a chain are linked by single bonds the compound is **saturated**. If the fatty acid tails of fats and oils contain one or more double bonds, the compounds are **unsaturated**: If only some of the double bonds are allowed to react, the oil only partially solidifies.

Partially solidified oils are used to make soft margarines that are easy to spread. If all of the double bonds react, the margarine is relatively hard.

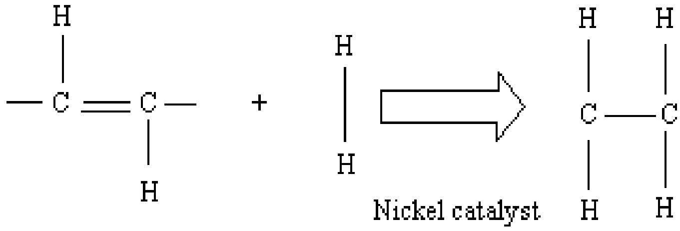
Question: What is the difference between saturated and unsaturated hydrocarbons?

Question: How can an unsaturated compound be turned into a saturated compound?

____

Margarine was invented in 1869 as a cheap replacement for butter. There was not enough real butter to go round. If a margarine pack says partially hydrogenated or partially polyunsaturated then some of the double bonds are still there.

One industrial use of vegetable oils is to make margarine. Unfortunately vegetable oils are unsaturated, making most of them too runny. The first stage is to 'harden' them – to turn them into saturated compounds. Hydrogen is bubbled through the oil at about 200C using a nickel catalyst. The hydrogen reacts with the double bond and turns them into single bonds:



If only some of the double bonds are allowed to react, the oil only partially solidifies. Partially solidified oils are used to make soft margarines that are easy to spread. If all of the double bonds react, the margarine is relatively hard.

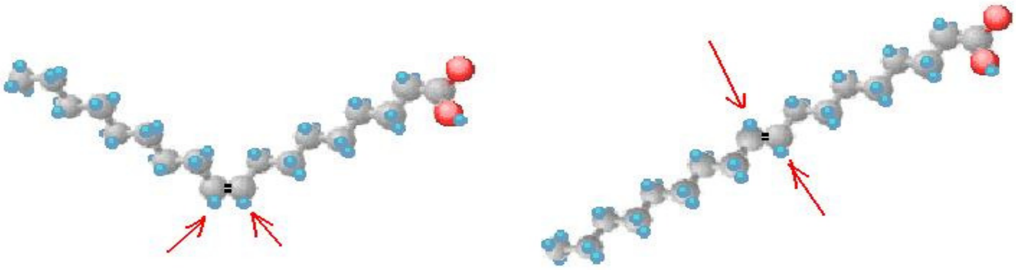
The first margarines were made by bubbling hydrogen through oil with a nickel catalyst. The hydrogen hardens the oil by adding to the double bonds and turning it to a saturated fat. This is called **hydrogenated vegetable oil**. It preserves longer than normal vegetable oil.

Question: We have learned that the fewer carbon – carbon double bonds there are in the fatty acids of a fat molecule, the straighter they are and the closer they can pack together. Does this mean that the hydrogenated vegetable oil will become more solid or more liquid? Explain.

____

____

Trans and cis fats



Cis-9-octadecenoic acid
(Oleic acid)

Trans-9-octadecenoic acid
(Elaidic acid)

Cis Configuration

Trans Configuration

Question: From the above diagram, what do you notice about the shape of a fatty acid molecule in a fat molecule, if both hydrogens of the double bond are on the same side? This occurs in the cis form. Will this lead to cis fats being more liquid or more solid?

____

____

Question: From the previous diagram, what do you notice about the shape of a fatty acid molecule in a fat molecule, if one of the hydrogen atoms of the double bond is on one side and the other hydrogen is on the other side? This occurs in the trans form. Will this lead to trans fats being more liquid or more solid?

____

____

Trans-fatty acids can form during the hydrogenation process used to make some 'hard' margarines.

It is thought that 'trans fats' may lead to heart disease! However, the research to prove this continues!

There is another method of hardening vegetable oils [turn them into margarine] without the hydrogenation process!

In this method a catalyst is used to simply swap fatty acid chains from one fat molecule to another so that they all stack together more neatly!

Question: When this happens, what will happen to the melting point of the hardened vegetable oil [now margarine]. Explain

____

____

Fats, oils and health

Saturated fats and oils usually come from animals and unsaturated fats and oils from plants. 'Polyunsaturated' means the compound contains more than one double bond. People whose diet is rich in unsaturated fats and oils have lower levels of the type of cholesterol that causes heart disease.

Some fatty acids are called 'essential fatty acids'. This means that human cells cannot make them. They must be found in our diet.

There are two types of essential fatty acid called linolenic and linoleic acid.

Linolenic fatty acid is of two forms [a] Omega-3 fatty acids found in oily fish and can reduce pain in joints [b] omega-6 fatty acids found in margarines

Getting help with mixing

Fats and oils mix with water much more easily if soap is added – and the soap is made from fats and oils!

Soap is made by reacting vegetable oils with sodium hydroxide.

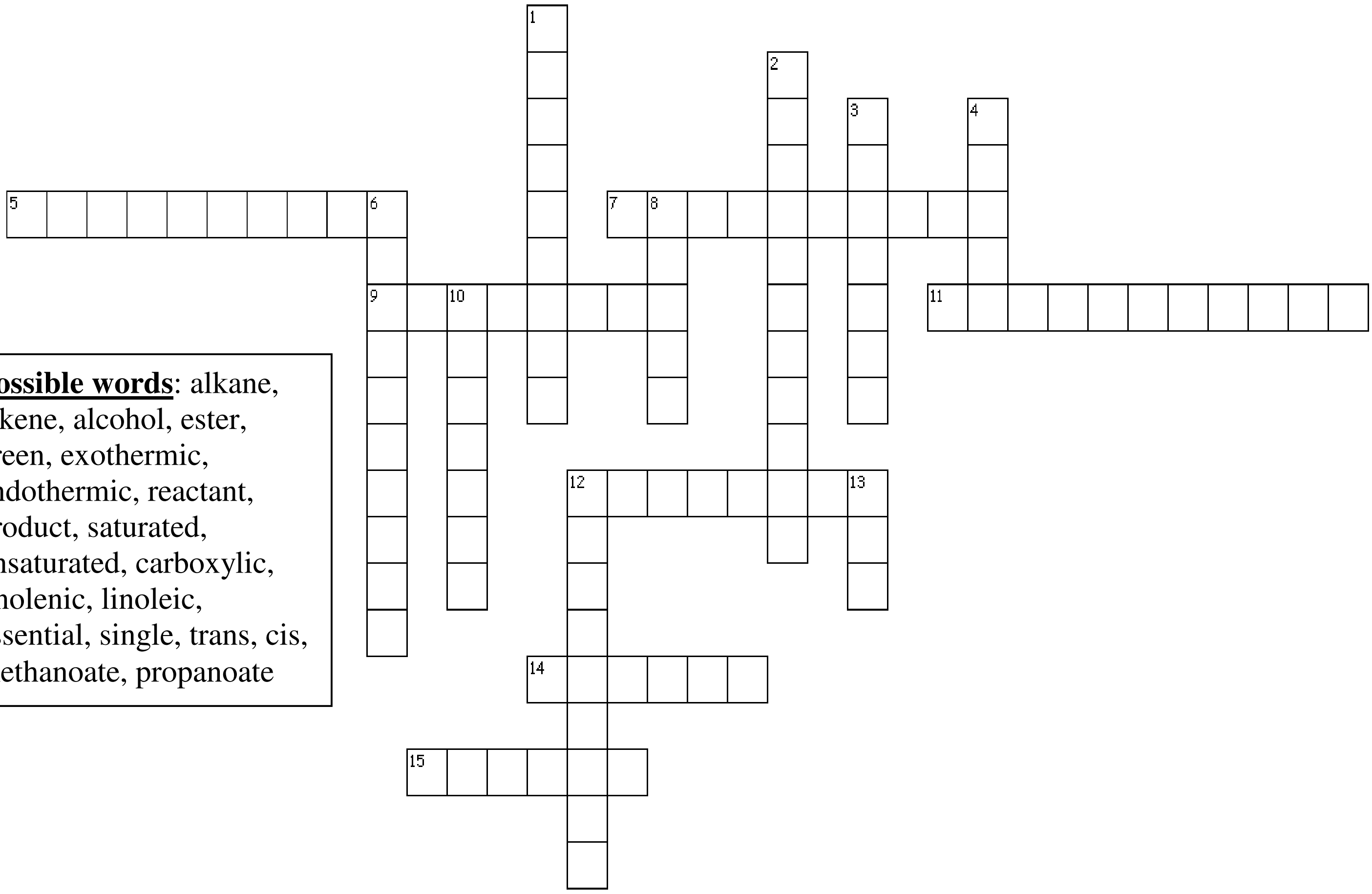
Question: Guess which well-known soap brand is made from a mixture of palm oil and olive oil? What would these vegetable oils need to be reacted with to make the soap?

____

Question: If you cut a pack of butter when it is cold there is little water on the butter where the knife went through. Where has the water come from? Would you consider butter to be an oil-in-water emulsion or a water-in-oil emulsion?

____

C7 [1] Crossword



Possible words: alkane, alkene, alcohol, ester, green, exothermic, endothermic, reactant, product, saturated, unsaturated, carboxylic, linolenic, linoleic, essential, single, trans, cis, methanoate, propanoate

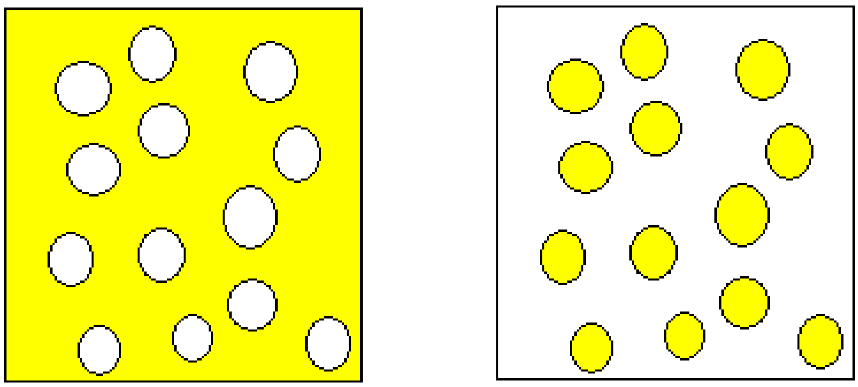
Across
5. The heat taken in to break the bonds in the reactant molecules is less than the heat given off making new bonds in the product molecules.
7. Methanoic acid heated with ethanol acid will produce the ester molecule called ethyl __________.
9. Molecule that starts off a chemical reaction.
11. The heat taken in to break the bonds in the reactant molecules is more than the heat given off making new bonds in the product molecules.
12. Another type of essential fatty acid.
14. Hydrocarbon with single carbon - carbon bonds
15. Hydrocarbon with all single carbon - carbon bonds except for one double bond.

Down
1. Alkanes are this where each carbon atom is not bonded to the maximum number of other atoms that it can using single bonds.
2. Alkenes are this where each carbon atom is bonded to the maximum number of other atoms that it can using single bonds.
3. Molecule that is produced in a chemical reaction.
4. Type of chemistry where the impact on the environment is minimal.
6. Type of acid produced when one of the hydrogen atoms of an alkene is replaced with this functional group containing one carbon atom, two oxygen atoms and one hydrogen atom.
8. Bond formed between an alcohol and a carboxylic acid molecule.
10. Alkane with one hydrogen atom replaced by a hydroxide [OH] group.
12. Essential fatty acid
13. Type of fatty acid whereby both hydrogen atoms of the carbon-carbon double bond are on the same side of the molecule.

Getting fats into water

Oil and water are **immiscible** liquids. They usually do not mix. They do not dissolve in each other, but it is possible to disperse tiny droplets of one liquid inside the other. This is called an **emulsion** (an example of a colloid where one state or phase is dispersed through out another).

Milk is a good example of an oil-in-water emulsion. Cold cream and margarine are water-in-oil emulsions.



Water-in-oil emulsion contains droplets of water spread through oil.

Oil-in-water emulsion contains droplets of oil spread through water.

Water and oil can make two types of emulsion

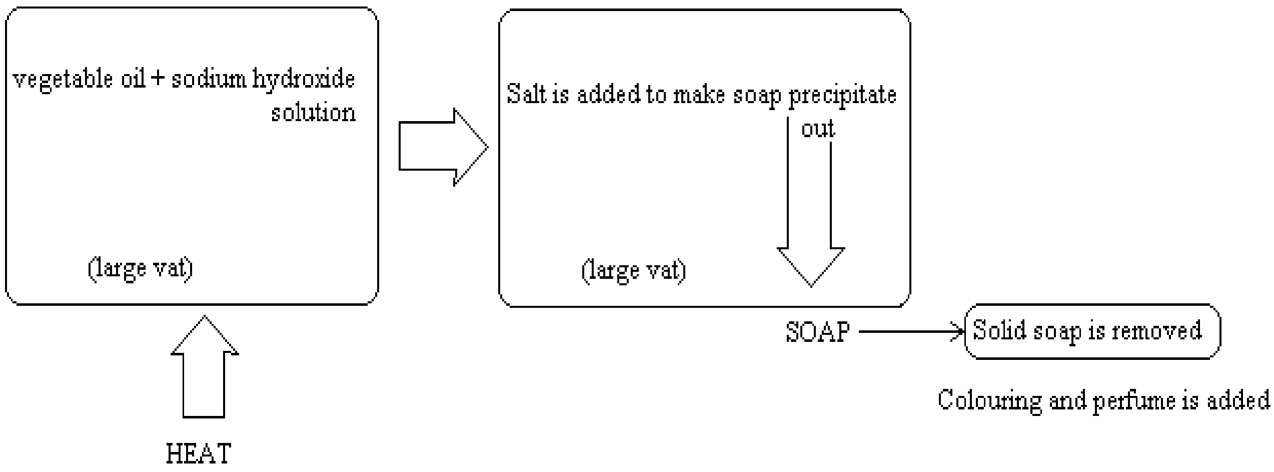
Making soap

Fats and oils are difficult to wash from clothes because they do not dissolve in water. However, fats and oils are the starting point for making soap. The fat molecule is an ester molecule combining a fatty acid [carboxylic acid] with a glycerol molecule [alcohol]. In water it would take an extremely long time to split this bond. However, in the presence of a strong catalyst such as sodium hydroxide [alkali], this occurs quickly

Fat + sodium hydroxide [acts as catalyst] = fatty acid [carboxylic acid] + glycerol [alcohol]

Salt contains sodium ions [Na^+] or potassium ions [k^+] which is then added to precipitate out the fatty acids to make soap [sodium or potassium salts of fatty acids.

The reaction between an oil and an alkali is sometimes called saponification. The latin word for soap is 'sapo'



How was soap discovered

One theory is that ancient tribes daubed themselves with ash from their cooking fires before battle. They realised that ash made them cleaner. Fat, which dripped from cooking meat, had reacted with alkalis in the ash to make soap.

During saponification, the ester bond between fatty acids and glycerol is broken.
The reaction is really the reaction of alkaline water (water molecules are required for the hydrolysis). This hydrolysis reaction is a saponification reaction.

Question: What would the soap be called if potassium hydroxide were used to hydrolyse glyceryl palmitate? ____

Reacting an alcohol with an organic acid makes esters. They are used in perfumes, and as solvents. Some perfume ingredients are natural, while others are synthetic - made artificially. Nail varnish, for example, dissolves in nail varnish remover, but not in water.

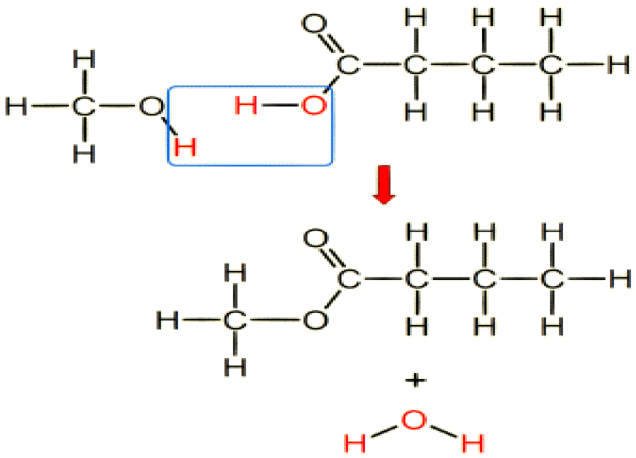
More on esters

Esters are chemicals with pleasant smells. They are used in perfumes, and as solvents. Esters occur naturally, but can be made in the laboratory by reacting an alcohol with an organic acid. A little sulphuric acid is needed as a catalyst. Here is the general word equation for the reaction:

alcohol + organic acid →= ester + water

For example : methanol + butanoic acid →= methyl butanoate + water

The diagram shows how this happens, and where the water comes from:



What they smell like

Different esters have different smells.

alcohol	organic acid	ester made	smell of ester
pentanol	ethanoic acid	pentyl ethanoate	pears
octanol	ethanoic acid	octyl ethanoate	bananas
pentanol	butanoic acid	pentyl butanoate	strawberries
methanol	butanoic acid	methyl butanoate	pineapples

Question: Complete the following reactions:

[a] pentanol + butanoic acid =

[b] octanol + methanoic acid =

[c] methanol + propanoic acid =

Question: Chemists sometimes describe fats and oils as 'triglycerides'. Why is it appropriate an appropriate name for these compounds?

____

____

Animal fats are generally solid at room temperature. Butter and lard are examples. Vegetable oils are usually liquid, as illustrated by corn oil, sunflower oil and olive oil.

Chemically the difference between fats and oils arises from the structure of the carboxylic acid which may / may not contain a carbon – carbon double bond.

Perfumes

Perfumes have a pleasant smell - they stimulate sense cells in the nose. Some perfumes are obtained from natural sources, such as lavender oil or sandalwood oil. Others are made synthetically, as shown on the previous page.

Commercial perfumes need particular properties to be successful.

Summary of the properties of perfume

property	why it is important
non-toxic	does not poison the wearer
does not irritate the skin	prevents the wearer from suffering rashes
evaporates easily - very volatile	perfume molecules reach the nose easily
insoluble in water	it is not washed off easily
does not react with water	avoids the perfume reacting with perspiration

Cosmetics testing

It has been illegal to test cosmetics on animals in the UK since 1998, and in the rest of the EU from 2009. However, cosmetic ingredients with medical uses must still be tested on animals.

Animal testing is carried out to ensure that ingredients are safe to use. But some people have ethical concerns about such tests.

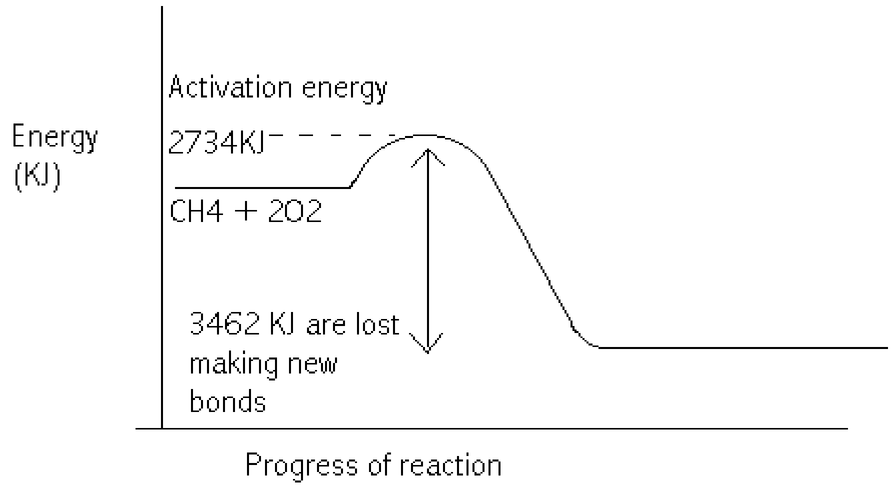
Energy level diagrams

When a reaction takes place, atoms are rearranged and bonds are broken and made. When this happens, energy is taken in and given out.

The fuel and oxygen have chemical energy in them.

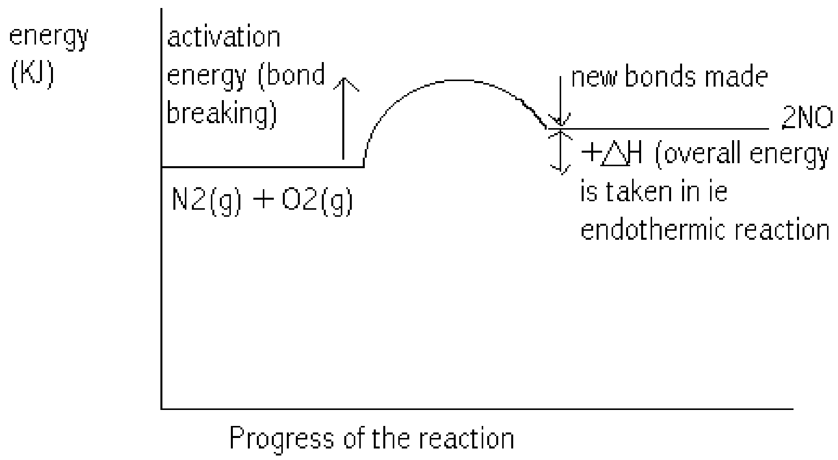
If the fuel is hydrogen, the reaction is: $2H_2 + O_2 \longrightarrow 2H_2O$

Energy has to be put into the hydrogen and oxygen molecules to break the bonds between the atoms. Energy is then lost as heat as new bonds are formed between the atoms in the water molecules.



This is shown in an energy diagram as above.

An **exothermic** reaction gives out more energy when making new bonds than energy absorbed breaking bonds in reactant molecules. Activation energy refers to the total amount of energy needed to break bonds in reactant molecules.

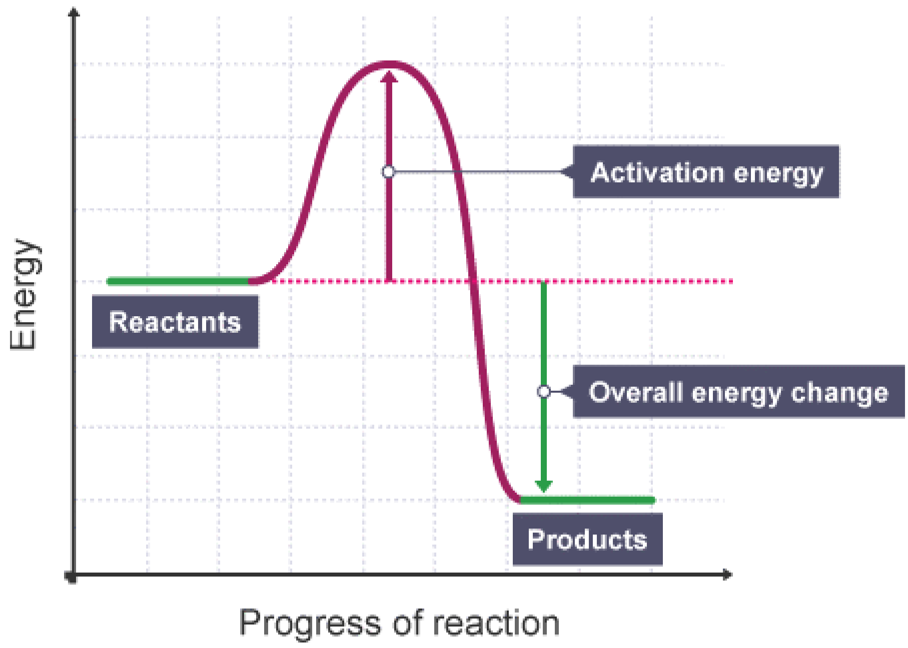


An **endothermic** reaction gives out less energy when making new bonds than energy absorbed breaking bonds in reactant molecules.

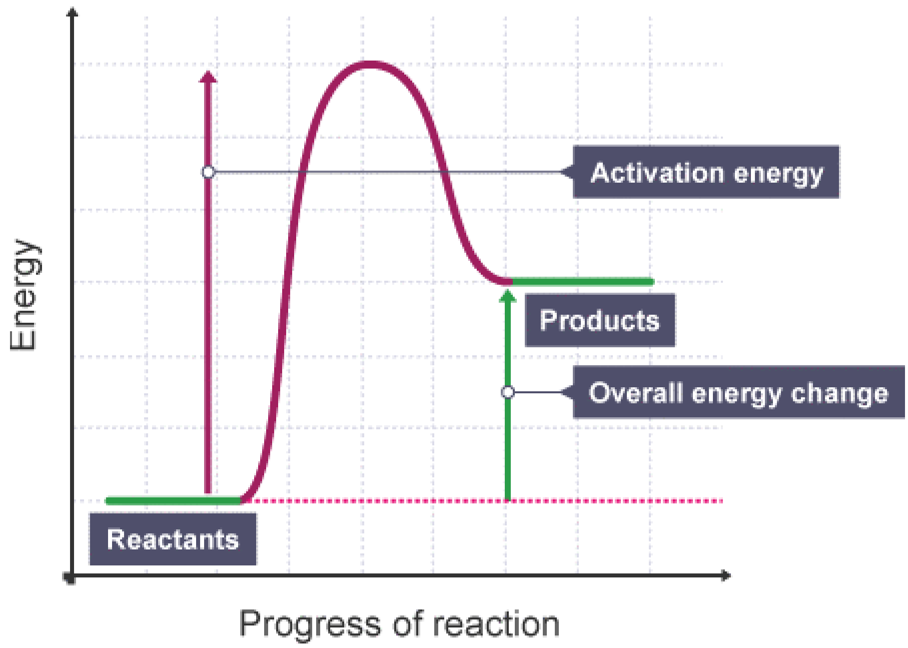
To start a reaction, the chemicals must absorb energy in order to break some of the chemical bonds in the *reactants*.

The amount of energy needed to start a reaction in this way is called the **activation energy**. This explains why many reactions (even exothermic ones), need a spark or some heat to start them off.

Breaking the chemical bonds in the reactants always requires energy – it is an **endothermic** process.



And here is an energy level diagram for an *endothermic* reaction:



Important: When reactant molecules collide into each energy, some of their kinetic energy is used up breaking the bonds between the atoms in the molecules.

The activation energy is a measure of the amount of energy required to break the bonds in a mole of reactant molecules to turn them into separate atoms.

Energy is therefore absorbed and used up in bond breaking for this to occur and the overall kinetic energy levels of the reactant molecules must be raised to the activation energy for this to occur.

Question: Some reactions start with a simple lighted match. Some need the continuous input of energy with a Bunsen flame. Explain this difference.

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Question: When new bonds are made between atoms to form the new reactant molecules, energy is given off.

[a] If more energy is absorbed by reactant molecules, then is released during bond making in product molecule formation, what type of reaction is this?

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[b] If less energy is absorbed by reactant molecules, then is released during bond making in product molecule formation, what type of reaction is this? ___________________________________

Question: Draw a labelled energy diagram in the space below for the combustion of hydrogen.

Question: Explain the energy changes that occur in (a) an exothermic reaction (b) endothermic reaction.

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Bond energy calculations – Higher tier

It is possible to calculate the energy change of a reaction using **bond energy values**.

This is how to calculate the energy change when steam is made from hydrogen and oxygen:

$2H_2(g) + O_2(g) = 2H_2O(g)$

The bond energy values will be given in the exam. The units of bond strength are **kJ**, (which stands for kilojoules). These bond strengths allow us to calculate energy changes:

H-H is 436 kJ / mol

O=O is 498 kJ / mol

H-O is 464 kJ / mol

Here are the steps needed to calculate the energy change:

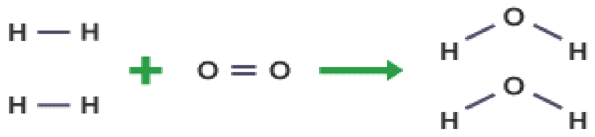
[1] Draw out the bonds in each of the *reactants* and *products*.

[2] Calculate the energy absorbed when all of the reactant bonds are broken.

[3] Calculate the energy released when all of the new bonds in the products are made.

[4] Subtract the total for the new bonds from the total for the old bonds. A negative final answer means that the reaction is exothermic.

Worked example (using example bond strengths given above)



Energy bond

2 x (H-H)

= 2 x 436

1 x (O=O)

= 1x 498

Total energy in = 872 + 498

= 1370 kJ

4 x (O-H)

= 4 x 464

Total energy out

= 1856 kJ

Energy change = 1370 – 1856

= **-486 kJ** (negative value - so it is exothermic)

Question:

Bond	Bond Energy (in kJ per mole)
H—H	436
Cl—Cl	242
H—Cl	431

Balance this equation: **H_2 [g] + Cl_2 [g] = HCl [g]**

Use bond energy calculations to work out whether this is an exothermic or endothermic reaction

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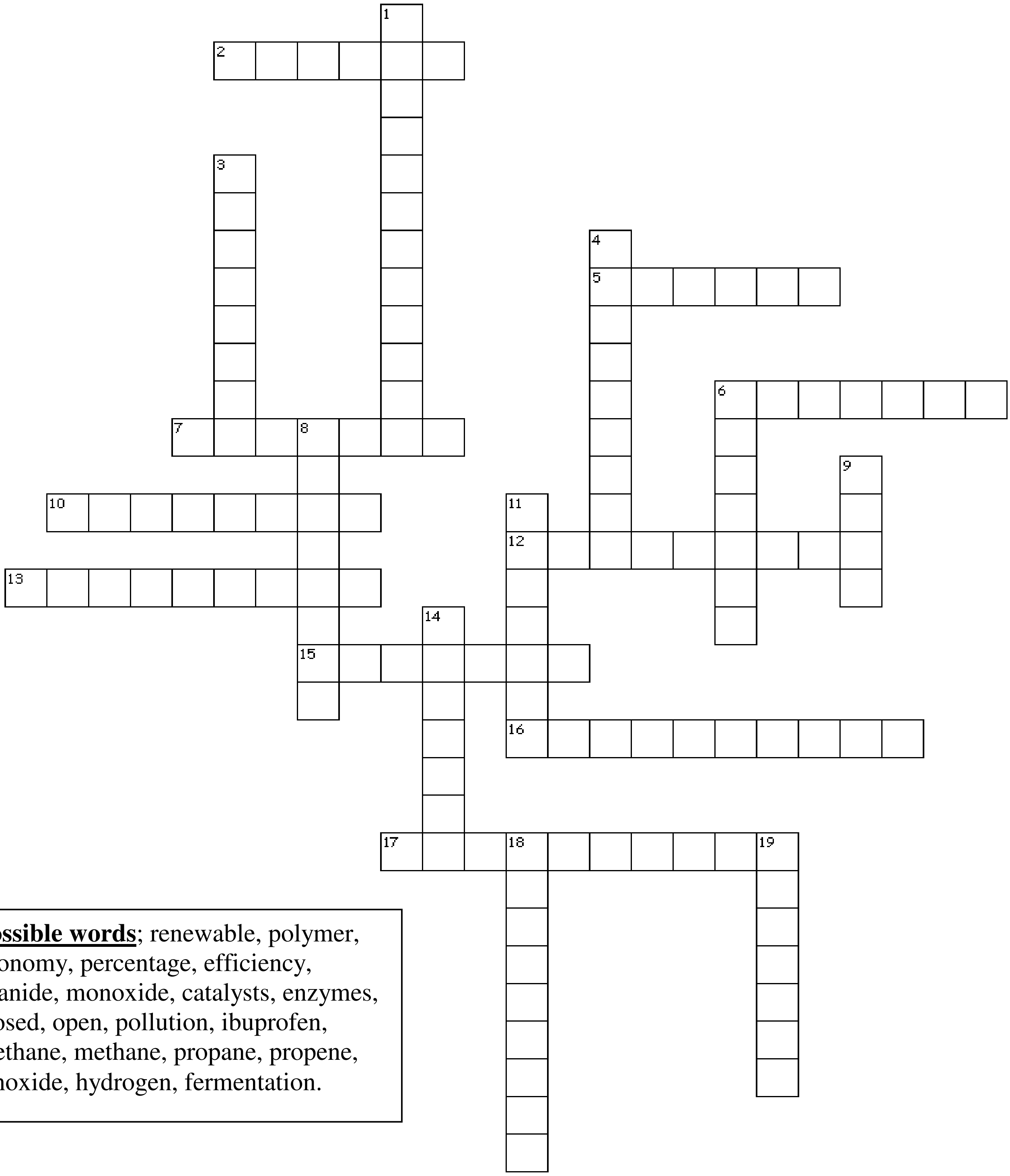
C7 [2] Crossword



Possible words; renewable, polymer, economy, percentage, efficiency, cyanide, monoxide, catalysts, enzymes, closed, open, pollution, ibuprofen, methane, methane, propane, propene, ethoxide, hydrogen, fermentation.

Across

2. Recycling is at its best when the waste material that is collected can be used to manufacture the same product with no loss in quality.
5. Hydrocarbon with four carbon atoms and all the carbon atoms have single bonds.
6. Joining monomer molecules together such as ethene
7. Alkane with one carbon atom.
10. Carbon _________ is used with methanol to make polycarbonate plastics. It is safer than using phosgene, which has previously been used as a poison gas in warfare.
12. Product molecules that can be used more than once.
13. Unwanted waste from a chemical process which gets into the environment.

15. If the temperature gets too high, sugar will not be fermented into alcohol by yeasts because these will be denatured.
16. Super-heated steam used raising the temperature of reactants can also be used for heating a chemical plant. It can escape from leaking valves on steam pipes and so reduce the energy ________ of the manufacturing processes.
17. Actual yield divided by theoretical yield times one hundred percent gives this yield.

Down

1. The process that occurs with yeast cells when changing sugar to ethanol.
3. Hydrolyse [split using water] ethanol and treat with sodium ions and we get sodium ________
4. Made by Boots and the Celanese cooperation.
6. Alkane with three carbon atoms.
8. Carboxylic acid molecules lose these _________ before combining with sodium ions to make soap.
9. In this type of recycling, waste from one product is recovered and used in the manufacture of another, lower quality product.
11. Hydrocarbon with three carbon atoms and one carbon - carbon double bond.
14. Originally Hydrogen ________ was used to make weed killer but now a new method has been developed with a different starting material, which runs under milder conditions because of a copper catalyst.
18. These lower the activation energy of a chemical reaction.
19. Mass of atoms in product divided by mass of atoms in reactants times one hundred percent.

AFL Question: Reacting an alcohol with a carboxylic acid can make an ester. The technique used involves four stages: **reflux**, **distillation**, **purification** and **drying**.

In the **reflux** stage, the alcohol and ester are heated with a little concentrated sulfuric acid in a flask with a condenser attached in an upright position. Evaporated liquid is allowed to run back into the flask.

In the **distillation** stage, the mixture is placed in a flask connected to a sloping condenser and heated. The product is collected at its boiling point.

Describe the stages of **purification** and **drying**.

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[Total: 5]