C1: Carbon Chemistry

1. Making crude oil useful

Crude oil is a mixture of hydrocarbons. These are separated into useful products, such as fuels, using a process called fractional distillation.

The demand for short hydrocarbon molecules is greater than their supply in crude oil, so a reaction called cracking is used. Cracking converts long alkane molecules into shorter alkanes and alkenes, which are more useful. The exploitation of oil can damage the environment - for example, through oil spills.

Fossil fuels

Crude oil, coal and gas are **fossil fuels**. They were formed over millions of years, from the remains of dead organisms,

- coal was formed from dead plant material
- crude oil and gas were formed from dead marine organisms.

Fossil fuels are non-renewable. They took a very long time to form and we are using them up faster than they can be renewed. Fossil fuels are also finite resources. They are no longer being made or are being made extremely slowly. Once they have all been used up, they cannot be replaced.

How crude oil was formed (background information only)

Crude oil is found trapped in some of the *sedimentary* rocks of the Earth's crust.

Millions of years ago, huge numbers of microscopic animals and plants - plankton - died and fell to the bottom of the sea. Their remains were covered by mud.

As the mud sediment was buried by more sediment, it started to change into rock as the temperature and pressure increased. The plant and animal remains were 'cooked' by this process, and slowly changed into crude oil.

Oil is less dense than the water in the rocks and will rise as a result of pressure from below (as can be seen in the animation above). often the oil will escape altogether if the rocks are permeable (liquids can pass through them).

If some of the rocks above the oil are impermeable the oil cannot rise through them, so it gets trapped underneath.

Problems of exploiting oil

Geologists can often tell where oil is trapped by looking at the structure of the rocks. Oil tends to be trapped where rocks are domed upwards, or where permeable rocks are in contact with impermeable rocks at a fault line.

Drilling for oil

Oil companies can drill down through the impermeable rocks to get it out. They are then able to turn the oil into products that we can use.

Crude oil takes millions of years to form, and we are using it up more quickly than it is created. Present estimates suggest world supplies of crude oil will run out in about 30 years, unless we use it more efficiently. There are additional reserves of oil in rocks called oil shale. However, it is expensive to extract oil from oil shale because it needs to be heated to release it.

Environmental problems

Oil is carried from oil fields to refineries using ocean-going tankers. If it is spilled, it causes considerable damage to the environment:

- oil slicks travel across the sea, far from the original spill
- beaches and wildlife are harmed when they are coated with oil.

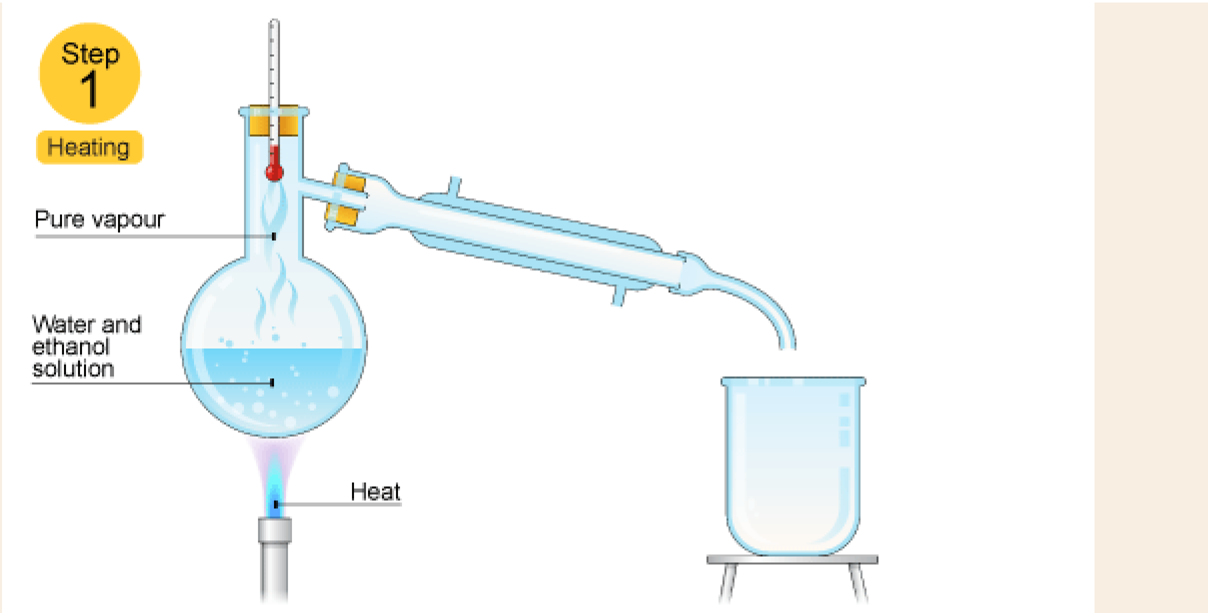
The oil damages feathers and birds may die. Detergents are often used to help clean up oil slicks, but these in turn may harm wildlife.

Oil spills cause a lot of harm to the environment, both at sea and on land

Distillation

Distillation is a process that can be used to separate a pure liquid from a mixture of liquids. It works when the liquids have different boiling points. Distillation is commonly used to **separate ethanol** (the alcohol in alcoholic drinks) **from water**.

Distillation process to separate ethanol from water



Step 1 - water and ethanol solution are heated

The mixture is heated in a flask. Ethanol has a lower boiling point than water so it evaporates first. The ethanol vapour is then cooled and condensed inside the condenser to form a pure liquid.

The thermometer shows the boiling point of the pure ethanol liquid. When all the ethanol has evaporated from the solution, the temperature rises and the water evaporates.

This is the sequence of events in distillation:

heating → evaporating → cooling → condensing

Fractional distillation

Hydrocarbons have different boiling points. They can be solid, liquid or gas at room temperature,

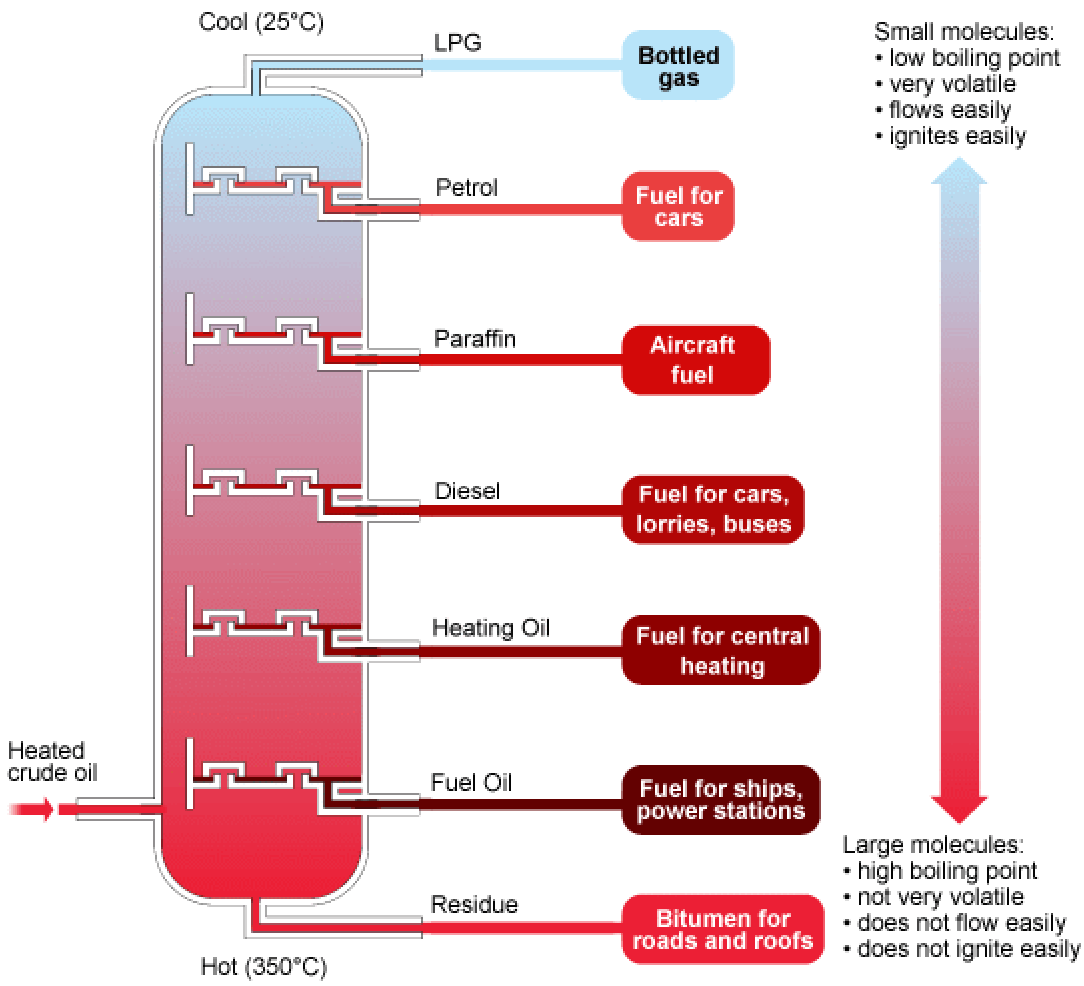
- small hydrocarbons with only a few carbon atoms have low boiling points and are gases
- hydrocarbons with between five and 12 carbon atoms are usually liquids
- large hydrocarbons with many carbon atoms have high boiling points and are solids.

Because they have different boiling points, the substances in crude oil can be separated using fractional distillation.

The fractionating column

Fractional distillation is different from distillation in that it separates a mixture into a number of different parts, called fractions. A tall column is fitted above the mixture, with several condensers coming off at different heights. The column is hot at the bottom and cool at the top. Substances with high boiling points condense at the bottom and substances with lower boiling points condense on the way to the top.

The crude oil is evaporated and its vapours condense at different temperatures in the fractionating column. Each fraction contains hydrocarbon molecules with a similar number of carbon atoms.



Oil fractions and their uses

Cracking

Fuels made from oil mixtures containing large *hydrocarbon* molecules are not efficient. They do not flow easily and are difficult to ignite. Crude oil often contains too many large hydrocarbon molecules, and not enough small hydrocarbon molecules, to meet demand. This is where **cracking** comes in.

Cracking allows large hydrocarbon molecules to be broken down into smaller alkane and alkene molecules,

- smaller hydrocarbons are more useful as fuels, such as petrols
- alkenes are useful, because they are used to make polymers.

Fractions containing large hydrocarbon molecules are vaporised and passed over a hot catalyst. This breaks chemical bonds in the molecules and forms smaller hydrocarbon molecules.Cracking is an example of a thermal decomposition reaction.

2. Using carbon fuels

Fuels react with oxygen to release energy. Complete combustion happens in a plentiful supply of air and incomplete combustion occurs when the supply of air is limited.

Complete combustion releases more energy than incomplete combustion. Incomplete combustion also creates carbon monoxide, and more soot. Several factors must be considered when choosing the best fuel for a particular purpose.

2. Factors influencing the use of a fuel

The fossil fuels include coal, oil and natural gas. Various factors need to be considered when deciding how to use a fossil fuel. These include:

- the energy value of the fuel in kJ/g of fuel
- the availability of the fuel
- how the fuel can be stored
- the cost of the fuel
- the toxicity of the fuel - whether it is poisonous
- any pollution caused when the fuel is used, such as acid rain
- how easy it is to use the fuel.

You are expected to be able to list factors such as the ones above.

Factories can cause air pollution

In general, solids such as coal are easier to store than liquids and gases but they are often more difficult to light. Liquids and gases ignite more easily. They also flow, which means they can be transported through pipelines.

Carbon dioxide is a greenhouse gas that contributes to global warming. The table shows some approximate energy values of the different fossil fuels, and the typical mass of carbon dioxide they produce when they burn.

Energy values of fuel

fuel	energy content (kJ/g)	mg of carbon dioxide produced for each kJ
natural gas	52	53
petrol	43	71
coal	24	93

Coal releases the least amount of energy per gram of fuel. It also produces the most carbon dioxide for a given amount of energy released when it burns.

You should be able to interpret data to choose the best fuel for a particular purpose.

Combustion

Fuels are substances that react with oxygen to release useful energy. Most of the energy is released as heat, but light energy is also released.

About 21 per cent of the air is oxygen. When a fuel burns in plenty of air, it receives enough oxygen for **complete combustion**.

Complete combustion

Complete combustion needs a plentiful supply of air so that the elements in the fuel react fully with oxygen.

Fuels such as natural gas and petrol contain **hydrocarbons**. These are compounds of hydrogen and carbon only. When they burn completely:

- the carbon oxidises to carbon dioxide
- the hydrogen oxidises to water (remember that water, H_2O, is an oxide of hydrogen).

In general, for complete combustion:

hydrocarbon + oxygen → carbon dioxide + water

Here are the equations for the complete combustion of propane, used in bottled gas:

propane + oxygen → carbon dioxide + water

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Incomplete combustion

Incomplete combustion occurs when the supply of air or oxygen is poor. Water is still produced, but carbon monoxide and carbon are produced instead of carbon dioxide.

In general for incomplete combustion:

hydrocarbon + oxygen → carbon monoxide + carbon + water

The carbon is released as soot. Carbon monoxide is a poisonous gas, which is one reason why complete combustion is preferred to incomplete combustion. Gas fires and boilers must be serviced regularly to ensure they do not produce carbon monoxide.

Here are the equations for the incomplete combustion of propane, where carbon is produced rather than carbon monoxide:

propane + oxygen → carbon + water

$C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$

The Bunsen burner

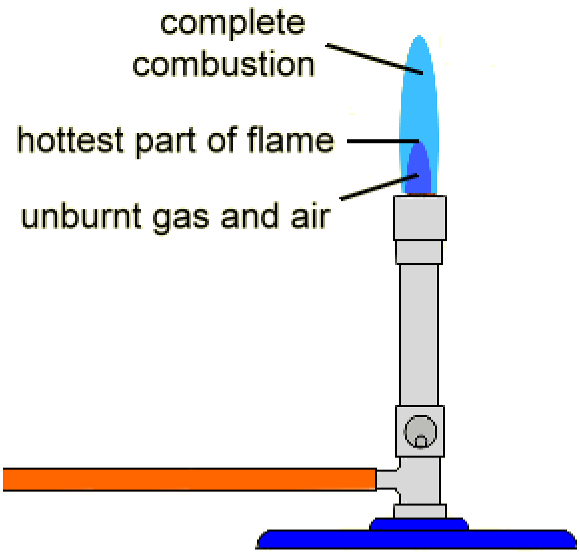
The Bunsen burner is commonly used in school laboratories to heat chemicals. Its fuel is natural gas, which is almost pure methane, CH_4. Methane is a hydrocarbon. So the Bunsen burner has an air hole that allows complete or incomplete combustion.

Air hole open

When the air hole is open, air is drawn into the chimney, where it mixes with the natural gas. This ensures complete combustion:

methane + oxygen → carbon dioxide + water

A very hot, blue flame is produced.

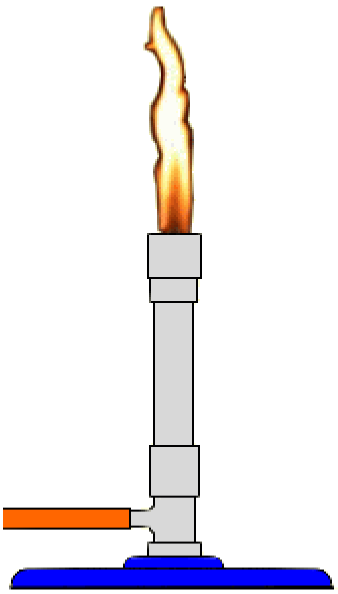


The hottest part of the flame is at the tip of the dark blue cone

Air hole closed

When the air hole is closed the natural gas can only mix with air at the mouth of the chimney. Incomplete combustion occurs as a result:

methane + oxygen → carbon monoxide + carbon + water



The yellow flame is often called the safety flame

Combustion - Higher tier

You should be able to write balanced symbol equations for the complete combustion - or incomplete combustion - of a simple hydrocarbon fuel, if you are given its molecular formula.

The formula of oxygen gas is O_2.

The table summarises the formulas of the possible combustion products from hydrocarbon fuels.

Formulas of the possible combustion products from hydrocarbon fuels

name	formula	formed in complete combustion	formed in incomplete combustion
carbon dioxide	CO_2	yes	
carbon monoxide	CO		yes
soot	C		yes
water	H_2O	yes	yes

Here are some examples of how to balance symbol equations for combustion. Remember that you should have the same number of atoms of each element on each side of the arrow.

Example 1

Complete combustion of methane, CH_4

Write formulae for each substance

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

Balance the number of H atoms

$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$

Balance the number of O atoms

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Example 2

Incomplete combustion of ethane, C_2H_6

Write formulae for each substance

$C_2H_6 + O_2 \rightarrow CO + C + H_2O$

Balance the number of H atoms

$C_2H_6 + O_2 \rightarrow CO + C + 3H_2O$

Balance the number of O atoms

$C_2H_6 + 2O_2 \rightarrow CO + C + 3H_2O$

3. Clean air

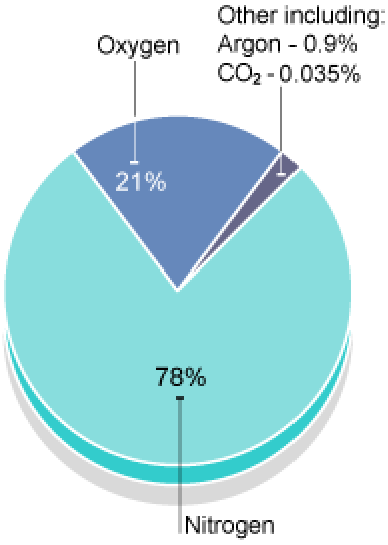
The atmosphere consists mainly of nitrogen and oxygen, with smaller proportions of other gases such as carbon dioxide. The amount of carbon dioxide in the atmosphere is maintained through a balance between processes such as photosynthesis, respiration and combustion. But human activities are polluting the atmosphere.

Photosynthesis by plants is thought to be a key process in the evolution of the Earth's atmosphere.

Composition of the atmosphere

You need to know the proportions of the main gases in the atmosphere.

The Earth's atmosphere has remained much the same for the past 200 million years. The pie chart shows the proportions of the main gases in the atmosphere.



The composition of air

It is clear that the main gas is nitrogen at 78 per cent. Oxygen is the next most abundant gas at 21 per cent. This is the gas that allows animals and plants to *respire*, and fuels to burn. These two gases are both elements and account for about 99 per cent of the gases in the atmosphere.

The remaining gases are found in much smaller proportions. These include carbon dioxide (0.035 per cent), water vapour and noble gases such as argon.

Evolution of the atmosphere

Scientists believe the Earth was formed about 4.5 billion years ago, and that its early atmosphere was probably created from the gases escaping from the Earth's interior. It is thought that this early atmosphere consisted of mostly carbon dioxide and water vapour, with a smaller proportion of ammonia, NH_3.

Photosynthesis

Photosynthesis is the process that plants use to produce their food. For photosynthesis, plants absorb carbon dioxide from the atmosphere and release oxygen as a by-product. Photosynthesis increased the proportion of oxygen in the atmosphere until it reached today's level, 21 per cent.

The carbon cycle

The level of carbon dioxide in the atmosphere is maintained by several processes, including photosynthesis, respiration and combustion.

Plants remove carbon dioxide from the atmosphere by photosynthesis. Living organisms, including all plants and animals, release energy from their food using respiration. Respiration and combustion both release carbon dioxide into the atmosphere.

These processes form a carbon cycle in which the proportion of carbon dioxide in the atmosphere remains about the same.

Atmospheric pollutants

The use of fossil fuels, for example in vehicle engines and power stations, causes air pollution. The table shows some of the common air pollutants and how they are formed.

Some of the common air pollutants and how they are formed

pollutant	how it is formed
carbon monoxide	incomplete combustion of the fuel in car engines
oxides of nitrogen, NOx	formed from the heat and pressures found in a car engine
sulfur dioxide	sulfur impurities in the fuel burn

Carbon monoxide is a poisonous gas. Oxides of nitrogen (NOx) react with other pollutants in sunlight to form a photochemical **smog**, which causes breathing difficulties. NOx and sulphur dioxide also form **acid rain**. This has several effects on the environment, including:

- killing plants and aquatic life
- eroding stonework
- corroding metals

Catalytic converters

Car exhaust systems have catalytic converters. These convert carbon monoxide into carbon dioxide:

carbon monoxide + nitrogen oxide → nitrogen + carbon dioxide

$2CO + 2NO \rightarrow N_2 + 2CO_2$

Note that nitrogen oxide is also converted into harmless nitrogen in the process.

One possible theory- Higher tier

How did the Earth's early atmosphere become the way it is today? One assumption that scientists make when developing their theories is that the early atmosphere was similar to the composition of gases released by volcanic activity today. Their theories then have to explain why the proportions of water vapour and carbon dioxide in the atmosphere went down, and the proportions of oxygen and nitrogen went up.

Earth

Water vapour went down because:

- as the Earth cooled down, most of the water vapour condensed and formed the oceans.

Carbon dioxide went down because:

- it was absorbed by plants during photosynthesis
- it was locked up in fossil fuels
- it dissolved in the oceans.

Nitrogen went up because:

- it is not very reactive and, once formed, it is not easily removed from the atmosphere again.

Oxygen went up because:

- it was released by plants during photosynthesis

4. Making polymers

Hydrocarbons are compounds made from carbon and hydrogen atoms joined by covalent bonds. Alkanes are saturated - they have only single bonds. Alkenes have a double bond - they are unsaturated. Alkenes react with brown bromine water and decolourise it, but alkanes do not.

Alkenes can act as monomers. Under high pressure and in the presence of a catalyst many monomer molecules join together to make polymer molecules. These polymer molecules are saturated.

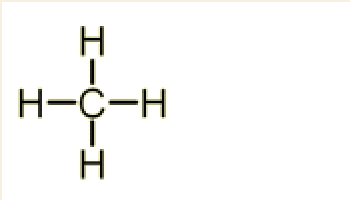
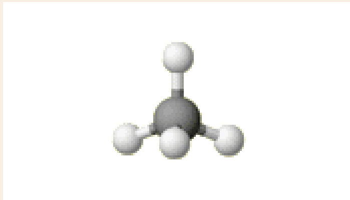
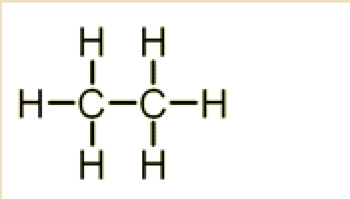
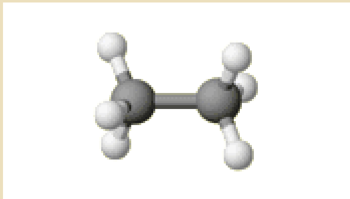
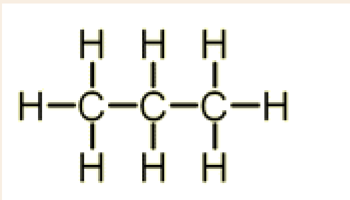
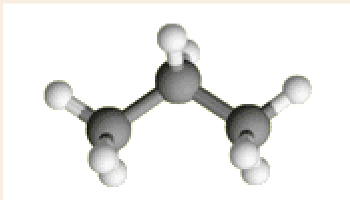
Alkanes

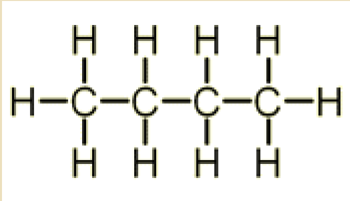
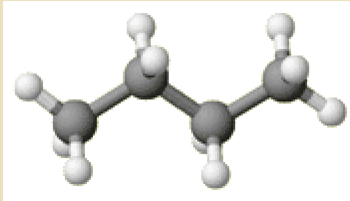
Most of the compounds in crude oil are hydrocarbons. This means they only contain hydrogen and carbon atoms, joined together by covalent bonds. Remember that a covalent bond is a shared pair of electrons. Alkanes are a type of hydrocarbon.

The number of hydrogen atoms in an alkane is double the number of carbon atoms, plus two. For example, the molecular formula of methane is CH4. For ethane, it is C_2H_6.

Alkane molecules can be represented by displayed formulas in which each atom is shown as its symbol (C or H), and the covalent bonds between them by a straight line. The table shows four alkanes.

Structure of alkanes

alkane	molecular formula	structural formula	molecular model
methane	CH_4		
ethane	C_2H_6		
propane	C_3H_8		

alkane	molecular formula	structural formula	molecular model
butane	C_4H_{10}		

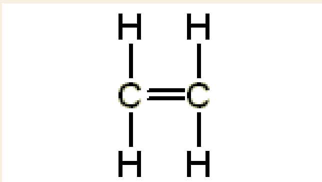
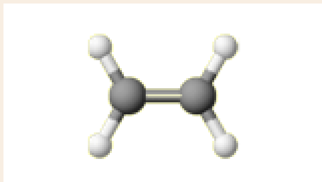
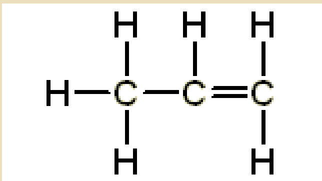
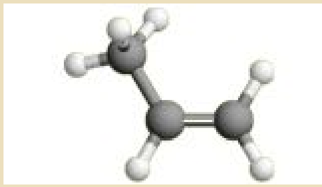
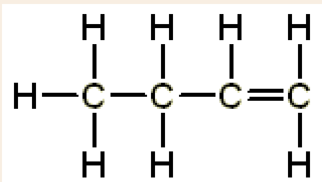
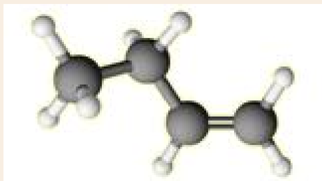
Notice that the molecular models on the right show that the bonds are not really at 90º.

Alkanes are saturated hydrocarbons. This means their carbon atoms are joined to each other by single covalent bonds.

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 C_2H_4, while for propene it is C_3H_6. The table shows three alkenes.

Structure of alkenes

alkene	molecular formula	structural formula	molecular model
ethene	C_2H_4		
propene	C_3H_6		
butene	C_4H_8		

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.

Testing for alkenes

Bromine water is an orange solution of bromine. It becomes colourless when shaken with an alkene. Alkenes can decolourise bromine water, while alkanes cannot.

Higher tier

The reaction between bromine and alkenes is an example of a type of reaction called an addition reaction. The bromine is decolourised because a colourless dibromo compound forms. For example:

ethene + bromine → dibromoethane

$C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$

Monomers and polymers

Polymers plastics - are very large molecules made from many smaller molecules called *monomers* Alkenes are able to act as monomers because they contain a double bond. They can join end-to-end in a reaction called addition polymerisation. The polymers they form are called addition polymers. In general:

A lot of monomers → a polymer molecule

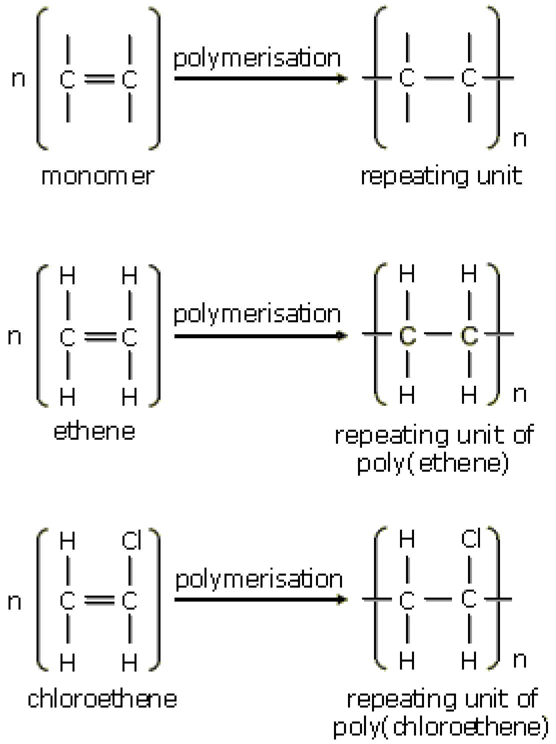
For example:

- ethene → polyethene
- propene → polypropene
- chloroethene → polychloroethene (also called polyvinylchloride

Displayed formulas of polymers

Polymer molecules are very large compared with most other molecules, so the idea of a repeating unit is used when drawing a displayed formula. When drawing one, starting with the monomer:

- change the double bond in the monomer to a single bond in the repeating unit
- add a bond to each end of the repeating unit.



Addition polymerisation

5. Designer polymers

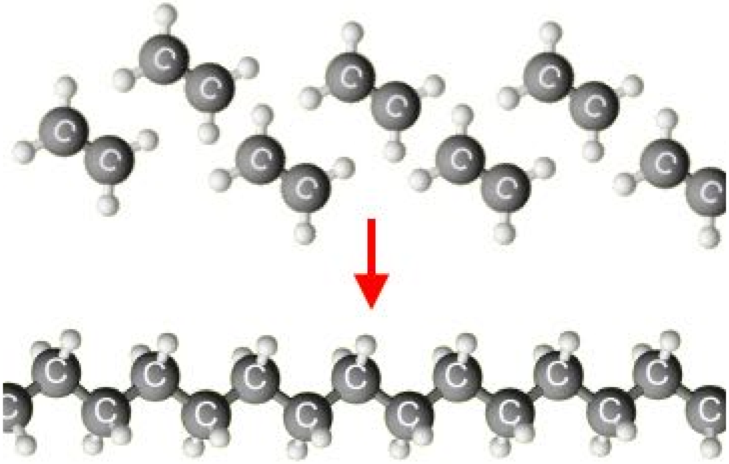
A lot of everyday items are made from polymers. Many of these polymers are not biodegradable - microbes cannot digest them and they take a long time to break down. Polymers are usually disposed of by burying them in landfill sites or burning them in incinerators. These methods of disposal cause environmental problems, and waste valuable resources.

The properties of polymers depend on the structure and bonding found in their molecules. Smart materials such as Gore-Tex® have more useful properties than other polymers.

Polymer properties and uses

Monomers can join together to form *polymers*. Additional polymers are formed from alkenes. For example:

- ethene can polymerise to form polyethene, which is also called polythene
- styrene can polymerise to form polystyrene.



Ethene makes polyethene

Typical uses for polythene include plastic shopping bags and plastic bottles, while polystyrene is typically used for insulation and protective packaging.

Branches

Polymer molecules can have branches coming off them, which change the properties of the polymer. You should be able to suggest the properties a polymer has for a particular purpose. The table compares two types of polythene.

Two types of polythene

	LDPE low-density polyethene	HDPE high-density polyethene
branches on polymer molecules	many	few
relative strength	weak	strong

	LDPE low-density polyethene	HDPE high-density polyethene
maximum useable temperature	85 ºC	120 ºC

HDPE is more suited for use in making disposable cups for hot drinks, for example.

Other polymers

Some polymers are not made from alkene monomers and these are called condensation polymers. Nylon and polyesters are examples of this. They can be drawn into very fine fibres and woven into cloth for clothing. Often, natural fibres such as cotton are mixed with nylon or polyester fibres to make a soft but hard-wearing cloth.

Waterproof clothing

Nylon has some desirable properties. It does not let ultraviolet light pass through it, and it is:

- tough
- lightweight
- waterproof.

Unfortunately, nylon does not let water vapour pass through it either. This means nylon waterproof clothing traps sweat, so that after a while the inside of the clothing becomes wet and unpleasant to wear.

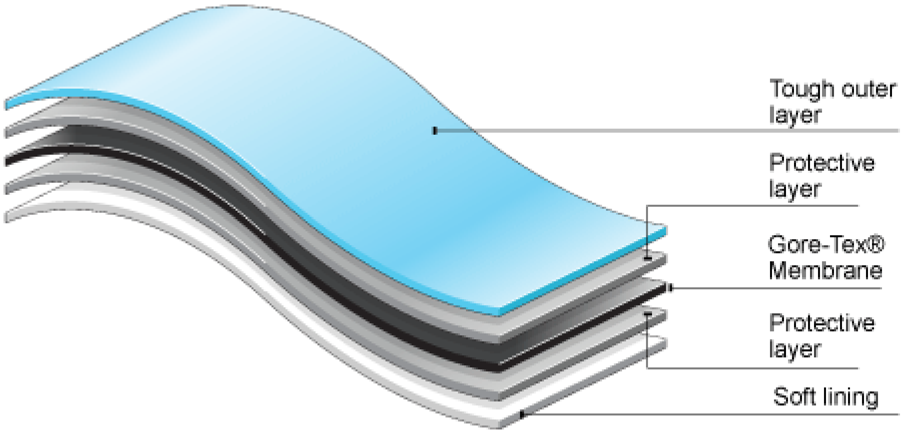
Gore-Tex®

Gore-Tex has the desirable properties of nylon, but is also 'breathable'. It lets water vapour from sweat pass to the outside, but it stops rain drops from passing to the inside. Clothing made of Gore-Tex is very useful to hikers and other people who work or play outside.

The construction of Gore-Tex- Higher tier

Teflon® is the trade name for a polymer called polytetrafluoroethene, or PTFE. It is very slippery, so is used to make non-stick coatings for pans. It is also used in Gore-Tex.

Gore-Tex contains layers of nylon, PTFE and polyurethane. The PTFE contains a lot of tiny holes called pores - there are around 14 million per square millimetre. Each one is too small for water droplets to pass through, but big enough to let water molecules from sweat out. Without the nylon, the layers would be too fragile to be useful.



Gore-Tex® fabric is a sandwich of materials

Disposing of polymers

One of the useful properties of polymers is that they are unreactive, so they are suitable for storing food and chemicals safely. Unfortunately, this property makes it difficult to dispose of polymers. They are often buried in landfill sites or incinerated - burned.

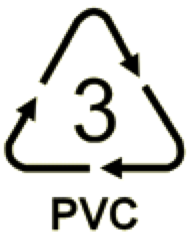
Landfill

Waste polymers are disposed of in landfill sites. This uses up valuable land, and suitable sites often fill up quickly.

Incineration

Polymers release a lot of heat energy when they burn. This energy can be used to heat homes or generate electricity. But there are problems with incineration. Carbon dioxide is produced, which adds to global warming. Toxic gases are also produced, unless the polymers are incinerated at high temperatures.

Recycling



Polymers have recycling symbols like this one for PVC to show what they are

Many polymers can be recycled. This reduces disposal problems and the amount of crude oil used. But first the different polymers must be separated from each other. This can be difficult and expensive.

New types of polymers

Chemists are developing new types of polymers. Most polymers, including polyethene and polypropene, are not biodegradable. This means microorganisms cannot break them down, so they may last for many years in rubbish dumps. However, it is possible to include chemicals that cause the polymer to break down more quickly. Carrier bags and refuse bags made from degradable polymers are already available.

Some polymers are water-soluble, which means they dissolve in water. These polymers are often used to wrap products such as dishwasher tablets and pouches containing detergent for washing machines.

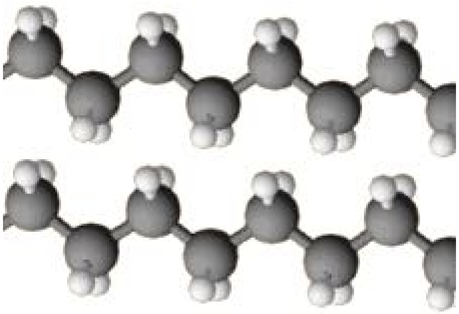
Polymers properties- Higher tier

Strong covalent bonds join atoms to each other in individual polymer molecules. Weak intermolecular forces attract polymer molecules towards each other. The properties of solid materials like polymers depend on:

- how their molecules are arranged
- the strength of the forces between these molecules.

A polymer will melt when the intermolecular forces are overcome. The stronger the forces, the more energy is needed to break them, and the higher the material's melting point.

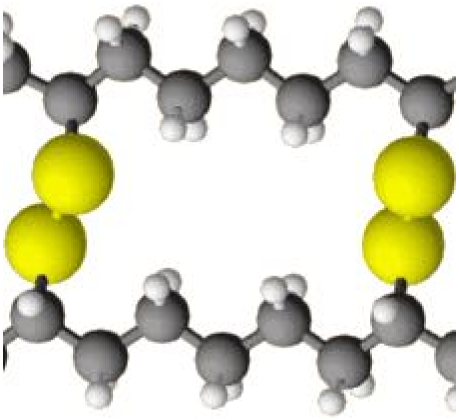
Polymer chains



Polymer with no cross-links

Many polymers, such as polyethene, contain long molecules that lie side by side. These can uncoil and slide past each other, making the material flexible. Long polymer chains have stronger forces of attraction than shorter ones: they make stronger materials.

Cross-linking



Polymer with cross-links

Cross-linking is where the polymer chains are chemically joined together in places, by covalent bonds. The polymer molecules cannot slide over each other so easily. This makes materials tougher and less flexible, and they cannot be easily stretched. Cross-linking also gives materials high melting points.

Vulcanised rubber has cross-links. Its polymer molecules are cross-linked by sulfur atoms. It is tough but flexible, and used for making tyres.

6. Cooking food and additives

Cooking brings about chemical changes in food. The texture and taste changes when food is cooked. Baking powder contains sodium hydrogencarbonate. This breaks down when heated, releasing carbon dioxide that helps cake mixtures to rise during baking.

Food additives are included in food to improve their shelf-life, appearance and flavour. Antioxidants such as ascorbic acid prevent food from going off by reacting with oxygen. Emulsifiers help oil and water to mix - for example, in mayonnaise.

Cooking and chemical changes

Cooking involves chemical changes:

- new substances are made
- the process is irreversible
- an energy change occurs.

For example, bread turns brown as it is toasted. Sugars in the bread break down to form carbon. This change needs heat energy from the toaster, and it cannot be reversed.

Proteins

Meat and eggs are good sources of protein. The protein molecules change shape as a result of the heat energy they absorb. This is called denaturing and it is permanent. Denaturing causes changes in the appearance and texture of the meat and eggs when they are cooked. For example:

- meat becomes firmer and turns from red to brown
- egg white solidifies and becomes white instead of transparent.

Carbohydrates

Potatoes are a good source of carbohydrate, mainly as a complex carbohydrate called starch. Raw potato is hard and has an unpleasant taste but it becomes softer and easier to digest when is cooked. This is beacuse:

- the cell walls break, leading to a softer texture
- the starch grains in the cells swell and spread out.

- **Food additives**
- Everything in food is made from chemicals. Some of these are natural, and some are artificial. Processed foods, including vegetable oils, may have chemicals added to them. These additives have different roles, including extending a product's shelf-life and improving its taste and appearance.
- The table below describes some of the main types of food additives.
- **Types of food additives**

type of additive	reason for adding it
antioxidants	stop food from reacting with oxygen
colourings	improve the colour of food
flavour enhancers	improve the flavour of food
emulsifiers	help oil and water mix, and not separate out

- Additives with an E number have been licensed by the European Union. Some are natural, some artificial, but they have all been safety tested and passed for use.

Emulsions and emulsifiers

Immiscible liquids do not mix together. For example, if you add oil to water, the oil floats on the surface of the water. Then if you shake the two together, tiny droplets of one liquid become spread through the other liquid, forming a mixture called an emulsion.

Emulsions

Mayonnaise and emulsion paints are emulsions. The table describes two other emulsions.

Two types of emulsion

type of emulsion	example	minor component	major component
water in oil	butter	water	fat
oil in water	milk	fat	water

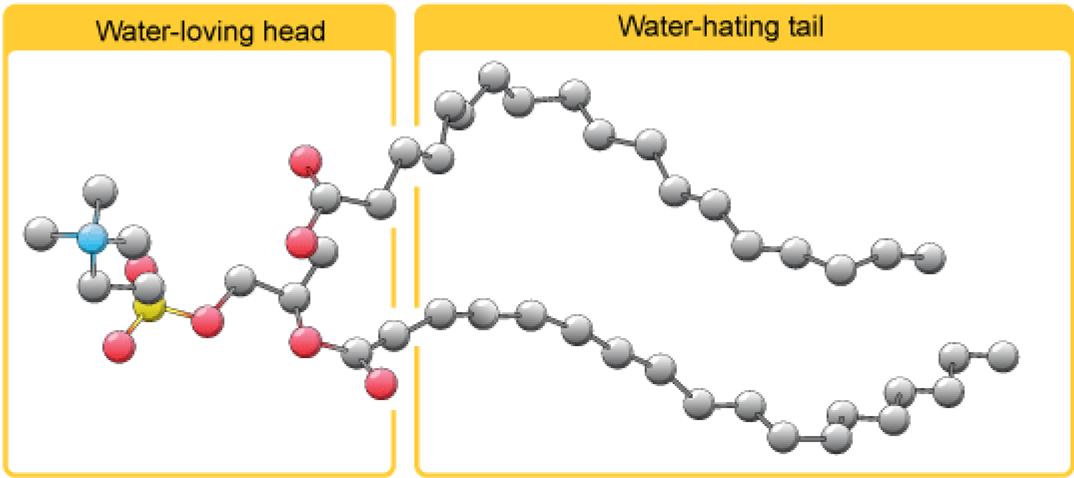
In an emulsion, the oil and water gradually separate out again. Tiny droplets join together until eventually the oil is floating on the water again. To stop the two liquids separating, we need a substance called an emulsifier.

Emulsifiers

Emulsifiers are molecules that have two different ends:

- a hydrophilic end - 'water-loving' - that forms chemical bonds with water but not with oils
- a hydrophobic end - 'water-hating' - that forms chemical bonds with oils but not with water.

Lecithin is an emulsifier commonly used in foods. It is obtained from oil seeds and is a mixture of different substances. A molecular model of one of these substances is seen in the diagram.



Emulsifier molecules

The hydrophilic 'head' dissolves in the water and the hydrophobic 'tail' dissolves in the oil. In this way, the water and oil droplets become unable to separate out. The emulsion is stabilised.

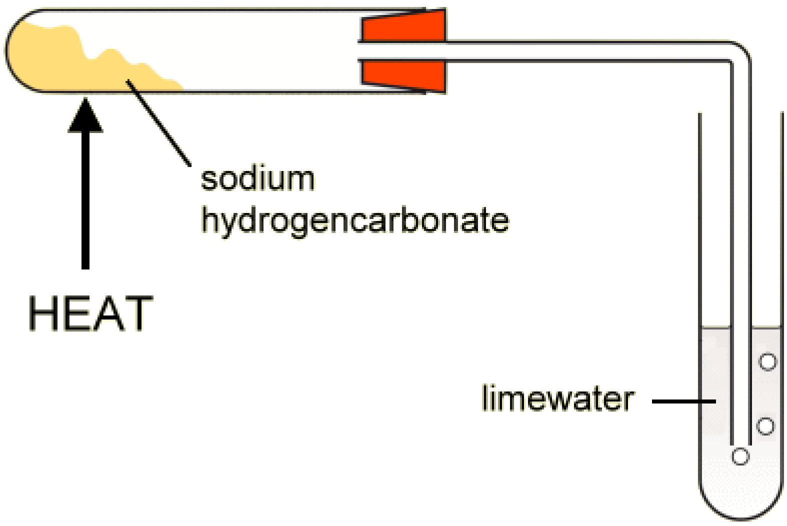
Baking powder

Baking powder is used for baking cakes. It contains sodium hydrogencarbonate, which breaks down when heated to form carbon dioxide gas. The carbon dioxide helps to make the cake mixture rise, so that it is light and fluffy.

Here are the equations for the reaction:

sodium hydrogencarbonate → sodium carbonate + carbon dioxide + water

$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$



Thermal decomposition of sodium hydrogencarbonate

Testing for carbon dioxide

Carbon dioxide can be detected using a simple laboratory test. Limewater turns cloudy white when carbon dioxide is bubbled through it.

7. Smells

Esters are made by reacting an alcohol with an organic acid. They are used in perfumes, and as solvents. Nail varnish dissolves in nail varnish remover, but not in water.

Perfumes

Perfumes have a pleasant smell and they stimulate receptors in the nose. Some perfumes are obtained from natural sources, such as lavender oil or sandalwood oil. Others are made synthetically.

Commercial perfumes need particular properties to be successful. The table summarises these properties and why they are needed.

Summary of the properties of perfume

property	why the property 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

Volatility - Higher tier

Volatile liquids evaporate easily. They readily change from a liquid to a gas. This is because there are only weak attractive forces between particles in the substance. These forces are overcome easily, so particles with enough energy can escape from the liquid.

Esters

Esters are chemicals with pleasant smells. They are used in perfumes, and as solvents.

Making esters

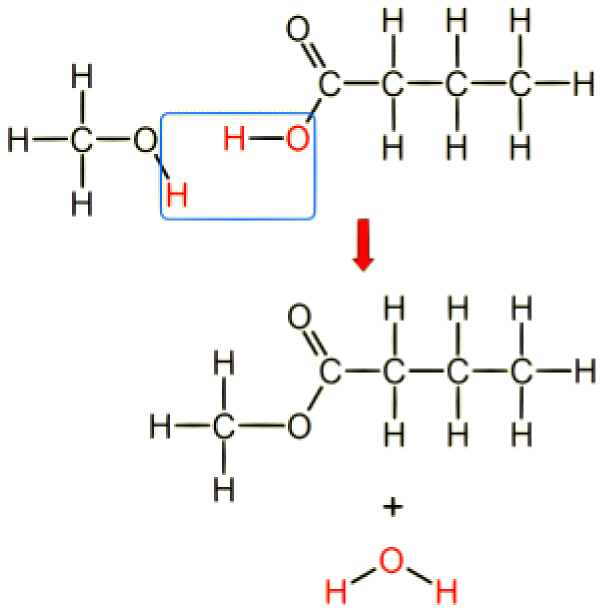
Esters occur naturally, but can be made in the laboratory by reacting an alcohol with an organic acid. A little sulfuric acid is needed as a catalyst. This is the general word equation for the reaction:

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:



Making esters

What esters 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

Solvents

A **solvent** is a liquid that dissolves substances. The substance that dissolves is called the **solute** and the mixture formed by a solvent and solute is called a **solution**. The components of a solution are mixed together completely and do not separate out.

Substances that can dissolve in a particular solvent are **soluble**. Substances that cannot dissolve in a particular solvent are **insoluble**.

Water is not the only solvent. Esters act as solvents, too.

Nail varnish does not dissolve in water - it is insoluble in water. But it does dissolve in nail varnish remover. It may contain ethyl ethanoate, an ester.

Solvents- Higher tier

Whether or not a substance will dissolve in a particular solvent depends on the relative strengths of the attractive forces:

- between the solute particles
- between the solvent particles
- between the solute particles and solvent particles.

The attraction between water and nail varnish particles is weaker than the attraction that joins water to water and the attraction that joins nail varnish to nail varnish. The attractive force between water and nail varnish particles is too weak to break those other bonds, so nail varnish will not dissolve in water.

Cosmetics testing

Medicines

New medical drugs have to be tested to ensure they work and are safe before they can be prescribed. There are three main stages:

1. The drugs are tested using computer models and human cells grown in the laboratory.
2. Drugs that pass the first stage are tested on animals. A typical test involves giving a known amount of the substance to the animals, then monitoring them carefully for any side-effects.
3. Drugs that have passed animal tests are used in clinical trials. They are tested on healthy volunteers to check they are safe. The substances are then tested on people with the illness that the drugs are designed to treat to ensure that they are safe and work properly.

Cosmetics

Most substances do not pass all the tests and trials, so drug development is expensive and takes a long time. In the UK, new medicines have to be tested on animals. However, it has been illegal to test cosmetics on animals in this country 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. However some people have ethical concerns about such tests.

8. Paints and pigments

Pigments are coloured substances used in paint. Paints are a type of mixture called a colloid. They contain several components, including the pigment, a solvent and a binding medium.

Thermochromic and phosphorescent pigments are very useful, and extend the normal properties of paints.

Paints

Paints are used to decorate surfaces or protect them from damage. A **pigment** is a coloured substance used in paint.

Paints contain these ingredients:

- a pigment - gives the paint its colour
- a binding medium - a liquid polymer that hardens to form a continuous layer when the paint dries
- a solvent - dissolves the binding medium and makes the paint more fluid.

Emulsion paints

Emulsion paints are water-based. Their solvent is water and they dry when the water evaporates.

Oil paints

The pigments in oil paints are dispersed in oil, which may itself be dissolved in a solvent.

The solvent evaporates away when the paint dries. This leaves the pigment and oil behind. The oil oxidises to form a hard film. This happens because the oil reacts with oxygen in the air.

Colloids

Paints are a type of mixture called a **colloid**. In a colloid, particles of one substance are mixed and dispersed with particles of another substance - but they are not dissolved in it. The components do not separate out because their particles are small enough not to settle at the bottom.

Thermochromic and phosphorescent pigments

Thermochromic pigments are sensitive to temperature. They change colour when they are heated up or cooled down. This property is useful for indicating if the drink in a cup is hot, or if the water in a kettle is hot.

Phosphorescent pigments glow in the dark. They are able to absorb light energy and store it. This stored energy is released as light energy over a period of time.

Phosphorescent pigments are useful for watching faces that glow in the dark. They may also be used in fire safety signs placed near fire extinguishers. In the event of a fire, the location of the fire extinguishers can be seen even if the lights fail.

Higher tier

In the past, glow-in-the-dark watch faces used radioactive paints. Phosphorescent pigments are much safer, though.