

Cambridge OCR GCSE Chemistry A — Chemistry

Topic C6

Global challenges

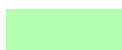
Specification J248 · Cambridge OCR

Free edition

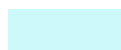
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

This booklet is a study aid written from the published specification.
It is not affiliated with, endorsed by or approved by Cambridge OCR.

Free to download and share for personal study.

Please do not sell or republish it as your own.

For enquiries, please email pcfgyrdi@gmail.com

Cambridge OCR GCSE (9–1) Chemistry A (Gateway Science) J248, until 2025 called OCR · Specification reference C6 · Paper 2 (Foundation) / Paper 4 (Higher)

This topic integrates chemical systems and processes and applies them to global challenges, so it draws together concepts from every earlier topic — expect synoptic questions on Papers 2 and 4.

Define Phytoextraction

- growing plants that absorb metal compounds, then burning them and processing the ash.

Define Compromise conditions

- conditions chosen to balance yield, rate and cost rather than to maximise any one.

Define Alloy

- a mixture of a metal with one or more other elements, designed to improve its properties.

Define Sacrificial protection

- attaching a more reactive metal so that it corrodes instead.

Define Composite

- a **matrix** or binder reinforced by fibres or fragments of another material.

Define Homologous series

- a family of compounds with the same general formula and functional group, differing by CH_2 , with a gradual trend in properties.

Define Alkane

- a saturated hydrocarbon, general formula $\text{C}_n\text{H}_{2n+2}$. **Alkene** — an unsaturated hydrocarbon with a $\text{C}=\text{C}$ double bond, C_nH_{2n} .

Define Ore

- a rock containing enough of a metal compound to make extraction worthwhile.

HIGHER TIER

Define Reduction

- loss of oxygen (or **HT ONLY** gain of electrons); how a metal is freed from its ore.

Define Bioleaching

- using bacteria to produce a leachate solution containing metal compounds.

Define Life-cycle assessment (LCA)

- an evaluation of the use of resources and the environmental impact of every stage of a product's life.

Define Corrosion

- destruction of a metal by reaction with its surroundings; **rusting** is the corrosion of iron.

Define Ceramic

- a hard, brittle, non-metallic material such as glass or fired clay.

Define Hydrocarbon

- a compound of hydrogen and carbon only.

Define Functional group

- the atom or group of atoms that gives a homologous series its characteristic reactions.

Define Fractional distillation

- separation of a mixture of liquids by their different boiling points.

Define Cracking

- breaking long-chain hydrocarbons into shorter, more useful molecules, producing alkenes.

Define Addition polymerisation

- many alkene monomers joining, with no other product.

Define Fuel cell

- a cell in which a fuel is oxidised electrochemically to produce a potential difference.

Define Potable water

- water that is safe to drink; not the same as pure water.

Define Monomer

- a small molecule that joins to others to form a polymer.
Repeat unit — the section of a polymer that recurs.

HIGHER TIER

Define HT ONLY Condensation polymerisation

- monomers joining with the loss of a small molecule such as water each time.

Define Greenhouse effect

- the absorption and re-radiation of long-wavelength infrared by gases in the atmosphere, warming the Earth.

C6.1 Improving processes and products

Materials were historically developed by trial and error, but as our understanding of structure and of chemical processes has improved we are increasingly able to manipulate and design new materials. Industry continually seeks products with better performance that are sustainable to produce. This sub- topic also explores the extraction of raw materials and their use in making new products.

Extracting metals by electrolysis (C6.1b)

Explain why and how electrolysis is used to extract some metals from their ores.

Why. Metals **more reactive than carbon** hold their oxygen too strongly to be reduced by it, so the only way to give the metal ion the electrons it needs is to supply them directly from a power supply.

How. The ore is purified, then **melted** (or dissolved) so the ions are **free to move** and can carry charge. **Aluminium** is extracted from purified bauxite dissolved in **molten cryolite**, which drops the melting point from over 2000 °C to about 950 °C and saves a great deal of energy. At the **cathode** $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$; at the **anode** O^{2-} ions lose electrons to give oxygen, which burns away the carbon anodes so they need regular replacement.

Electrolysis is **expensive** — energy both to melt the compound and to drive the current — so it is used only where carbon will not work.

Extracting metals with carbon (C6.1a)

Explain, using the position of carbon in the reactivity series, the principles of industrial processes used to extract metals, including the extraction of a non-ferrous metal, to include the principles of using carbon to extract iron and other metals from their ores.

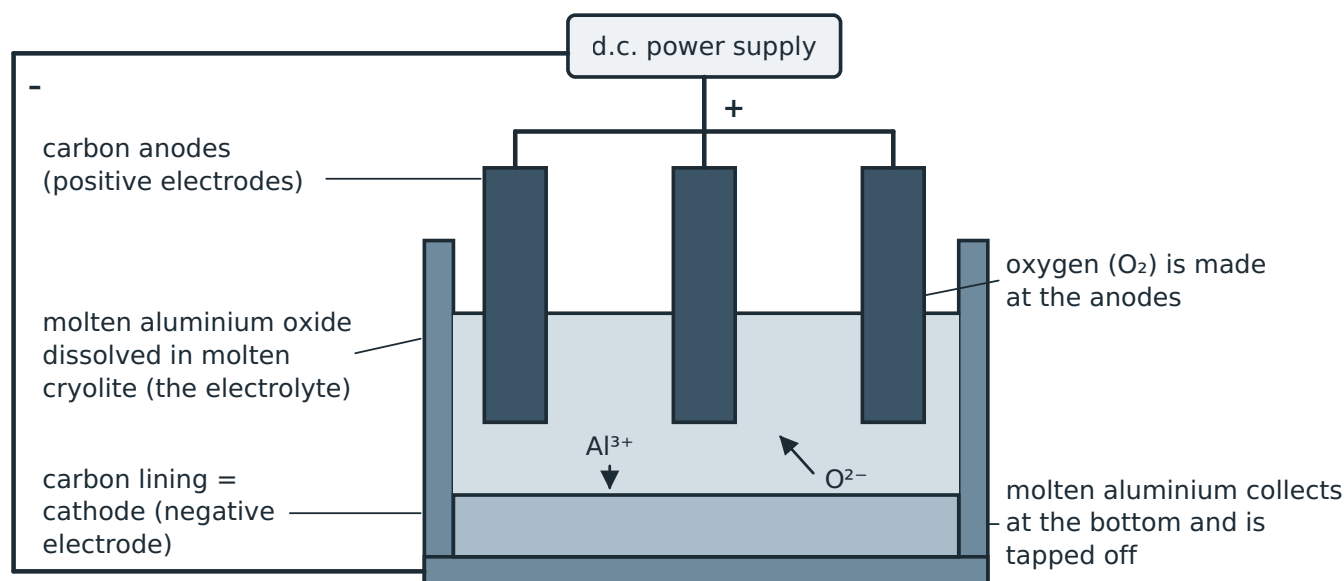
Most metals occur as **oxides or other compounds**, so extraction is a **reduction**. One comparison decides the method: **is the metal above or below carbon in the reactivity series?**

- **Below carbon** (zinc, iron, tin, lead, copper) — carbon is more reactive, so it takes the oxygen away: the ore is **heated with carbon or carbon monoxide** and the metal is **reduced**.
- **Above carbon** (potassium, sodium, calcium, magnesium, aluminium) — carbon cannot displace them, so **electrolysis** is required (C6.1b).
- **Very unreactive** metals such as gold occur **native**, as the element, and need no chemical extraction at all.

Iron in the blast furnace is the standard example: iron(III) oxide is reduced by carbon monoxide, $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$.

The **non-ferrous** example the spec demands is **copper**: copper(II) oxide heated with carbon gives copper, $2\text{CuO} + \text{C} \rightarrow 2\text{Cu} + \text{CO}_2$. Copper is then purified by **electrolysis** to the purity that electrical wiring needs.

Extracting aluminium by electrolysis of aluminium oxide dissolved in molten cryolite.



Why cryolite is added

Aluminium oxide melts at over 2000 °C. Dissolving it in molten cryolite lowers the melting point, so less energy is needed and it is cheaper. Aluminium is too reactive to be extracted by reduction with carbon.

Why the anodes must be replaced

Oxygen is made at the positive electrodes. It reacts with the hot carbon of the anodes to make carbon dioxide, so the anodes burn away and have to be replaced regularly. The process uses a lot of energy — costly.

HT only — Half equations

Cathode (reduction):



Anode (oxidation):



Overall:



aluminium oxide is reduced to aluminium

HIGHER TIER

HT ONLY Biological methods of metal extraction (C6.1c)

HT ONLY Evaluate alternative biological methods of metal extraction, to include bacterial and phytoextraction.

- HT ONLY Bioleaching — bacteria are grown on low-grade ore; their metabolism produces a leachate solution containing metal compounds, from which the metal is obtained by displacement with scrap iron or by electrolysis.
- HT ONLY Phytoextraction — plants are grown on soil or spoil containing metal compounds; they absorb the compounds and concentrate them, and are then harvested and burned. The ash contains a relatively high concentration of metal compound, which is processed as an ore.

HT ONLY Evaluation. Both let low-grade ores and mine waste be used, extending limited reserves; both need far less energy than smelting or electrolysis and cause much less landscape damage, noise and dust than opencast mining. Against that, both are very slow (growing seasons for phytoextraction, months or years for bioleaching), yields are low, bioleaching can release toxic acidic leachates, and burning the biomass gives off carbon dioxide.

HIGHER TIER

HT ONLY CHEMISTRY ONLY Rate against equilibrium position — the trade-off (C6.1d)

HT ONLY CHEMISTRY ONLY Explain the trade-off between rate of production of a desired product and position of equilibrium.

For a reversible, exothermic reaction the two demands pull in opposite directions:

- Le Chatelier (C5.3c) says a low temperature shifts an exothermic equilibrium towards the products, raising the yield.
- Collision theory (C5.2d) says a low temperature makes the reaction slow, so the yield takes a very long time to arrive.

A plant giving a 90% yield in a fortnight is worth less than one giving 15% every minute and recycling what did not react. The condition chosen is therefore a compromise — a moderate temperature giving an acceptable yield at an acceptable rate. Pressure trades off differently: high pressure may raise the yield, but compressing gases costs energy and demands thick, expensive, high-maintenance plant.

HIGHER TIER

HT ONLY CHEMISTRY ONLY Interpreting graphs of conditions against rate and yield (C6.1e)

HT ONLY CHEMISTRY ONLY Interpret graphs of reaction conditions versus rate.

The standard graph shows **percentage yield of ammonia against temperature**, with one curve for each pressure. Read it in three steps: **describe** the trend along one axis, **describe** the trend between the curves, then **explain** each using Le Chatelier and collision theory.

HIGHER TIER

HT ONLY CHEMISTRY ONLY Commercial conditions — the Haber and Contact processes (C6.1f)

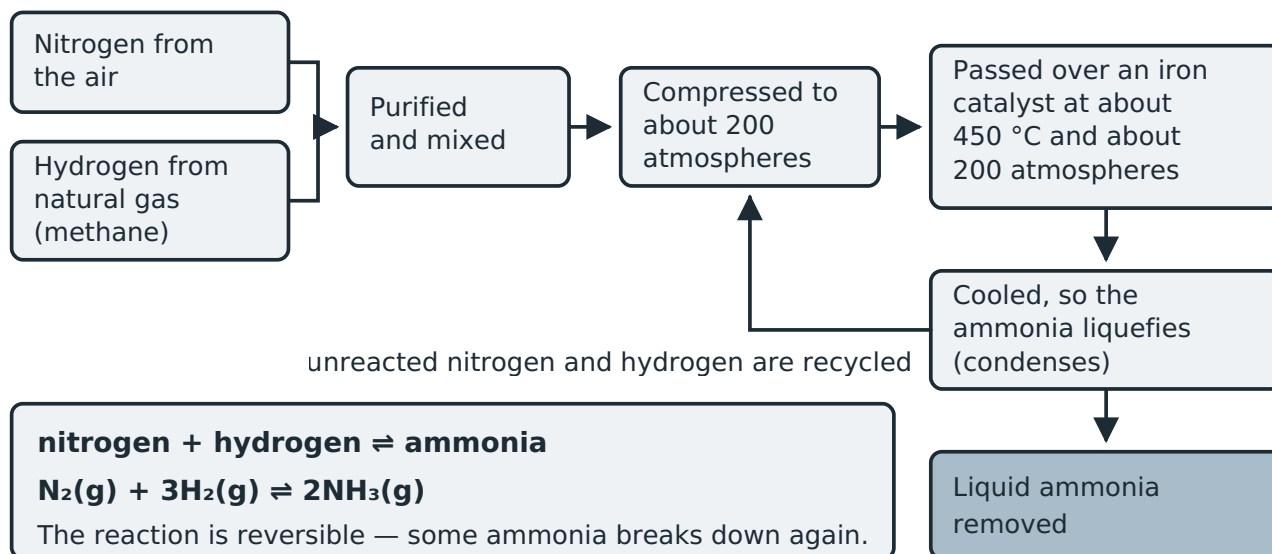
HT ONLY CHEMISTRY ONLY Explain how the commercially used conditions for an industrial process are related to the **availability and cost of raw materials and energy supplies, control of equilibrium position and rate**, to include the Haber process and the Contact process.

The Haber process makes ammonia: $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$, exothermic in the forward direction. Raw materials are cheap and abundant: **nitrogen from the fractional distillation of liquid air**, and **hydrogen from natural gas (methane)**. The gases are purified, compressed, passed over the catalyst, and the ammonia is **cooled and condensed to a liquid** and run off; unreacted nitrogen and hydrogen are **recycled**.

Condition	Value used	Why not more?	Why not less?
Temperature	450 °C	A lower temperature would give a higher yield (the forward reaction is exothermic) but the rate would be uneconomically slow	A higher temperature would be faster but the equilibrium yield would collapse
Pressure	200 atmospheres	Higher pressure gives a higher yield (4 gas molecules → 2) but costs far more energy to compress and needs stronger, costlier and more dangerous plant	Lower pressure would be cheaper and safer but the yield and rate would both fall
Catalyst — iron	Present throughout	—	Without it the reaction would be far too slow at 450 °C; it speeds up the reaction without shifting the equilibrium , so it lets a lower temperature be used
Recycling	Continuous	—	Removing the ammonia and recycling the unreacted gases shifts the equilibrium right and means the low single-pass yield wastes almost nothing

The Haber process, and why each of its conditions is a compromise.

chemistry only



Condition	Why it is a compromise	HT only
About 450 °C	The forward reaction is exothermic, so a lower temperature would give a higher yield of ammonia — but the reaction would be too slow. 450 °C is a compromise between rate of production and yield.	
About 200 atm	High pressure moves the equilibrium to the right (4 molecules of gas $\rightarrow$ 2) and increases the rate, but very high pressures need strong, expensive equipment and are dangerous — 200 atm is a compromise with cost and safety.	
Iron catalyst	Speeds up the reaction so equilibrium is reached sooner. It does not change the position of equilibrium, so it does not change the yield.	

The **Contact process** makes sulfuric acid. Its key equilibrium step, $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$, is again exothermic with fewer gas molecules on the right, and the conditions are set the same way: about **450 °C** as a rate–yield compromise, a **vanadium(V) oxide catalyst**, and only about **2 atmospheres**, because the yield is already around 96% at low pressure and higher pressures would not repay their cost. The sulfur trioxide is absorbed into concentrated sulfuric acid and then diluted, rather than added straight to water, which would be dangerously violent.

The general lesson: conditions are set by **availability and cost of raw materials**, **cost of energy**, **control of equilibrium position** and **control of rate** — and cost usually decides between them.

WATCH OUT

OCR's own note for this sub-topic: "*Learners often think that chemical reactions will continue until all the reactants are exhausted. They also think that equilibrium is a static condition.*"

Both errors wreck Haber answers. A reversible reaction in a closed system **stops changing while reactants are still present** — that is what an equilibrium is, and it is exactly why the single-pass yield of ammonia is only a fraction of the theoretical maximum however long you wait. And equilibrium is **dynamic**: the forward and reverse reactions are still running at equal rates, which is why removing ammonia keeps drawing the system to the right. See also the C5.3 misconception box on constant versus equal concentrations.

CHEMISTRY ONLY The importance of the Haber process, and fertilisers (C6.1g, C6.1i, C6.1j)

CHEMISTRY ONLY Explain the importance of the Haber process in agricultural production (C6.1g); recall the importance of nitrogen, phosphorus and potassium compounds in agricultural production (C6.1i); describe the industrial production of fertilisers as several integrated processes using a variety of raw materials (C6.1j), to include ammonium nitrate and ammonium sulfate.

Plants take nitrogen, phosphorus and potassium out of the soil as they grow, and harvesting removes them permanently.

Fertilisers replace them, so crop yields rise and far more people can be fed from the same land. The three elements do different jobs: **nitrogen** for proteins and leaf growth, **phosphorus** for roots and for respiration and photosynthesis, **potassium** for flowering, fruiting and enzyme action. **NPK fertilisers** are formulated mixtures supplying all three.

The Haber process is the pivot: it **fixes unreactive atmospheric nitrogen into ammonia**, from which all nitrogen fertilisers are made. Industrial production is a chain of **integrated processes**, each feeding the next:

1. Natural gas and air → **hydrogen** and **nitrogen**.
2. Haber process → **ammonia**.
3. Part of the ammonia is **oxidised** over a catalyst → **nitric acid**.
4. **Ammonia + nitric acid** → **ammonium nitrate**, and **ammonia + sulfuric acid** → **ammonium sulfate** (the sulfuric acid coming from the Contact process).
5. Potassium and phosphorus salts are **mined** — potassium chloride, potassium sulfate, phosphate rock — and phosphate rock is treated with acid to make soluble phosphates.
6. The salts are blended into an **NPK** formulation.

Building the processes on one site means the product of one is the feedstock of the next, and waste heat from the exothermic stages can be reused.

CHEMISTRY ONLY Industrial against laboratory synthesis (C6.1h)

CHEMISTRY ONLY Compare the industrial production of fertilisers with laboratory syntheses of the same products.

	Laboratory (e.g. titration)	Industrial
Scale	A few grams	Hundreds of tonnes a day
Process	Batch — set up, run, clean out, start again	Continuous — runs for months without stopping
Reactants	Ready-made acid and alkali, bought in	Made on site from air, natural gas and mined rock
Method	Titrate to find the exact volume, repeat without indicator, then crystallise	Metered continuous feeds, automated control, no indicator needed
Purity	Small quantity of very pure crystals	Purity sufficient for the use; often granulated and coated
Cost and safety	Labour-intensive per gram, cheap to set up; small quantities of dilute solutions	Very expensive plant but low cost per tonne; high temperatures and pressures and large inventories of hazardous material

Life-cycle assessment (C6.1k, C6.1l)

Describe the basic principles in carrying out a life-cycle assessment of a material or product (C6.1k) and interpret data from a life-cycle assessment of a material or product (C6.1l).

An LCA assesses the **use of resources** and the **impact on the environment** at every stage of a product's life. The spec sets out four stages:

1. **Making the materials for the product from raw materials, through to the process used to make the product** — extraction of raw materials, energy used, land damage, waste produced during manufacture.
2. **The use of the product** — energy or water it consumes in service, how long it lasts, any pollutants released.
3. **Transport of the product** — distance travelled, fuel used at each stage of distribution.
4. **The method used for its disposal at the end of its life** — landfill, incineration, reuse or recycling, and the energy and pollution involved.

At every stage, account for **energy, water, raw materials** and **waste and pollutants**.

Interpreting the data. Compare stage by stage rather than by a single total, and state the trade-off: a plastic bag needs less energy and water to make than a cotton bag but takes centuries to break down, while the cotton bag's large manufacturing footprint is only repaid after dozens of uses. Note too that **energy and mass figures are objective but the weighting of different impacts is a judgement**, so a manufacturer's own LCA may not be unbiased (WS1.1f, WS1.1g, WS1.1i).

CHEMISTRY ONLY Alloys (C6.1o)

CHEMISTRY ONLY Describe the composition of some important alloys in relation to their properties and uses, to include **steel, brass, bronze, solder and duralumin**.

A pure metal has layers of identical atoms in a regular arrangement, and those layers **slide** over one another easily, which makes it soft. Alloying adds atoms of a **different size**, which **distort the layers and stop them sliding**, so the alloy is harder and stronger.

Recycling (C6.1m, C6.1n)

Describe a process where a material or product is recycled for a different use, and explain why this is viable (C6.1m); evaluate factors that affect decisions on recycling (C6.1n).

Recycling for a **different** use — sometimes called downcycling — is viable when the recovered material still has the properties the new use needs, even though it is no longer good enough for the original one:

- **PET drinks bottles** are sorted, shredded, washed, melted and spun into **polyester fleece and fibre filling**. Colour and slight contamination do not matter in fabric but would fail a food-contact bottle, and the energy needed is far less than making new polymer from crude oil.
- **Crushed glass (cullet)** too mixed in colour to remake into bottles becomes **aggregate in roads and concrete**, or a filtration medium: it keeps the hardness and inertness needed.
- **Old tyres** are granulated into playground and sports surfaces.

Factors affecting the decision to recycle:

Factor	Questions to ask
Energy	Does recycling use less energy than extracting or synthesising afresh? (Recycling aluminium uses about 5% of the energy of extracting it by electrolysis.)
Resources	Are the raw materials finite ? Recycling conserves ore and crude oil and reduces quarrying and mining.
Cost	Collection, sorting, transport and cleaning all cost money; recycling is viable only if it competes with the price of virgin material.
Sorting and contamination	Mixed or contaminated waste — especially mixed plastics — is expensive or impossible to separate economically.
Quality	Some materials degrade each time they are reprocessed, so they can be reused only for lower-grade purposes.
Environment and society	Less landfill, less pollution, fewer greenhouse gas emissions; but also jobs, public willingness to sort waste, and the emissions of collection lorries.

Alloy	Main composition	Key properties	Typical uses
Steel	Iron + a small, controlled amount of carbon (plus other metals in alloy steels)	Much harder and stronger than pure iron; low- carbon steel is softer and easily shaped, high- carbon steel is harder but brittle; stainless steel (with chromium and nickel) resists corrosion	Buildings, bridges, car bodies, tools, cutlery
Brass	Copper + zinc	Harder than copper, corrosion-resistant, attractive gold colour, easily machined	Taps, door fittings, musical instruments
Bronze	Copper + tin	Harder and more corrosion-resistant than copper	Statues, bells, ships' propellers, medals
Solder	Tin + lead (modern solders tin + copper or silver)	Low melting point , so it melts without damaging the parts joined; conducts electricity	Joining electrical components and pipework
Duralumin	Aluminium + copper (with magnesium and manganese)	Nearly as strong as steel but with a much lower density	Aircraft bodies and structures

CHEMISTRY ONLY Corrosion and its prevention (C6.1p, C6.1q)

CHEMISTRY ONLY Describe the process of corrosion and the conditions which cause corrosion, to include iron and other metals (C6.1p); explain how mitigation of corrosion is achieved by creating a physical barrier to oxygen and water and by sacrificial protection (C6.1q).

Corrosion is the gradual destruction of a metal by reaction with substances in its surroundings — an **oxidation**. For iron the product is **hydrated iron(III) oxide**, **rust**, and **both oxygen and water must be present**:

iron + oxygen + water → hydrated iron(III) oxide

Rusting is accelerated by **salt** and by **acidic** conditions, which is why cars corrode fastest on gritted roads and in coastal air.

Rust is **flaky and porous**, so it falls away and exposes fresh metal beneath — iron corrodes all the way through. **Aluminium behaves differently**: its oxide layer is **tough and firmly attached**, so it seals the surface and protects the metal underneath, which is why aluminium appears not to corrode at all.

Mitigation works in two distinct ways:

- A **physical barrier** keeps oxygen and water away from the metal — painting, oiling and greasing, coating with plastic, **electroplating** with tin or chromium, or **galvanising** with zinc. A barrier fails as soon as it is scratched.
- **Sacrificial protection** attaches a **more reactive metal**, usually **zinc** or magnesium. Being more reactive, it **loses electrons and corrodes in preference to the iron**, protecting it even where the surface is broken; the blocks are replaced when eaten away. Galvanising does both jobs at once — the zinc is a barrier *and* is sacrificial where it is scratched.

CHEMISTRY ONLY Comparing materials, and choosing them (C6.1r, C6.1s)

CHEMISTRY ONLY Compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals (C6.1r); explain how the properties of materials are related to their uses and select appropriate materials given details of the usage required (C6.1s).

Material class	Density	Strength and stiffness	Behaviour under stress	Other
Glass and clay ceramics	Moderate ($\approx 2.5 \text{ g/cm}^3$)	Very high compressive strength and very stiff	Brittle — shatters without bending; weak in tension	Hard, heat-resistant, chemically inert, electrical insulators
Metals and alloys	High (Al ≈ 2.7 , Fe $\approx 7.9 \text{ g/cm}^3$)	High tensile and compressive strength	Malleable and ductile — bend and stretch before failing	Conduct heat and electricity; many corrode
Polymers	Low ($\approx 0.9\text{--}1.4 \text{ g/cm}^3$)	Low to moderate strength, low stiffness	Flexible : thermosoftening polymers deform on heating	Cheap, mouldable, waterproof, insulating, often non-biodegradable
Composites	Low to moderate	Very high strength-to-weight ratio	Combine the stiffness of the fibres with the toughness of the matrix	Properties tailored by choice of fibre and matrix; hard to recycle

Selecting a material means matching properties to the demands stated in the question, explicitly: *"aircraft need a high strength-to-weight ratio, so carbon-fibre composite is chosen over steel; steel is stronger for the same volume but much heavier, and the extra fuel cost over the aircraft's life outweighs its lower purchase price."* Bring in cost, availability, corrosion resistance and disposal wherever the data allows.

NOTE

Maths for C6.1. CM6.1i arithmetic computation and ratio (M1a, M1c); CM6.1ii drawing and interpreting graphs (M4b, M4c); CM6.1iii **CHEMISTRY ONLY** determining gradients as a measure of rate of change (M4d, M4e); CM6.1iv **CHEMISTRY ONLY** proportionality when comparing factors (M1c).

C6.2 Organic chemistry

Carbon chemistry is the basis of life on Earth and of many of the materials we produce. Organic compounds are covalent in nature and react in predictable patterns, and crude oil forms the basis of many useful products.

CHEMISTRY ONLY Functional groups and homologous series (C6.2a, C6.2i)

CHEMISTRY ONLY Recognise functional groups and identify members of the same homologous series (C6.2a), to include alkanes, alkenes, alcohols and carboxylic acids; recall that it is the generality of reactions of functional groups that determines the reactions of organic compounds (C6.2i).

A **homologous series** is a family of compounds that share a **functional group** and a **general formula**, with each member differing from the next by CH_2 , and showing a gradual trend in physical properties (boiling point rises with chain length).

Series	Functional group	General formula	First member	Ending
Alkanes	C–C single bonds only (saturated)	$\text{C}_n\text{H}_{2n+2}$	methane, CH_4	-ane
Alkenes	C=C double bond (unsaturated)	C_nH_{2n}	ethene, C_2H_4	-ene
Alcohols	–OH	$\text{C}_n\text{H}_{2n+1}\text{OH}$	methanol, CH_3OH	-ol
Carboxylic acids	–COOH	$\text{C}_n\text{H}_{2n+1}\text{COOH}$	methanoic acid, HCOOH	-oic acid

The point of C6.2i is powerful: **the functional group, not the length of the chain, decides how a compound reacts**. Once you know that alkenes decolourise bromine water, you know it for every alkene, including ones you have never met — which is why you can be asked to predict the products for "other given members" of a series.

CHEMISTRY ONLY Naming and drawing the first four members (C6.2b)

CHEMISTRY ONLY Name and draw the structural formulae, using fully displayed formulae, of the first four members of the straight-chain alkanes, alkenes, alcohols and carboxylic acids.

The stems are fixed by the number of carbon atoms: **meth-** (1), **eth-** (2), **prop-** (3), **but-** (4).

Alkane	Alkene	Alcohol	Carboxylic acid
methane CH_4	—	methanol CH_3OH	methanoic acid HCOOH
ethane C_2H_6	ethene C_2H_4	ethanol $\text{C}_2\text{H}_5\text{OH}$	ethanoic acid CH_3COOH
propane C_3H_8	propene C_3H_6	propan-1-ol $\text{C}_3\text{H}_7\text{OH}$	propanoic acid $\text{C}_2\text{H}_5\text{COOH}$
butane C_4H_{10}	butene C_4H_8	butan-1-ol $\text{C}_4\text{H}_9\text{OH}$	butanoic acid $\text{C}_3\text{H}_7\text{COOH}$

n

1

2

3

4

There is no "methene": a $\text{C}=\text{C}$ bond needs two carbons. A **fully displayed formula** shows **every atom and every bond**, so ethanol is drawn with two carbons, five $\text{C}-\text{H}$ bonds, a $\text{C}-\text{O}$ bond and an $\text{O}-\text{H}$ bond — the $\text{O}-\text{H}$ shown separately, not as "OH" on a stick.

CHEMISTRY ONLY Addition polymerisation (C6.2d, C6.2g)

CHEMISTRY ONLY Recall the basic principles of addition polymerisation by reference to the functional group in the monomer and the repeating units in the polymer (C6.2d); deduce the structure of an addition polymer from a simple alkene monomer and vice versa (C6.2g), using the representation $[\text{repeat unit}]_n$.

In addition polymerisation, many alkene monomers join end to end. The **$\text{C}=\text{C}$ double bond opens** and forms single bonds to the neighbouring molecules, so **the polymer is the only product** — nothing else is made, and the polymer has **exactly the same atoms in the same proportions** as the monomer, giving an atom economy of **100%**.

Deducing the repeat unit from the monomer: draw the monomer, change the **double bond to a single bond**, and draw a **bond extending from each end** out through the brackets, with **n** outside. Reverse the steps to go from polymer back to monomer.

CHEMISTRY ONLY Predicting the products of reactions (C6.2c)

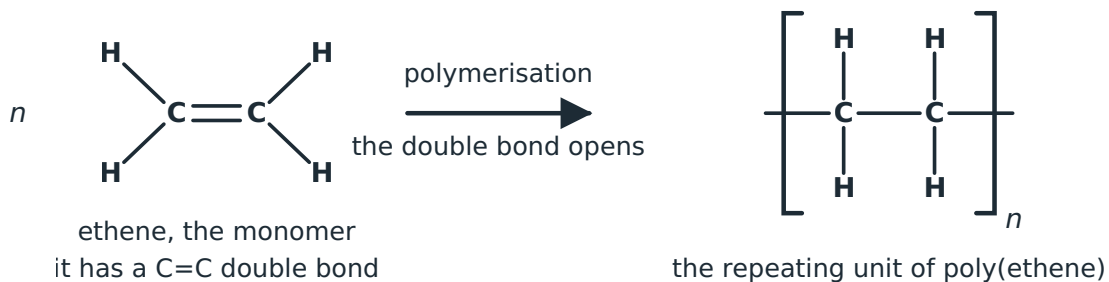
CHEMISTRY ONLY Predict the formulae and structures of products of reactions of the first four and other given members of the homologous series of alkanes, alkenes and alcohols, to include **combustion; addition of bromine and hydrogen across a double bond; oxidation of alcohols to carboxylic acids using potassium manganate(VII)**.

- **Complete combustion** of any hydrocarbon or alcohol in plenty of oxygen gives **carbon dioxide and water**, and is strongly exothermic: $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$. **Incomplete combustion**, in a limited supply of oxygen, gives **carbon monoxide** and **carbon (soot)** as well.
- **Addition across the $\text{C}=\text{C}$ double bond.** The double bond opens and one atom adds to each carbon. With **bromine**: ethene + $\text{Br}_2 \rightarrow$ **1,2-dibromoethane**, $\text{C}_2\text{H}_4\text{Br}_2$ — the reaction that **decolourises orange bromine water** and so distinguishes an alkene from an alkane. With **hydrogen**, over a nickel catalyst: ethene + $\text{H}_2 \rightarrow$ **ethane**, C_2H_6 .
- **Oxidation of alcohols.** Warming an alcohol with **acidified potassium manganate(VII)** oxidises it to the **carboxylic acid** with the same number of carbon atoms, and the purple solution is decolourised:

ethanol $\rightarrow$ **ethanoic acid**, CH_3COOH . The same change happens slowly when wine is left open to the air and turns to vinegar.

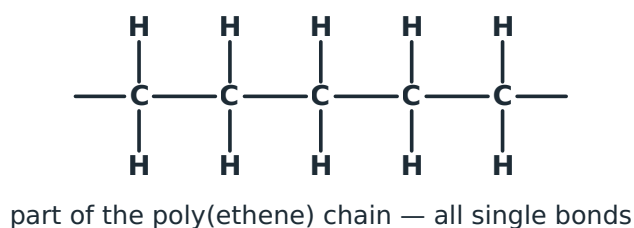
Addition polymerisation of ethene, and the repeat unit of poly(ethene).

Chemistry only



Many small molecules (monomers) join together to form one very large molecule, the polymer.

The C=C double bond opens up, so no other molecule is formed: the repeating unit has the same atoms as the monomer.



A monomer for addition polymerisation always contains a C=C double bond, and n stands for a very large number of repeating units. Poly(propene) is made from propene in exactly the same way.

HT ONLY CHEMISTRY ONLY Condensation polymerisation (C6.2e, C6.2f)

HT ONLY CHEMISTRY ONLY Explain the basic principles of condensation polymerisation by reference to the functional groups of the monomers, the minimum number of functional groups within a monomer, the number of repeating units in the polymer, and the simultaneous formation of a small molecule (e.g. a polyester or polyamide), using block diagrams to represent polymers (C6.2e); describe practical techniques to make a polymer by condensation (C6.2f).

HT ONLY In condensation polymerisation two monomers join and a small molecule — usually water — is lost each time a link forms. So, unlike addition, there are two products, and the atom economy is below 100%.

- **HT ONLY** Each monomer must have at least two functional groups, one at each end. A monomer with only one functional group can join at one end only and the chain stops there.
- **HT ONLY** Typically two different monomers are used, each with two identical groups: a **di-carboxylic acid** (two -COOH) with a **diol** (two -OH) gives a **polyester**; a di-carboxylic acid with a **diamine** (two -NH_2) gives a **polyamide** such as nylon.
- **HT ONLY** For n molecules of each monomer, you get a polymer of n repeat units and $2n - 1$ molecules of water — treated at GCSE as $2n$, since n is very large. For a single monomer type carrying both groups, n monomers give n repeat units and n water molecules.
- **HT ONLY** **Block diagrams** are the required representation: draw each monomer as a rectangle with its functional groups at the ends, then show the rectangles joined in a chain with the small molecules coming off at each junction.

CHEMISTRY ONLY Naturally occurring polymers (C6.2h)

CHEMISTRY ONLY Recall that DNA is a polymer made from four different monomers called nucleotides, and that other important naturally-occurring polymers are based on sugars and amino acids, to include the names of the nucleotides.

DNA is a natural polymer of **nucleotides**, of which there are four, named after their bases: **adenine (A)**, **cytosine (C)**, **guanine (G)** and **thymine (T)**. Two strands coil into a **double helix**, and the order of the nucleotides carries the genetic code.

Two other classes of natural polymer are named by the spec:

- polymers **based on sugars** — glucose monomers polymerise to give **starch and cellulose**;
- polymers **based on amino acids** — around twenty different amino acid monomers polymerise to give **proteins**, whose properties depend on the order in which they are joined.

Both, like nylon, are formed by **condensation** with the loss of water, which is why they can be broken down again by adding water.

Crude oil and fractional distillation (C6.2j, C6.2k, C6.2l, C6.2m, C6.2n)

Describe the separation of crude oil by fractional distillation (C6.2j), to include the names of the fractions; **explain the separation of crude oil by fractional distillation (C6.2k)**, to include molecular size and intermolecular forces; **describe the fractions as largely a mixture of compounds of formula $\text{C}_n\text{H}_{2n+2}$ which are members of the alkane homologous series (C6.2l)**; **recall that crude oil is a main source of hydrocarbons and is a feedstock for the petrochemical industry (C6.2m)**; **explain how modern life is crucially dependent upon hydrocarbons and recognise that crude oil is a finite resource (C6.2n)**.

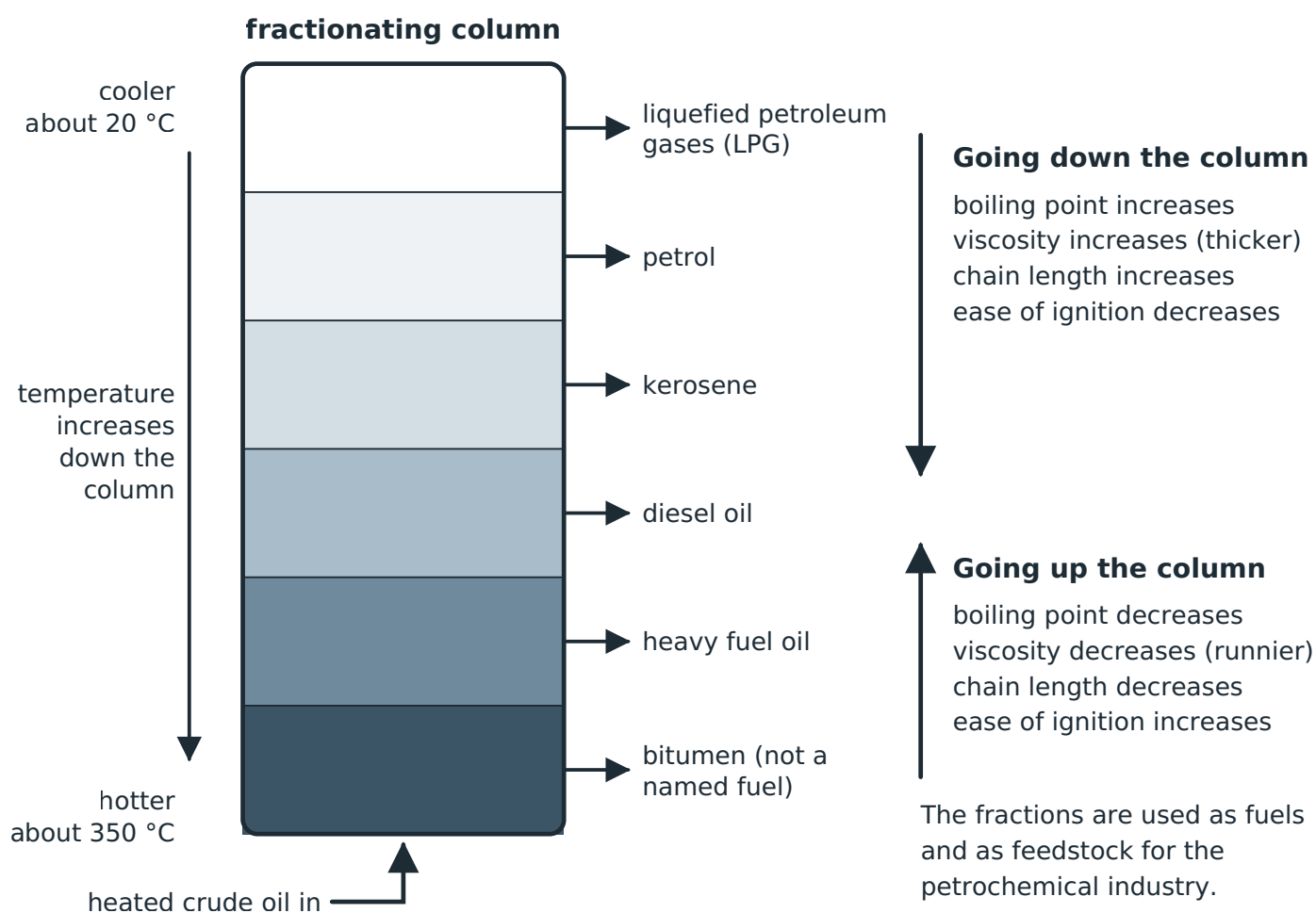
Crude oil is the remains of ancient marine organisms buried under mud, compressed and heated over millions of years. It is a **mixture of hydrocarbons**, mostly **alkanes of general formula $\text{C}_n\text{H}_{2n+2}$** , and because they are a mixture the components are **not chemically joined** and can be separated by a **physical** method.

Describing the process (C6.2j). The oil is **heated** until it vaporises and fed into the bottom of a **fractionating column** which is **hot at the bottom and cooler at the top**. Vapours rise; each fraction **condenses** when it reaches the level where the temperature falls to its boiling point, and is drawn off as a liquid at that level. The fractions collected are **not pure compounds** but **mixtures of hydrocarbons with similar boiling points and similar numbers of carbon atoms**.

Explaining it (C6.2k). The separation works because of a trend in molecular size: **the longer the hydrocarbon chain, the stronger the intermolecular forces between molecules**, so more energy is needed to separate them and the **boiling point is higher**. Long molecules therefore condense low down, where it is hottest; short molecules stay as vapour and reach the top. Along the same trend, longer chains are **more viscous, less volatile, less flammable and harder to ignite**.

Fraction (top to bottom)	Approximate chain length	Uses
Refinery gases	C ₁ –C ₄	Bottled gas (LPG) for heating and cooking
Petrol (gasoline)	C ₅ –C ₁₀	Fuel for cars
Naphtha	C ₆ –C ₁₁	Feedstock for the petrochemical industry — plastics, medicines, dyes
Kerosene (paraffin)	C ₁₀ –C ₁₆	Aircraft fuel, domestic heating
Diesel oil (gas oil)	C ₁₄ –C ₂₀	Fuel for lorries, buses, trains, ships
Fuel oil	C ₂₀ –C ₅₀	Fuel for large ships and power stations
Bitumen	C ₅₀ +	Road surfacing, roofing

The fractionating column, the fractions it separates and how their properties change down it.



Crude oil is heated until it evaporates. The vapours rise up the column, which is cooler near the top. Each fraction condenses at a different temperature and is collected. A fraction contains molecules with a similar number of carbon atoms.

Why it matters (C6.2m, C6.2n). Crude oil is the **main source of hydrocarbons** and the **feedstock of the petrochemical industry** — polymers, solvents, lubricants, detergents, medicines, dyes and fertilisers all come from it — and modern life depends on hydrocarbons for transport, heating, electricity generation and almost every manufactured material. But crude oil is **finite and non-renewable**: it is used far faster than it forms, and the molecules burned as fuel are the same ones that could be feedstock.

Cracking (C6.2o)

Describe the production of materials that are more useful by cracking, to include **the conditions and reasons for cracking**, and **some of the useful materials produced**.

Cracking is the breaking of long-chain hydrocarbon molecules into shorter, more useful ones. It is a **thermal decomposition** reaction.

The reason is a mismatch of supply and demand: fractional distillation produces far more of the **long-chain, low-demand** fractions (fuel oil, bitumen) than the market wants, and far less of the **short-chain, high-demand** fractions, especially **petrol**. Cracking converts the surplus into the shortage. It also produces **alkenes**, which distillation cannot, and alkenes are the starting materials for **polymers**, ethanol and other petrochemicals.

The conditions are either:

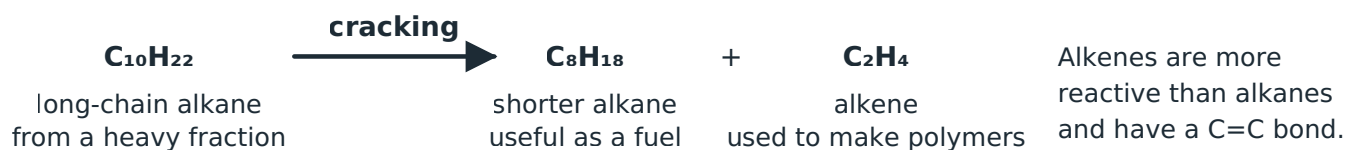
- **catalytic cracking** — heat the vapour to about **550 °C** and pass it over a hot **catalyst** (a zeolite or aluminium oxide); or
- **steam cracking** — mix the vapour with **steam** and heat to a **much higher temperature**, around 850 °C, with no catalyst.

The products. Every cracking reaction gives a **shorter alkane plus one or more alkenes**, and the equation must **balance**:

$\text{C}_{10}\text{H}_{22} \rightarrow \text{C}_8\text{H}_{18} + \text{C}_2\text{H}_4$ (decane → octane, for petrol, plus ethene, for poly(ethene))

Hydrogen is also produced in some cracking reactions, and is used in the Haber process and in fuel cells. The alkenes are tested for with **bromine water**, which they decolourise (C6.2c).

Cracking long-chain hydrocarbons into shorter alkanes and alkenes, and why it is done.



Catalytic cracking

Heat the long-chain hydrocarbon to vaporise it, then pass the vapour over a hot catalyst.

Steam cracking

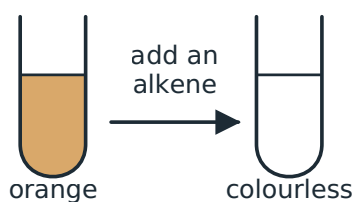
Heat the hydrocarbon to vaporise it, mix it with steam and heat it to a very high temperature.

Why crack hydrocarbons?

There is a high demand for fuels with small molecules, and cracking turns less useful long-chain hydrocarbons into shorter ones. Alkenes are used to make polymers and other useful chemicals.

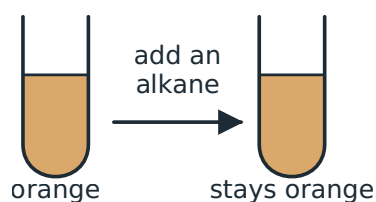
Testing with bromine water

with an alkene



Bromine water turns from orange to colourless.

with an alkane



The bromine water stays orange: no reaction. Alkenes are more reactive.

ANALOGY

Cracking — breaking up the pallet of long planks. A timber yard receives far more four-metre planks than anyone wants, while every customer is asking for one-metre lengths. Cutting the long planks into short ones does not create wood, it just **redistributes what you already have into the lengths people will pay for** — and every cut also produces useful offcuts (the alkenes) that can be made into something else entirely. Where the analogy stops: sawing is physical, whereas cracking **breaks covalent bonds**, needs high temperatures or a catalyst, and makes genuinely new substances.

CHEMISTRY ONLY Chemical cells and fuel cells (C6.2p, C6.2q)

CHEMISTRY ONLY Recall that a chemical cell produces a **potential difference** until the reactants are used up (C6.2p); **evaluate the advantages and disadvantages of hydrogen/oxygen and other fuel cells for given uses** (C6.2q), to include the chemistry of the hydrogen/oxygen fuel cell.

A **chemical cell** converts chemical energy into electrical energy: two different metals in an electrolyte produce a **potential difference**, the greater the difference in their reactivity the greater the potential difference. In a simple cell the reaction is not reversible, so the cell works **only until its reactants are used up**, and then goes flat.

A **fuel cell** avoids that: the fuel is **supplied continuously from outside**, so the cell runs for as long as it is fed. In the **hydrogen/oxygen fuel cell** the hydrogen is oxidised electrochemically rather than burned:

overall: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

HT ONLY at the negative electrode: $2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$ (oxidation)

HT ONLY at the

positive electrode: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$ (reduction)

The electrons pushed out at the negative electrode travel round the external circuit, doing work, and the only product is **water**.

NOTE

Maths for C6.2. CM6.2i **CHEMISTRY ONLY** represent three-dimensional shapes in two dimensions and vice versa when looking at chemical structures, e.g. the allotropes of carbon (M5b). A displayed formula is a flat drawing of a molecule that is not flat.

Advantages	Disadvantages
The only product at the point of use is water — no CO_2 , CO, NO_x or particulates	Hydrogen is usually made from natural gas or by electrolysis, so CO_2 may be released elsewhere
More efficient than a combustion engine, because there is no combustion or moving-parts stage	Hydrogen is explosive and needs careful handling
No recharging and no run-down: refuelling takes minutes	Hydrogen is a gas , so it is hard to store and transport, and must be compressed or liquefied
Few moving parts, so quiet and reliable; well suited to spacecraft and to vehicles	Expensive catalysts (platinum); very little refuelling infrastructure

For a **given use**, say which factors dominate: for a spacecraft, the mass saving and the drinkable water product are decisive; for a family car, the lack of refuelling stations and the storage problem currently favour a battery.

WATCH OUT

OCR's own note for this sub-topic: "*Learners tend not to bring the concepts from general chemistry in their study of organic chemistry. They have difficulty identifying functional groups and naming and drawing the compounds.*"

Organic chemistry is not a separate subject with its own rules. Balancing an equation, conservation of mass, covalent bonding, intermolecular forces, exothermic combustion and the reasoning behind catalysts are all exactly the same here as in C1–C5 — a cracking equation must balance like any other, and boiling point trends come straight from the intermolecular forces of C2.

For the naming and drawing, work in a fixed order: **count the carbons** to get the stem (meth-, eth-, prop-, but-), **find the functional group** to get the ending (-ane, -ene, -ol, -oic acid), then draw the carbon chain first, add the functional group, and only then fill every remaining bond on each carbon with hydrogen so that **every carbon has exactly four bonds**. A fully displayed formula with a carbon showing three or five bonds is the single most common drawing error.

C6.3 Interpreting and interacting with Earth systems

As our understanding of materials and chemical processes has improved, we are increasingly able to interpret chemical and Earth systems. Understanding how we interact with them matters to our survival as a species. This sub-topic starts with the history of the atmosphere and moves on to how human activity could be affecting its composition.

The early atmosphere (C6.3a)

Interpret evidence for how it is thought the atmosphere was originally formed, to include how the atmosphere has changed over time.

There are **no direct measurements** of an atmosphere from 4.6 billion years ago, so all theories are built on **indirect evidence** and are therefore uncertain and open to revision.

The most widely accepted account is that for the first billion years the Earth's surface was molten, and intense **volcanic activity** released gases that formed the early atmosphere. It is thought to have consisted mainly of **carbon dioxide**, with **water vapour**, and smaller amounts of **methane** and **ammonia** — and **little or no oxygen**, much like the atmospheres of Mars and Venus today. As the Earth cooled, the water vapour **condensed to form the oceans**.

The evidence includes the gases released by volcanoes today, the atmospheres of neighbouring planets, **iron compounds in ancient rocks** that could only have formed without oxygen (overlaid by banded iron formations that could only have formed with it), and the ages of the oldest fossils. Every line is indirect, which is why the theory has been revised repeatedly (WS1.1a).

An oxygen-rich atmosphere (C6.3b)

Describe how it is thought an oxygen-rich atmosphere developed over time, to include knowledge of how the composition of the atmosphere developed over time.

Once the oceans had formed, two changes ran together:

- **Carbon dioxide fell.** It **dissolved in the oceans**; dissolved carbonates were **precipitated as sediments** which became carbonate rocks; marine organisms used carbonates to build **shells and skeletons**, which formed limestone; and the remains of plants and plankton, buried and compressed, locked carbon away as **coal, crude oil and natural gas**.
- **Oxygen rose.** About 2.7 billion years ago **algae**, and later **green plants**, began **photosynthesis**: **carbon dioxide + water → glucose + oxygen**. Oxygen accumulated slowly — first oxidising dissolved iron in the oceans, then building up in the air — until it reached a level that allowed animals to evolve.

Today's atmosphere is roughly **80% nitrogen, 20% oxygen**, with small proportions of argon, carbon dioxide and water vapour. It has been broadly stable for about the last 200 million years.

How the composition of the atmosphere is thought to have changed over 4.6 billion years.

1 Volcanoes

Intense volcanic activity released:

- mostly carbon dioxide
 - water vapour
 - nitrogen
 - small amounts of methane, ammonia
- Little or no oxygen.

2 Oceans form

Water vapour condensed to form the oceans. Carbon dioxide dissolved in the water. Carbonates were precipitated as sediments, so CO₂ in the air fell.

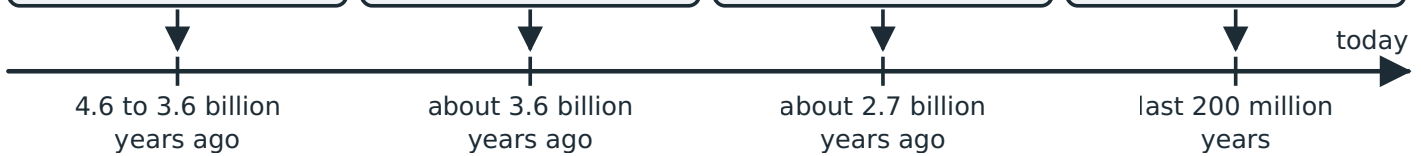
3 Photosynthesis

About 2.7 billion years ago algae made oxygen by photosynthesis. Plants evolved over the next billion years, so oxygen rose and animals could evolve.

4 CO₂ locked up

Carbon dioxide was locked up in:

- sedimentary rocks such as limestone
 - fossil fuels: coal, crude oil, gas
- For 200 million years the atmosphere has been as it is today.



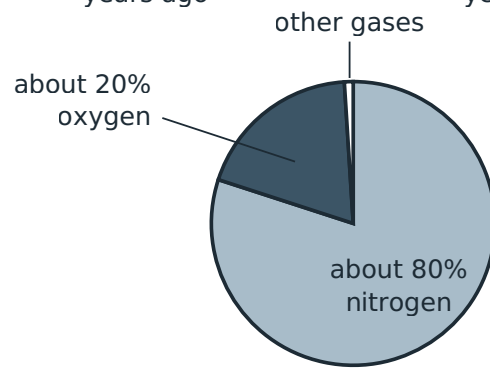
How oxygen increased

carbon dioxide + water → glucose + oxygen



Algae first produced oxygen about 2.7 billion years ago; the percentage of oxygen then rose gradually until animals could evolve.

Evidence for the early atmosphere is limited because of the 4.6 billion year time scale.



Today's atmosphere

other gases: carbon dioxide, water vapour and noble gases

The greenhouse effect (C6.3c)

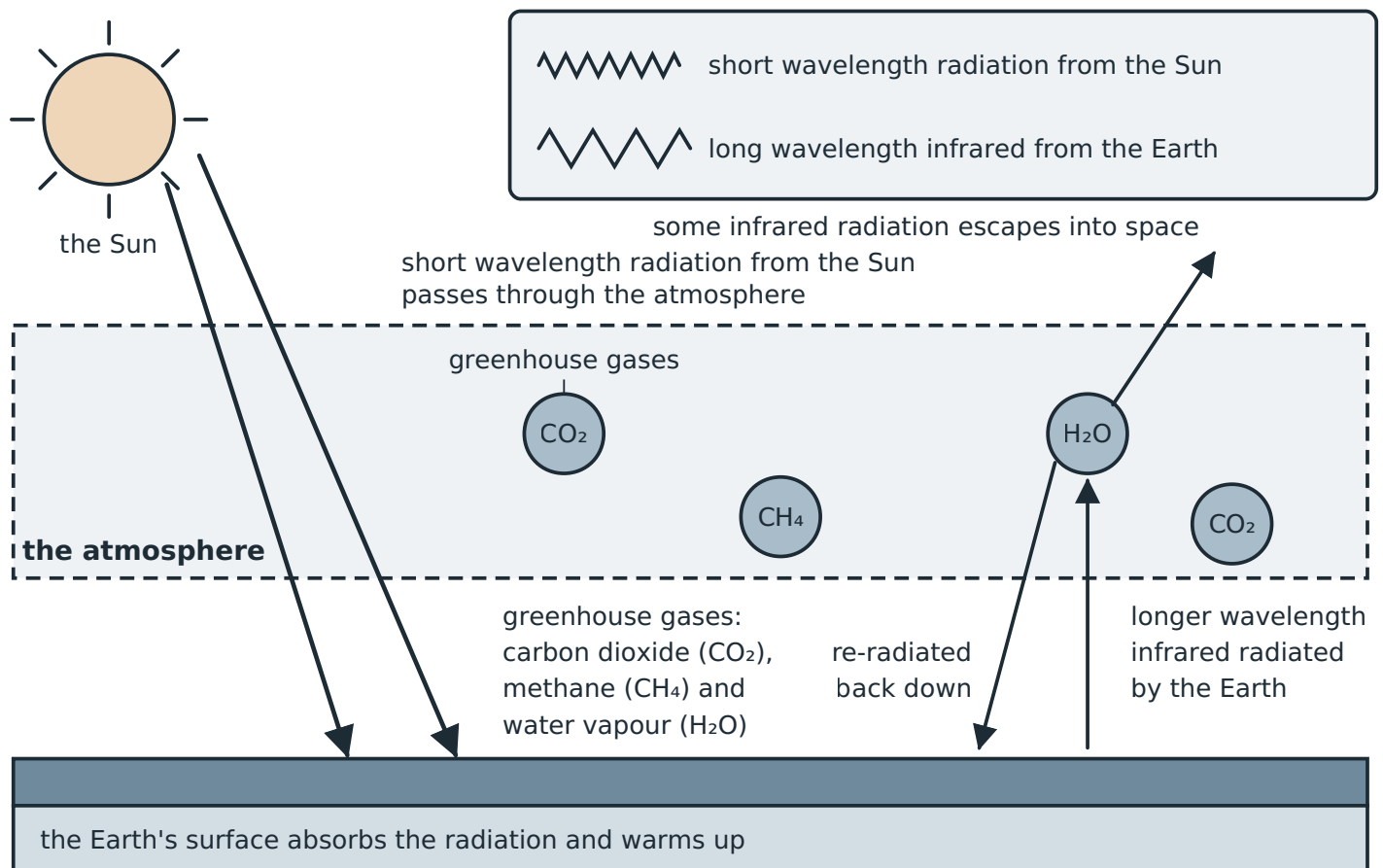
Describe the greenhouse effect in terms of the interaction of radiation with matter, to include within the atmosphere.

The greenhouse effect is a **natural and essential** process — without it the Earth's mean surface temperature would be around -18°C . In terms of the interaction of radiation with matter:

1. **Short-wavelength radiation**, mostly visible light, from the Sun passes **through** the atmosphere, because greenhouse gases do not absorb these wavelengths.
2. It is **absorbed by the Earth's surface**, warming it.
3. The warmed surface **re-emits energy as longer-wavelength infrared radiation**.
4. **Greenhouse gases — carbon dioxide, methane and water vapour — absorb this infrared** and re-radiate it in all directions, including **back towards the surface**.
5. The energy is therefore **trapped in the lower atmosphere**, keeping the Earth warmer than it would otherwise be.

The **greenhouse gases** are named in the spec as carbon dioxide, methane and water vapour. Adding more of them thickens the "blanket": more infrared is absorbed and re-radiated downwards, and the surface warms further.

How greenhouse gases absorb and re-radiate the infrared emitted by the Earth's surface.



Greenhouse gases absorb the longer wavelength infrared radiation and re-radiate it, some of it back towards the Earth's surface.

Evidence for human-caused climate change (C6.3d)

Evaluate the evidence for additional anthropogenic (human activity) causes of climate change, and describe the uncertainties in the evidence base, to include the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels.

The evidence for. Atmospheric carbon dioxide has risen from about 280 ppm before the Industrial Revolution to over 400 ppm now, and the rise **correlates closely with the consumption of fossil fuels**. Global mean surface temperature has risen over the same period. Ice cores give hundreds of thousands of years of paired temperature and CO₂ data, and the mechanism (C6.3c) is well understood and reproducible in the laboratory.

The uncertainties. The climate system is **enormously complex**, with interacting variables and **feedback loops** — melting ice reflects less, warming oceans release dissolved CO₂ — that are hard to model. **Correlation does not prove causation**. Data from before direct measurement are **proxy** data from ice cores, tree rings and sediments, each with its own error, and models rest on **simplifying assumptions**, so different models predict differently. Natural causes — volcanic activity, solar variation, orbital cycles — also affect climate.

Evaluating. No single line of evidence is conclusive, but the **correlation, the known mechanism, the scale of emissions and the agreement of independent datasets together** make the anthropogenic contribution very strongly supported, which is why it is the consensus of **peer-reviewed** science even though individual predictions carry real uncertainty (WS1.1f, WS1.1h, WS1.1i).

WATCH OUT

OCR's own note for this sub-topic: "*Learners think that the atmosphere is large and that small increases of carbon dioxide or a few degrees of temperature change do not make a difference to the climate. They may consider that global warming is caused by the ozone hole and that human activities alone cause the greenhouse effect.*"

Three corrections. (i) **Small numbers are not small effects** — see the worked example above; a change of a few degrees in the *global mean* represents an enormous redistribution of energy, even though a few degrees of local weather is unremarkable. (ii) **The ozone hole is a different problem**. Ozone depletion, caused by CFCs, lets more ultraviolet through; the greenhouse effect is about **infrared** being absorbed on its way out. They involve different gases, different wavelengths and different consequences. (iii) **The greenhouse effect is natural and necessary** — without it the Earth would be frozen. Human activity is causing an **enhanced** greenhouse effect by adding to gases that were already there.

Effects of increased carbon dioxide and methane, and mitigation (C6.3e)

Describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate, and how these effects may be mitigated, to include consideration of scale, risk and environmental implications.

Sources. Carbon dioxide comes chiefly from **burning fossil fuels** and from **deforestation**, which also removes the trees that would absorb it. Methane comes from **cattle, rice paddy fields, landfill sites** and leaks from natural gas extraction; there is much less of it, but each molecule absorbs far more infrared than a CO₂ molecule.

Potential effects. Rising global mean temperature; **melting ice caps and glaciers** and **thermal expansion of the oceans**, raising sea levels and flooding low-lying land; **more extreme weather** — storms, droughts, floods; **changes in the amount and distribution of rainfall**, affecting where crops can be grown; loss of habitats and changes in species distribution; and the **oceans becoming more acidic** as they absorb more CO₂, damaging shell-forming organisms.

Mitigation.

- Use **renewable and nuclear energy** instead of fossil fuels.
- Improve **energy efficiency** and reduce demand.
- **Carbon capture and storage** — trapping CO₂ from power stations and storing it underground.
- **Planting trees** and stopping deforestation.
- **Carbon taxes, caps and international agreements** to make emissions costly.
- Reduce methane at source: alternative livestock feed, capturing landfill gas, better rice-field management.

Scale, risk and environmental implications. Every measure has drawbacks: the scale is global and the timescale decades; carbon capture is unproven at scale and may leak; wind and solar are intermittent and alter landscapes; nuclear power leaves long-lived waste. Because emissions and consequences fall on different countries, action needs politically difficult international agreement. A good six-mark answer names measures, gives their limitations and reaches a supported judgement.

Atmospheric pollutants (C6.3f)

Describe the major sources of carbon monoxide, sulfur dioxide, oxides of nitrogen and particulates in the atmosphere, and explain the problems caused by increased amounts of these substances.

Most of these come from **burning fuels**, which is why they usually appear together in a question about a car engine or a power station.

Pollutant	Major source	Problems caused
Carbon monoxide, CO	Incomplete combustion of hydrocarbon fuels where the oxygen supply is limited — faulty boilers, car engines	Toxic : binds to haemoglobin in place of oxygen, so less oxygen is carried; causes drowsiness, unconsciousness and death. Colourless and odourless , so it gives no warning
Sulfur dioxide, SO ₂	Sulfur impurities in fuels, especially coal and heavy fuel oil, oxidised on burning	Dissolves in cloud droplets to form acid rain , which damages trees and aquatic life, erodes limestone buildings and statues, and corrodes metals; also a respiratory irritant
Oxides of nitrogen, NO _x	Nitrogen and oxygen from the air reacting in the high temperatures inside engines and furnaces	Acid rain : respiratory problems including asthma; contribute to photochemical smog
Particulates (soot and unburnt solids)	Incomplete combustion , especially of diesel	Cause and worsen respiratory disease and are linked to cancer; deposit on buildings as global dimming reduces the sunlight reaching the surface

Note the distinction the examiner is looking for: **carbon dioxide is not a pollutant in this sense** — it is not toxic and does not cause acid rain; its problem is the enhanced greenhouse effect.

Potable water (C6.3g)

Describe the principal methods for increasing the availability of potable water in terms of the separation techniques used, to include the ease of treatment of waste, ground and salt water.

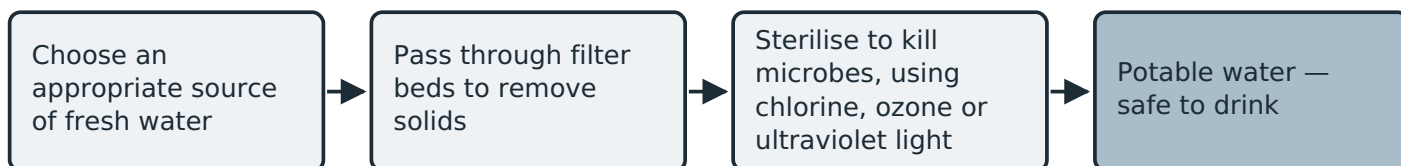
Potable water is water that is safe to drink. It is **not pure water**: it contains dissolved salts and low levels of other substances, at concentrations low enough not to be harmful. Pure water contains only H₂O.

Source	Treatment, in order	How easy?
Ground and surface fresh water (rivers, lakes, aquifers)	Screening to remove large solids → sedimentation to settle out fine solids → filtration through sand and gravel → sterilisation with chlorine, ozone or ultraviolet light	Easiest and cheapest : low levels of dissolved salts, so no desalination needed. The usual UK method
Salt (sea) water	Desalination by distillation or by reverse osmosis through a membrane, then sterilisation	Hardest and most expensive — huge amounts of energy to boil or to force water through a membrane; used where fresh water is scarce
Waste water (sewage, agricultural and industrial)	Screening and grit removal → sedimentation producing sludge and effluent → anaerobic digestion of the sludge → aerobic biological treatment of the effluent	Intermediate : it needs more stages than fresh water because of the organic matter and harmful microbes, but far less energy than desalination. Industrial waste may also need specific treatment for toxic metals

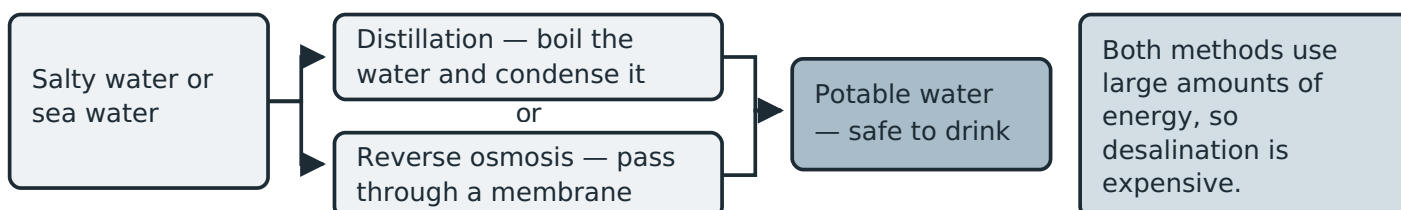
The **less treatment a source needs, the cheaper and less energy-intensive** it is, so fresh water is used wherever it exists and desalination is a last resort.

Treating fresh water, sea water and waste water to make it potable.

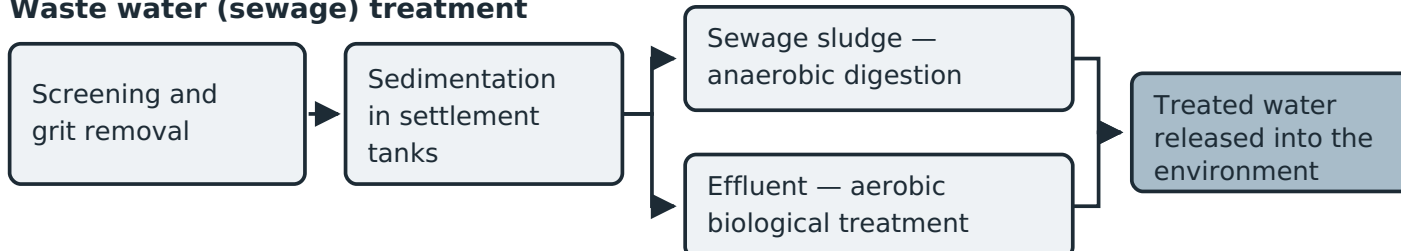
Potable water from fresh water (ground water, lakes and rivers)



Potable water from salty water or sea water — desalination



Waste water (sewage) treatment



Potable water is not pure water in the chemical sense — it still contains dissolved substances.

Ease of obtaining potable water: fresh water is easiest, then waste water; salty water is hardest because desalination needs the most energy.

NOTE

Maths for C6.3. CM6.3i extract and interpret information from charts, graphs and tables (M2c, M4a); CM6.3ii use **orders of magnitude** to evaluate the significance of data (M2h). Both are examined by giving you a data set on CO₂, temperature or pollutant levels and asking you to describe, calculate and evaluate — not to recall figures.