

Fuels and Earth science

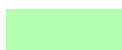
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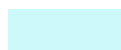
Revision notes for one topic, free to download.

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

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Define Crude oil

- a complex mixture of hydrocarbons, formed over millions of years; a finite resource.

Define Feedstock

- a raw material fed into an industrial process; crude oil is the feedstock for the petrochemical industry.

Define Fractional distillation

- separating a mixture of liquids using the differences in their boiling points.

Define General formula

- a formula that works for every member of a homologous series, e.g. C_nH_{2n+2} .

Define Alkene

- an unsaturated hydrocarbon containing a C=C double bond.

Define Unsaturated

- containing at least one carbon-carbon double bond.

Define Complete combustion

- burning a fuel in a plentiful supply of oxygen, producing carbon dioxide and water and giving out energy (8.7).

Define Cracking

- breaking down larger, saturated hydrocarbon molecules into smaller, more useful ones, some unsaturated (8.16).

Define Acid rain

- rain made acidic by dissolved sulfur dioxide and oxides of nitrogen.

Define Hydrocarbon

- a compound that contains carbon and hydrogen only (8.1).

Define Finite resource

- a resource being used up far faster than it is made, so supplies will run out.

Define Fraction

- a mixture of hydrocarbons with boiling points within a certain range, collected from a fractionating column.

Define Homologous series

- compounds with the same general formula, differing by CH_2 , showing gradual variation in physical properties and having similar chemical properties (8.6).

Define Alkane

- a saturated hydrocarbon containing only single carbon-carbon bonds.

Define Saturated

- containing only single bonds between carbon atoms.

Define Viscosity

- how thick a liquid is; high viscosity means it flows slowly.

Define Incomplete combustion

- burning in a limited supply of oxygen, also producing carbon monoxide and/or carbon (soot).

Define Non-renewable fossil fuel

- a fuel formed from the remains of living organisms, not replaced as fast as it is used (8.15).

Define Greenhouse effect

- gases in the atmosphere absorb heat radiated from the Earth and release energy, keeping the Earth warm (8.24).

There is **no core practical** in Topic 8 — the specification lists suggested practicals only, given at the end of this topic.

8.1–8.2, 8.15 Hydrocarbons and crude oil

- A **hydrocarbon** contains **carbon and hydrogen only** (8.1). Any oxygen, nitrogen or sulfur in the molecule and it is not a hydrocarbon.
- Crude oil** is (8.2): **a a complex mixture of hydrocarbons; b** made of molecules whose carbon atoms are in **chains or rings** (names, formulae and structures of ring molecules are not required); **c** an important **source of useful substances** — **fuels and feedstock for the petrochemical industry** (polymers, solvents, detergents, drugs, dyes); **d** a **finite resource**, formed over millions of years from buried remains of ancient organisms and used far faster than it forms.
- Non-renewable fossil fuels** to recall (8.15): **petrol, kerosene and diesel oil** from crude oil, and **methane**, found in natural gas.

WATCH OUT

"Crude oil is a compound." No — it is a **mixture**, which is exactly why it separates by a *physical* method with no chemical reaction, and why it has no fixed boiling point.

8.3–8.4 Fractional distillation and the fractions

Fractional distillation separates crude oil into **fractions** — mixtures whose molecules have similar chain lengths and so boil over a similar temperature range (8.3).

- Crude oil is **heated** until most of it **evaporates**; the vapour enters the bottom of a **fractionating column**.
- The column is **hot at the bottom, cooler at the top**.
- Vapours rise and **condense** at the level where the temperature falls to their **boiling point**.
- Long chains** have **strong intermolecular forces** and **high boiling points**, so condense low down.
- Short chains** have weaker forces and **low boiling points**, so rise higher; the shortest leave the top as gases.
- Each fraction collected is still a **mixture**, not a pure substance.

ANALOGY

FRACTIONAL DISTILLATION

A crowd climbing a heated tower block that gets colder higher up. The heavy, sluggish molecules give up on the ground floor; the light, energetic ones sprint to the roof. Nobody is *changed* by the climb — they are only sorted by how far they get, which is why this is a physical separation, not a reaction.

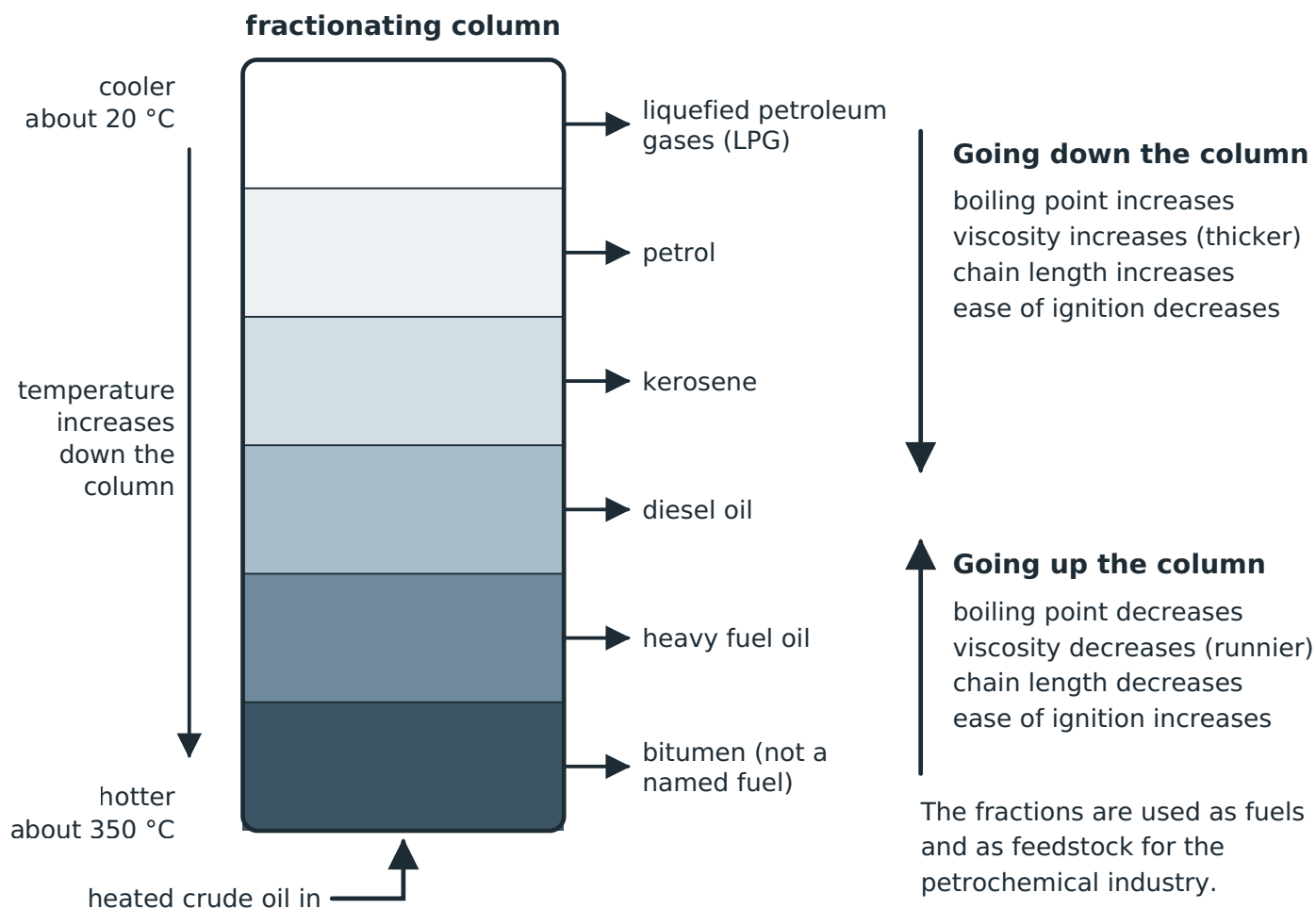
NOTE

THE FRACTIONS AND THEIR USES (8.4)

Fraction	Use (learn exactly)	Molecule size and boiling point	Ease of ignition and viscosity
Gases	Domestic heating and cooking	Shortest chains, lowest bp	Ignite most easily; least viscous
Petrol	Fuel for cars	Short chains, low bp	Ignites easily; runny
Kerosene	Fuel for aircraft	Medium chains	Fairly easy to ignite; fairly runny
Diesel oil	Fuel for some cars and trains	Longer chains	Harder to ignite; more viscous
Fuel oil	Fuel for large ships and some power stations	Long chains, high bp	Hard to ignite; very viscous
Bitumen	Surfacing roads and roofs	Longest chains, highest bp	Hardest to ignite; a thick, near- solid tar

Order down the column: **G**ases, **P**etrol, **K**erosene, **D**iesel, **F**uel oil, **B**itumen.

Fractional distillation of crude oil and the fractions



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.

8.5 How the fractions differ

The fractions are **mostly members of the alkane homologous series** and differ in four ways (8.5):

- **a Number of carbon and hydrogen atoms** — molecules get larger down the column.
- **b Boiling point** — **increases** with molecule size: more electrons and larger molecules mean **stronger intermolecular forces**, needing more energy to overcome.
- **c Ease of ignition** — **decreases** with size. Small molecules evaporate readily, mix with air and light easily.
- **d Viscosity** — **increases** with size. Long chains tangle and attract strongly, so flow poorly.

WATCH OUT

Ignition and viscosity are often given the wrong way round. Anchor on **bitumen**: biggest molecules, treacle-like (very viscous), will not light (hard to ignite). Everything else follows.

8.6 Homologous series and the alkanes

A **homologous series** is a series of compounds which (8.6): **a** have the **same general formula**; **b** differ by CH_2 in molecular formulae from neighbouring compounds; **c** show a **gradual variation in physical properties**, exemplified by **boiling points**; **d** have **similar chemical properties** (same functional group).

8.7 Complete combustion

Complete combustion happens in a **plentiful supply of oxygen** (8.7): **a carbon dioxide and water** are produced; **b energy is given out** — combustion is **exothermic**. A clean blue flame indicates complete combustion and releases the **most energy** per gram of fuel.

8.8–8.10 Incomplete combustion, carbon monoxide and soot

In a **limited supply of oxygen** there is not enough oxygen to oxidise every carbon atom to carbon dioxide (8.8). Some carbon is only **partially oxidised** to **carbon monoxide (CO)**; some is not oxidised at all and is released as **carbon (soot)**. Water is still produced, and **less energy is released**.

Why carbon monoxide is toxic (8.9)

- CO is **colourless and odourless**, so it cannot be detected by the senses.
- It binds to **haemoglobin** in red blood cells **in place of oxygen**, and binds far more strongly.
- This **reduces the oxygen the blood can carry**, causing drowsiness, unconsciousness and death.

Problems in appliances burning carbon compounds (8.10)

- Faulty or badly ventilated boilers, heaters and stoves produce **carbon monoxide**, which builds up indoors and can kill.
- **Soot** is deposited inside appliances, flues and chimneys, **blocking pipes and burners** so combustion becomes even more incomplete, and it can **catch fire** in a chimney.
- Soot released into the air **blackens buildings** and, breathed in, **damages the lungs**.
- Incomplete combustion also **wastes fuel** — less energy per gram.

8.11–8.13 Sulfur dioxide, acid rain and oxides of nitrogen

Sulfur dioxide (8.11). Some hydrocarbon fuels contain **sulfur impurities**. When the fuel burns the sulfur is **oxidised to sulfur dioxide**: $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$.

Acid rain (8.12). Sulfur dioxide **dissolves in rain water** to form an acidic solution, which falls as **acid rain**. Problems:

- it **erodes buildings and statues** made of limestone and marble, and **corrodes metal** structures;
- it **lowers the pH of lakes and rivers**, killing fish and other aquatic organisms;
- it **damages trees and plants**, directly and by acidifying soils so mineral ions are washed out;
- the pollution **travels on the wind**, so the acid rain may fall in a different country from the one that produced it;
- sulfur dioxide also causes **breathing difficulties**.

Oxides of nitrogen (8.13). Nitrogen is normally very **unreactive**, but inside an **engine** the temperature is **very high**. At these high temperatures nitrogen and oxygen from the **air** **have enough energy to react together**, forming **oxides of nitrogen** (NO and NO₂, written NO_x). These are pollutants: they contribute to **acid rain**, cause **respiratory problems** and help form **photochemical smog**.

NOTE

POLLUTANTS FROM BURNING FUELS

Pollutant	How it is produced	Problems it causes
Carbon dioxide, CO ₂	Complete combustion of any hydrocarbon fuel	A greenhouse gas — enhanced greenhouse effect and climate change
Carbon monoxide, CO	Incomplete combustion, limited oxygen	Toxic; colourless and odourless; binds to haemoglobin so blood carries less oxygen
Carbon (soot)	Incomplete combustion, limited oxygen	Blocks and fouls appliances; blackens buildings; damages lungs
Sulfur dioxide, SO ₂	Sulfur impurities in the fuel oxidised on burning	Dissolves in rain water to give acid rain — erodes buildings, kills aquatic life, damages trees; breathing problems
Oxides of nitrogen, NO _x	Nitrogen and oxygen from the air react at the high temperatures in engines	Acid rain; respiratory problems; photochemical smog
Water vapour, H ₂ O	Complete or incomplete combustion	Also a greenhouse gas (8.24)

8.14 Hydrogen as a fuel in cars

An "evaluate" question (8.14) needs both sides **and** a judgement.

Judgement: hydrogen is far cleaner *at the point of use*, but is only genuinely low-carbon if the electricity used to make it is renewable.

Advantages of hydrogen	Disadvantages of hydrogen
The only combustion product is water — no CO ₂ , CO, soot or SO ₂	A gas , so a large volume is needed; must be stored at high pressure or very low temperature
No greenhouse gas released at the point of use	Highly flammable/explosive with air, so storage and refuelling are hazardous
Can be made from water by electrolysis, so supply need not be finite	Making it uses energy , often from fossil fuels, so pollution is moved elsewhere
Releases a large amount of energy per gram	Very few filling stations ; engines need modifying or replacing
No sulfur impurities, so no acid rain	Expensive to produce, transport and store

8.16–8.17 Cracking

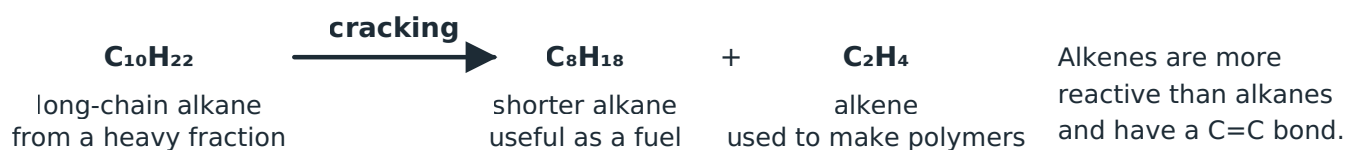
Cracking is the **breaking down of larger, saturated hydrocarbon molecules (alkanes) into smaller, more useful ones, some of which are unsaturated (alkenes)** (8.16).

- The large alkane is **heated to vaporise it** and passed over a **hot catalyst** (or mixed with steam at high temperature); **carbon-carbon bonds break**.
- It is a **thermal decomposition**: one reactant, several products.
- Every cracking equation gives **at least one alkene**, because the fragments lack the hydrogen needed to be fully saturated.

Why cracking is necessary (8.17)

- **Supply and demand for the fractions do not match**: distillation gives a **surplus of long-chain fractions** (fuel oil, bitumen) and **not enough short-chain fractions**, especially **petrol**, which is in **high demand**.
- Cracking converts the surplus into **shorter, more useful molecules** that burn more easily and are worth more.
- It also makes **alkenes**, the monomers for **polymers** and other petrochemicals.
- It therefore **makes better use of a finite resource**.

Cracking a long-chain alkane



Catalytic cracking

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

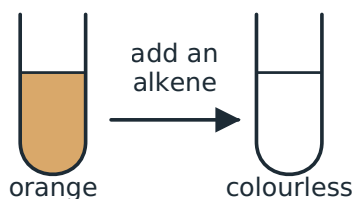
Steam cracking

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

Why crack hydrocarbons?

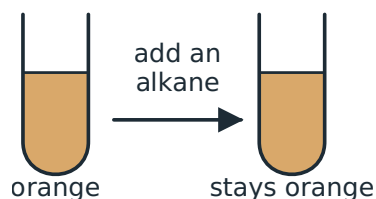
There is a high demand for fuels with small molecules, and cracking turns less useful long-chain hydrocarbons into shorter ones. Alkenes are used to make polymers and other useful chemicals.

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

A timber yard is stuck with a warehouse of three-metre planks nobody wants, while every customer queues for shelf-length pieces. Cracking is the saw. And like sawing, you also get useful offcuts — the alkenes — which turn out to be worth more than the planks.

8.18–8.19 The Earth's early atmosphere

- The gases produced by **volcanic activity** formed the Earth's early atmosphere (8.18) — intense volcanic activity in the first billion years released gases from inside the Earth.
- The early atmosphere is **thought to have contained** (8.19): **a little or no oxygen; b a large amount of carbon dioxide; c water vapour; d small amounts of other gases**, including ammonia and methane. It is believed to have been similar to the atmospheres of **Mars and Venus** today.

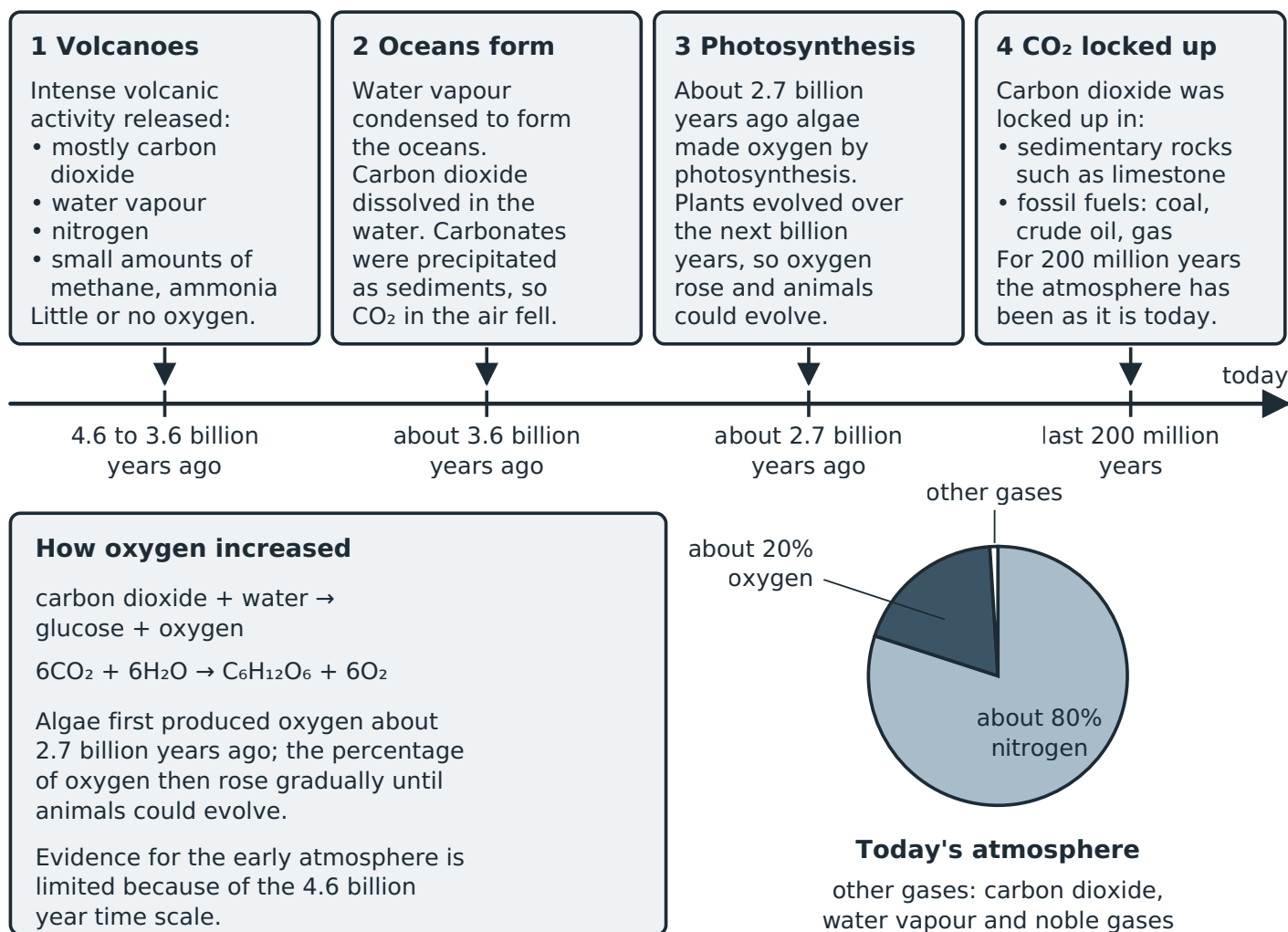
Interpreting the evidence (8.19)

- The evidence is **indirect**: gases from present-day volcanoes; the atmospheres of other planets; gas bubbles trapped in ancient rocks and ice; and the chemistry of the oldest rocks (banded iron formations only form when oxygen is scarce).
- Because these events happened around **4.6 billion years ago** with **no direct measurement**, all theories are **tentative**. Evidence is scarce, rocks have been altered or destroyed, and scientists interpret the same data differently — so theories have **changed over time**.

8.20–8.22 How today's atmosphere evolved

1. **Oceans formed (8.20)**. As the Earth **cooled**, **water vapour condensed** to liquid water, fell as torrential rain and collected in hollows in the crust as the **oceans**.
2. **Carbon dioxide fell (8.21)**. CO_2 is soluble, so as the oceans formed large amounts of **carbon dioxide dissolved, decreasing the amount in the atmosphere**. In the oceans it formed **carbonates**, precipitated as **sediments** that became sedimentary rock such as limestone, and shells and skeletons of marine organisms locked carbon away. Some carbon also became locked in **fossil fuels**.
3. **Oxygen rose (8.22)**. **Primitive plants** evolved in the oceans. They **used carbon dioxide and released oxygen by photosynthesis**, so **the amount of oxygen gradually increased** over about two billion years — slowly at first, as early oxygen reacted with dissolved iron. Rising oxygen allowed animals to evolve.

How the Earth's atmosphere evolved



8.23 The chemical test for oxygen

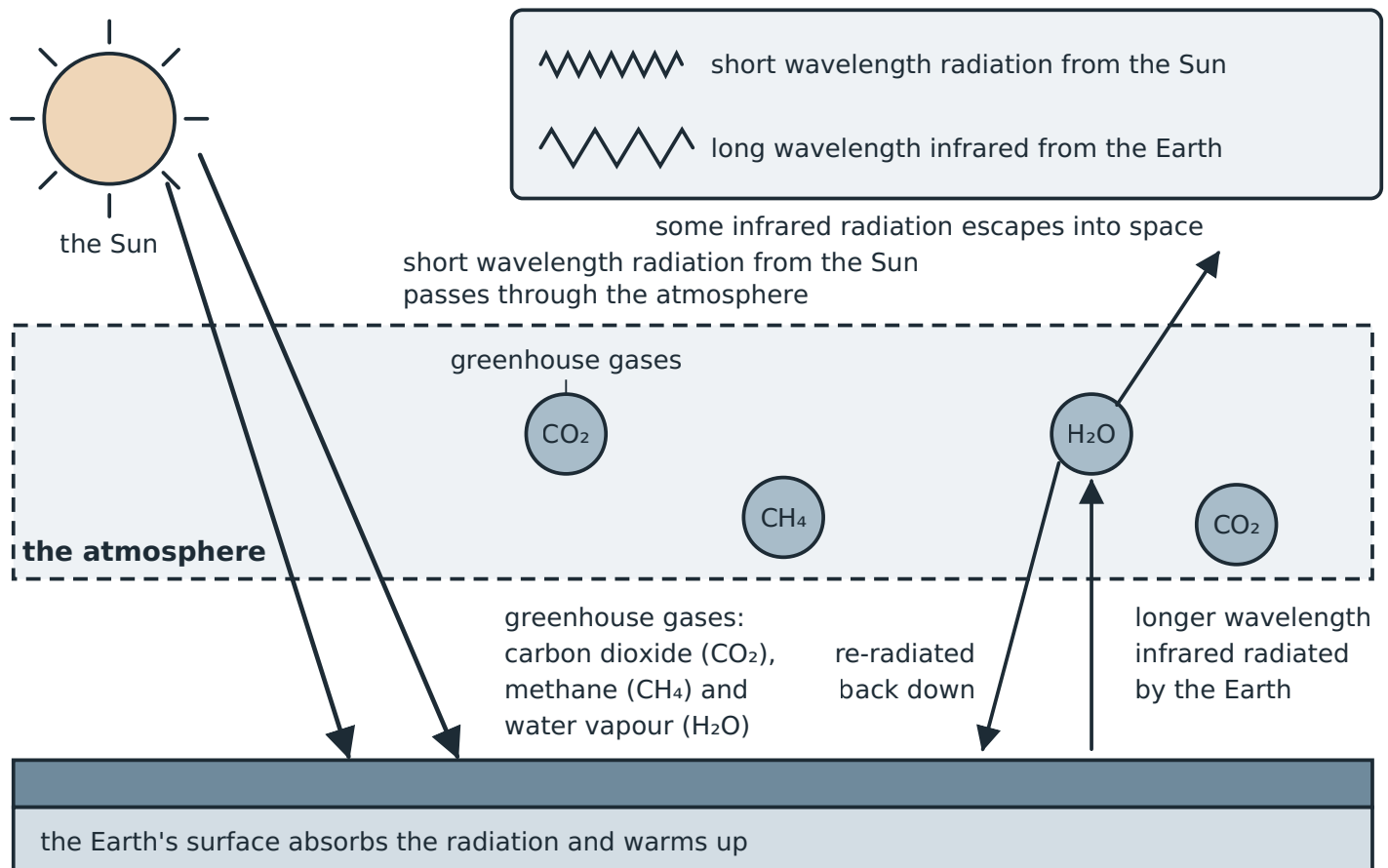
8.24 The greenhouse effect

Various gases, including carbon dioxide, methane and water vapour, absorb heat radiated from the Earth and subsequently release energy, which keeps the Earth warm (8.24).

1. Short-wavelength radiation from the Sun passes through the atmosphere and is absorbed by the Earth's surface, warming it.
2. The warmed Earth radiates energy back out as longer-wavelength infrared.
3. Greenhouse gases absorb this outgoing heat radiation.
4. They release energy, some back towards the Earth, keeping the surface warmer than it would otherwise be.

The greenhouse effect is **natural and essential** — without it the average temperature would be about -18°C . The problem is the **enhanced** greenhouse effect caused by human activity raising the concentration of these gases.

The greenhouse effect



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

ANALOGY

THE GREENHOUSE EFFECT

A greenhouse gas works like a duvet, not a mirror. Sunlight passes straight through to warm you; the heat you radiate back is absorbed by the duvet and re-emitted in all directions, including back onto you. More CO₂ and methane is a thicker duvet — the Sun does not get hotter, but less of your heat escapes. (Where it breaks down: a real greenhouse mostly works by stopping warm air mixing away.)

8.25–8.26 Climate change: evidence, risks and uncertainties

The composition of today's atmosphere (8.26a)

Water vapour is also present but variable, which is why these figures are for *dry* air.

Evidence that human activity is causing climate change (8.25)

- **a** There is a **correlation** between three data sets over the last two centuries: **atmospheric carbon dioxide concentration** has risen, **consumption of fossil fuels** has risen, and **average global temperature** has risen. Ice cores, monitoring stations and temperature records show the same pattern.
- **b** Uncertainties: **the location where measurements are taken** — a station in a city, by an airport or beside industry gives higher CO₂ and temperature readings than a rural or oceanic site, so few or badly-chosen sites are unrepresentative; and **historical accuracy** — older records used **less accurate instruments**, at irregular times and by different methods, and pre-instrumental data is **indirect** (ice cores, tree rings), so less reliable.
- **Correlation does not prove causation** — but the correlation is strong and the mechanism (the greenhouse effect) is well understood, so the **vast majority of scientists** accept human activity is the cause.

Gas	Approximate proportion of dry air
Nitrogen	about 78% (four-fifths)
Oxygen	about 21% (one-fifth)
Argon and other noble gases	about 0.9%
Carbon dioxide	about 0.04%

WATCH OUT

"Scientists cannot agree about climate change." There is a **scientific consensus** that human activity is causing it. The real uncertainties in 8.25b concern **how much** and **how fast**, and the reliability of particular measurements — not whether the greenhouse effect is real.

Potential effects of increased carbon dioxide and methane (8.26b)

Human activities include **burning fossil fuels** (releasing CO₂ locked away for millions of years), **deforestation** (fewer trees removing CO₂), and **livestock farming** and landfill (releasing **methane**). Potential effects:

- **rising average global temperatures;**
- **melting polar ice and glaciers** plus **thermal expansion of the oceans**, so **sea levels rise** and low-lying land floods;
- **changed rainfall patterns** — drought in some regions, flooding in others, reduced crop yields;
- **more frequent, more severe extreme weather;**
- **changed species distribution**, habitat loss and reduced biodiversity;
- more CO₂ **dissolving in the oceans**, making them more acidic.

Mitigation: scale, risk and environmental implications (8.26c)

- **Scale** — the measure must be big enough to matter. Individuals driving less helps, but global emissions are on a vastly larger scale, so international agreements and whole-grid changes are needed, and cost rises sharply with scale.
- **Risk** — carbon capture and storage risks the stored CO₂ leaking; large-scale geo-engineering has effects that cannot be reliably predicted or reversed.
- **Environmental implications** — renewables, forest planting and hydrogen all have knock-on effects: land use, habitat loss, and mining for batteries.
- Measures include **renewable energy**, **energy efficiency**, **planting trees**, reducing **livestock farming**, **carbon capture and storage**, and international carbon targets. Mitigation is possible but expensive and needs **international cooperation**.

Use of mathematics for this topic

- **Extract and interpret information from charts, graphs and tables** (2c, 4a) — CO₂ and temperature against time; boiling point against chain length.
- **Use orders of magnitude to evaluate the significance of data** (2h) — CO₂ is only about 0.04% of the atmosphere, so a rise from 280 to 420 ppm is a small *absolute* change but a 50% *relative* increase; decide which comparison is meaningful.

Suggested practicals for this topic

No core practical, but practical-skills questions may be set on these.

- **Fractional distillation of synthetic crude oil, and the ease of ignition and viscosity of the fractions** — heat in a boiling tube with a thermometer, collect distillate over set temperature ranges into separate tubes, then compare how fast each runs down a tilted tile and how easily each burns on mineral wool. Later fractions are darker, more viscous, harder to ignite and burn more smokily.
- **Products of the complete combustion of a hydrocarbon** — draw the products of a burning candle through a cooled U-tube (the colourless liquid turns anhydrous copper(II) sulfate white → blue, showing **water**) and then through limewater (turns **milky**, showing **carbon dioxide**).
- **Cracking paraffin oil** — heat paraffin-soaked mineral wool, pass the vapour over hot broken pot or pumice as catalyst, collect the gas over water. **Bromine water** turns orange → colourless, showing an **alkene**. Remove the delivery tube from the water *before* you stop heating, to prevent suck-back.
- **Investigate the proportion of oxygen in the atmosphere; the presence of water vapour and carbon dioxide in the atmosphere; the volume of air used up and products formed when candles are burned; and carry out the test for oxygen** (8.23).