

9 • Chemistry of the atmosphere

AQA • GCSE • Chemistry

Chemistry of the atmosphere: explain the evidence

An engine can produce several invisible gases. A thermometer alone cannot tell us which gas caused a change. This topic links observations to chemical explanations: how air changed, how radiation transfers energy, and how the products of burning depend on the fuel and conditions.

Use a three-part answer: **source or action** → **chemical process** → **consequence**. Distinguish a measured result from an interpretation. The numbered sections below cover AQA 8462 4.9.1.1–4.9.3.2, both tiers. Earlier topics supply balanced equations, percentages, combustion and the carbon cycle; practical performance is separate.

Today's atmosphere: fractions and samples (4.9.1.1)

For about 200 million years, the main proportions have been much as today: roughly **four-fifths nitrogen** and **one-fifth oxygen**. Small amounts include noble gases, carbon dioxide and water vapour. The more precise familiar dry-air approximations are about 78% nitrogen and 21% oxygen; these do not imply that the remaining 1% is all carbon dioxide. Water-vapour content varies, so specify dry air if using a dry-air composition.

Worked sample. Estimate the nitrogen volume in 250 cm³ of air using the syllabus approximation. Assume all gas volumes refer to the same temperature and pressure.

$$V(\text{N}_2) = f(\text{N}_2)V(\text{air}) = \frac{4}{5} \times 250 \text{ cm}^3 = 200 \text{ cm}^3$$

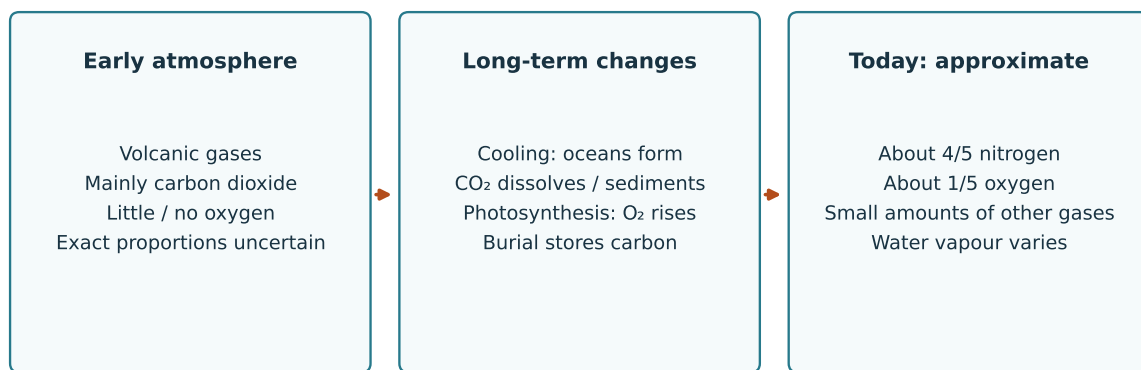
The matching oxygen estimate is $\frac{1}{5} \times 250 = 50 \text{ cm}^3$. These rough fractions deliberately ignore the small components; do not combine 80% nitrogen with a separate exact 21% oxygen as though they were one consistent dataset.

An early atmosphere: a theory with limited evidence (4.9.1.2)

Earth formed about 4.6 billion years ago. Direct atmospheric measurements from that time do not exist; geological material has also changed over this long time. Evidence for the earliest atmosphere is limited, so theories develop when evidence improves. Ancient ice records later atmospheres, not a sample of the air from Earth's formation.

One theory is that intense **volcanic activity** during the first billion years released the gases forming the early atmosphere. It was mainly carbon dioxide, with little or no oxygen, possibly like the present atmospheres of Mars and Venus. Volcanoes also released nitrogen, water vapour and small amounts of methane and ammonia. A comparison with another planet supports a possible explanation; it is not proof that

Earth's gas percentages were identical.



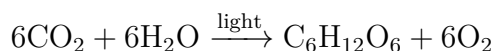
Qualitative sequence — boxes are not measured gas fractions or a time scale

Condensation changes water vapour into liquid. As Earth cooled, water vapour **condensed** into liquid water, forming oceans. Carbon dioxide dissolved in the water; carbonates precipitated and formed sediments, removing carbon dioxide from the atmosphere. Nitrogen gradually built up. Do not say cooling changed water into carbon dioxide or that volcanoes supplied the later oxygen rise.

Evidence judgement. A modern volcano releases carbon dioxide, nitrogen and steam. This makes a volcanic origin plausible, but it does not measure the exact composition of the atmosphere billions of years ago. State both the supporting observation and the limitation.

How oxygen increased (4.9.1.3)

Algae first produced oxygen by **photosynthesis** about 2.7 billion years ago. Plants evolved later. Over the next billion years, oxygen gradually increased to a level that enabled animals to evolve. This was a long change, not an instant jump to today's percentage.



Carbon dioxide + water → glucose + oxygen, using light energy. Count six carbon, twelve hydrogen and eighteen oxygen atoms on each side. Photosynthesis removes carbon dioxide and releases oxygen; respiration has the opposite overall gas effect. A plant does both, so consider the balance of processes when discussing net change.

How carbon dioxide decreased: rocks and fuels (4.9.1.4)

Several processes removed carbon dioxide. Dissolving in oceans and forming carbonate sediments began before plants. Later, algae and plants used carbon dioxide to make biomass by photosynthesis. Burial kept some carbon out of the atmosphere for very

long periods.

- **Limestone** forms from accumulated calcium carbonate sediments, including shells and skeletons of marine organisms, which become rock. Carbon in this carbonate is stored outside the atmosphere.
- **Coal** forms from buried plant material, compressed and changed over millions of years under conditions that limit complete decay.
- **Crude oil** and **natural gas** form mainly from the buried remains of small marine organisms, changed by heat and pressure over millions of years.

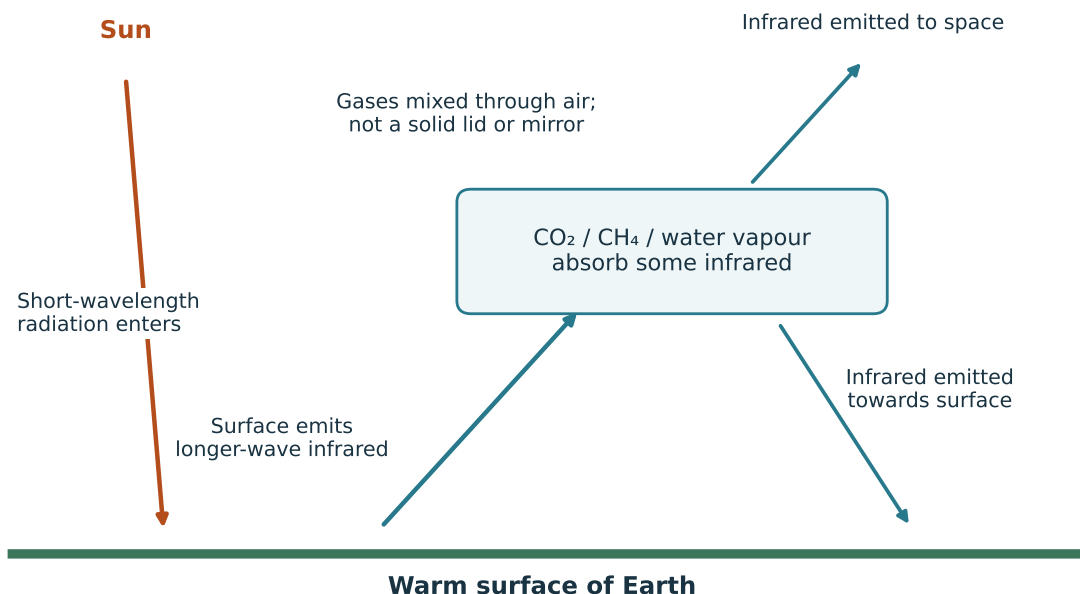
Coal, crude oil and natural gas are **fossil fuels**. They do not form from carbon dioxide simply freezing or dissolving. Burning these stores returns carbon mainly as carbon dioxide. Rock storage is long-term, not literally permanent: geological processes can return carbon too.

Worked explanation. Why can both limestone formation and coal formation lower atmospheric carbon dioxide? Limestone stores carbon in carbonate rock after removal from water/air. Plants first remove carbon dioxide by photosynthesis; burial of their remains then stores that carbon in coal rather than returning all of it by decay. Name the route as well as the final store.

Greenhouse gases and energy transfer (4.9.2.1)

A **greenhouse gas** absorbs and emits infrared radiation. Water vapour, carbon dioxide and methane are greenhouse gases. The natural **greenhouse effect** keeps Earth's surface warm enough for life; the question about human influence concerns an increase in this warming.

Short-wavelength radiation from the Sun passes through the atmosphere and warms the surface. The warm surface emits longer-wavelength **infrared radiation**. Greenhouse gases absorb some of this outgoing infrared and emit infrared in all directions, including towards the surface. Some radiation escapes to space. Increased greenhouse-gas amounts can reduce the initial rate of energy loss for the same surface temperature, so the surface warms towards a new energy balance.



The gases are mixed through the air, not a solid lid. Absorption and emission are not mirror reflection. Do not describe the ozone hole as the cause, or say that greenhouse gases stop all radiation leaving Earth.

Human activities and judging climate evidence (4.9.2.2)

Recall at least two activities for **each** gas. Burning fossil fuels increases carbon dioxide. Deforestation reduces carbon dioxide removal by photosynthesis and may release stored carbon through burning or decay. Methane increases through cattle farming and decay of organic waste in landfill; flooded rice fields can also release methane.

When reading a climate report, check the measured variable, units, dates, geographical coverage and whether the graph shows a trend or just one unusual year. A relationship between two graphs is evidence to examine, not by itself a complete causal explanation. Mechanism measurements and several independent datasets strengthen an explanation.

Peer review means other specialists examine a study's methods, evidence and reasoning before publication. It can reveal weaknesses; it does not guarantee every conclusion is correct. Communicating results clearly helps people judge the evidence. A headline based on one selected period or an unexplained graph may be biased. Complex climate systems require simplified models, which have assumptions and uncertainties; uncertainty about the exact size of an effect is not evidence that no effect exists.

Original data example. A fictional classroom dataset gives a global mean temperature anomaly of 0.30°C in period A and 0.70°C in period B. This is a difference from a stated reference average, not Earth's absolute temperature.

$$\Delta T = T_B - T_A = 0.70 - 0.30 = 0.40\text{ }^{\circ}\text{C}$$

This supports warming between these two period means. It does not establish a temperature rise in every place or every year, and does not alone identify the cause. Compare uncertainties and other evidence before a broader conclusion.

Climate effects: scale, risk and uncertainty (4.9.2.3)

Global climate change involves long-term patterns, not today's weather. Four potential effects are rising sea levels, changing rainfall, changes in the frequency or severity of extreme weather, and changes in habitats/species distributions.

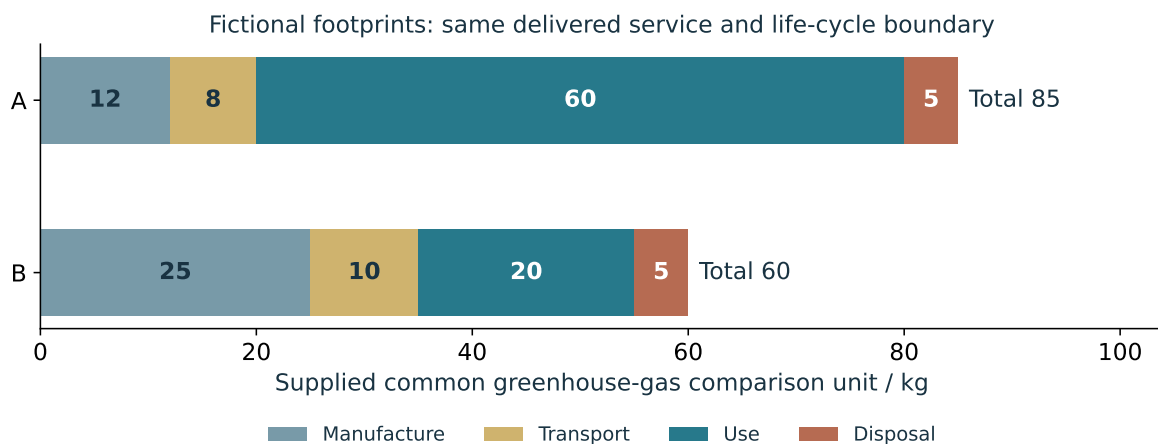
Link each effect to a consequence. Rising seas can flood low coastal land; changing rainfall can cause water shortages or damage crops; severe events can harm people and infrastructure; shifting habitats can threaten organisms unable to move or adapt. Warming can raise sea level through thermal expansion of seawater and melting land ice. Melting floating sea ice does not have the same direct sea-level effect as adding meltwater from land.

Discuss **scale** (how many people/which area and over what time), **risk** (likelihood and seriousness), and environmental implications rather than listing disasters. Exact future regional effects depend on emissions, model assumptions and complex feedbacks. Give a conditional prediction supported by the supplied evidence, not a guarantee that every location will become hotter and drier.

Carbon footprints: totals, choices and limits (4.9.2.4)

A **carbon footprint** is the total carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event. Include raw materials, manufacture, transport, use and disposal where they apply. A footprint is not just carbon dioxide from using an object and is not the mass of carbon atoms in it. When a problem supplies all gases in a common comparison unit, use that unit consistently; conversion factors are not required unless given.

Compare the same service, such as 100 journeys of the same distance, over the same lifetime and **system boundary**. A product with greater manufacturing emissions can still have lower total emissions after repeated use.



Worked comparison, fictional supplied data. Both options deliver the same service. A has 12 kg manufacture + 8 kg transport + 60 kg use + 5 kg disposal; B has 25 + 10 + 20 + 5 kg in the same supplied greenhouse-gas comparison unit.

$$F_A = 12 + 8 + 60 + 5 = 85 \text{ kg}, \quad F_B = 25 + 10 + 20 + 5 = 60 \text{ kg}$$

$$\text{reduction} = \frac{F_A - F_B}{F_A} \times 100\% = \frac{25}{85} \times 100\% \approx 29.4\%$$

B has the lower total despite higher manufacturing emissions. This conclusion depends on the supplied use stage and equal service; it does not prove B has less water demand or less waste.

Reduce carbon dioxide through efficient equipment, insulation, reduced fossil-fuel use, suitable lower-emission energy sources or protecting forests. Reduce methane through preventing organic waste, capturing landfill gas and changing suitable farming practices. Explain limitations: initial cost, available infrastructure, energy supply, land needs, competing food demands or public acceptance. Captured methane still releases carbon dioxide if burned, but prevents direct methane release and can supply useful energy. No single action guarantees zero footprint.

Predict combustion products from fuel and conditions (4.9.3.1)

Most fuels contain carbon and/or hydrogen and may contain sulfur. First inspect the fuel's elements; then inspect oxygen supply and temperature. Complete combustion of a **pure hydrocarbon** in sufficient oxygen produces carbon dioxide and water. This statement does not mean every fuel, under every condition, produces only these two gases.

With limited oxygen, **incomplete combustion** can produce carbon monoxide and carbon particles (soot), as well as some carbon dioxide and water.

Particulates include solid particles and unburned hydrocarbons released to air. Burning sulfur impurities forms sulfur dioxide. At high temperatures, nitrogen

and oxygen in air can react to form oxides of nitrogen, even when the fuel contains no nitrogen.

Fuel/condition supplied	Supported prediction and reason
Pure hydrogen, sufficient oxygen	Water; no carbon in the fuel to form carbon dioxide or soot
Pure methane, sufficient oxygen	Carbon dioxide and water; complete hydrocarbon combustion
Methane, limited oxygen	Carbon monoxide and/or soot possible; not enough oxygen for full oxidation
Carbon fuel containing sulfur	Carbon oxides and sulfur dioxide; sulfur is oxidised
High-temperature engine using sulfur-free fuel	Nitrogen oxides still possible from nitrogen/oxygen in air



Worked prediction. Removing sulfur from an engine fuel reduces sulfur dioxide; it does not automatically remove nitrogen oxides because their nitrogen can come from air. More oxygen may reduce incomplete-combustion products, but does not remove carbon dioxide from complete combustion.

Pollutant properties, effects and appropriate action (4.9.3.2)

Pollutant	Important property/effect	Action linked to its source
Carbon monoxide, CO	Toxic, colourless and odourless; reduces blood's oxygen transport	Improve combustion/ventilation and use appropriate detection; smell cannot identify it
Sulfur dioxide, SO ₂	Respiratory problems and acid rain	Remove sulfur or treat exhaust gases with a suitable alkali
Oxides of nitrogen, NO _x	Respiratory problems and acid rain	Reduce formation or use suitable exhaust treatment
Particulates	Health/respiratory problems and global dimming	Improve combustion and use suitable particle filters

Acid rain damages ecosystems and reacts with some buildings and stone.
Global dimming is reduced sunlight reaching the surface because of par-

ticles; it is not the same process as greenhouse-gas absorption of outgoing infrared. A filter that catches particles does not necessarily remove dissolved/gaseous carbon monoxide. Distinguish CO, the poisonous incomplete-combustion gas, from CO₂, a greenhouse gas.

When an exhaust treatment question gives a reagent, use its stated reaction. Calcium oxide can neutralise sulfur dioxide to calcium sulfite; further oxidation can produce sulfate. Do not silently write calcium sulfate as the product of CaO + SO₂ alone: an extra oxygen source is required. A suitable catalytic converter can use carbon monoxide to reduce nitrogen monoxide to nitrogen while forming carbon dioxide; it does not simply split every nitrogen oxide into nitrogen and oxygen without other chemistry.

Independent transfer check

A town replaces sulfur-containing fuel with sulfur-free fuel and fits particle filters. Its report claims “all climate and breathing problems are solved”. Explain the two changes’ likely benefits, then reject the overclaim using the remaining carbon dioxide, possible carbon monoxide and high-temperature nitrogen oxides. State what measurements would be needed before judging the size of any improvement. Use the independent questions in sheets 9.1–9.3 to check the full set of methods.