

Chemistry of the atmosphere

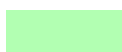
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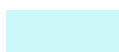
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These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Greenhouse gas

- a gas that absorbs long wavelength (infrared) radiation and re-radiates it, keeping the Earth warm enough to support life: water vapour, carbon dioxide and methane.

Define Carbon footprint

- the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event.

Define Complete combustion

- burning in plenty of oxygen, giving carbon dioxide and water only.

Define Particulates

- solid particles (soot and unburned hydrocarbons) in the atmosphere.

Define Global dimming

- less sunlight reaching the Earth's surface because of particulates in the atmosphere.

Define Fossil fuels

- coal, crude oil and natural gas, formed over millions of years from the remains of dead organisms; they lock up carbon.

Define Greenhouse effect

- the process by which greenhouse gases maintain temperatures on Earth high enough to support life.

Define Global climate change

- long-term changes to the Earth's climate, caused mainly by a rise in average global temperature.

Define Peer review

- checking of results and conclusions by other scientists before publication.

Define Incomplete combustion

- burning in a limited supply of oxygen, giving carbon monoxide and/ or carbon (soot) as well as water.

Define Acid rain

- rain made acidic by sulfur dioxide and oxides of nitrogen dissolving in the water in clouds.

Define Sedimentary rocks

- rocks such as limestone, formed from precipitated carbonates and the shells of marine organisms; they lock up carbon.

9.1 The composition and evolution of the Earth's atmosphere

9.1.1 The proportions of different gases in the atmosphere

For **200 million years** the proportions of gases in the atmosphere have been much the same as today:

Gas	Proportion
Nitrogen	about four-fifths (approximately 80%)
Oxygen	about one-fifth (approximately 20%)
Other gases — carbon dioxide, water vapour and the noble gases	small proportions

9.1.2 The Earth's early atmosphere

- Theories about the early atmosphere and how it formed have changed and developed over time. Evidence is limited because of the timescale — **4.6 billion years**.
- One theory: during the **first billion years** there was **intense volcanic activity** that released the gases forming the early atmosphere, and water vapour that condensed to form the oceans.
- At the start of this period the atmosphere may have been like those of Mars and Venus today: mainly carbon dioxide, with little or no oxygen gas.
- Volcanoes also produced nitrogen, which gradually built up in the atmosphere, and there may have been small proportions of methane and ammonia.
- When the oceans formed, carbon dioxide dissolved in the water and carbonates were precipitated, producing sediments, reducing the carbon dioxide in the atmosphere.
- No knowledge of other theories is required, but you must be able to interpret evidence and evaluate different theories when given information.

9.1.3 How oxygen increased

- Algae and plants produced the oxygen that is now in the atmosphere by photosynthesis.
- Algae first produced oxygen about 2.7 billion years ago, and soon after, oxygen appeared in the atmosphere.
- Over the **next billion years plants evolved**, and the percentage of oxygen gradually increased to a level that enabled animals to evolve.

9.1.4 How carbon dioxide decreased

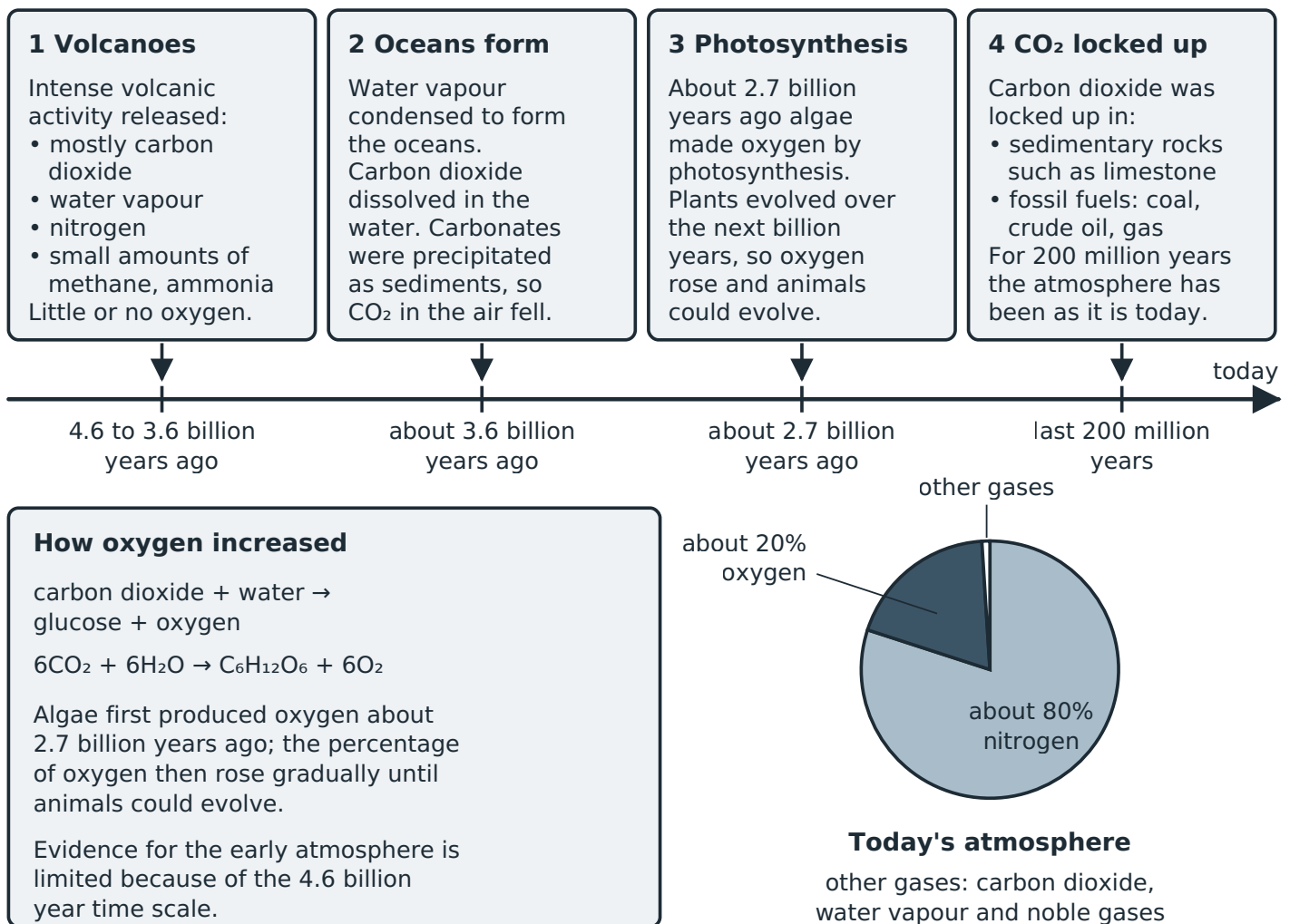
Carbon dioxide was removed from the early atmosphere in three ways:

- **Photosynthesis** by algae and plants decreased the percentage of carbon dioxide.
- It dissolved in the oceans, and carbonates were precipitated as sediments.
- Carbon became locked up in sedimentary rocks and in fossil fuels.

- You must be able to describe the main changes in the atmosphere over time and their likely causes, and explain the formation of limestone, coal, crude oil and natural gas.

Deposit	How it formed
Limestone	Carbonates precipitated from sea water, with the shells and skeletons of marine organisms, deposited as sediment and compressed over millions of years
Coal	Thick deposits of dead plant material laid down in swamps, buried by sediment and compressed without oxygen
Crude oil and natural gas	Remains of plankton buried in mud on the sea floor, compressed at high pressure and temperature over millions of years

How the Earth's atmosphere changed from its early composition to today

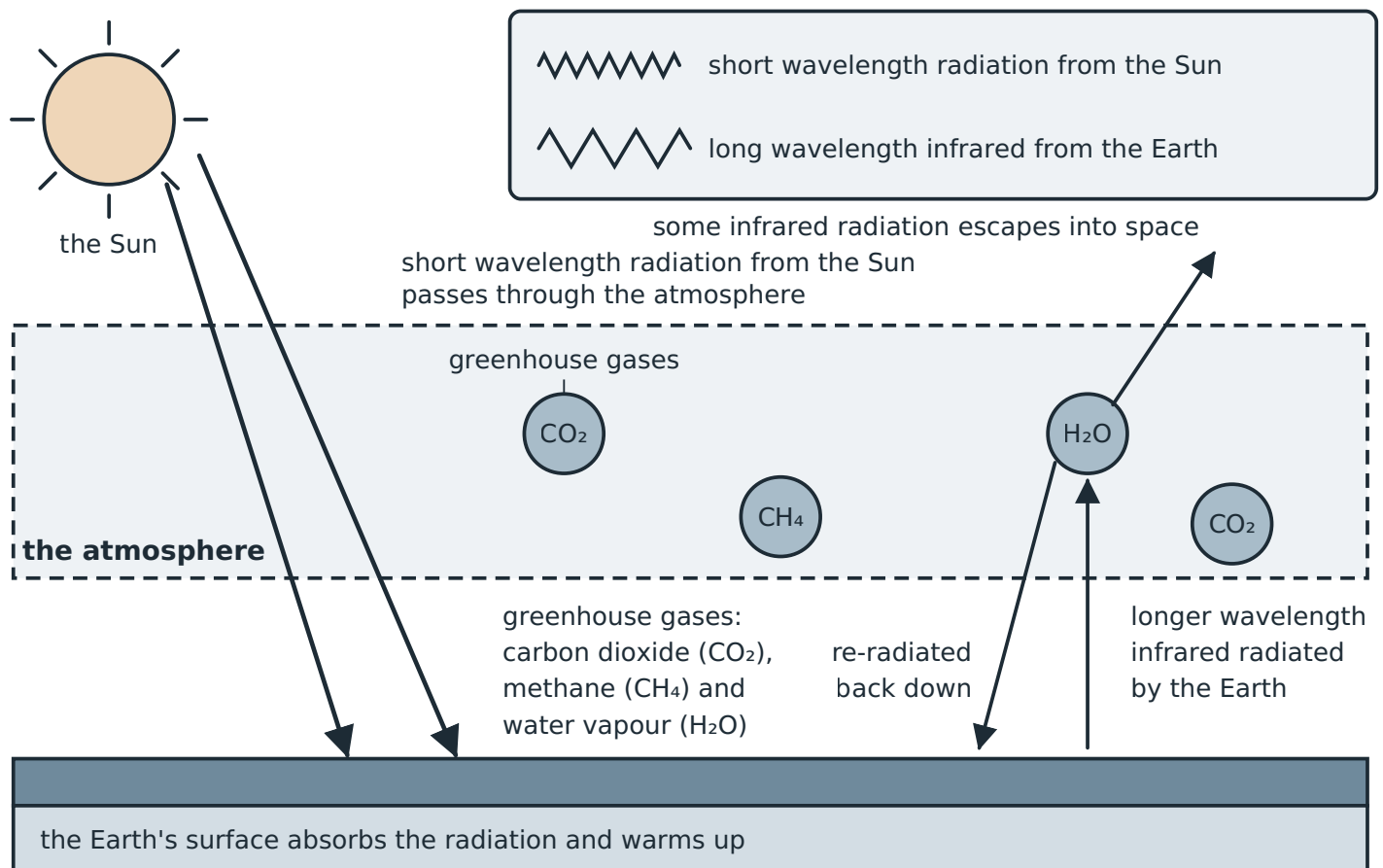


9.2 Carbon dioxide and methane as greenhouse gases

9.2.1 Greenhouse gases

- Greenhouse gases in the atmosphere maintain temperatures on Earth high enough to support life. They are water vapour, carbon dioxide and methane.
- You must be able to describe the greenhouse effect in terms of the interaction of short and long wavelength radiation with matter: 1. **Short wavelength radiation** (visible light and ultraviolet) from the Sun passes through the atmosphere. 2. It is absorbed by the Earth's surface, which warms up. 3. The warm Earth **re-radiates** energy at a **longer wavelength** — **infrared**. 4. Greenhouse gases absorb this long wavelength infrared and re-radiate it in all directions, including back towards the Earth's surface. 5. This keeps the surface warmer than it would otherwise be.

The greenhouse effect: short wavelength radiation in, long wavelength infrared re-radiated



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

ANALOGY

A car left in the sun, or a blanket. Sunlight passes through the windscreen and is absorbed by the seats, which warm up and give out infrared; the glass does not let that infrared straight back out, so the car gets hot. A blanket is similar: it makes no heat, it just slows the escape of energy, and more blankets means warmer.

Where it breaks down: a car and a blanket work mainly by **stopping warm air moving away**. Greenhouse gases do not trap air or "bounce heat back like a mirror" — they absorb long wavelength infrared and re-radiate it in all directions. Use that wording in the exam.

WATCH OUT

The greenhouse effect is not the hole in the ozone layer. The **greenhouse effect** is greenhouse gases (carbon dioxide, methane, water vapour) absorbing and re-radiating **long wavelength infrared** low in the atmosphere, raising the surface temperature. The **ozone layer** is high in the atmosphere and absorbs **ultraviolet**; it was thinned by CFCs, not carbon dioxide, and holes in it do not cause global warming. Also: the greenhouse effect is essential — without it the Earth would be too cold for life. It is the extra greenhouse gases that are the problem.

9.2.2 Human activities which contribute to an increase in greenhouse gases in the atmosphere

Some human activities increase the amounts of greenhouse gases. You must be able to recall two human activities for each gas.

Greenhouse gas	Human activities that increase it
Carbon dioxide	Burning fossil fuels (power stations, vehicles, homes, industry); deforestation — fewer trees means less photosynthesis, and burning the wood releases more
Methane	Cattle farming (methane from the digestion of livestock); landfill sites and rice paddy fields, where waste and plant material decay anaerobically
•	Based on peer-reviewed evidence, many scientists believe that human activities will cause the temperature of the Earth's atmosphere to increase at the surface, and that this will result in global

9.2.3 Global climate change

- An increase in average global temperature is a major cause of climate change.
- Four potential effects you must be able to describe briefly:
- Melting polar ice and glaciers and rising sea levels, causing flooding, coastal erosion and habitat loss.
- **More frequent and severe extreme weather** — storms, heatwaves, floods, droughts.
- Changes in the amount, timing and distribution of rainfall, affecting crops and water supply.
- Changes to the distribution of wild species, some migrating and others facing extinction.
- **Scale, risk and environmental implications:** the changes are global, affect very large numbers of people (especially in low-lying and poorer countries), and the risk is uncertain but potentially very high — so action is argued for even though predictions are imprecise.

climate change.

- However, it is difficult to model such complex systems as global climate change. This leads to simplified models, speculation and opinions presented in the media that may be based on only parts of the evidence and which may be biased.
- Why the evidence and predictions are uncertain: the climate has a huge number of **interacting variables**, so models are simplified; data from the distant past is indirect (ice cores, tree rings); media reports may use **only part of the evidence**, may be biased, and may not be **peer reviewed**.
- **Peer review matters:** other scientists check results before publication, catching errors and false claims. Results must also be communicated to a wide range of audiences so the public and governments can act.
- To evaluate the quality of evidence in a report, ask: is it peer reviewed? Is the sample and timescale big enough? Is the source independent? Does the conclusion go further than the data allows?

9.2.4 The carbon footprint and its reduction

- The **carbon footprint** is the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event.
- "Full life cycle" means the lot: raw materials, manufacture, packaging, transport, use and disposal.
- The carbon footprint can be reduced by reducing emissions of carbon dioxide and methane. Actions include:
- Using **renewable energy** or **nuclear power** instead of fossil fuels.
- Increasing **energy efficiency** — insulation, more efficient vehicles and appliances.
- **Carbon capture and storage** — trapping carbon dioxide and storing it underground.
- **Carbon taxes, carbon-offsetting** (eg planting trees) and **licences** capping emissions.
- Cutting methane by changing livestock farming and diets and capturing methane from landfill.
- **Why actions may be limited:** the cost of new technology; **lack of international co-operation**, since global agreements are hard to reach; incomplete information and scepticism, so people are not convinced they must act; lifestyle changes are unpopular (cars, flights, meat); and some developing countries depend on cheap fossil fuels.

9.3 Common atmospheric pollutants and their sources

9.3.1 Atmospheric pollutants from fuels

- The combustion of fuels is a major source of atmospheric pollutants. Most fuels, including coal, contain carbon and/or hydrogen and may also contain some sulfur.
- The gases released when a fuel burns may include carbon dioxide, water vapour, carbon monoxide, sulfur dioxide and oxides of nitrogen. Solid particles and unburned hydrocarbons may also be released, forming particulates in the atmosphere.
- How each is produced: carbon dioxide and water vapour from **complete combustion** (the carbon and hydrogen are fully oxidised); carbon monoxide and soot from **incomplete combustion**, when there is not enough oxygen; **sulfur dioxide** from oxidation of the **sulfur impurities** in the fuel; **oxides of nitrogen** when nitrogen and oxygen from the air react at the **high temperatures inside an engine**.
- You must be able to **predict the products of combustion** of a fuel from its composition and the conditions. For example, a sulfur-containing hydrocarbon burned in a limited air supply gives carbon dioxide, carbon monoxide, carbon (soot), water and sulfur dioxide.

9.3.2 Properties and effects of atmospheric pollutants

- Carbon monoxide is a toxic gas. It is colourless and odourless and so is not easily detected.
- Sulfur dioxide and oxides of nitrogen cause respiratory problems in humans and cause acid rain.
- Particulates cause global dimming and health problems for humans.

Pollutant	How it forms	Problems it causes
Carbon dioxide	Complete combustion of fuels containing carbon	A greenhouse gas — contributes to global climate change
Carbon monoxide	Incomplete combustion of carbon-containing fuels in a limited supply of oxygen	Toxic — it combines with haemoglobin so the blood carries less oxygen; colourless and odourless, so it is not easily detected
Soot / particulates (carbon particles and unburned hydrocarbons)	Incomplete combustion; unburned fuel released as solid particles	Global dimming and health problems such as lung damage; also dirties buildings
Sulfur dioxide	Oxidation of the sulfur impurities in the fuel when it burns	Respiratory problems in humans and acid rain
Oxides of nitrogen	Nitrogen and oxygen from the air reacting at the high temperatures inside engines	Respiratory problems in humans and acid rain

- Acid rain forms when sulfur dioxide and oxides of nitrogen dissolve in the water in clouds. It damages buildings and statues (especially limestone), **kills trees** and acidifies lakes and rivers so fish and other organisms die.
- Global dimming is caused by particulates reflecting sunlight back into space, so **less sunlight reaches the Earth's surface**.