Chemistry of the atmosphere

Model answers and marking points

GCSE science 6-mark questions

This topic online

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

1 Scientists think that Earth's early atmosphere was very different from the air we breathe today. Today the atmosphere is about four-fifths nitrogen and one-fifth oxygen, with small amounts of argon and carbon dioxide.

Describe how the atmosphere is thought to have changed from Earth's early atmosphere to the atmosphere today.

(6 marks)

Model answer

During the first billion years of Earth's history there was intense volcanic activity. The volcanoes released gases that formed the early atmosphere. It was mostly carbon dioxide with little or no oxygen, a bit like the atmospheres of Mars and Venus now. Volcanoes also gave out water vapour and nitrogen, and maybe small amounts of methane and ammonia.

As the Earth cooled, the water vapour condensed and formed the oceans. A lot of carbon dioxide dissolved in the oceans, which lowered the amount in the air. Some of this formed carbonate compounds that settled as sediments.

Around 2.7 billion years ago algae began to photosynthesise. They took in carbon dioxide and released oxygen. Later, plants evolved and did the same, so over the next billion years the oxygen level rose until animals could evolve.

Carbon from the carbon dioxide was locked away in sedimentary rocks such as limestone, and in fossil fuels like coal, crude oil and natural gas, formed from dead plants and sea creatures.

Nitrogen is unreactive, so it was not removed and slowly built up until it made up about four-fifths of the atmosphere.

Marking points (credit any 6 relevant points, linked in a sensible order)

- in the first billion years intense volcanic activity released gases that formed the early atmosphere
- the early atmosphere was mainly carbon dioxide with little or no oxygen, similar to Mars and Venus today
- volcanoes also released water vapour and nitrogen, and possibly small amounts of methane and ammonia
- as Earth cooled the water vapour condensed to form the oceans
- carbon dioxide dissolved in the oceans, reducing the amount in the atmosphere
- dissolved carbon dioxide formed carbonates that precipitated as sediments
- algae and later plants photosynthesised, using carbon dioxide and releasing oxygen
- about 2.7 billion years ago algae first produced oxygen; over time oxygen built up until animals could evolve
- carbon from carbon dioxide was locked up in sedimentary rocks such as limestone and in fossil fuels such as coal, crude oil and natural gas
- nitrogen built up because it is unreactive and stayed in the atmosphere

How it is marked

- 5-6 marks: describes the volcanic origin, the formation of the oceans, the removal of carbon dioxide by dissolving and by photosynthesis, the build-up of oxygen and carbon being locked into rocks and fuels, in a clear order.
- 3-4 marks: describes the early atmosphere and at least two ways it changed, such as photosynthesis and oceans forming, with some gaps in the sequence.
- 1-2 marks: makes one or two correct points, such as the early atmosphere had lots of carbon dioxide or plants made oxygen.

What loses marks

- saying the early atmosphere was mainly oxygen
- saying animals made the oxygen
- missing out how carbon dioxide was removed

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

- describing events in a jumbled order

2 Without any greenhouse gases, the average temperature at Earth's surface would be well below freezing. Carbon dioxide, methane and water vapour are greenhouse gases.

Explain how greenhouse gases keep Earth warm, and explain how human activities are increasing the amounts of carbon dioxide and methane in the atmosphere. (6 marks)

Model answer

The Sun gives out radiation, mostly of short wavelength, which passes through the atmosphere and reaches the Earth's surface. The surface absorbs it and warms up.

The warm surface then gives out radiation of a longer wavelength, infrared. Greenhouse gases such as carbon dioxide, methane and water vapour absorb some of this long wavelength radiation. They then re-emit it in all directions, and some goes back towards the surface. This means less energy escapes to space, so the surface and lower atmosphere stay warmer.

Humans are increasing carbon dioxide mainly by burning fossil fuels such as coal, oil and gas in power stations, vehicles and home boilers. Deforestation also adds carbon dioxide, because there are fewer trees to absorb it by photosynthesis and burning the cleared trees releases more.

Methane levels are rising because of farming. Cattle release methane as they digest grass, and flooded rice fields give off methane. Landfill sites also release methane when rubbish decomposes.

Because there are more of these gases, more long wavelength radiation is absorbed and re-emitted, so the average temperature is rising.

Marking points (credit any 6 relevant points, linked in a sensible order)

- radiation from the Sun, mainly short wavelength, passes through the atmosphere and reaches Earth's surface
- the surface absorbs this radiation and warms up
- the warm surface gives out radiation of longer wavelength (infrared)
- greenhouse gases absorb some of this long wavelength radiation
- they then re-emit it in all directions, including back towards the surface
- this keeps the lower atmosphere and surface warmer than it would otherwise be
- burning fossil fuels in power stations, cars and boilers releases carbon dioxide
- deforestation means fewer trees take in carbon dioxide by photosynthesis, and burning trees releases more
- cattle farming releases methane from the animals' digestion, and rice paddy fields release methane
- landfill sites release methane as waste decomposes

How it is marked

- 5-6 marks: explains the full chain from incoming short wavelength radiation to absorption and re-emission of long wavelength radiation, and gives several human sources of both gases with reasons.
- 3-4 marks: explains that greenhouse gases trap heat with some correct detail about radiation, and gives at least one human source of each gas.
- 1-2 marks: states that greenhouse gases trap heat or names a human activity that releases carbon dioxide.

What loses marks

- saying greenhouse gases absorb the incoming sunlight
- talking about the ozone layer or a hole letting heat in
- saying the heat 'bounces off' the gases
- giving human activities without saying which gas they release

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

3 A secondary school in Norwich wants to reduce its carbon footprint. The eco-committee, led by Chloe and Hamza, has costed three options.

Option	Cost in £	Carbon dioxide saved per year in tonnes	Notes
solar panels on the sports hall	60 000	18	lasts about 25 years, cuts electricity bills
replace gas boilers with heat pumps	150 000	40	needs better insulation first
walk or cycle to school campaign	2 000	6	depends on pupils and staff taking part

Evaluate the three options and recommend what the school should do. Use the data and your knowledge of carbon footprints.

(6 marks)

Model answer

A carbon footprint is the total amount of carbon dioxide and other greenhouse gases released over the whole life of something, in this case running the school.

Heat pumps save the most, 40 tonnes a year, because the school would stop burning gas, a fossil fuel. However they cost £150 000, about £3750 per tonne saved in the first year, and the school would also have to pay for insulation first.

Solar panels cost £60 000 and save 18 tonnes a year, about £3300 per tonne. They last about 25 years, so they would save roughly 450 tonnes in total and also cut the electricity bills.

The campaign is by far the cheapest, about £330 per tonne, but it only saves 6 tonnes and is the least certain, because it depends on people choosing to change how they travel.

Making solar panels and heat pumps also releases some carbon dioxide, so the real savings are a little smaller than shown.

I recommend starting the campaign straight away because it costs very little, and fitting the solar panels as the best value large project. The school should then add insulation and heat pumps later when it can afford them, because this gives the biggest long term cut.

Marking points (credit any 6 relevant points, linked in a sensible order)

- 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
- heat pumps save the most carbon dioxide (40 tonnes per year) but cost the most
- cost per tonne saved in the first year: solar about £3300, heat pumps about £3750, campaign about £330
- the campaign is cheapest per tonne but saves the least and is uncertain because it depends on people changing behaviour
- solar panels last about 25 years, so they save about 450 tonnes in total and also lower bills
- heat pumps need extra spending on insulation, which adds to the cost but also cuts heat loss
- making the panels and heat pumps also releases carbon dioxide, which reduces the overall saving
- replacing gas boilers stops burning a fossil fuel on site
- reducing emissions can be difficult because of cost and people being unwilling to change
- recommendation: start the campaign and solar panels now, and plan heat pumps with insulation as money allows

How it is marked

- 5-6 marks: uses the data to compare cost and saving for all three options, considers at least one wider factor such as lifetime, reliability or life cycle emissions, and makes a justified recommendation.
- 3-4 marks: compares at least two options using the data and gives a recommendation with a reason.

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

- 1-2 marks: picks an option because it saves the most or is cheapest, with little use of the data.

What loses marks

- choosing an option using only one column of the table
- defining carbon footprint as just the carbon dioxide from burning fuel on the day
- ignoring how reliable each saving is
- giving a recommendation with no reason

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

4 Older diesel buses in city centres release several pollutants, including carbon monoxide, sulfur dioxide, oxides of nitrogen and soot particles.

Compare how carbon monoxide and sulfur dioxide are formed when fuels burn, and compare the problems each one causes.

(6 marks)

Model answer

Both gases are made when fuels such as diesel are burned, but they form in different ways.

Carbon monoxide forms from incomplete combustion. When there is not enough oxygen, some of the carbon in the hydrocarbon fuel is only partly oxidised, so carbon monoxide is made instead of carbon dioxide. Sulfur dioxide forms because many fuels contain sulfur as an impurity. When the fuel burns, the sulfur reacts with oxygen to make sulfur dioxide. So carbon monoxide comes from the fuel itself, while sulfur dioxide comes from an impurity in it.

This means they are reduced in different ways. Carbon monoxide can be reduced by supplying more air, but extra air does not help with sulfur dioxide. Instead the sulfur has to be removed from the fuel before it is burned.

Their effects are also different. Carbon monoxide is toxic. It combines with haemoglobin in red blood cells, so the blood carries less oxygen. It has no colour or smell, so people do not notice it. Sulfur dioxide irritates the lungs and causes breathing problems. It also dissolves in rainwater to form acid rain, which damages limestone buildings, harms trees and makes lakes too acidic for fish.

Carbon monoxide does not cause acid rain, so sulfur dioxide does more damage to the environment.

Marking points (credit any 6 relevant points, linked in a sensible order)

- carbon monoxide forms from incomplete combustion of the fuel when there is not enough oxygen
- sulfur dioxide forms when sulfur impurities in the fuel react with oxygen
- carbon monoxide comes from the carbon in the hydrocarbon; sulfur dioxide comes from an impurity, not the hydrocarbon itself
- more air reduces carbon monoxide, but removing sulfur from the fuel is needed to reduce sulfur dioxide
- carbon monoxide is toxic: it binds to haemoglobin and reduces the oxygen the blood can carry
- carbon monoxide is colourless and odourless, so it is hard to detect
- sulfur dioxide causes respiratory problems and irritates the lungs
- sulfur dioxide dissolves in rainwater and causes acid rain
- acid rain damages buildings and statues, harms plants and makes lakes acidic
- both are gases that can be reduced by better engines, cleaner fuels or switching to electric buses

How it is marked

- 5-6 marks: compares the formation of both gases, including where the atoms come from, and compares their health and environmental effects point by point.
- 3-4 marks: gives correct formation and effects for both gases, with only some direct comparison.
- 1-2 marks: gives one or two correct facts about one of the gases.

What loses marks

- saying carbon monoxide causes acid rain
- saying sulfur dioxide comes from incomplete combustion
- listing facts about each gas with no comparison
- confusing carbon monoxide with carbon dioxide

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

5 The table shows approximate values for carbon dioxide in the atmosphere and the global average temperature compared with the 1951-1980 average.

Year	Carbon dioxide in parts per million	Temperature difference in °C
1960	317	-0.03
1980	339	+0.26
2000	370	+0.40
2020	414	+1.01

Marcus says: "This proves that carbon dioxide causes global warming."

Use the data and your knowledge to discuss Marcus's statement and describe two possible effects of global climate change.

(6 marks)

Model answer

The data show that carbon dioxide in the atmosphere went up from 317 ppm in 1960 to 414 ppm in 2020, an increase of about 97 ppm. Over the same time the temperature difference rose from -0.03 °C to +1.01 °C. Both increase together, so there is a positive correlation.

However, a correlation on its own does not prove that one causes the other. There are only four points in the table, and the climate is very complex, so other factors also affect temperature and it is hard to model.

On the other hand, there is a clear mechanism. Carbon dioxide is a greenhouse gas: it absorbs long wavelength radiation given out by the Earth and re-emits it, keeping the surface warmer. Most climate scientists agree, from peer-reviewed evidence, that human activities that release carbon dioxide are very likely to be causing the rise.

So the data strongly support Marcus's idea, but "proves" is too strong a word.

One effect of climate change is rising sea levels as ice melts and sea water expands, which leads to flooding and coastal erosion. Another is more frequent and severe storms and changes in rainfall, which can affect food production.

Marking points (credit any 6 relevant points, linked in a sensible order)

- carbon dioxide rose from 317 ppm in 1960 to 414 ppm in 2020, an increase of about 97 ppm
- the temperature difference rose from -0.03 °C to +1.01 °C over the same period
- both values rise together, so there is a positive correlation
- a correlation alone does not prove that one causes the other
- there is a known mechanism: carbon dioxide absorbs and re-emits long wavelength radiation, so the link is plausible
- most scientists agree, based on peer-reviewed evidence, that human activities are very likely to be causing the temperature rise
- the climate is complex, so it is hard to model and other factors also affect temperature; only four data points are given
- effect: sea levels rise, causing flooding and coastal erosion
- effect: more frequent and severe storms, changes in rainfall, and changes to where species can live and to food production
- conclusion: the data support Marcus's view but 'proves' is too strong

How it is marked

- 5-6 marks: describes both trends with values, explains why correlation is not proof, uses the mechanism or scientific agreement to support the link, mentions a limitation and gives two correct effects.
- 3-4 marks: describes the trends with some data and makes a sensible comment on Marcus's claim, with at least one effect.
- 1-2 marks: states that both go up or gives an effect of climate change, with no discussion.

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

What loses marks

- agreeing that the data prove the link without mentioning correlation
- describing the trend without using any numbers
- giving effects that are not linked to climate change, such as acid rain
- saying only one effect when two are asked for

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.