DP IB Biology: HL

Your notes

4.2 Carbon Cycling & Climate Change

Contents

Your notes

4.2.1 Carbon Cycle: Carbon Dioxide

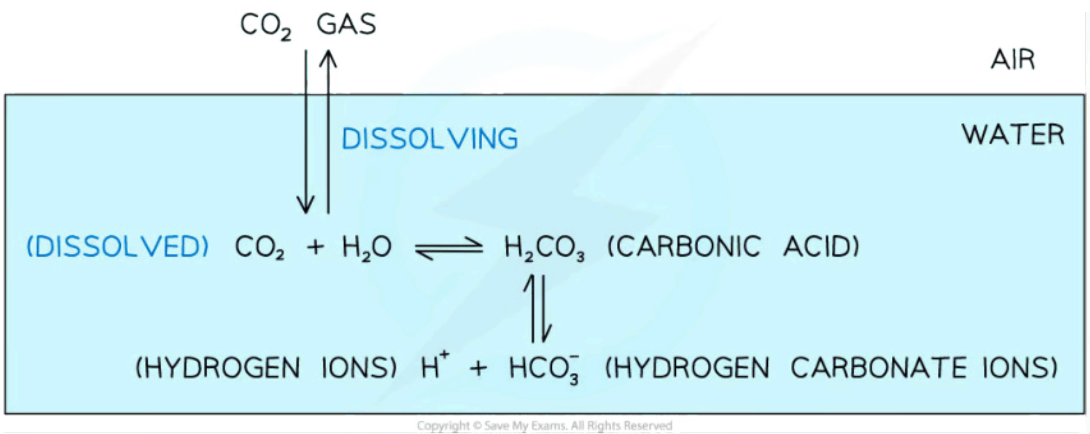
Carbon Fixation

- **Carbon** is present in the **atmosphere** in the form of **carbon dioxide gas**
- Carbon is taken out of the atmosphere by plants to be used in photosynthesis
- Plants are **autotrophs**
- Autotrophs use **light energy** to **convert carbon dioxide** from the **environment** into **carbon compounds**, such as:
  - Carbohydrates
  - Lipids
  - Amino acids
- This reduces the amount of carbon present in the atmosphere and stores it in the tissues of plants

Carbon Dioxide in Solution

Your notes

- Where the atmosphere comes into contact with bodies of water, carbon dioxide in the atmosphere can **dissolve in water**
  - The oceans are thought to store significantly more carbon than the atmosphere
- Some of the carbon in aquatic systems is in the form of **dissolved carbon dioxide**
- Some dissolved carbon dioxide reacts with water to form carbonic acid, (H_2CO_3), which then dissociates to produce **hydrogen carbonate ions** (HCO_3^-), and hydrogen (H^+) ions
  - H^+ ions in the water cause it to become **more acidic**; as more carbon dioxide dissolves in the oceans, the pH of the oceans decreases and this can cause problems for some marine organisms
- **Aquatic producers** (such as aquatic plants and phytoplankton) can **absorb dissolved carbon dioxide** and **hydrogen carbonate ions** for photosynthesis, using light energy from the sun to convert this carbon into other carbon compounds such as carbohydrates



Carbon is present in water in the form of dissolved carbon dioxide and hydrogen carbonate ions

Carbon Dioxide & Coral Reefs

Your notes

- The impact of increasing carbon dioxide levels on the atmosphere is well known; it is a **greenhouse gas** and therefore **increases the warming of the atmosphere** as its atmospheric concentration increases
- The impact of increasing carbon dioxide levels on the oceans is less well-understood by the public but could be **significant for the ocean** biodiversity because of the effect of carbon dioxide on **ocean chemistry**
  - The oceans dissolve huge amounts of carbon dioxide, and much of the dissolved carbon dioxide **reacts with seawater** to form **carbonic acid** (H_2CO_3)

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

  - Carbonic acid then **dissociates** to form **hydrogen ions** (H^+) and **hydrogen carbonate ions** (HCO_3^-)

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

  - Hydrogen carbonate ions can then **dissociate again** to form more hydrogen ions and **carbonate ions** (CO_3^{2-})

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

- Provided that this series of reactions takes place at the appropriate rate, the oceans remain **slightly alkaline**, and there is a steady supply of **carbonate ions** for organisms that need them
  - Many marine organisms need carbonate ions in order to **secrete calcium carbonate** for the building of the hard parts of their bodies
    - **Molluscs** such as mussels and clams build their shells from calcium carbonate
    - **Coral** is made up of many tiny organisms called **coral polyps** which secrete **hard exoskeletons built from calcium carbonate**; these exoskeletons form the complex structures of corals which are a **key part of coral reef** ecosystems

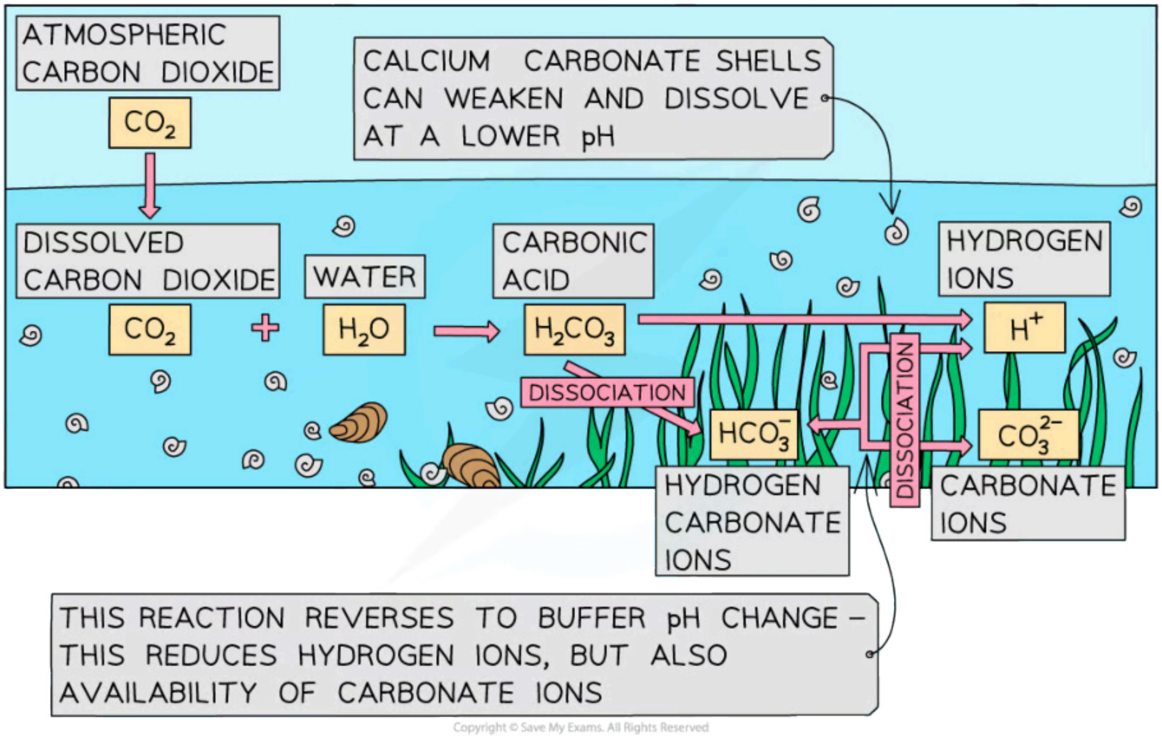
- However, as atmospheric carbon dioxide levels increase, so too does the **amount of carbon dioxide that dissolves** in the oceans
- As more carbon dioxide dissolves, **more carbonic acid forms and dissociates**, and **more hydrogen carbonate ions form and dissociate**, the end result of which is **increasing numbers of hydrogen ions** in a seawater solution
- Increasing concentrations of hydrogen ions in solution cause that solution to **become more acidic**; in this case the process is known as **ocean acidification**
  - Note that the oceans are **still alkaline**, but the **pH has decreased**, so they are closer to neutral

- There are **significant consequences** to ocean acidification
  - The calcium carbonate exoskeletons of, e.g. corals, can be **weakened** and even **dissolve**
  - The reaction during which hydrogen carbonate ions dissociate to form hydrogen ions and carbonate ions reverses to buffer the increasing number of hydrogen ions, **reducing the availability of carbonate ions** for the building of hard exoskeletons

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

- When the effects of ocean acidification are combined with coral bleaching that results from warming oceans, the consequences for coral reefs could be very serious
  - With coral reefs thought to be the most diverse ecosystem we know, this could be **bad news for ocean biodiversity**

Your notes



Increased atmospheric carbon dioxide increases the number of hydrogen ions in seawater, and reduces the availability of carbonate ions

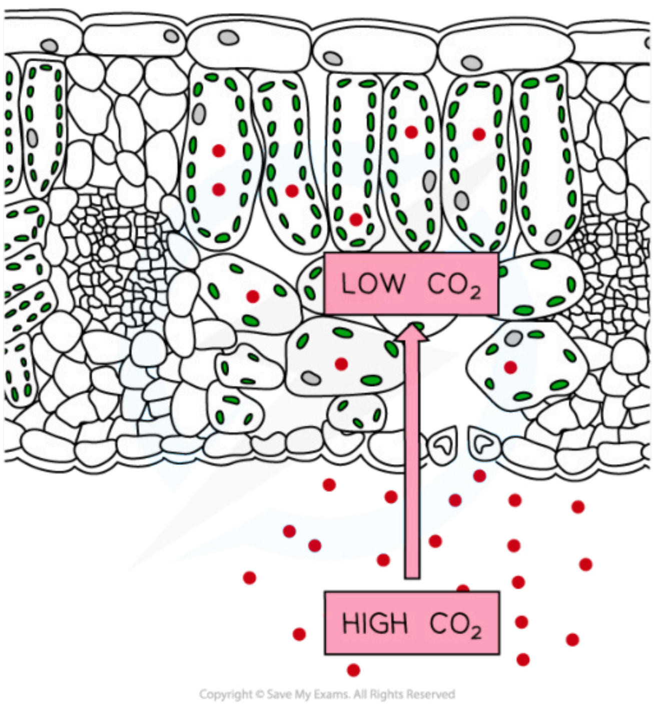
Examiner Tip

Note that while ocean acidification shares the same cause as global warming (increased atmospheric carbon dioxide), it is not a direct result of global warming.

Carbon Dioxide Absorption

Your notes

- Autotrophs **absorb carbon dioxide** from their surroundings (either **air** or **water**) before converting it into carbon compounds in their tissues
- This absorption takes place by diffusion into the leaves of plants
- Carbon dioxide diffuses down its **concentration gradient** from a region of **high concentration** (outside the leaves) to a region of **low concentration** (inside leaves)
  - The cells inside leaves use carbon dioxide in photosynthesis so the concentration is always low inside the photosynthesising cells, **maintaining the concentration gradient**
- This diffusion takes place through the stomata of land plants, and directly into the cells of aquatic plants



Carbon dioxide diffuses into the leaves of plants down its concentration gradient

4.2.2 Carbon Cycle: Carbon Dioxide in the Atmosphere

Your notes

Respiration & Carbon Dioxide

- All living cells carry out some form of cellular respiration, from bacteria, to plants, to animals
- Many organisms carry out **aerobic respiration**
- Aerobic respiration requires the uptake of oxygen and **produces carbon dioxide as a waste product**

Aerobic respiration produces carbon dioxide as a waste product

- Because carbon dioxide is being constantly produced inside cells, a concentration gradient between the inside and the outside of cells is **maintained**
  - Carbon dioxide leaves cells by diffusion
- This carbon dioxide is eventually **released into the environment;** either **air** or **water**
  - Single-celled organisms release carbon dioxide by **diffusion** at the cell surface
  - Terrestrial plants release carbon dioxide by **diffusion** from their stomata into the surrounding air
  - Animals release carbon dioxide into the surrounding air or water by **diffusion** via their gas exchange surfaces e.g. mammalian lungs or fish gills

Fluctuations in Carbon Dioxide Levels

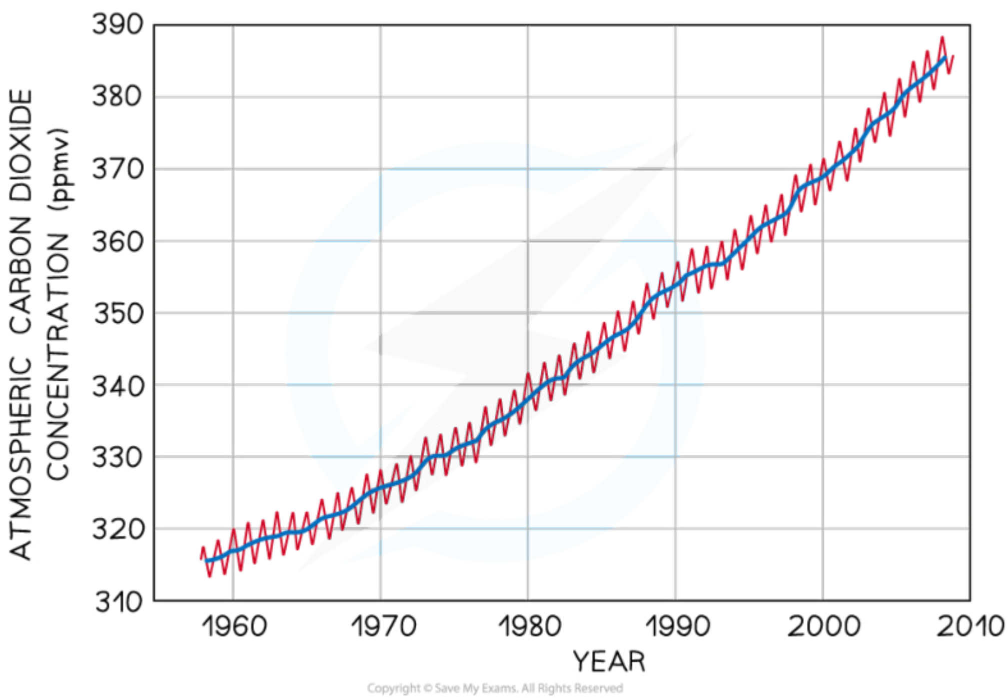
Your notes

NOS: Making accurate, quantitative measurements; it is important to obtain reliable data on the concentration of carbon dioxide and methane in the atmosphere

- The amount of **carbon** in the atmosphere is constantly changing due to seasonal fluctuations in rates of photosynthesis and due to **human activities**
  - **Photosynthesis** removes carbon dioxide from the atmosphere, meaning that **atmospheric carbon dioxide levels decrease** in whichever hemisphere is experiencing spring and summer
  - The **combustion** of fossil fuels by humans **releases carbon dioxide** into the atmosphere
  - Livestock such as cattle **release methane** into the atmosphere
- Both carbon dioxide and methane gases contribute to atmospheric carbon levels, and both of these gases have important impacts on the planet
  - Carbon dioxide influences the **pH of seawater** and the process of **photosynthesis**, and both carbon dioxide and methane influence **global temperatures**
- Because of the significance of the effects of these gases, it is important to **accurately monitor** their concentrations in the atmosphere
  - Quantitative atmospheric measurements can be taken
  - Accurate, quantitative monitoring over a long period of time enables scientists to **identify trends**, and **test hypotheses**
    - E.g. Scientists have hypotheses such as:
      - Increased atmospheric carbon dioxide is due to human activities
      - Increased carbon dioxide causes increasing global temperatures
    - Data enables scientists to see that levels of atmospheric carbon have increased in line with human burning of fossil fuels, and that increasing atmospheric carbon levels correspond with increasing global temperatures
  - Quantitative data enables scientists to **make predictions**
    - E.g.
      - Studying the connection between atmospheric carbon levels and global temperatures enables scientists to predict the level of impact of the release of specific amounts of carbon into the atmosphere
      - Understanding the impact of global photosynthesis rates on atmospheric carbon levels means that scientists can accurately predict the impact of projects such as large-scale tree planting and rewilding
  - **Statistical analysis** can be carried out on quantitative data, enabling **statistical significance** to be established
    - E.g, scientists can be sure that current carbon dioxide levels are **significantly higher** than they would have been without the combustion of fossil fuels
- Scientists from the World Meteorological Organisation and research stations (e.g. the Mauna Loa Observatory) have been taking **quantitative measurements** of the atmospheric carbon dioxide and methane concentrations for many years

Your notes

- Scientists have records for carbon dioxide levels dating back to 1958, and for methane levels from 1984
- It is possible for scientists to find information about concentrations of atmospheric gases over a longer period of time by analysing gas bubbles from deep ice cores



Changes in atmospheric carbon dioxide levels measured at the Mauna Loa Observatory (ppmv = parts per million by volume). The yearly fluctuations shown in red are due to seasonal changes in photosynthesis rates.

Combustion

- Carbon can be returned to the atmosphere by the burning of **fossil fuels** and **organic material**; a process known as **combustion**
  - Complete combustion releases **carbon dioxide** and water as byproducts
- **Fossil fuels** form when animals and plants die in conditions where decomposing microorganisms are not present; the carbon in their bodies is converted, over millions of years and with significant pressure, into **fossil fuels** such as coal and oil
  - The combustion of fossil fuels releases carbon that has been **stored** for millions of years
  - **Increased use of fossil fuels** is contributing to an increase in the carbon dioxide content of the atmosphere
- **Organic material**, or biomass, burns when fires occur in e.g. forests or grasslands
  - Such fires can have natural causes e.g. lightning hitting hot, dry ground, or can be set by humans e.g. when clearing land for the purpose of farming
  - Biomass can also be burned as a fuel in e.g. wood fires or biomass boilers

Your notes

Your notes

4.2.3 Carbon Cycle: Methane

Methanogenesis

- **Methane** (CH_4) is a simple **hydrocarbon**
- It is present as a **gas** in the atmosphere, and underground, and is the main component of **natural gas** fossil fuel
- Methane can be produced by the **naturally occurring process** known as **methanogenesis** by organisms known as **methanogens**
  - Before methanogenesis can occur, a series of bacteria convert organic matter into a compound called acetate, as well as carbon dioxide and hydrogen
  - A group of single-celled organisms called **archaeans** then carry out methanogenesis via two different mechanisms:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

  - CH_3COOH is acetic acid, a compound that can be formed from acetate

- Archaeans carry out methanogenesis in a range of environments
  - **Waterlogged mud**
    - E.g. in naturally occurring wetlands, or in man-made rice fields
  - The **guts of ruminant mammals** such as cattle
  - **Landfill sites** containing organic matter such as food waste
  - **Anaerobic digesters** used for the break down of organic waste

- Depending on the location of methanogenesis, the methane is either **released directly into the atmosphere** or into the surrounding soil
  - Methane can **accumulate in the ground**, but it can gradually make its way to the surface where it is released into the atmosphere

- **Human activities** such as livestock farming and landfill disposal of waste food are leading to an **increase in the release of methane into the atmosphere**
  - Note that anaerobic digesters are sealed units for the production of biogas, and the methane produced is collected and used for fuel

Examiner Tip

Note that you don't need to know the chemical processes by which methane is produced. Make sure that you know that methane is produced by methanogenic archaeans and released into the atmosphere or into underground stores.

Oxidation of Methane

- The lifetime of methane gas once it reaches the atmosphere is around 10–12 years
- This is because methane is oxidised in the atmosphere
  - This oxidation involves a reaction with molecules called **hydroxyl radicals** (·OH)
    - Hydroxyl radicals are **highly reactive** molecules that form in the presence of sunlight from other gases in the atmosphere e.g. nitrous oxides
  - Hydroxyl radicals **react with methane** in a series of reactions that produce **carbon dioxide and water**
- **Methane oxidation** keeps levels of methane in the atmosphere **relatively constant**
  - Recent increases in atmospheric methane have led to concern that levels of hydoxyl radicals in the atmosphere may be declining

Your notes

4.2.4 Carbon Cycle: Organic Matter

Your notes

Formation of Peat

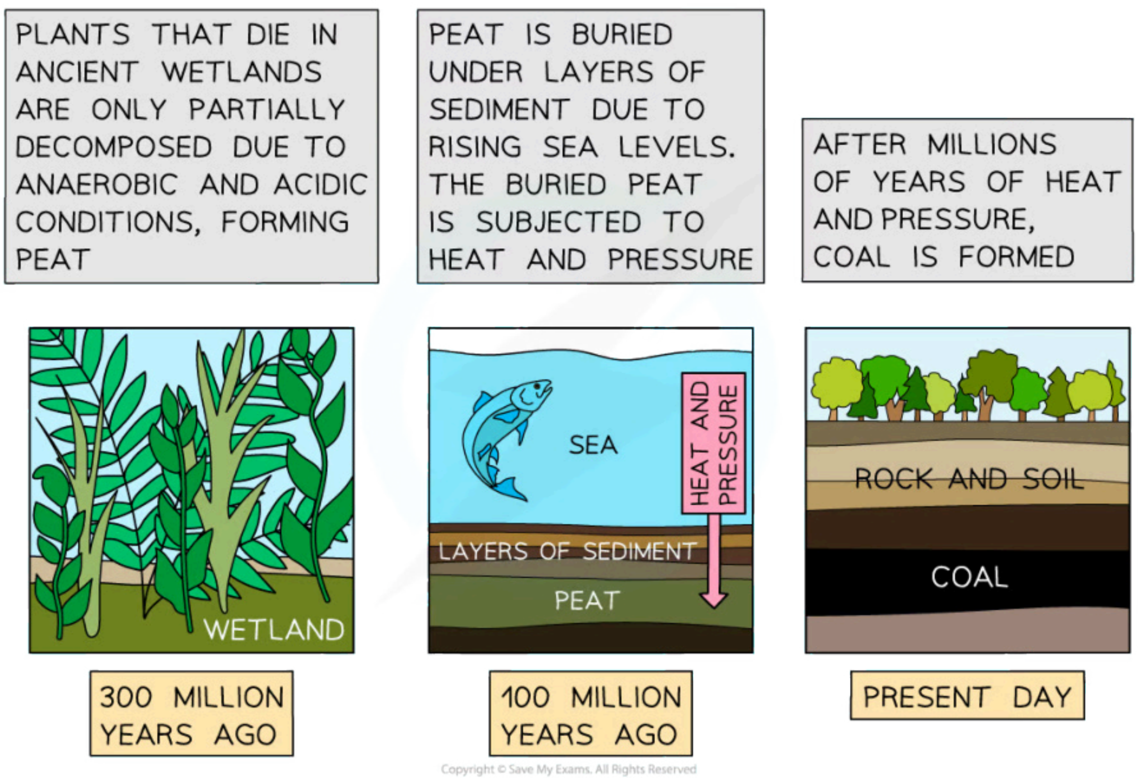
- Under normal conditions the tissues of dead organisms are completely broken down by decomposers known as saprotrophs and detritivores
- These decomposers require specific conditions, such as **oxygen** availability and the **correct pH**
- If ground is **waterlogged** or **acidic**, most decomposers cannot survive, and only **partial decomposition** takes place
  - Waterlogging occurs when levels of rainfall exceed levels of evaporation
    - When ground is waterlogged, the air spaces in the soil is filled with water, and the conditions become **anaerobic**
  - Low pH can occur due to mineral leaching, acidic bedrock, bacterial activity, and the growth of certain types of plant
- Under waterlogged and acidic conditions partly decomposed organic material, such as **dead plant matter, accumulates**, and becomes **compacted** under its own weight over time; this compacted, partially decomposed plant matter forms **peat**
  - The place where peat accumulates is known as a **peat bog**, or **peatland**
  - There are various types of peat bog e.g. blanket bog and raised bog, depending on the landscape and conditions in which it forms
- The **carbon compounds** in plant material are trapped in peat
  - Over millions of years, peat can develop into the fossil fuels coal, oil, or natural gas
- Peat is considered to be a valuable resource, and digging up peat bogs has been a common practice
  - Peat can be burned as a **fuel** due to its carbon content
  - The high nutrient content of peat means that it is often used in **compost**
- The importance of peat bogs as a **carbon store** and unique, **biodiverse, habitat** is now better understood, and many people work to protect and restore peat bogs

Examiner Tip

Make sure you know that peat is formed from partly decomposed plant matter that results from acidic and waterlogged (anaerobic) conditions.

Fossilisation

- If animals and plants die in **acidic** or **anaerobic** conditions then **complete** decomposition **cannot take place**
  - Micro-organisms that carry out decomposition cannot survive in acidic or anaerobic conditions
- The carbon in remaining tissues can be converted into **fossil fuels** over **millions of years**
  - This means that carbon taken into the tissues of living organisms during **past geological eras** is locked up in fossil fuels
- **Coal** forms when **peat** (see above) that forms in acidic and anaerobic conditions is **buried, compressed,** and **heated** e.g. after a rise in sea levels

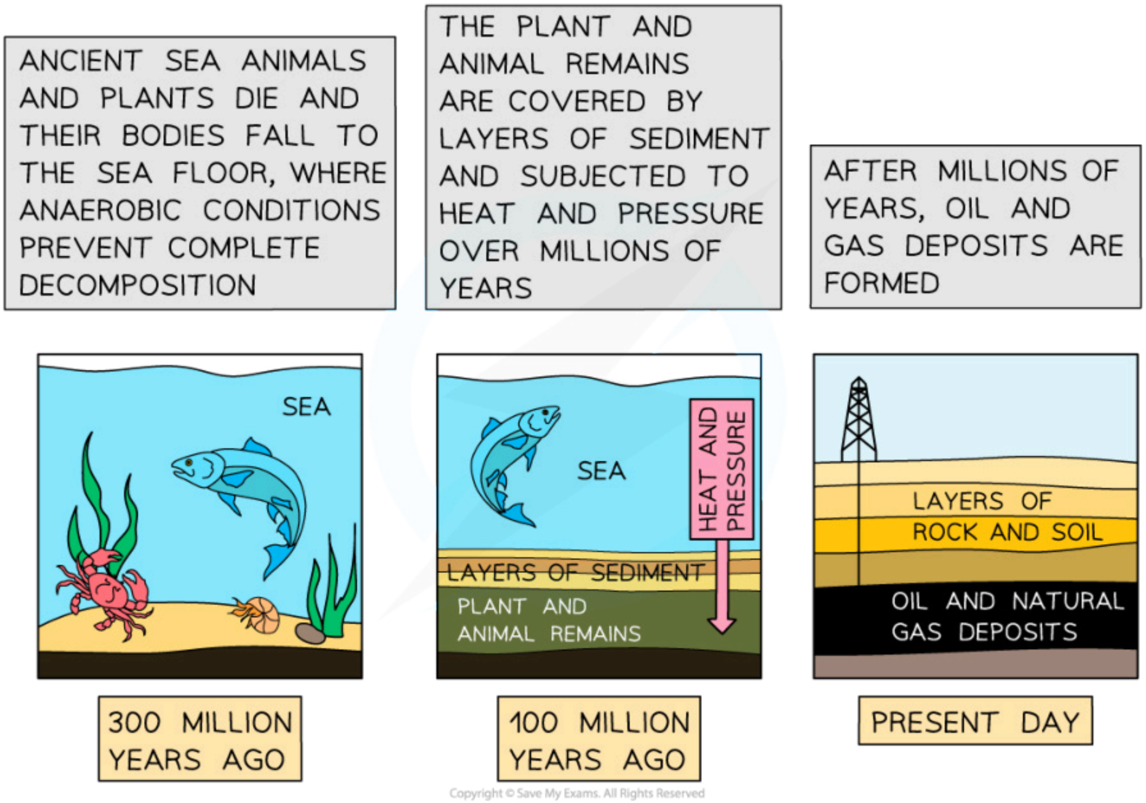


Formation of coal from peat

- **Oil** and **natural gas** form in anaerobic conditions at the bottom of seas and lakes when **aquatic organisms** die and are covered by **layers of sediment**, and are then **compressed** and **heated.**
  - Natural gas forms **deposits** in **porous rock** when surrounding non-porous rock prevents it from escaping to the surface

Your notes

Your notes



Formation of oil and gas from the bodies of aquatic organisms

- When fossil fuels are burned (the process is known as **combustion**), the carbon combines with oxygen and **carbon dioxide is released** into the atmosphere
- **Increased use of fossil fuels** is contributing to an increase in the carbon dioxide content of the atmosphere

Limestone Formation

Your notes

- Many **marine** (sea-living) **organisms** extract **carbon** from their surroundings in order to produce **calcium carbonate**, from which they build certain body parts. For example:
  - The shells of **molluscs** (e.g. mussels and clams)
  - The hard bodies (exoskeletons) of **corals**
- When these organisms die, the soft parts of their bodies are broken down by decomposers, but their **calcium carbonate outer shells remain** and fall to the seafloor
- The **layers of sediment** that form on the seafloor are rich in the calcium carbonate shells of marine organisms, and as the layers are **compacted** with their own weight and that of the sea above them, they harden, and **limestone** is formed
- The carbon in the hard shells of these marine organisms is **locked up** in limestone rocks e.g. chalk
- Ocean acidification can cause the calcium carbonate shells of marine organisms to dissolve, releasing this carbon back into the surrounding water

4.2.5 Climate Change: Greenhouse Effect

Your notes

The Main Greenhouse Gases

- When **radiation from the sun** hits the earth, it is **radiated back** from the earth's surface as **long-wave radiation**
- A **greenhouse gas** is a gas that **absorbs** this re-radiated radiation, **trapping it in the earth's atmosphere** so that it is not lost to space
  - Greenhouse gases in the atmosphere have a similar effect to the glass in a **greenhouse**, hence the term **greenhouse gas**, and their effect being known as the **greenhouse effect**
- The greenhouse effect is important to ensure that Earth is **warm enough for life**; if it were not for the insulating effects of greenhouse gases, Earth would see similar dramatic **temperature fluctuations** to its neighbouring planets
  - Temperatures on Mars range between 20°C and -153°C
- There are many greenhouse gases, and those that contribute most to the greenhouse effect are:
  - **Water vapour**
  - **Carbon dioxide**
- Water vapour enters the atmosphere when it **evaporates from the surface of the oceans**, and when it is released by transpiration
- Carbon dioxide enters the atmosphere when **living organisms** respire, or when **organic matter** or **fossil fuels are burned**

Other Greenhouse Gases

Your notes

- While water vapour and carbon dioxide are the greenhouse gases with the most significant impact on the greenhouse effect, there are various **other greenhouse gases** which have a lesser effect, e.g.
  - **Methane**
  - **Nitrous oxides**
- Methane is released by:
  - Methanogenic **bacteria** when they break down organic waste
    - Methanogenic bacteria carry out **methanogenesis** in anaerobic environments such as waterlogged ground and landfill sites, and in the stomachs of some types of livestock
  - **Coal mining** when deposits of methane are released from rock
- Sources of nitrous oxides include:
  - **Fossil fuel combustion** e.g. vehicle exhausts
  - **Agriculture** e.g. the production and use of fertilisers
  - The activity of some types of **bacteria**

Examiner Tip

You may have heard of a separate environmental concern, described as the 'hole in the ozone layer'; this is **not** something that you need to know about. Ozone is an atmospheric gas that absorbs harmful UV radiation before it reaches earth, but any concerns about ozone depletion have nothing to do with the greenhouse effect. The problem of ozone depletion is one that has improved significantly due to measures taken to reduce certain types of emissions; humans can get it right sometimes!

Greenhouse Effect

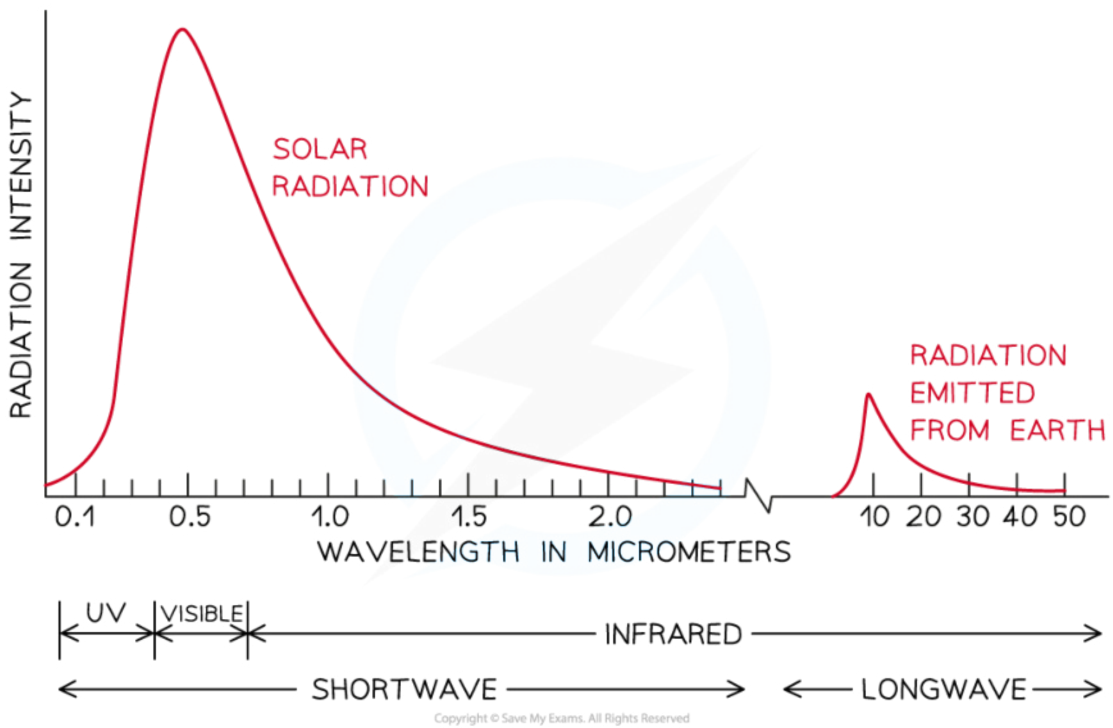
Your notes

Factors affecting the impact of a Greenhouse Gas

- The significance of the impact of any particular greenhouse gas depends on two factors:
  - Its **ability to absorb long-wave radiation**
  - Its **concentration** in the atmosphere
- A gas may have a strong ability to absorb radiation, but if its atmospheric concentration is relatively low, then it will be a low-impact greenhouse gas
  - This is the case for **methane**, which can absorb more long-wave radiation per molecule than carbon dioxide, but which is present at a much lower atmospheric concentration
- The **atmospheric concentration** of a greenhouse gas depends on:
  - The **balance between release and removal** of that gas from the atmosphere
    - A gas that is released into the atmosphere at a faster rate than it is removed will increase in concentration e.g. carbon dioxide is released by the combustion of fossil fuels at a faster rate than photosynthesis can remove it
  - The **length of time** that gas is present in the atmosphere
    - Methane only remains in the atmosphere for 10–12 years before it is oxidised, reducing the overall impact of methane on the greenhouse effect
    - Water vapour is the **most abundant greenhouse gas** in the atmosphere, but because water vapour usually only spends an average of **9 days** in the atmosphere before it returns to the ground, scientists are less concerned about its impact on the greenhouse effect than they are about carbon dioxide, which **accumulates in the atmosphere over hundreds of years**

The Earth emits longer-wave radiation

- The solar **radiation** that reaches Earth from the sun contains **a range of wavelengths**; **primarily shorter wavelengths** in the **UV** and **visible** parts of the light spectrum, with **some longer wavelength infra-red radiation**
- After Earth has absorbed this radiation, it **re-emits radiation** back into the atmosphere, but this re-emitted radiation is **entirely longer wavelength**, in the infra-red part of the spectrum



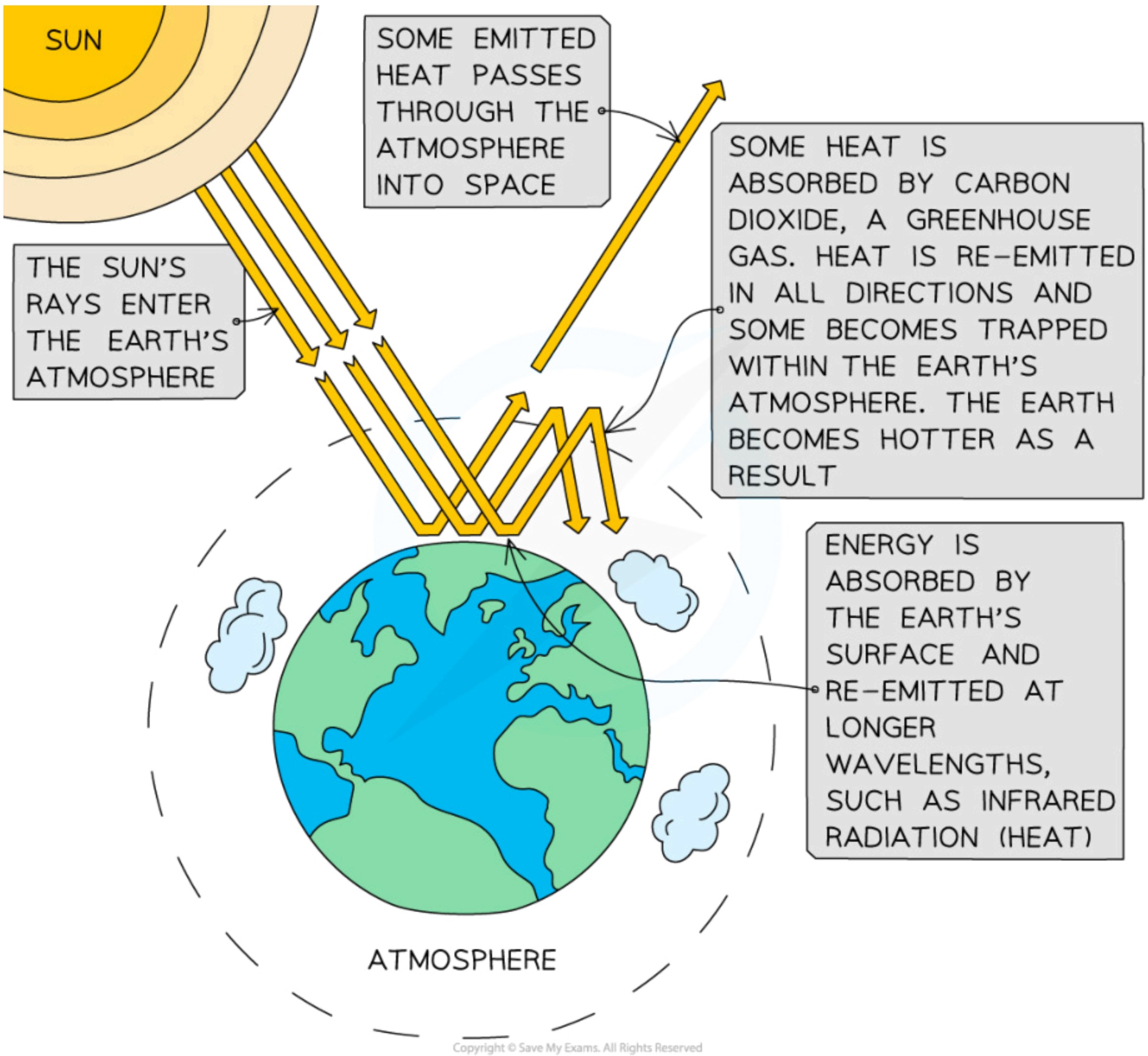
Solar radiation is primarily short-wave, while the radiation that is re-emitted by earth is long-wave radiation

Your notes

Greenhouse Gases absorb longer-wave radiation

- While only around **25%** of the (primarily short wavelength) solar radiation is **absorbed by the atmosphere on its way to Earth**, around **80% of the (long wavelength) re-emitted radiation** from Earth **is absorbed on its way back into the atmosphere**
  - E.g. incoming UV radiation is absorbed by ozone
  - Re-emitted radiation is absorbed by **greenhouse gases**
- This absorbed radiation keeps Earth at a habitable temperature

Your notes



Greenhouse gases absorb the long-wave radiation emitted by Earth, warming the atmosphere

4.2.6 Climate Change: Impact

Your notes

Greenhouse Gases & Climate Patterns

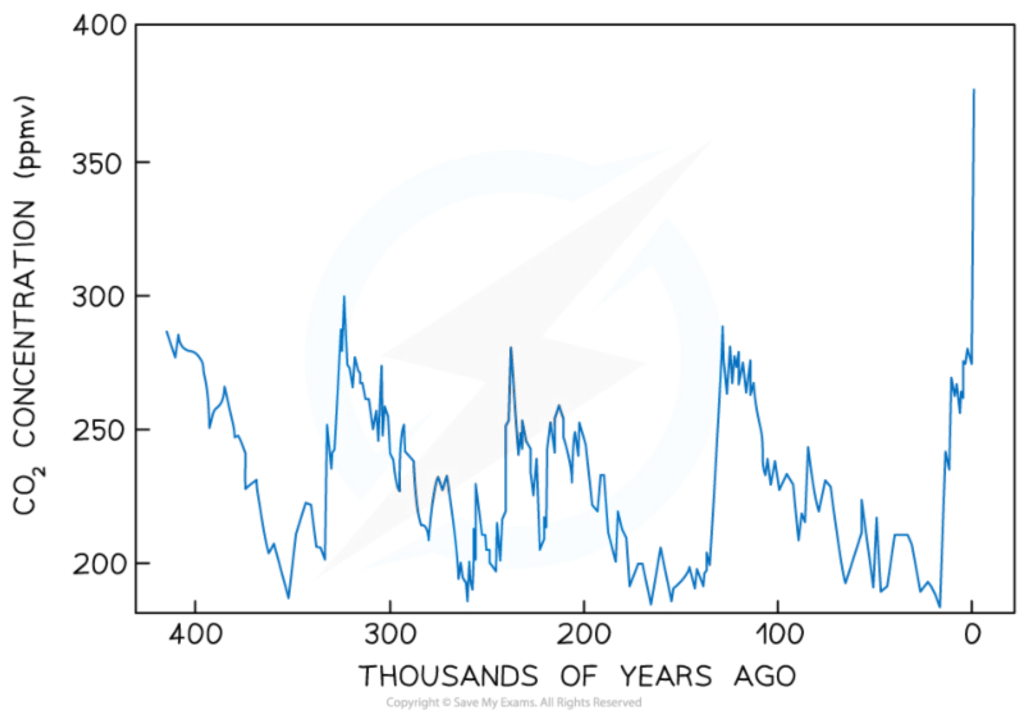
- **Greenhouse gases** absorb infrared radiation emitted by the earth, causing the atmosphere to warm
  - Without greenhouse gases, the earth would be much colder
- The **higher the concentration** of greenhouse gases in the atmosphere, the **more infrared radiation is absorbed**, and the **warmer the atmosphere** will become
- Increased atmospheric warming has had, and will have, multiple **impacts on climate patterns,** e.g.
  - **Weather events becoming more extreme** e.g. hotter, longer, heatwaves, and more violent storms
  - **Changes to ocean currents** leading to altered local climates e.g. the Gulf stream that currently brings warm water to the west coast of the UK might change direction, causing parts of the UK's climate to cool
  - Warmer air can hold more moisture, leading to **changes in patterns of rainfall**; more, heavier rainfall in some places could lead to reduced rainfall in other locations
- **Evidence** for some of these changes in climate patterns **can already be seen** in many parts of the world
  - Warming climates cause animals to **move towards the poles** or to **higher altitudes**
    - A concern is that these species may not be able to compete with, or may even out-compete, the species already present in these habitats, with either result leading to **decreased biodiversity**
    - Some species (such as plant species) may not be able to move or change their distributions fast enough to adapt to changing temperatures and may **go extinct** as a result
  - **Polar ice** and **glaciers are retreating**; it is thought that there may soon be no summer ice in the arctic if rates of warming there continue
    - The loss of glacier ice from mountain ranges may affect the water supplies of many people and surrounding wildlife
  - **Sea levels have been rising** faster in recent years, putting many more people at risk of being flooded out of their homes
    - Sea levels are rising due to the expansion of warmer water and due to melting polar ice

4.2.7 Climate Change: Causes

Your notes

Industrialisation & Increased Carbon Dioxide

- Atmospheric carbon dioxide levels have **fluctuated throughout Earth's history** due to events such as volcanic eruptions and the weathering of limestone rocks
  - Scientists know this from having analysed the gas composition of bubbles formed in ancient ice cores

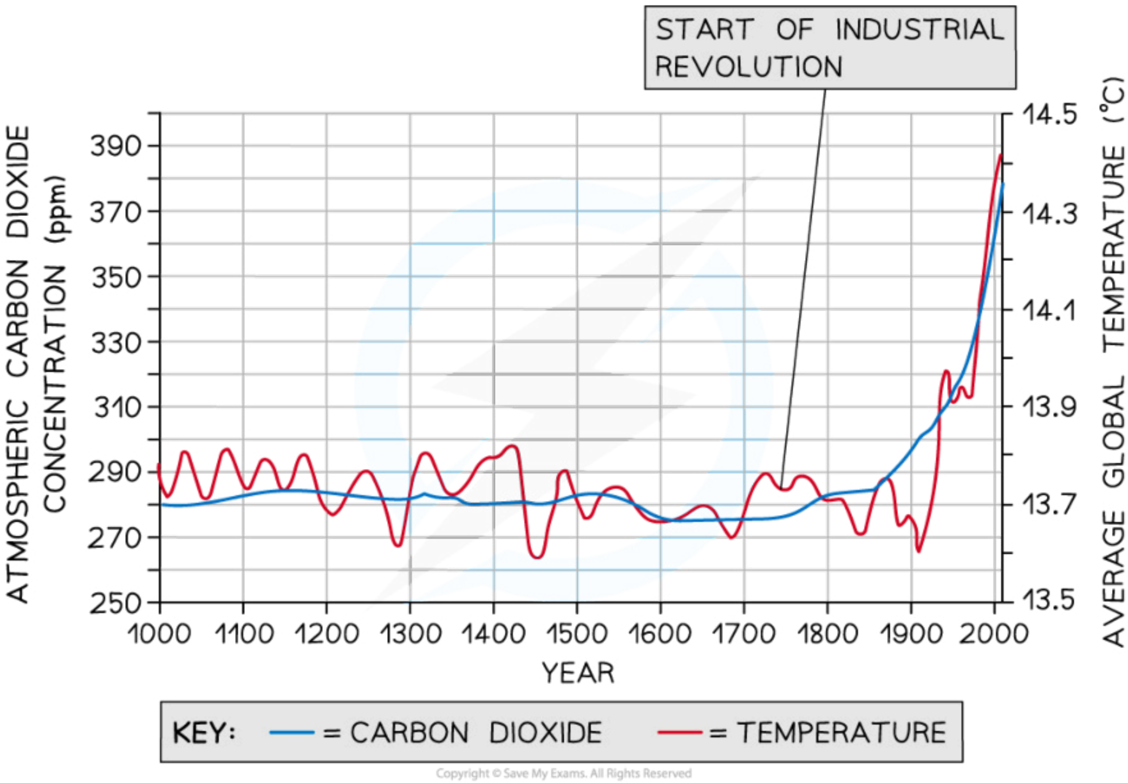


Atmospheric carbon dioxide levels have fluctuated throughout earth's history, but recent increases have been faster and higher than ever before (ppmv = parts per million by volume)

- Since the **industrial revolution**, however, atmospheric carbon dioxide levels have **risen to their highest in Earth's history**
  - Prior to the industrial revolution, the highest atmospheric carbon dioxide concentration was around 300 parts per million (ppm), and it is currently above 400 ppm
- The industrial revolution began in the late 1700s, when the **combustion of fossil fuels** to power **factories, transport**, and **homes** became commonplace
  - Fossil fuel combustion releases **carbon dioxide**
- A clear correlation can be seen between increasing **levels of carbon dioxide since the industrial revolution** and **increasing global temperatures**

Your notes

- Early data on global temperatures can be found using climate indicators such as tree growth and soil cores



There is a correlation between increasing carbon dioxide levels since the start of the industrial revolution and increasing global temperatures

Combustion of Fossil Fuels

Your notes

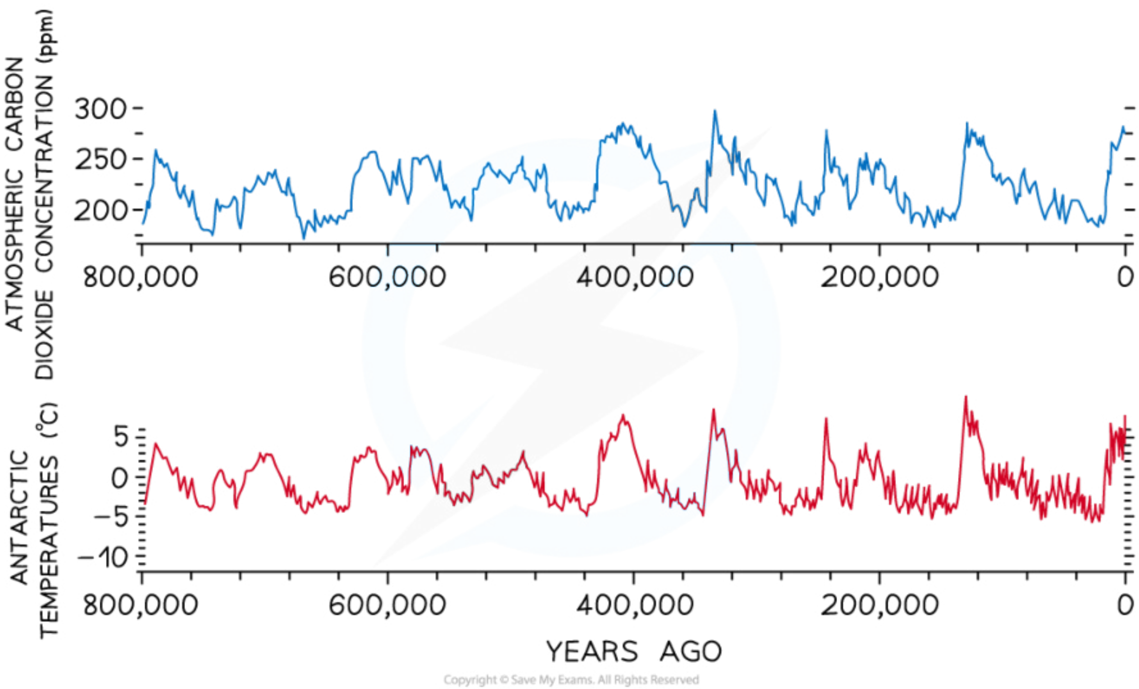
- The industrial revolution, beginning in the late 1700s, was the shift from hand production to **machine production**, often in **factories powered by steam**
- Factory production led to the need to **transport goods** over long distances, and so the **railways** were built, also powered by steam
- Steam would have been produced by the **combustion** (burning) of **fossil fuels**; initially **coal**, and later also **oil** and **gas**
  - The combustion of fossil fuels releases carbon that has been **stored for millions of years** into the atmosphere in the form of **carbon dioxide**
- The improved standard of living for many that resulted from the industrial revolution lead to huge **population growth**, further increasing the need for production and movement of goods, and therefore the need for fossil fuels
- Although we often associate the industrial revolution with the Victorian era, the fastest increase in fossil fuel combustion has taken place **since the 1950s**
- The increase in fossil fuel use since the 1950s is **correlated with the fastest increases in atmospheric carbon dioxide**, providing evidence that it is **human activity** changing the composition of the atmosphere

Temperatures & Increased Carbon Dioxide

- We know that greenhouse gases **absorb infrared radiation** and **warm the earth's atmosphere**, and we know that carbon dioxide is a greenhouse gas, so climate scientists have long hypothesised that **increasing carbon dioxide levels in the atmosphere will lead to warming global temperatures**
- Evidence to support this hypothesis can be found by **looking back** at the connection between atmospheric carbon dioxide levels and temperatures over time
- Information about the ancient atmosphere and climate can be found by analysing **ice cores,** obtained by drilling into antarctic ice
  - Ice is deposited as water freezes over time, so the deeper into the ice you go, the older it is
  - Analysing the **gas content** of bubbles in ice can tell scientists about atmospheric gas concentrations over time
  - Data about climate can be inferred by studying **ancient** pollen **grains** preserved in ice (certain plants would have survived in certain climates), as well as studying the **chemistry of the water molecules**
- Data show a **correlation** between changing atmospheric carbon dioxide levels and temperature over thousands of years
  - Note that carbon dioxide in the atmosphere is not thought to be the only factor affecting climate; it is known that events such as solar winds and sun spots can affect the climate on Earth, but scientists think that the effects of such events are small in comparison to that of atmospheric carbon dioxide
- **Correlation does not equal causation**, but together with what scientists know about **carbon dioxide as a greenhouse gas**, this is **strong evidence** that **carbon dioxide released since the industrial revolution is causing increasing global temperatures**

Your notes

Your notes



Data from antarctic sea ice show a correlation between atmospheric carbon dioxide and antarctic temperatures over the last 800 000 years

Investigating the Causes of Climate Change

Evaluating claims that human activities are not causing climate change

- Since scientists first began to associate burning fossil fuels with increasing global temperatures, there have been **many who have claimed that human activity is not the cause of climate change**

Evaluating Claims that Human Activities are Not Causing Climate Change Table

Claim	Evaluation
There have been changes in atmospheric carbon dioxide throughout Earth's history due to natural causes, and we are just experiencing another such change	Current carbon dioxide levels are higher than they have ever been at any point in Earth's history, suggesting that natural causes alone are not responsible
An oil company, when their scientists first predicted the climate impacts of continued combustion of fossil fuels, stated to the public that the evidence for a link between fossil fuels and climate change was 'inconclusive'	An oil company has a financial interest in people continuing to burn fossil fuels, so may not be telling the truth, or will at least be keen to play down the significance of research linking fossil fuels to climate change
Rates of warming have not been consistent; temperatures have cooled slightly at some points in the last 50 years, showing that global warming has stopped	Carbon dioxide levels are not the only factor that influences global temperatures; climate is highly complex and some factors may have a larger impact in some years than others

- It is important to **evaluate any statement** that is made about the causes of climate change in the light of scientific evidence
  - Consider whether a statement addresses **all of the evidence**, or only part of it
    - E.g. there may be some years when global temperatures go down, but there is strong evidence for an overall upward trend
  - Find out whether the statement comes from a **trustworthy, unbiased source**
    - E.g. Does the source have a financial or political interest in continuing to burn fossil fuels
      - Several countries wrote to the United Nations in 2021 to ask that urgent recommendations against burning fossil fuels were toned down; all of these countries had economies that depended on the use of fossil fuels

NOS: Assessing claims; assessment of the claims that human activities are producing climate change

- Whenever you come across **any scientific claim**, it is important to assess its reliability
- Scientists know that before they present a new idea, they must carry out **research** and provide **evidence** to support their claim

Your notes

- Any published research must be clear about the **level of certainty** that any data provide; this is the purpose of **statistical tests** such as the chi-squared test
- Research papers must include details of the **method** used so that other scientists can **evaluate it** and **potentially repeat it** to see if they achieve the same results
- When it is claimed that human activities are causing climate change, it is important to evaluate these claims while bearing the following factors in mind
  - There is a **great deal of scientific evidence** that has been tested and checked by other scientists that **supports the hypothesis that humans burning fossil fuels causes climate change**; this increases the likelihood that further claims of this nature are correct
  - **Climate is highly complex**, so scientists need to be careful not to state that one factor alone has led to a specific event
    - Climate can be affected by any number of factors in any given year; it is important to look at **all of the data**
      - You may have heard climate and weather experts in the media being asked about whether one particular extreme weather event is due to climate change; they always say that it is **wrong to draw conclusions from one event**, while also pointing to **that event's place in a trend** of increasingly extreme weather
    - Climate change is **not expected to be linear** in effect; scientists expect that there may be a **tipping point** beyond which changes happen faster
      - This makes it very **difficult to make predictions** about exact future climate conditions
  - People always have a **personal interest**; some are especially passionate about the environment, while others depend financially on fossil fuels
    - It is important that we are aware of the personal **biases** of those making claims about the causes of climate change
- If predictions about global warming are correct, then the potential impacts on the future of Earth are huge; as scientists, it is our responsibility to be aware of the important factors surrounding this debate so that we can help other to assess evidence thoroughly

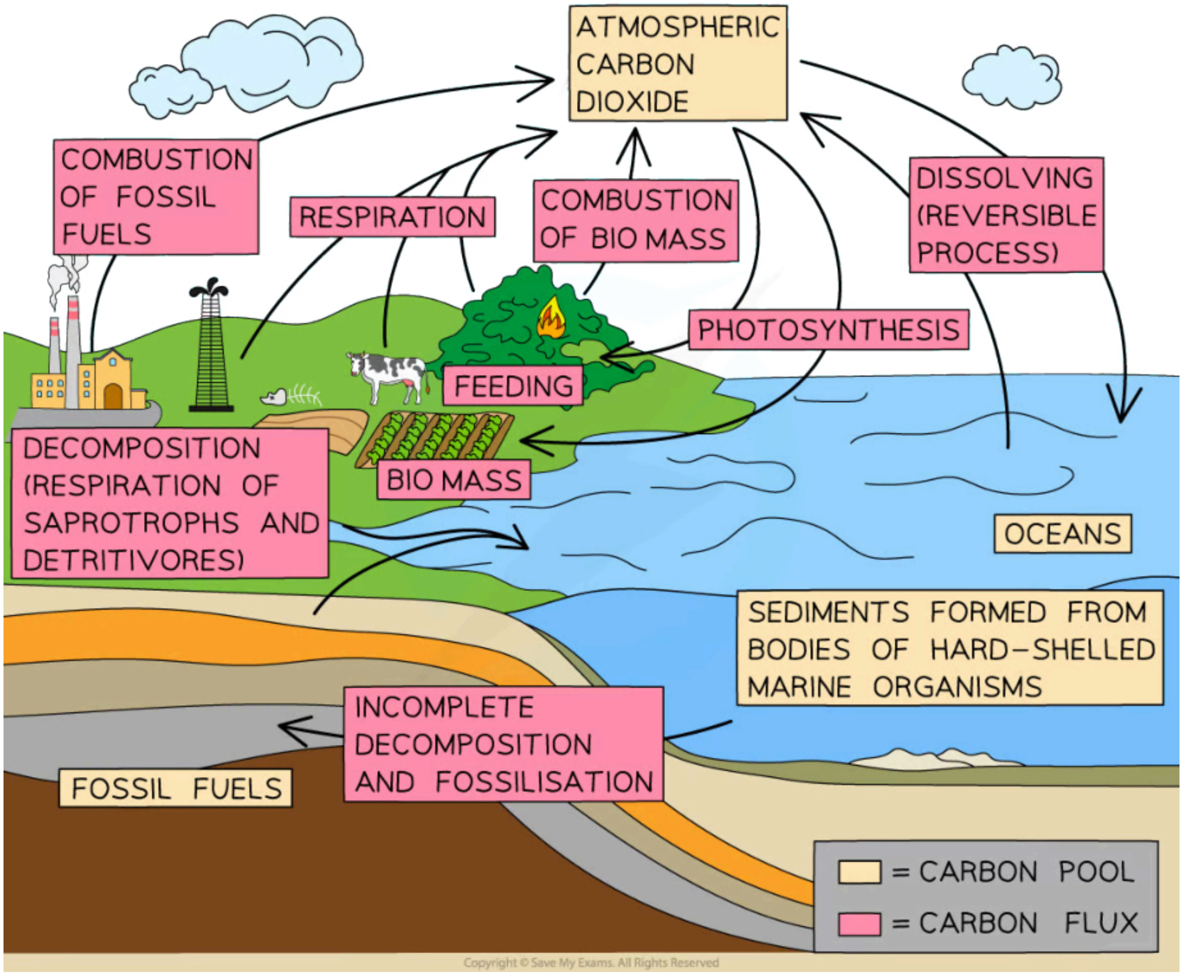
4.2.8 Skills: Carbon Cycling & Climate Change

Your notes

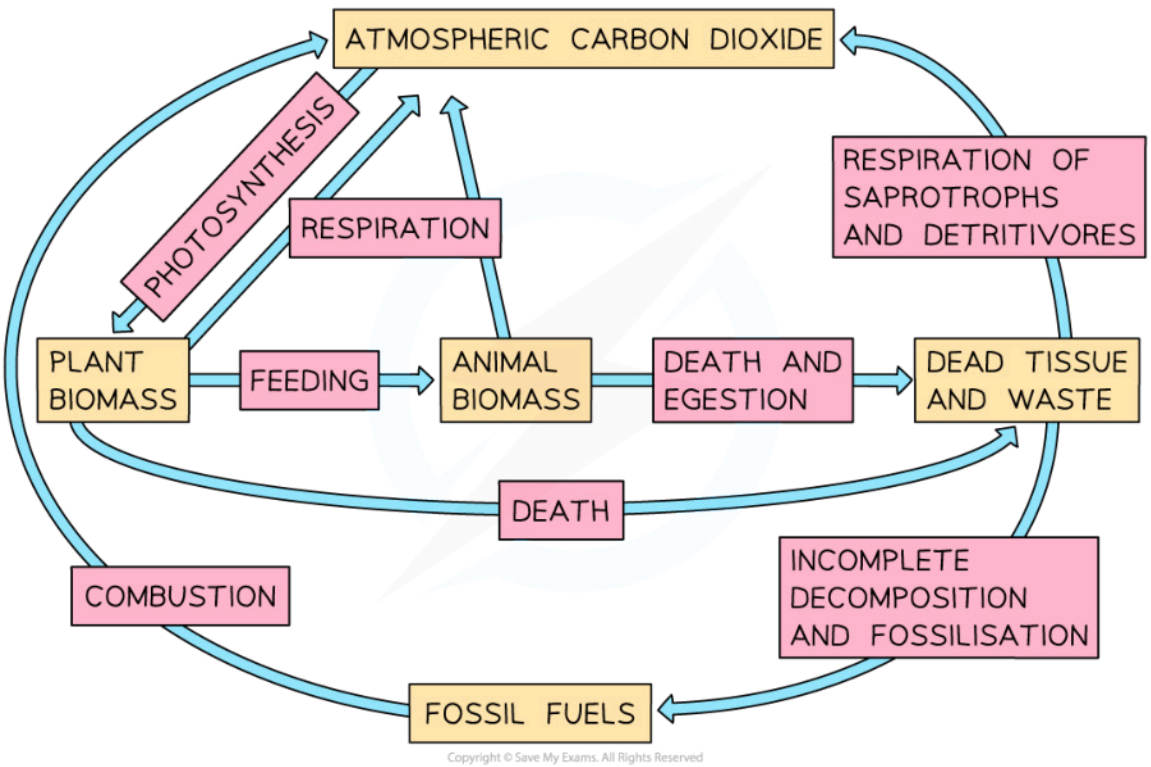
Drawing the Carbon Cycle

- The many processes by which carbon is transferred from one store to another are collectively known as the **carbon cycle**
  - During the carbon cycle, carbon is present in both **organic** and **inorganic** forms
    - Organic carbon is found in the biomass of living organisms e.g. in **carbohydrates** and **proteins**
    - Inorganic carbon is found in the **atmosphere** as **carbon dioxide** and in the **oceans** as e.g. **hydrogen carbonate ions**
- The carbon cycle can be represented using a **diagram**
  - Carbon cycle diagrams show:
    - Carbon stores, known as **pools,** e.g the ocean, fossil fuels, or living organisms
    - Processes of carbon transfer, known as **fluxes** e.g. dissolving, combustion, or photosynthesis
- Diagrams can be illustrated, or can be simple, containing just text boxes and arrows
- Diagrams can show **terrestrial** carbon cycling, **marine** carbon cycling, or **both combined** in one diagram

Your notes



An illustrated carbon cycle diagram showing both terrestrial and marine cycling



A simple carbon cycle diagram showing terrestrial carbon cycling

Your notes

Estimation of Carbon Fluxes

- The processes by which carbon is transferred from one pool to another are known as **fluxes**
- Fluxes can be measured **quantitatively**, showing **how much carbon** is transferred by a particular process
- The unit for carbon fluxes is **gigatonnes**, or GT
  - One gigatonne is a billion tonnes
- It is difficult to measure global carbon fluxes precisely, but scientists can make **estimates** by measuring smaller ecosystems and scaling these measurements up

Estimated Global Yearly Carbon Fluxes Table

Process of carbon transfer	Flux / GT $year^{-1}$
Photosynthesis	123
Respiration of terrestrial organisms	60
Respiration of decay organisms	60
Ocean dissolving	92
Release from the oceans	90
Marine sedimentation	0.4
Combustion of fossil fuels	6
Conversion of forests/grassland to farmland	2
Weathering and volcanic activity	0.4

- Estimating carbon fluxes is very important as humans seek to **predict the impacts of climate change** and **reduce carbon emissions**
  - By calculating the total carbon fluxes that remove carbon from the atmosphere and the total carbon fluxes that add carbon into the atmosphere scientists can calculate **atmospheric carbon increases**
  - This enables scientists to predict levels of atmospheric warming