IB Biology DP

YOUR NOTES

4. Ecology

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4.1 Species, Communities, Ecosystems & Energy Flow

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4.1.1 Species & Population

Species

- A species can be defined as:

A group of organisms that can interbreed to produce fertile offspring

- The ability to breed and produce fertile offspring is a useful method of distinguishing species for organisms that reproduce sexually but **can be difficult to apply** in some situations
    - Organisms that reproduce by asexual reproduction, such as bacteria, cannot be classified using this method
    - On rare occasions, **animals of different species breed together and produce fertile offspring**, such as the so-called 'wholphin'; the fertile offspring from a cross between a melon-headed whale and a common bottlenose dolphin
        - According to the species rule above the wholphin would be a new species, but while scientists do believe that hybridisation can lead to new species it needs to be a frequent event for this to occur, and wholphins are rare
        - Note that the melon-headed whale is actually a species of dolphin, so the name 'wholphin' is a bit inaccurate!
- The imperfect nature of this method of classifying species means that other characteristics are often used at the same time
    - Organisms of the same species share **similar** morphology
    - **DNA sequences** can be compared, with a certain level of similarity indicating that organisms are the same species

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Populations

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- A population can be defined as:

A group of organisms of the same species living in an area at one time

- A **population** can be isolated from other populations of the same species due to living in a different area
- This isolation means that members of the separate populations **cannot breed together** and **gene exchange** or **gene flow** cannot take place between them
- As long as these isolated populations could, in theory, interbreed to produce fertile offspring, they are the **same species**
- If the environmental conditions affecting each population are different, then **natural selection could act differently** on each population and eventually lead to speciation
    - Genetic drift can also lead to speciation
- Once speciation has taken place, the **two species** can no longer produce fertile offspring; they are **reproductively isolated**

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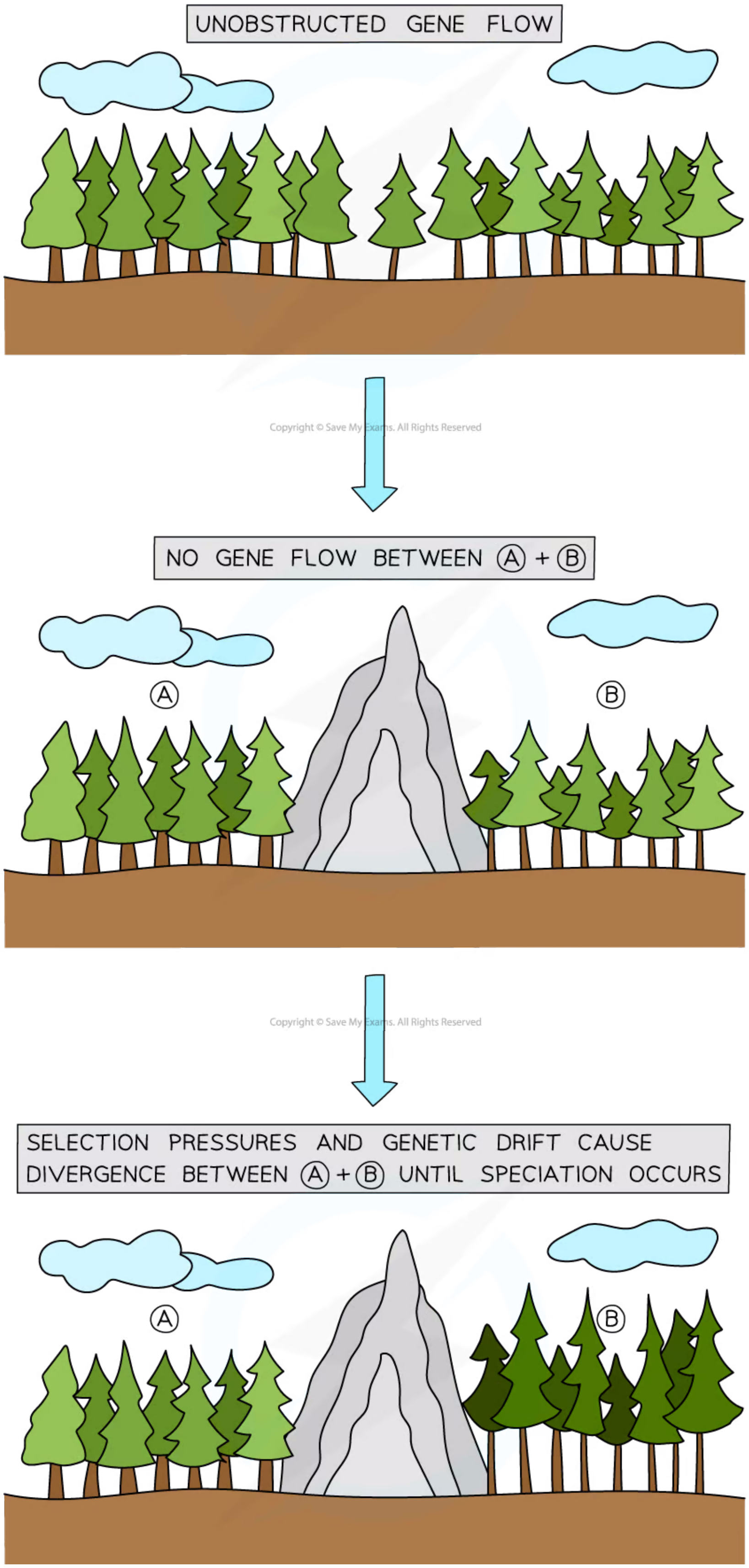

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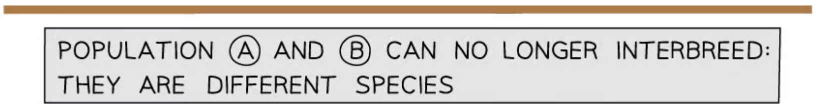

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Reproductive isolation of two populations of trees can occur when the populations are separated for a long period of time

Exam Tip

Make sure that you can state the definition for a species - organisms belong to the same species if they can interbreed to produce **fertile** offspring

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4.1.2 Methods of Nutrition

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Autotroph vs Heterotroph

- Organisms need **energy in the form of** ATP to survive
- The energy stored in ATP comes from other **organic molecules, such as carbohydrates,** and is transferred during the process of **respiration**
- The method by which an organism gains organic molecules to fuel respiration is known as its **mode of nutrition**
- There are two main modes of nutrition; **autotrophy** and **heterotrophy**

Autotrophs

- An **autotroph synthesises**, or produces, **its own organic molecules** from simple inorganic substances in its environment
- **Photosynthetic organisms use light energy** to **convert carbon dioxide from the air into organic molecules** such as carbohydrates
    - Some autotrophs use energy from the oxidation of inorganic compounds instead of light energy
    - Autotrophs that use light energy are known as photoautotrophs, while those that use energy from oxidation of chemicals are known as chemoautotrophs
- Because autotrophs make their own organic molecules without relying on other organisms, they are known as **producers**
- Most green plants are autotrophs, along with algae such as seaweeds, and photosynthetic bacteria such as cyanobacteria

Heterotrophs

- **Heterotrophic organisms** gain their organic molecules by ingesting the tissues of **other organisms**
- There are several types of heterotroph, including **consumers, detritivores**, and **saprotrophs**

Mixing modes of nutrition

- Some organisms are able to make use of **more than one mode of nutrition**, such as **auto-** and **heterotrophy**
    - These organisms are referred to as mixotrophs
- **Euglena** is a **single-celled eukaryotic organism** that makes use of both autotrophy and heterotrophy
    - Euglena cells can **take in bacterial cells** by endocytosis, and then digest them using **digestive enzymes stored in** lysosomes
    - Euglena cells also contain a **light-sensitive spot** that enables them to position themselves so that **maximum light reaches their chloroplasts**

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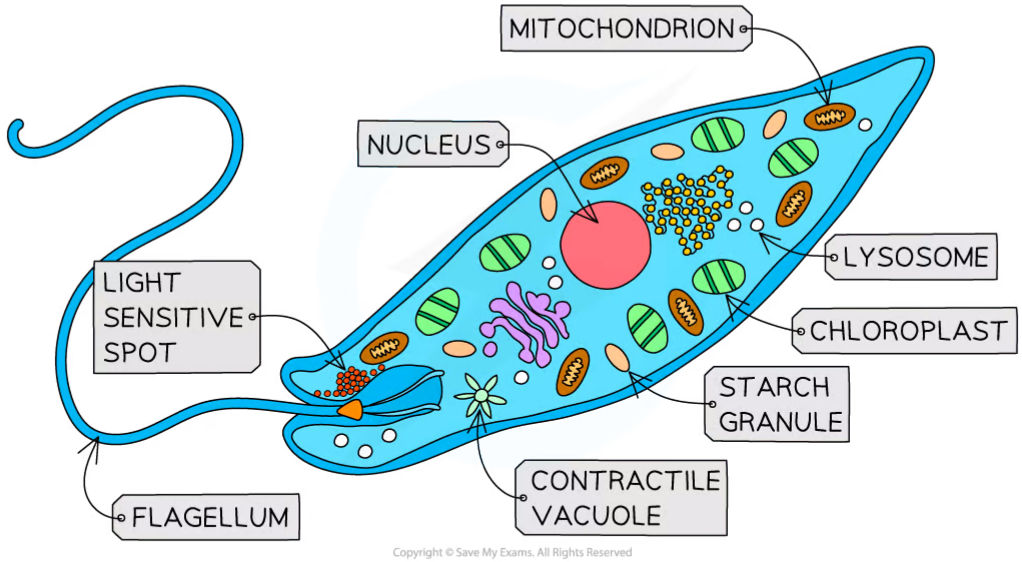

Euglena is a single-celled eukaryote that makes use of autotrophic and heterotrophic nutrition

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Plant & Algal Nutrition

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NOS: Looking for patterns, trends and discrepancies; plants and algae are mostly autotrophic but some are not

- The majority of plants and algae are **photosynthetic,** meaning that they are **autotrophs** that rely on energy from the sun to convert carbon dioxide in the air into organic molecules in their tissues
- Their photosynthetic cells contain **pigments which absorb light energy**
    - The main pigment in green plants is chlorophyll, which primarily absorbs light at the red and blue ends of the visible spectrum, reflecting green light
    - Green plants also have carotenoid pigments, known as accessory pigments, which extend the range of light wavelengths that can be absorbed; these pigments appear to be red, yellow, or purple and remain in mature leaves after chlorophyll degrades
    - Brown algae, such as the seaweed kelp, contain a brown pigment called fucoxanthin
    - Red algae and green algae have pigments called phycobilins

- There are some **unusual exceptions** to the autotrophic mode of nutrition used by most plants and algae
    - Some plants parasitise **the roots of other plants**, tapping into the roots of these plants to gain their organic molecules
        - E.g. groundcone plants look like upright pine cones sitting on the ground, but are in fact parasitic plants, having no photosynthetic pigments of their own, and gaining their organic molecules from the roots of surrounding trees

    - Some plants **parasitise fungi**, a feeding mode known as mycoheterotrophy, gaining their organic molecules from the network of fungal cells in the soil
        - The rare plant E*pipogium aphyllum*, also known as the ghost orchid, has no leaves and no chlorophyll, gaining its organic molecules from the fungi that form associations with tree roots

- When exceptions to accepted trends are observed in the natural world, it can sometimes mean that established modes of thinking are incorrect, so it is important to consider discrepancies carefully
    - In the case of non-photosynthetic plants and algae:
        - They are rare
        - They appear to have evolved on multiple occasions from autotrophic ancestors

    - There is not enough evidence to disprove the mode of thinking that says that plants and algae are autotrophs, but we can say that there are a few exceptions to this rule

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Types of Heterotrophic Nutrition

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- There are several ways in which heterotrophs gain organic molecules from other organisms

Consumers

- **Consumers** gain their organic molecules by **ingesting the tissues of other living organisms or recently dead organisms**
- The consumers that eat plants are known as **herbivores**, and the consumers that eat other animals are known as **carnivores**

Detritivores

- **Detritivores** gain organic molecules by **ingesting the tissues of dead organisms** or **ingesting animal waste**
- Detritivores carry out **internal digestion**, meaning that they digest their food **inside** their bodies
- Examples of detritivores include **earthworms, woodlice** and **dung beetles**

Saprotrophs

- Saprotrophs also ingest the tissues of **dead organisms** and **waste material**, but they **secrete enzymes** onto their food, and **digest it externally**
- The **products** of this external digestion are then **absorbed**
- Examples of saprotrophs include **fungi** and **bacteria**
- Saprotrophs secrete a wide range of digestive enzymes that allow them to hydrolyse (break down) a large variety of biological molecules, releasing a large range of products as a result
  - Examples of these products include mineral ions, such as **ammonium ions** and **phosphate ions**

- Importantly, **not all** of the products of external digestion get absorbed by saprotrophs
- Instead, some of the products **remain in the surrounding soil** and become available to **other organisms** such as **plants**
  - This is why saprotrophs are such an **essential component** of ecosystems and food webs
  - Without them, the nutrients **locked up** in dead and waste matter would never be made available again and **producers** such as **plants** would not have access to **sufficient nutrients**

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4.1.3 Community

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Community

- Species do not exist by themselves in their own isolated environment; they **interact** with **other species**, forming **communities**
- A community can be defined as:

Multiple populations of different species living and interacting in the same area

- For example, a garden pond **community** is made up of populations of fish, frogs, newts, pond snails, damselflies and dragonflies and their larvae, pondweed, water lilies, and all other populations living in the pond

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Ecosystems

- Communities interact with the **non-living components** of the **environment** they live in, forming **ecosystems**
- An ecosystem can be defined as:

A community and its interactions with the non-living parts of its environment

- Ecosystems are mostly **self-contained**
- There is a **flow of energy** within an ecosystem and the **nutrients** within it are **recycled** (e.g. the carbon, nitrogen and phosphorus cycles)
- There are both biotic components and abiotic components within an ecosystem
- Ecosystems **vary greatly in size and scale**
  - Both a small pond in a back garden and the open ocean could be described as ecosystems
  - A human being could also be described as an ecosystem (there are thousands of species of bacteria living on and in every person)
- Ecosystems **vary in complexity**:
  - A desert is a relatively simple ecosystem
  - A tropical rainforest is a very complex ecosystem
- **No ecosystem is completely self-contained,** as organisms from one ecosystem are often linked with another ecosystem somehow
  - For example, many birds species are able to migrate long distances to find food sources or breeding locations from multiple ecosystems

Example of an ecosystem

- A forest is an example of a complex ecosystem
- There is a large community of organisms including trees, birds, small and large mammals, insects and fungi
- The **abiotic components** of the ecosystem include the soil type, dead leaves, water from the rain and streams, the rocks, and any other physical or chemical factors
- The abiotic components of the ecosystem **influence** the **community** of organisms (e.g. by providing **habitat**, **nutrients** and other resources organisms need in order to survive and reproduce)

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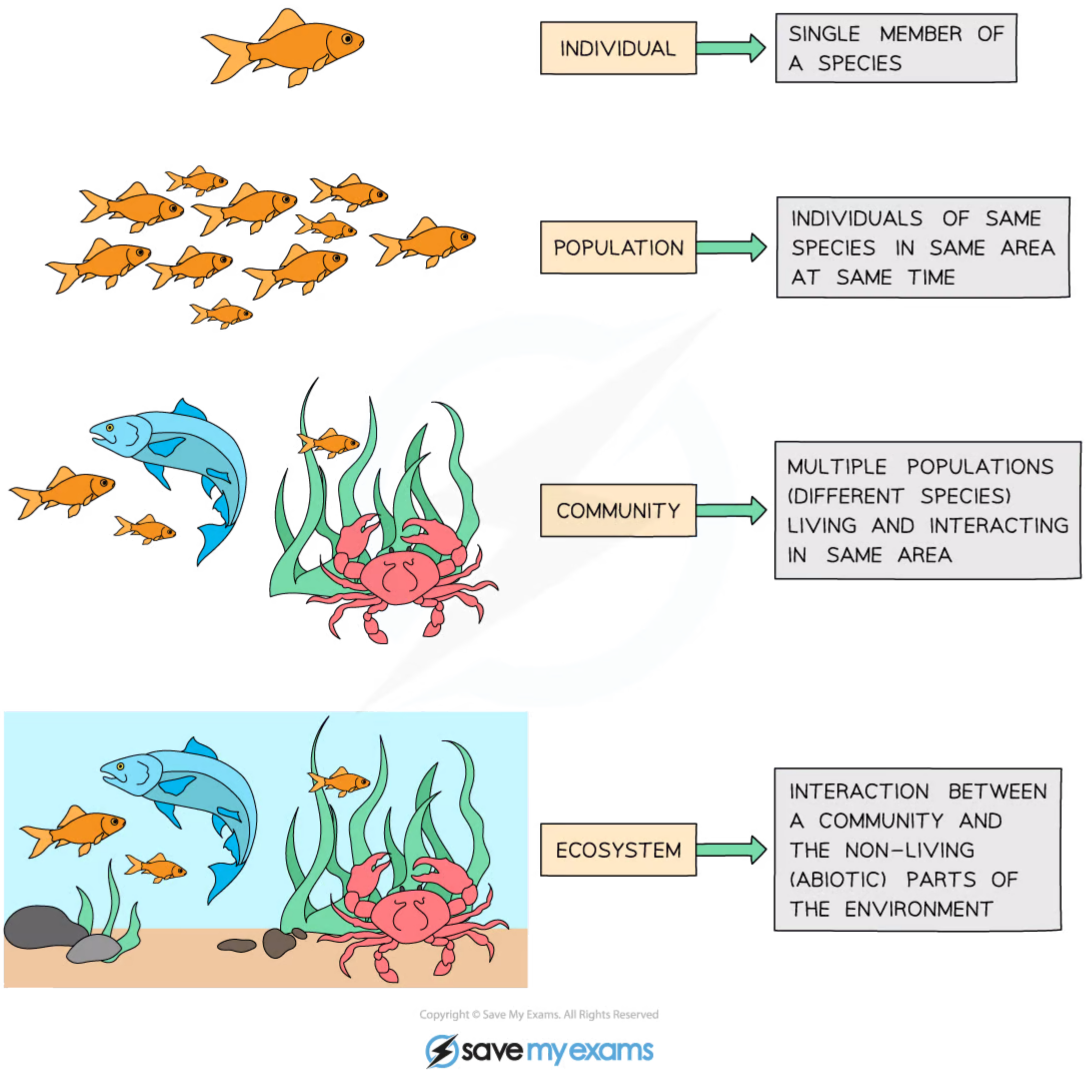

Levels of organisation in an ecosystem

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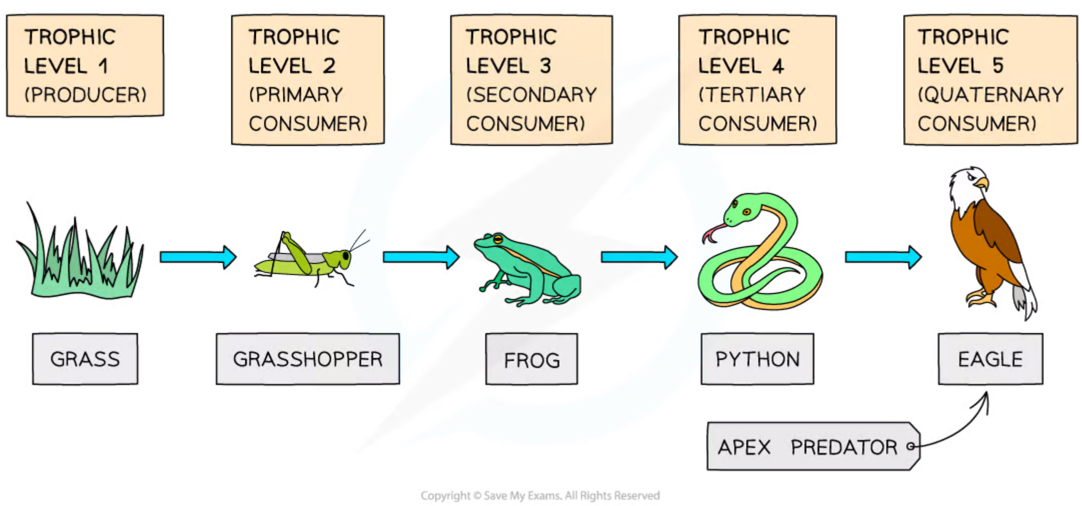
4.1.4 Nutrient Cycling

Obtaining Inorganic Nutrients

- The individual organisms in an ecosystem need organic molecules to build their cells and tissues
- These molecules contain **carbon, hydrogen, oxygen, nitrogen, and phosphorus**, as well as other elements
- Because these elements are present in the **abiotic environment** (such as the **air** and **soil**) in the form of inorganic compounds or nutrients, ecosystems depend on **producers** to transfer them into the food chain
    - Producers are **autotrophs**, producing organic molecules from inorganic carbon via **photosynthesis**
        - In **terrestrial** (land-based) ecosystems, plants use CO_2 from the **air**
        - In **aquatic** (water-based) ecosystems, plants use CO_2 **dissolved in the water**
    - Plants are also able to **absorb inorganic nutrients such as nitrates and phosphates** from the soil, incorporating them into organic molecules in their tissues as they grow
- The organic molecules in the tissues of producers can then be accessed by other organisms within the community via food chains
    - **Primary consumers** feed on producers, digesting their tissues and absorbing the organic molecules via their digestive system
    - **Secondary consumers** feed on primary consumers, and so on



The inorganic nutrients originally obtained by the producer from the abiotic environment are transferred to other organisms in the community via food chains

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Nutrient Cycling

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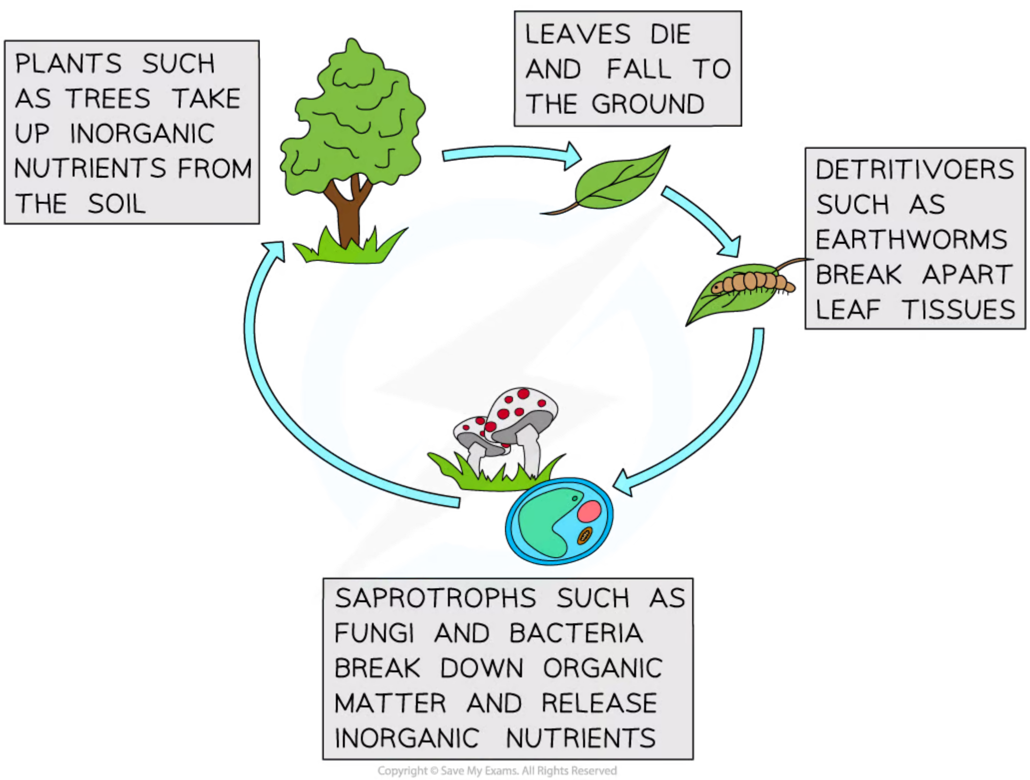
- When inorganic nutrients enter the food chain, they are converted into organic molecules and are **locked up inside the tissues of living plants and animals**
- Because the **supply of inorganic nutrients is finite**, it is essential that when these organisms die the **nutrients locked up in their tissues are released**
  - The organic molecules need to be converted back into inorganic nutrients that can be used by producers

- The process of breaking down the bodies of **dead organisms** and the **waste products** of living organisms is known as **decomposition,** and it enables the **cycling of nutrients**
  - **Detritivores** often begin the process of decomposition by breaking apart tissues
  - **Saprotrophs** release enzymes that break down the organic molecules in the tissues, **releasing inorganic nutrients**
  - While saprotrophs absorb some of these nutrients themselves, what is left in the soil becomes available for producers



The cycling of nutrients in an ecosystem

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Exam Tip

Remember that while an ecosystem's supply of inorganic nutrients is finite, the supply of energy from sunlight, although it may vary depending on weather conditions, is usually continuous. The concept of nutrient cycling discussed here is separate to the concept of energy flow covered elsewhere; the two ideas should not be confused with each other.

Sustainability of Ecosystems

- In a functioning ecosystem, the elements that living organisms need are **constantly recycled**
  - **Producers** access **inorganic nutrients** from the abiotic environment and convert them into **organic molecules**
  - **Consumers** gain organic nutrients from **ingesting the tissues** of producers and other consumers
  - **Detritivores** and **saprotrophs break down the organic molecules** in dead tissues and waste matter, making them **available again to producers**
- Provided that the conditions are right and this cycling process continues, ecosystems can be sustainable **over long periods of time**
- If nutrient cycling stops then an ecosystem can only be productive until the **finite supply of inorganic nutrients runs out**
  - Without the process of decomposition, nutrients **remain locked up** in dead tissues and cannot re-enter the food chain
- Nutrient cycling might stop if environmental conditions become **unsuitable for decomposition**
  - **Climate change** might cause an ecosystem to become too dry for saprotrophs to survive
  - **Harvesting** or **deforestation** removes organic matter from the environment and leaves nothing for saprotrophs to digest, meaning that the nutrients contained within this organic matter are not recycled back into the ecosystem and are instead completely removed from the ecosystem

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4.1.5 Energy Flow

Initial Source of Energy

- **The sun is the initial (first) source of energy for most food chains**
  - **Light energy** from the sun **is converted by producers into chemical energy** stored in the tissues of plants during the process of photosynthesis
  - Chemical energy stored in the tissues of plants **passes to primary consumers** when they ingest plants, and **on to secondary consumers** when the primary consumers are themselves ingested

- There are a few unusual exceptions, such as food chains located in deep sea volcanic vents that rely on bacteria gaining energy from chemical processes; these are chemoautotrophic bacteria

Light Energy Conversion

- **Photosynthesis** is the process of converting light energy into chemical energy
- The photosynthetic pigment chlorophyll **absorbs light energy** when sunlight lands on photosynthesising parts of a plant
- This light energy is used to power several processes which result in the **production of organic molecules,** or **carbon compounds**, including:
  - **Glucose**, which is used in respiration or stored in plant cells in the form of **starch**
  - **Lipids**
  - **Amino acids**

- Hydrolysing these carbon compounds releases energy, so they can be said to contain **stored chemical energy**
- These carbon compounds are used by the plant to build plant tissues, meaning that the energy stored in them is **stored within the tissues of the plant**

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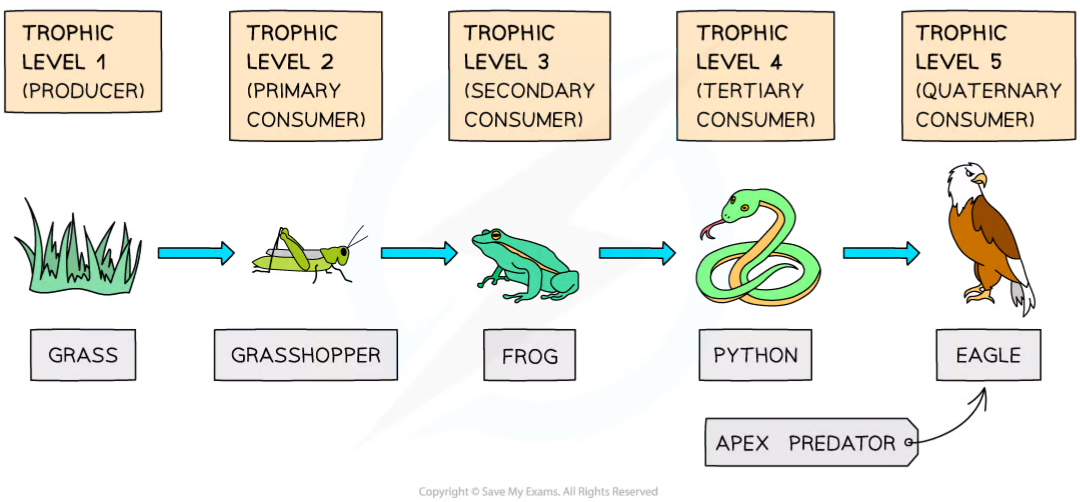
Energy Flow Through Food Chains

- Chemical energy, stored in **carbon compounds** in plant tissues, is **passed to the primary consumer** when the plant is **ingested**
  - The primary consumer **digests** the plant tissues and **absorbs** the carbon compounds containing **stored chemical energy**
  - These carbon compounds can either be used to fuel **respiration** or to build up animal tissue, meaning that the **stored chemical energy is transferred** to the tissues of the primary consumer

- When the primary consumer is ingested, the **carbon compounds in its tissues,** along with their **stored chemical energy**, pass to the **secondary consumer**, and so on up the food chain
- When an organism dies, the chemical energy stored in carbon compounds in its tissues passes to **detritivores** and **saprotrophs**
- In a food chain, the arrows represent the **transfer of energy**, in the form of stored chemical energy in carbon compounds, from one trophic level to the next, by the process of **feeding**



A simple food chain – the blue arrows show how the chemical energy originally stored by the producer is transferred to other organisms in the food chain

Exam Tip

Don't forget that the arrows in a food chain or food web represent the transfer of chemical energy from one trophic level to the next through feeding.

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Energy Lost by Respiration

- The chemical energy stored in ingested carbon compounds can be **released by the process of** respiration
    - The carbon compound **glucose** is the fuel for respiration
    - Other carbon compounds such as lipids **can be converted into glucose** before being respired
- The energy released during respiration can be used by organisms to carry out the **functions of life**
    - **M**etabolism - the enzyme-catalysed reactions taking place inside cells
    - **R**eproduction - the sexual or asexual production of offspring
    - **H**omeostasis - the maintenance of internal conditions within tolerable limits
    - **G**rowth - increasing in size
        - Note that during growth some of the chemical energy in the **carbon compounds** ingested by an organism is **incorporated into the tissues** of the organism as it grows; this **stored chemical energy can be passed to the next trophic level** in the food chain
    - **R**esponse - sensing and responding to the environment
    - **E**xcretion - disposal of metabolic waste
    - **N**utrition - gaining energy and nutrients
- The process of respiration also **releases heat as a by-product**

Energy Conversions

- The process of **respiration** in living organisms **releases heat as a by-product**
    - This applies in **producers, consumers, detritivores**, and **saprotrophs**
- Living organisms **cannot convert the heat energy that is released as a by-product of respiration into any other form of energy**
- This means that **heat energy is lost** from food chains at every trophic level, as well as during decomposition
- This **heat energy** is ultimately **lost to the environment**
- Ecosystems have enough energy to be sustainable because energy is always entering food chains via producers as **they capture light energy from the sun**

Exam Tip

Be careful with your language when discussing energy. You should always describe energy as being released, stored, converted (from one form to another), or transferred (e.g. lost to the environment), never as being produced, made, or destroyed.

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4.1.6 Energy Losses

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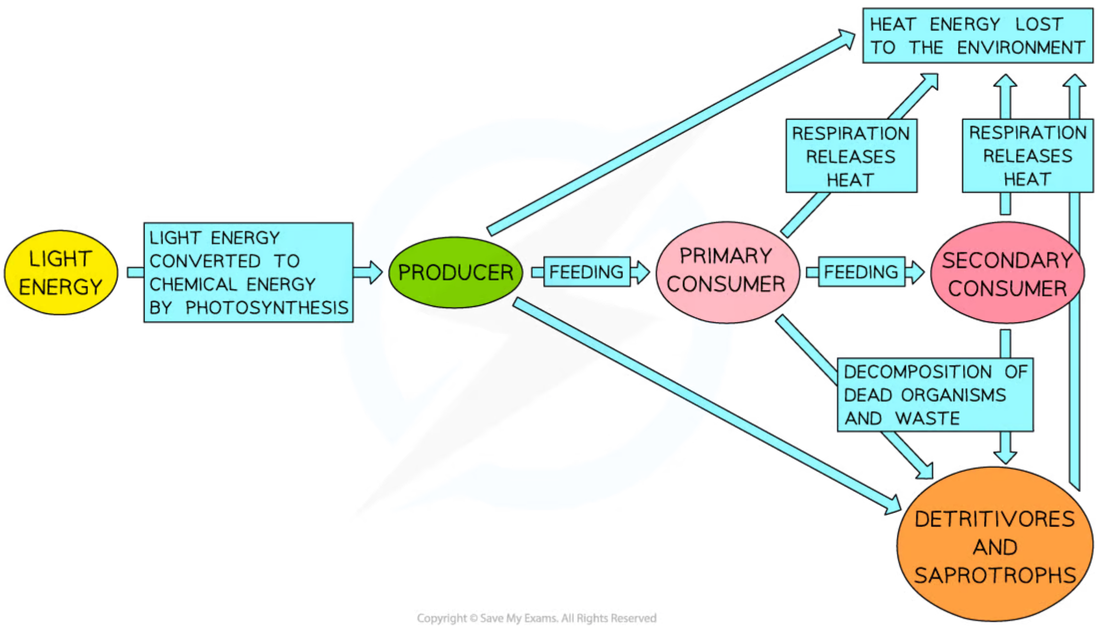
Wasted Energy - Heat

- The process of **respiration** in living organisms **releases heat as a by-product**
  - This applies in **producers, consumers, detritivores**, and **saprotrophs**
- This **heat energy is lost from ecosystems to the environment** at every trophic level, and during decomposition



Heat energy released during respiration is lost to the environment at every stage of the food chain

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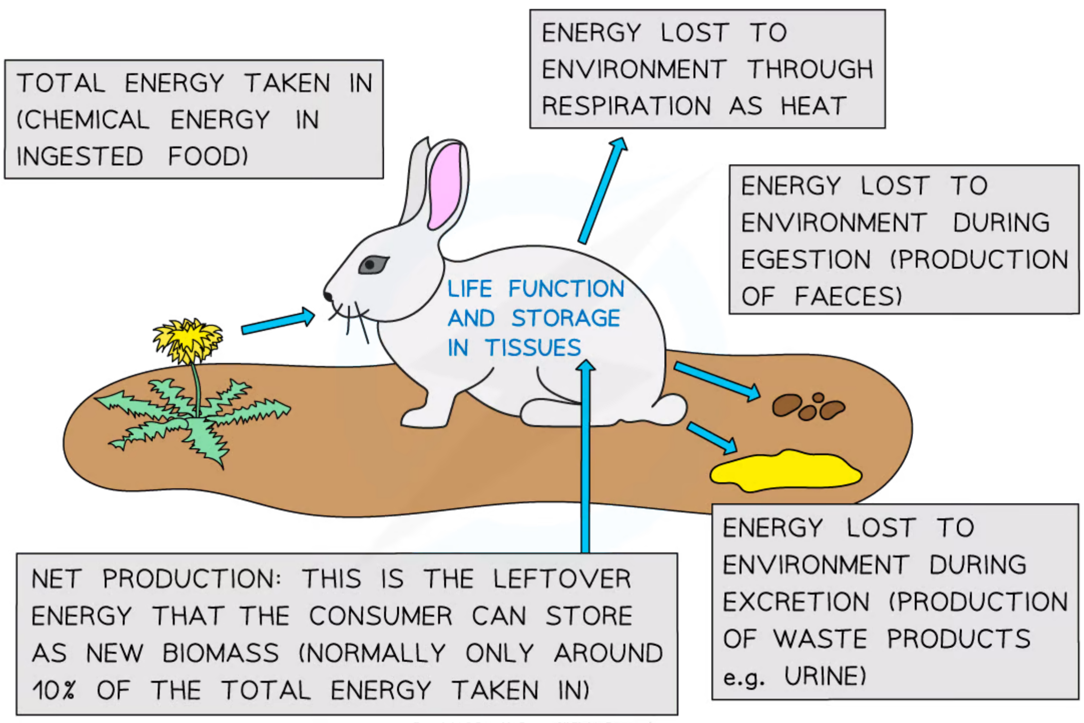
Energy Losses between Trophic Levels

- When a consumer ingests another organism **not all the chemical energy in the consumer's food is transferred to the consumer's tissues**
  - **Only around 10%** of the energy is available to the consumer to store in their tissues
  - This is because **around 90%** of the energy is **lost to the environment**
- Around 90% of the energy is lost to the environment because
  - **Not every part of the food organism is eaten,** e.g. the roots and woody parts of plants or the bones of animals, meaning that the chemical energy these uneaten tissues contain is **lost** to the **environment**
  - Consumers are **not able to digest** all of the food they ingest, e.g. cellulose in plants, or the fur of animals, so some is **egested** as **faeces**; the chemical energy in this undigested food is also lost to the environment
  - Energy is lost to the environment in the form of **heat** when consumers **respire**
  - Energy is lost to the environment when organisms **excrete** the waste products of metabolism e.g. urea in urine
- The energy that is left after these losses **is available to the consumer** to fuel their **life functions,** including being stored in **carbon compounds in their tissues during growth**



Energy is lost from the food chain as heat during respiration, due to incomplete digestion, and through excretion of the waste products of metabolism. Remaining energy fuels the organism's life processes or is stored in carbon compounds in the tissues.

NOS: Use theories to explain natural phenomena; the concept of energy flow explains the limited length of food chains

- Scientists can gather information about the world by **observing events**, or **phenomena**, before **formulating theories** that seek to explain those events

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- In the case of food chains:
  - Scientists **observe** that food chains are short and have a pyramid structure
  - **Theories** of energy flow and energy losses can provide an explanation for these phenomena
- **Food chains are limited in length**
  - Food chains rarely have more than around four or five trophic levels; this is because with energy losses at each trophic level, there is **less and less energy available to the consumer** as you go up the food chain
  - When a food chain gets longer than four or five trophic levels it becomes too difficult for a predator to hunt enough prey to gain the energy to survive
- Biomass **decreases with each trophic level**
  - Because only around 10% of the energy stored in a producer's tissues is available to a primary consumer, **primary consumers needs to consume a large amount of plant biomass to gain enough energy to survive**
  - Again, only around 10% of the energy stored in a primary consumer's tissues is available to a secondary consumer, meaning that **secondary consumers need to consume a large amount of prey biomass to gain enough energy to survive**
  - This leads to a large reduction in biomass at each trophic level and means that when represented in terms of biomass, food chains have a **pyramid** structure

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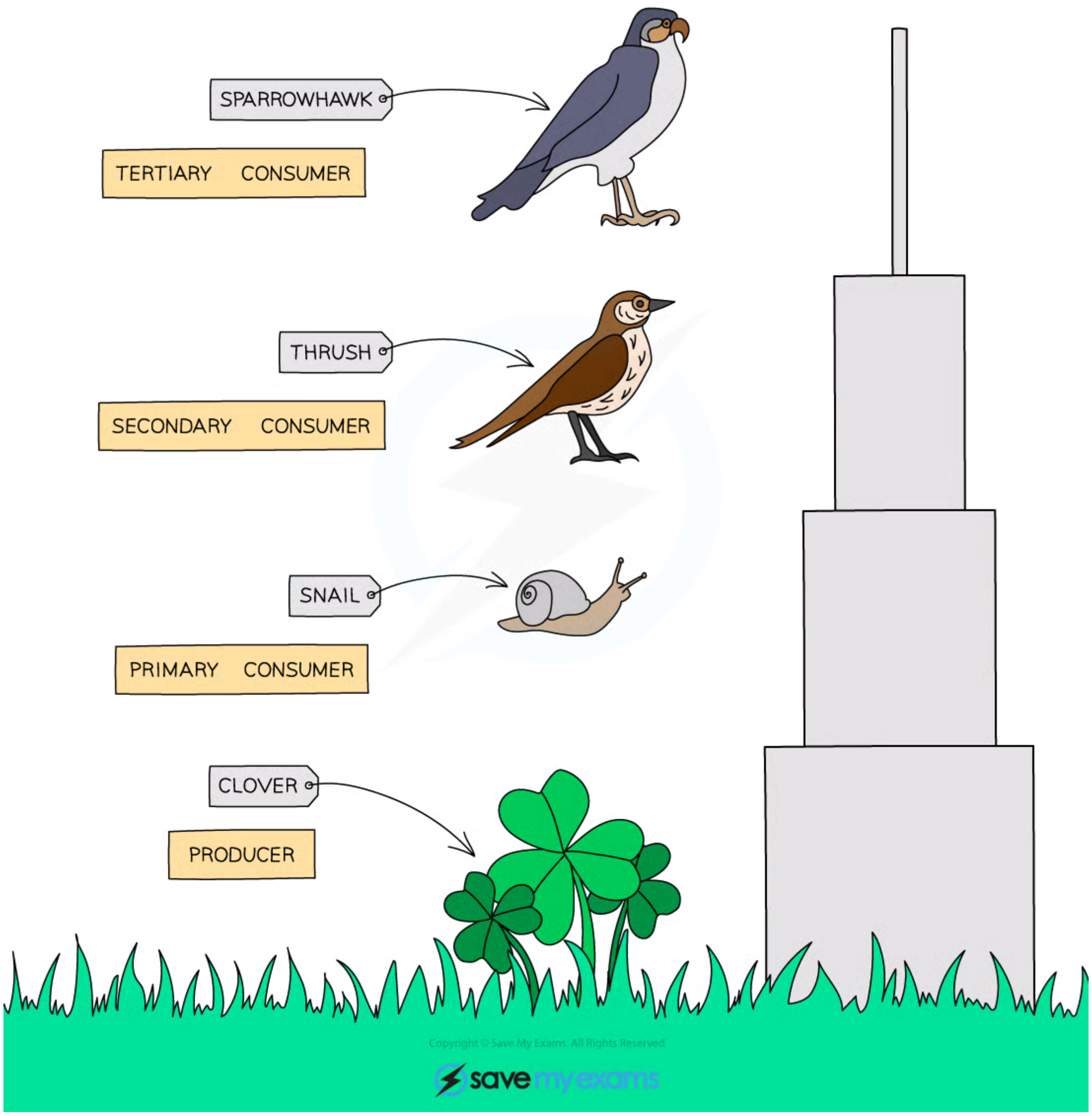

The biomass at each trophic level of a food chain can be represented as a pyramid of biomass. The pyramid shape results from the energy losses at each trophic level.

Exam Tip

Make sure that you know the different ways that energy can be lost from a food chain and that you can explain the effects that these losses have on food chain structure.Be careful not to mix up pyramids of biomass with pyramids of energy.

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Identification of Trophic Level

Classifying species as autotrophs, consumers, detritivores, or saprotrophs

- A species can be classified as an autotroph, consumer, detritivore, or saprotroph on the basis of its mode of nutrition

Autotrophs

- An **autotroph** synthesises, or produces, its own organic molecules from simple inorganic substances in its environment
  - **Photosynthetic organisms** use **light energy** to convert **carbon dioxide from the air** into organic molecules such as **carbohydrates**
  - Some autotrophs use energy from the oxidation of inorganic compounds instead of light energy
  - Autotrophs that use light energy are known as **photoautotrophs**, while those that use energy from oxidation of chemicals are known as **chemoautotrophs**
- Because autotrophs make their own organic molecules without relying on other organisms, they are known as **producers**
- Most **green plants** are autotrophs, with few exceptions
  - Some unusual plants are parasitic, gaining their nutrients from the roots of host plants, or via networks of fungi in the soil

Heterotrophs

- **Heterotrophic organisms** gain their organic molecules from **other organisms**
- There are several types of heterotroph, including **consumers**, **detritivores**, and **saprotrophs**

Consumers

- **Consumers** gain their organic molecules by ingesting the tissues of other living or recently dead organisms
- The consumers that eat plants are known as herbivores, and are the **primary consumers** in a food chain
- The consumers that eat other animals are carnivores, and those that eat the primary consumers are **secondary consumers**
- Carnivores that eat secondary consumers are **tertiary consumers**

Detritivores

- **Detritivores** gain organic molecules by **ingesting the tissues of dead organisms** or ingesting **animal waste**
- Detritivores digest their food inside their bodies
- Examples of detritivores include earthworms, woodlice and dung beetles

Saprotrophs

- **Saprotrophs** also gain their organic molecules from **dead matter**, but they **digest their food externally**

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- Saprotrophic organisms **secrete enzymes** onto dead matter, and these enzymes **break down the food before nutrients are absorbed**
- Saprotrophs include fungi and bacteria

Classifying Species as Autotrophs, Consumers, Detritivores, or Saprotroph Table

Species	Method of gaining organic molecules	Mode of nutrition
Common pin mould	Secretion of multiple enzymes onto dead plant material	Saprotrophic
Common nettle	Conversion of carbon dioxide from the air into carbon compounds using light energy	Autotrophic
Barn owl	Hunts and eats small rodents	Consumer (secondary)
White legged snake millipede	Ingests dead plant matter	Detritivore
Roe deer	Feeds on grass, leaves, and berries	Consumer (primary)

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Exam Tip

The two main modes of nutrition are autotrophism and heterotrophism, and within those modes are different types e.g. a heterotroph can be a consumer, a detritivore, or a saprotroph depending on its food source and its method of digestion

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Practical 5: Mesocosm – Sustainable Ecosystem

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Reasons for building mesocosms

- A **mesocosm** is an experimental container in which a **naturally occurring** ecosystem **is simulated**
- Mesocosms can be used to **study the response of an ecosystem to changes in specific factors** such as nutrient and light levels
- Unlike a real ecosystem, it is possible in a mesocosm to **control all of the factors other than the variable being studied**
- Mesocosms can be set up in many different ways for many purposes
  - Water tanks can be set up on land to study the effect of sewage pollution on ponds or lakes
  - Underwater enclosures can be built in coastal waters or lakes to study the effect of temperature change or dissolved carbon dioxide on ocean ecosystems
  - Trees can be planted in large greenhouse-like buildings to replicate a rainforest to investigate the passage of carbon through this ecosystem
- Mesocosm experiments can be **considered unrealistic** due to their enclosed nature and the level of control that can be achieved
  - **Realism can be improved** by designing large mesocosms that share more of the features of a real ecosystem e.g. enabling mixing of layers of water in a large ocean mesocosm

Building a mesocosm in the lab

- It is possible to build small mesocosms in the laboratory
- Factors to consider:
  - The container should be **transparent** to **enable sunlight to reach producers** inside the mesocosm
  - **Autotrophs** should be included so that **light energy** can be converted into **chemical energy** inside the mesocosm
  - Small primary consumers such as zooplankton or other small invertebrates could be included, but it is important to consider whether the mesocosm is likely to be large enough to support them
  - Do not include secondary consumers in a mesocosm because there will not be enough energy in the food chain to sustain them for long, and it could be considered **unethical** to allow the primary consumers to be eaten in this way
- Mesocosms can be set up as open systems, i.e. without a lid, but sealed systems are **more controlled**, and therefore more useful for experimental purposes
  - Sealed systems prevent organisms and substances from entering or leaving
- In the lab, a mesocosm can be set up and then a **known factor can be altered** to assess its effect
  - E.g. different **light** levels, different **temperatures** etc.
- In order to assess the impact of changing one factor, a **control** mesocosm must be set up at the same time
  - A control mesocosm will be **exactly the same** as the experimental mesocosm, **but the altered variable will not be changed**

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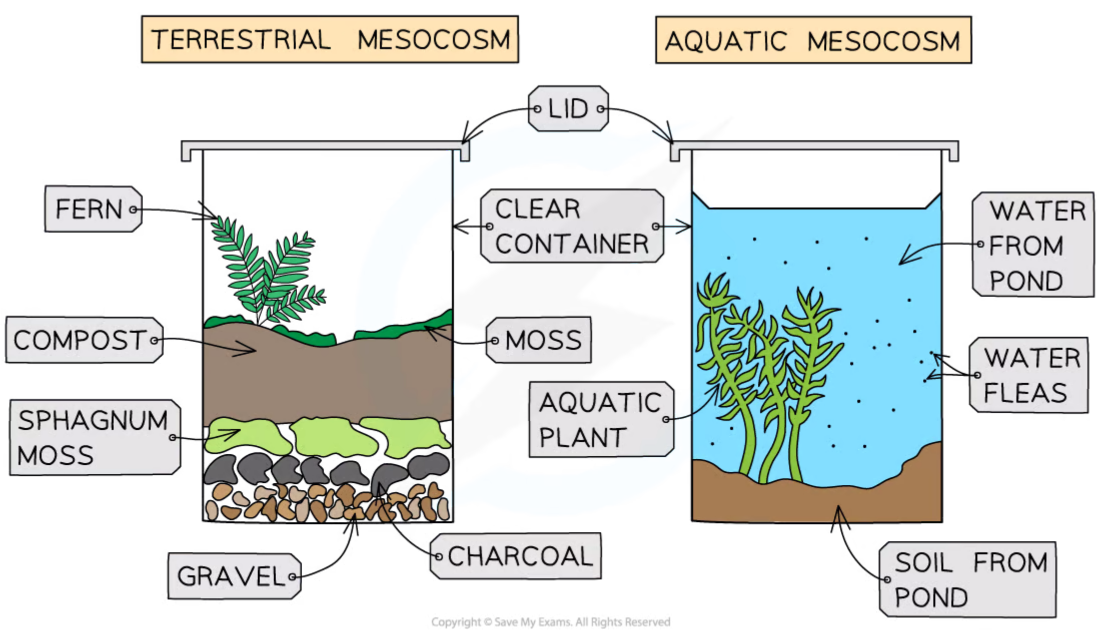
- The purpose of this is to demonstrate that any change in the mesocosm is **due to the altered factor and not another factor**

Terrestrial mesocosm

- Place **drainage material** such as gravel in the bottom of a clear container
- Add a layer of charcoal on top of the drainage layer; this can help to prevent the growth of mould
- Place a layer of sphagnum moss or filter paper on top of the charcoal to **provide separation** between the base layers and the organic matter above
- Add a layer of soil or compost above the separation layer; this provides **organic material and micro-organisms** to aid with nutrient cycling
- Plant **slow-growing producers** such as healthy mosses and ferns in the growth medium
- Water the growth medium before sealing the container with a lid
    - The mesocosm may need watering while it establishes, but **avoid excessive watering**; once the mesocosm has stabilised, the plants should release enough water vapour during respiration to maintain moisture levels
- Place the container in a **light location**, and ensure that the **temperature is stable**

Aquatic mesocosm

- The base layer of the mesocosm should consist of **organic substrate** from the bottom of a lake or pond; this will provide naturally occurring nutrients and microorganisms
- Add **lake or pond water**; this ensures that it contains the required microscopic organisms and avoids chemicals from tap water
- Add **healthy aquatic plants** to produce carbohydrates and **oxygenate the water**
- Small aquatic organisms such as water fleas or water snails can be added, but not more organisms than the size of mesocosm can support
- Place the container in a **light location**, and ensure that the **temperature is stable**



Building a terrestrial or aquatic mesocosm

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Chi-squared Test for Association

Looking for associations between species

- The distribution of species in a habitat is **rarely random**; it usually depends on factors such as soil type, water availability, and competition
- It is sometimes possible to observe an **association** between the distributions of different species within a habitat, e.g.
  - Species that are in a symbiotic relationship are likely to be **found next to each other**; we would say that there is **a positive association between the distributions of these two species**
  - Species that are in **direct competition** for the same resources will exclude each other from their immediate surroundings, and so are likely to be **found in different parts of a habitat**; there might be a **negative association between the distributions of these two species**
- If species have **no interaction** with each other, then there will be **no association between their distributions**, and any that appears to occur will be **due to chance**
  - We would say that such species have distributions that are **independent** of each other
- **Random sampling** with **quadrats**, along with a statistical test called the **chi-squared test**, can be used to test for an **association between two species**

Using quadrats to study the distribution of species

- A **quadrat** is a **square frame** that is placed within the area to be studied to provide a **sample**
  - Quadrats are used to study the **distribution** of sessile organisms
  - Quadrats can be **different sizes** depending on the species being studied
    - A 1 m^2 quadrat can be used to study small organisms such as herbaceous plants in a grassland or limpets on a rocky shore
    - A 400 m^2 quadrat can be used to study large organisms such as trees (quadrats like this will usually be marked out with string rather than a frame!)
  - Scientists can record **different types of data** from a quadrat depending on the aim of a study and the species involved
    - **Presence or absence** of a species
    - **Species frequency**; how many individuals are in the quadrat
    - **Species abundance**; measured on a scale called the **ACFOR** scale on which species are recorded as being abundant, common, frequent, occasional, rare, or none
    - **Percentage cover**; the percentage of the quadrat covered by a species
  - Quadrats can be divided up into smaller squares to allow percentage cover to be assessed more easily
- The use of quadrats enables researchers to obtain data that is a **representative sample** for the habitat being studied
  - Often an area being studied is very large and it is impractical to record data across an entire habitat, so quadrats provide small **samples** that **represent** the whole habitat

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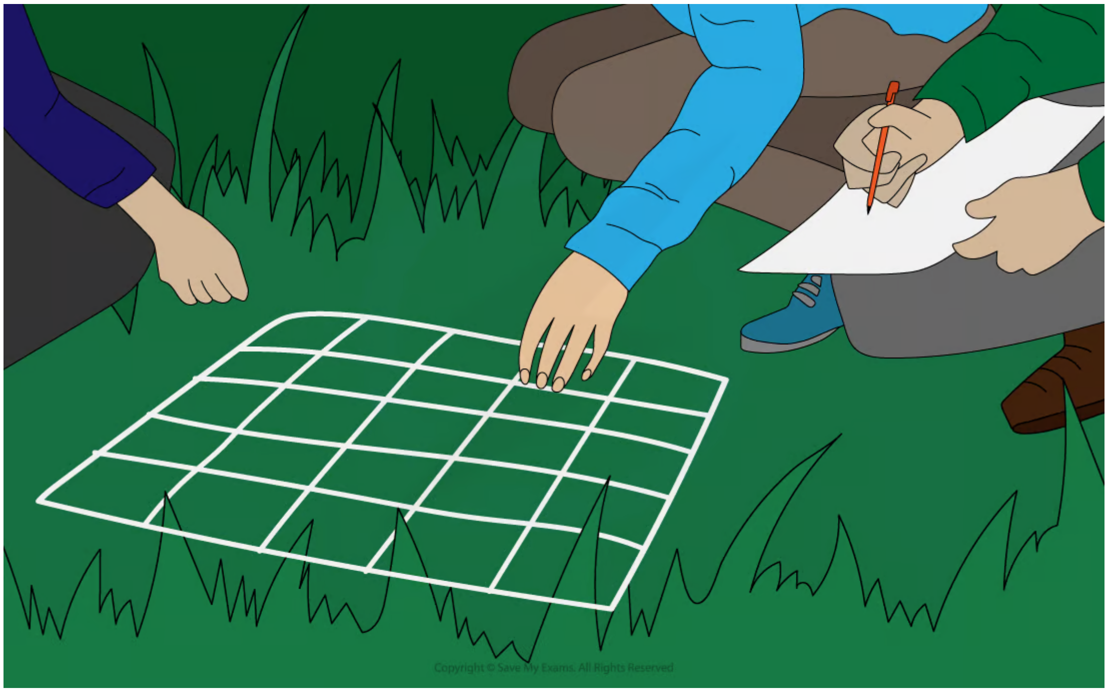
- For a sample to be representative, it needs to be:
  - **Large enough**; the larger and more diverse a habitat, the more quadrats need to be used
  - **Random**; this avoids bias e.g. when a student decides to place their quadrats in a particular place because it looks more interesting

- Randomness can be achieved by dividing a habitat up into **grid squares** and then using a **random number generator** to decide where to place each quadrat



Random sampling with quadrats can be used to study the distribution of organisms

The chi-squared test

- A statistical test called the **chi-squared test** determines whether there is a **significant difference** between the **observed and expected results** in an experiment
  - Its purpose is to assess whether any difference in these results is **due to chance**, or **due to an association** between the variables being tested

- A chi-squared test can be used to analyse data from quadrat sampling to determine whether or not there is a **statistically significant association** between the distributions of two species
  - To the eye there may appear to be an association between the two species, but if it is **not statistically significant** then researchers can conclude that species distributions are independent of each other, and any appearance of association is **due to chance**
  - If an association **is statistically significant** then it must be due to **an important factor**, such as a symbiotic relationship

- A chi-squared test enables scientists to test hypotheses
  - A **hypothesis** is a **testable statement** about the expected outcome of an experiment
  - There are two types of hypothesis:

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- A **null hypothesis** states that there is **no significant difference, or association,** between data sets e.g. that there is no association between the distributions of two species
- An **alternative hypothesis** states that there is **a significant difference, or association**, between data sets e.g. that there is an association (either positive or negative) between the distributions of two species

- The result of a chi-squared test enables scientists to either **accept** or **reject** a **null hypothesis**

Using the chi-squared test to test for association

- Step 1: Construct a **contingency table** for your results
  - This allows the number of quadrats that contain one, both, or neither species to be recorded

- Step 2: Calculate the row, column, and overall totals for your contingency table
- Step 3: Calculate the **expected** values (E) for your table
  - The results recorded in the contingency table are the **observed values** (O); to calculate the chi-squared value we need to calculate the **expected values** for each data point.
  - The expected values are what we would expect to see **if the null hypothesis were correct**
  - Note that this is the first step towards calculating the **chi-squared value**, the equation for which is:

$$\sum \frac{(O - E)^2}{E}$$

Σ = sum of   O = observed value   E = expected value

- Step 4: Calculate the **difference** between the observed and expected values
  - Subtract the expected values from the observed values (O - E); some of the resulting values will be negative

- Step 5: Square each difference
  - This eliminates negative values

- Step 6: Divide each squared difference by the expected value
- Step 7: Add all of the results from step 6 together
  - This gives the **chi-squared value**

- Step 8: Calculate the **degrees of freedom**
- Step 9: Establish a **probability** level or **p-value**
  - As biologists, we work with a probability level of **0.05**, or **5%**
  - This means that we can be 95% certain that any significant difference or association is **not due to chance**
  - Some studies require a higher level of certainty than this e.g. medical researchers may use a smaller p-value

- Step 10: Use a **critical values table** and the results of steps 8–9 to find the critical value

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- In order to understand what the chi-squared value says about the data, a table relating chi-squared values to probability is needed; this **critical values table** displays the probabilities that the differences between expected and observed values are due to chance

- Step 11: Compare the chi-squared value with the critical value to assess **the significance**

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Worked Example

A researcher decided to test for an association between the distribution of two types of mollusc on a rocky shore; limpets and dog whelks. Their **null hypothesis** was that there was no association between the distributions of limpets and dog whelks.They carried out 50 randomly placed quadrat samples on the rocky shore, recording either the presence or the absence of both limpets and dog whelks in each quadrat.They obtained the following results:

- Quadrats containing limpets only: 14
- Quadrats containing dog whelks only: 21
- Quadrats containing both limpets and dog whelks: 7
- Quadrats containing neither limpets nor dog whelks: 8

Use the chi-squared test to determine whether or not there is a **statistically significant association** between the distributions of limpets and dog whelks.

Step 1: Construct a contingency table

Contingency Table

	Limpets present	Limpets absent
Dog whelks present	7	21
Dog whelks absent	14	8

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Step 2: Calculate the row, column, and overall totals for your contingency table

Contingency Table

	Limpets present	Limpets absent	Row total
Dog whelks present	7	21	28
Dog whelks absent	14	8	22
Column total	21	29	50

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Step 3: Calculate the expected values

The equation for working out the expected values is:

$$\frac{\text{row total x column total}}{\text{overall total}}$$

E.g. to calculate the expected value for the category in which both dog whelks and limpets are present:

$$\frac{28 \times 21}{50} = 11.76$$

Step 4: Calculate the difference between the observed and expected values

O = 7

E = 11.76

7 - 11.76 = -4.76

Step 5: Square each difference

$-4.76^2 = 22.66$

Step 6: Divide each squared difference by the expected value

22.66 ÷ 11.76 = 1.93

Repeat steps 3–6 for all of the results in the contingency table

Chi-squared Working Out Table

	O	E	O−E	$(O-E)^2$	$(O-E)^2/E$
Limpets only	14	9.24	4.76	22.66	2.45
Dog whelks only	21	16.24	4.76	22.66	1.4
Both dog whelks and limpets	7	11.76	−4.76	22.66	1.93
Neither dog whelks nor limpets	8	12.76	−4.76	22.66	1.78

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Step 7: Add all of the results from step 6 together to obtain the chi-squared value

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2.45 + 1.4 + 1.93 + 1.78 = 7.56 (this is the **chi-squared value**)

Step 8: Calculate the degrees of freedom

Degrees of freedom can be calculated using the following equation:

Degrees of freedom = (number of columns - 1) x (number of rows - 1)

Columns and rows refer to the original contingency table.

In this example, there are 2 columns and 2 rows in the contingency table

Degrees of freedom = (2 - 1) x (2 - 1)

= 1 x 1

= 1

Step 9: Determine the probability level

As biologists, we work at a **probability of 0.05,** or **5%**

Step 10: Use a critical values table and the results of steps 8-9 to find the critical value

Chi-squared Critical Values Table

Degrees of freedom	Probability that the difference between observed and expected results is due to chance			
	0.1	0.05	0.01	0.001
1	2.71	3.84	6.64	10.83
2	4.60	5.99	9.21	13.82
3	6.25	7.82	11.34	16.27
4	7.78	9.49	13.28	18.46

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With **degrees of freedom** as **1**, and a **probability level** of **0.05**, the **critical value** can be read from the table as **3.84**

Step 11: Compare the chi-squared value with the critical value to assess significance

The chi-squared value of 7.56 **is larger than** the critical value of 3.84

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This means that there **is a significant association** between the two species (see section below on statistical significance)

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Exam Tip

When calculating a chi-squared value it is very helpful to create a table like the one seen in the worked example. This will help you with your calculations and make sure you don't get muddled up!

Statistical Significance

- The **chi-squared value**, once calculated, can be compared to a **critical value**; this allows **statistical significance** to be **assessed**
- If the chi-squared value is **larger** than the critical value, there is a **statistically significant difference** between observed and expected values, or a **statistically significant association** between two sets of results
    - In this case, the **null hypothesis** can be **rejected**
- If the chi-squared value is **equal to or smaller than** the critical value, there is no **statistically significant difference** between observed and expected values, or no **statistically significant association** between two sets of results
    - In this case, the **null hypothesis** can be **accepted**
- To determine the critical value biologists generally use a **probability level**, or **p-value**, of **0.05**, or **5%**
    - This means that if a difference or association is shown to be statistically significant **at this level**, there is only a **5% probability (i.e. probability = 0.05) that this result might be due to chance**

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4.1.9 Skills: Pyramids of Energy

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Pyramids of Energy

- Pyramids of energy illustrate the **amount of energy contained** within the biomass of organisms at each trophic level
- The **length** of each box, or bar, represents the quantity of energy present
  - Pyramids of energy **should be drawn to scale** so that each bar is **proportional** in size to the amount of energy that it represents
  - In some situations, however, a pyramid of energy may be an approximate sketch where each bar is a rough representation of the energy contained

- These pyramids are always **widest at the base** and decrease in size as they go up
  - The base is wide due to the large amount of energy contained within the biomass of producers

- Pyramids of energy show a **stepped decrease** in the energy contained at each level of the food chain rather than appearing as pyramid with smooth sides
- The levels of a pyramid of energy should be labelled **producer**, **first consumer**, **second consumer**, and so on
- The units used should be the amount of **energy, per unit area, per year** e.g. $kJ\ m^{-2}year^{-1}$
- As you move up the pyramid to higher trophic levels, the quantity of energy decreases as **not all energy is transferred** to the biomass of the next trophic level (roughly 10 % of the energy is passed on)
- Energy is lost at each trophic level due to
  - Incomplete consumption
  - Incomplete digestion
  - Loss of heat energy to the environment during respiration
  - Excretion of the waste products of metabolism e.g. carbon dioxide, water, and urea

- As a result of this, the biomass at each trophic level will also decrease as energy availability decreases

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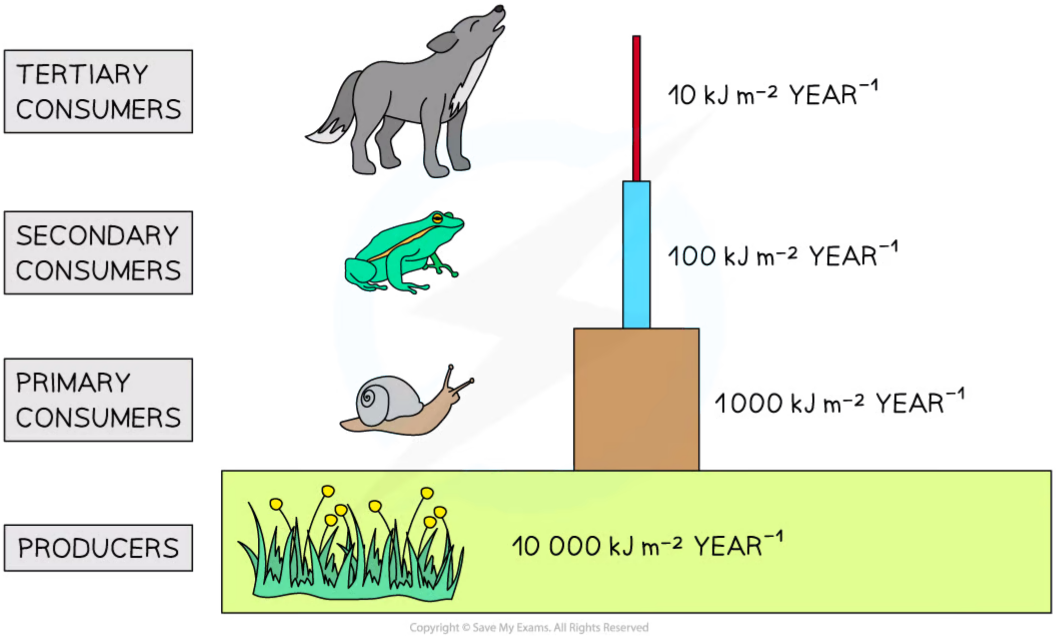

The energy stored in the biomass of organisms can be represented by a pyramid of energy

Exam Tip

Remember that pyramids of energy should be drawn to scale and the units used should be the amount of energy, per unit area, per year e.g. $kJ\ m^{-2} year^{-1}$

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4.2 Carbon Cycling & Climate Change

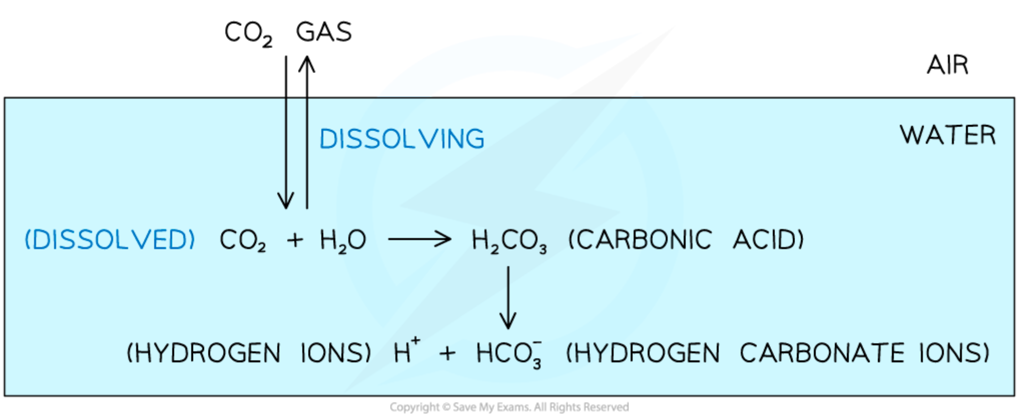
4.2.1 Carbon Cycle: Carbon Dioxide

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

- 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

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Carbon Dioxide & Coral Reefs

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- 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 are less well-understood by the public, but could be **significant for ocean** biodiversity because of the effect of carbon dioxide on **ocean chemistry**
  - Huge amounts of carbon dioxide are **dissolved** by the oceans, and much of the dissolved carbon dioxide **reacts with seawater** to form **carbonic acid** (H_2CO_3)

$$CO_2 + H_2O \rightarrow H_2CO_3$$

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

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

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

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

- 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

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

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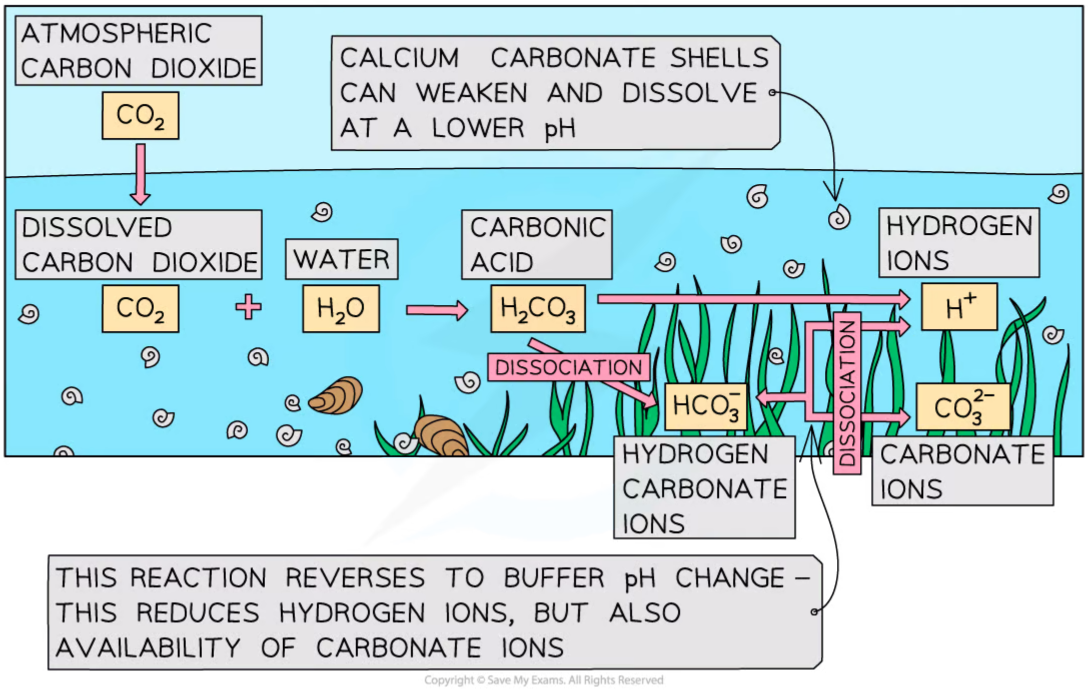
- When the effects of ocean acidification are combined with coral bleaching that results from warming oceans, the consequences for coral reefs could be very serious
  - With coral reefs thought to be the most diverse ecosystem we know, this could be **bad news for ocean biodiversity**



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

Exam 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.

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Carbon Dioxide Absorption

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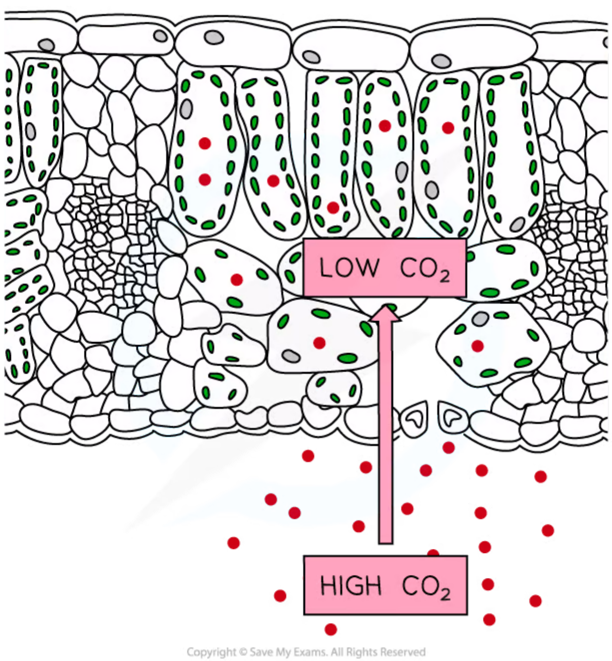
- Autotrophs **absorb carbon dioxide** from their surroundings (either **air** or **water**) before converting it into carbon compounds in their tissues
- This absorption takes place by diffusion into the leaves of plants
- Carbon dioxide diffuses down its **concentration gradient** from a region of **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

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4.2.2 Carbon Cycle: Carbon Dioxide in the Atmosphere

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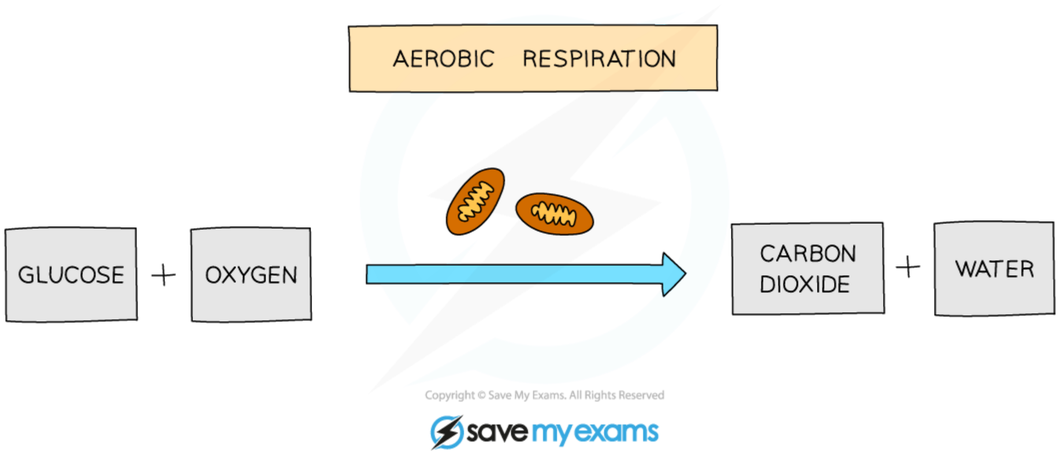
Respiration & Carbon Dioxide

- 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

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Fluctuations in Carbon Dioxide Levels

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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

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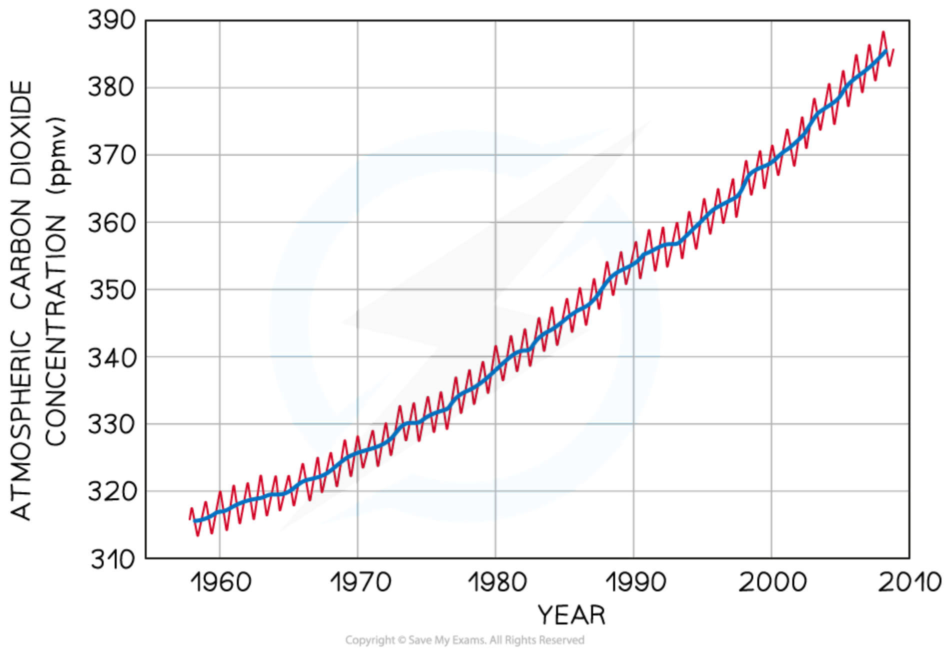
- Scientists have records for carbon dioxide levels dating back to 1958, and for methane levels from 1984

- 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

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4.2.3 Carbon Cycle: Methane

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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

Exam 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.

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Oxidation of Methane

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- 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

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4.2.4 Carbon Cycle: Organic Matter

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

Exam Tip

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

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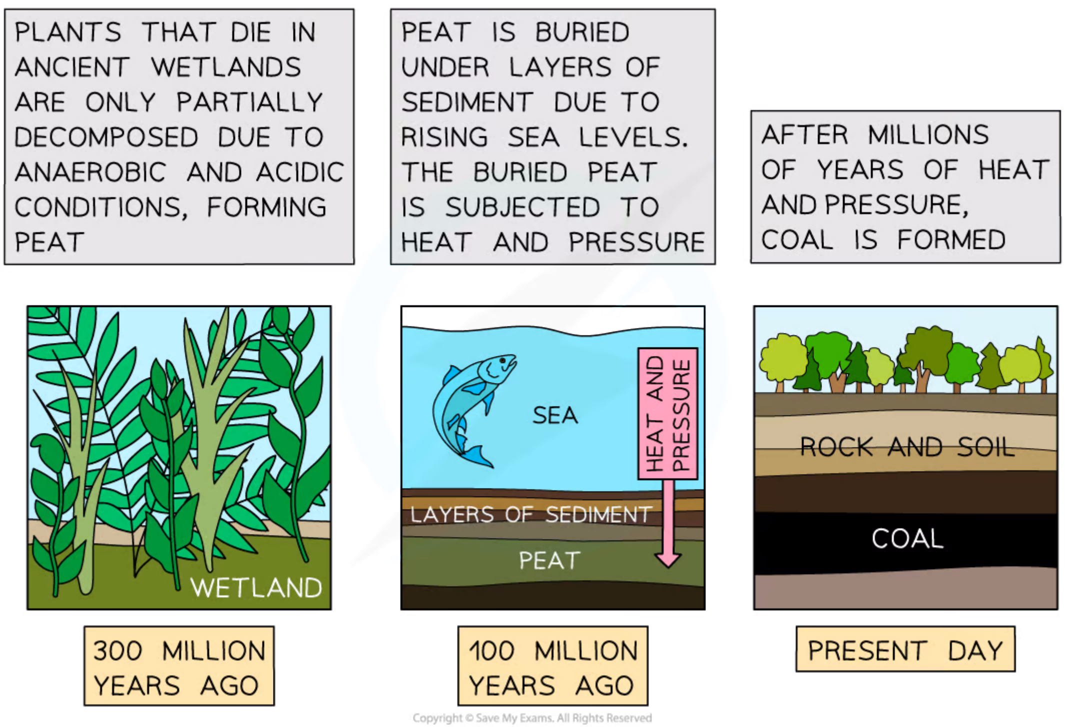
Fossilisation

- 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

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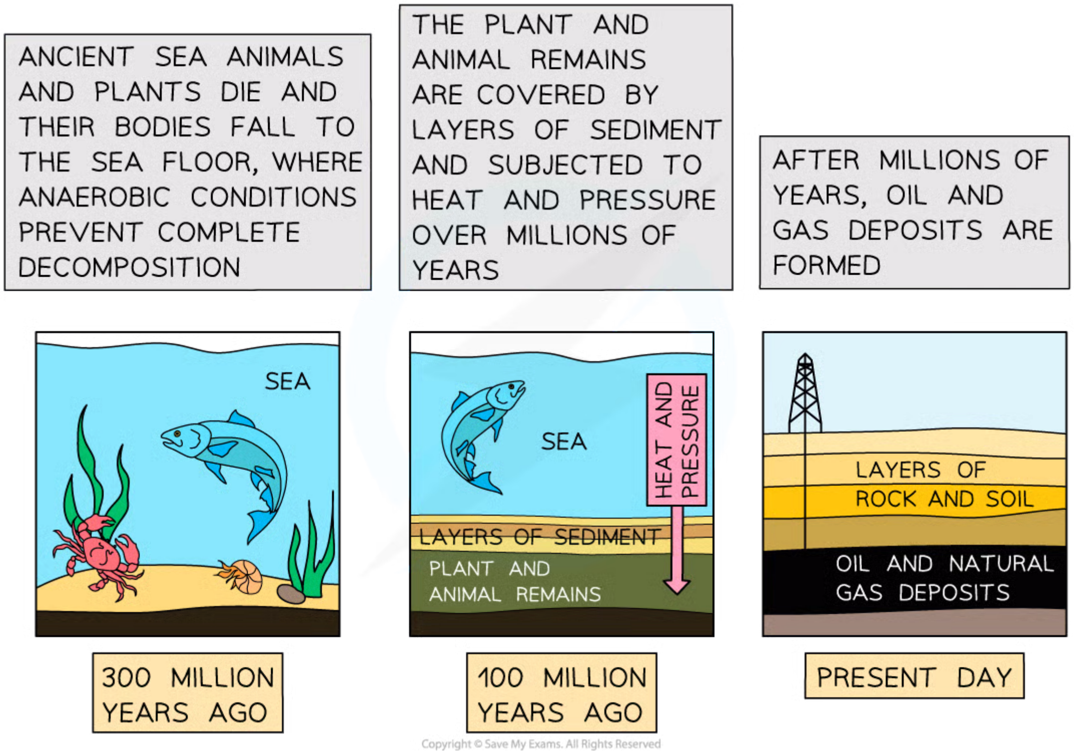

Formation of oil and gas from the bodies of aquatic organisms

- 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

- 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

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4.2.5 Climate Change: Greenhouse Effect

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**

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Other Greenhouse Gases

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- 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**

Exam 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!

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Greenhouse Effect

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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

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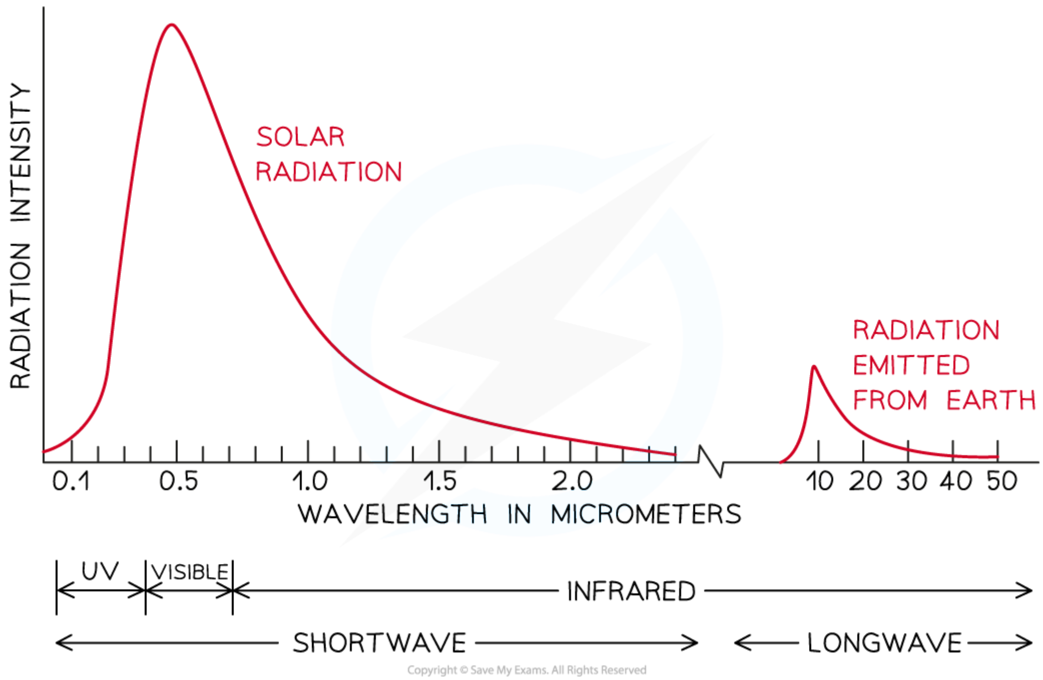

Solar radiation is primarily short-wave, while the radiation that is re-emitted by earth is long-wave radiation

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

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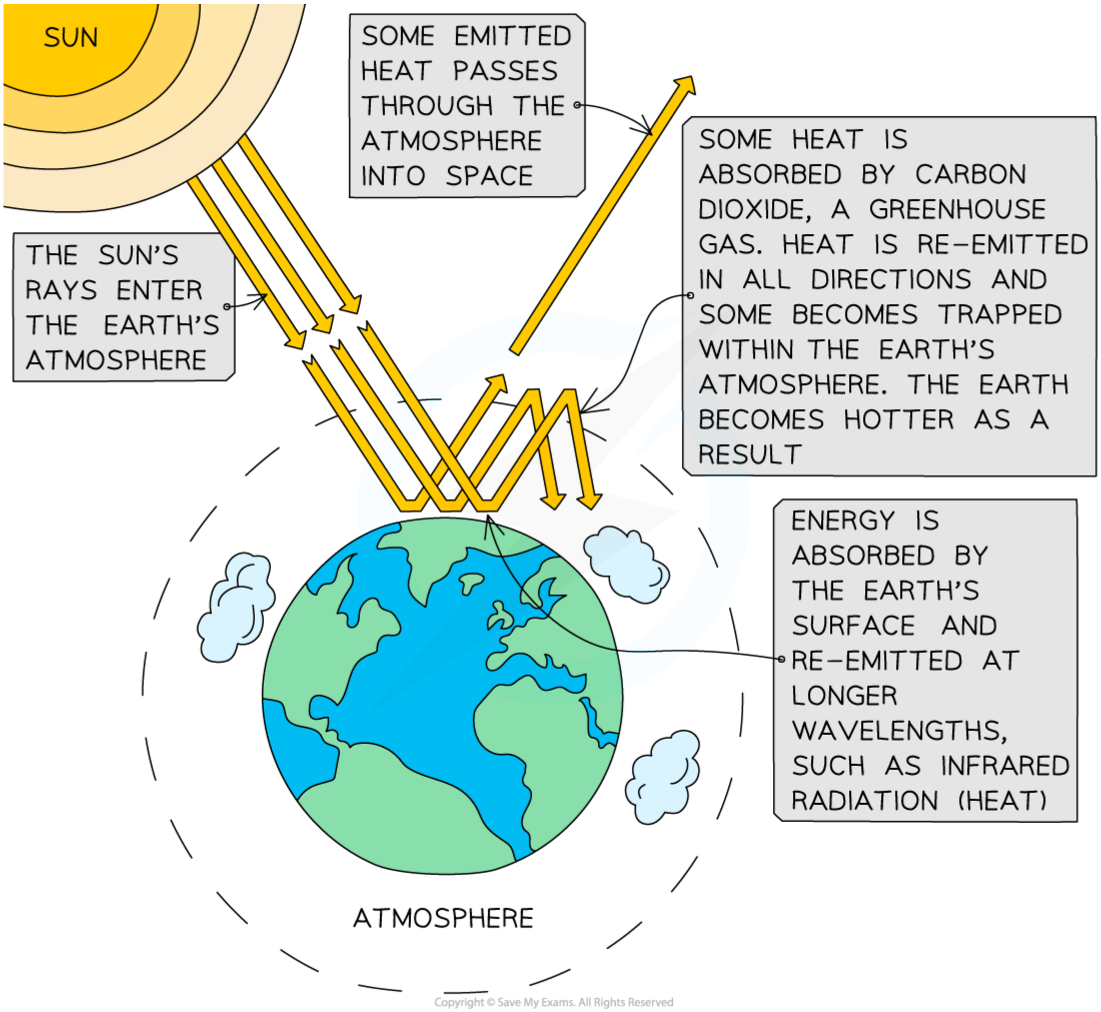

Greenhouse gases absorb the long-wave radiation emitted by Earth, warming the atmosphere

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4.2.6 Climate Change: Impact

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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

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4.2.7 Climate Change: Causes

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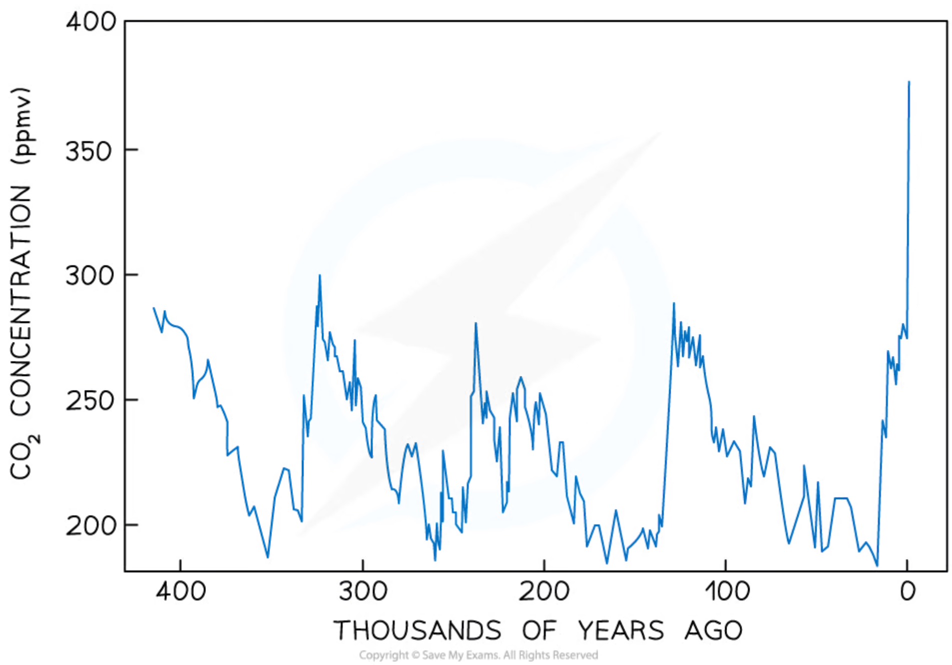
Industrialisation & Increased Carbon Dioxide

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

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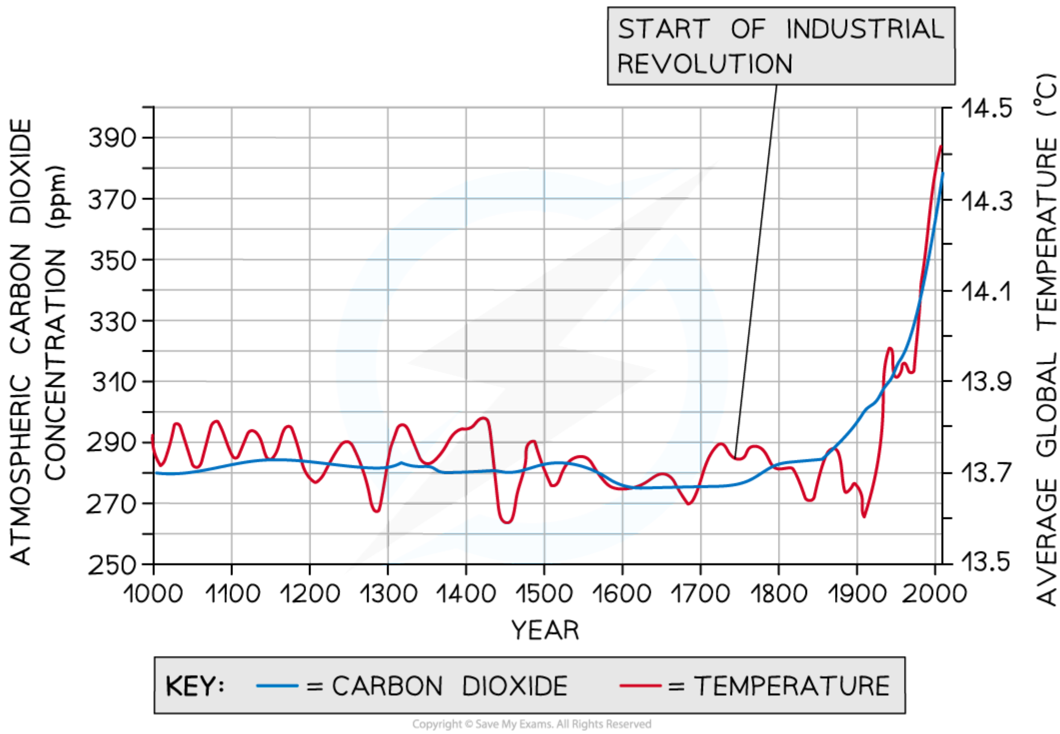

There is a correlation between increasing carbon dioxide levels since the start of the industrial revolution and increasing global temperatures

Combustion of Fossil Fuels

- 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

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Temperatures & Increased Carbon Dioxide

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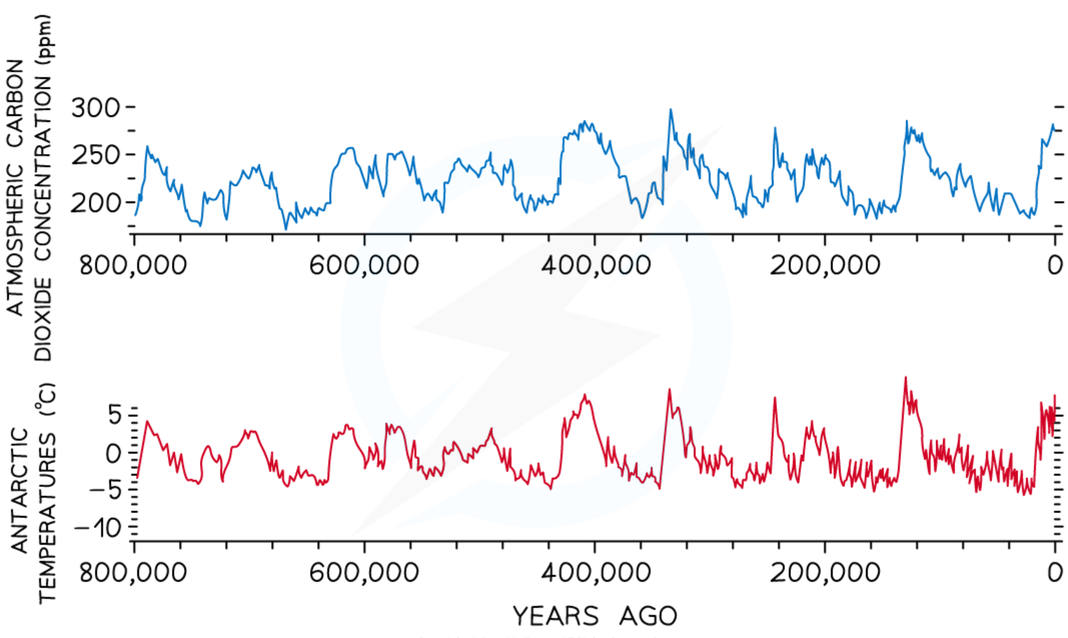
- We know that greenhouse gases **absorb infrared radiation** and **warm the earth's atmosphere**, and we know that carbon dioxide is a greenhouse gas, so climate scientists have long hypothesised that **increasing carbon dioxide levels in the atmosphere will lead to warming global temperatures**
- Evidence 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**



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

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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

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- 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
  - 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

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- 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

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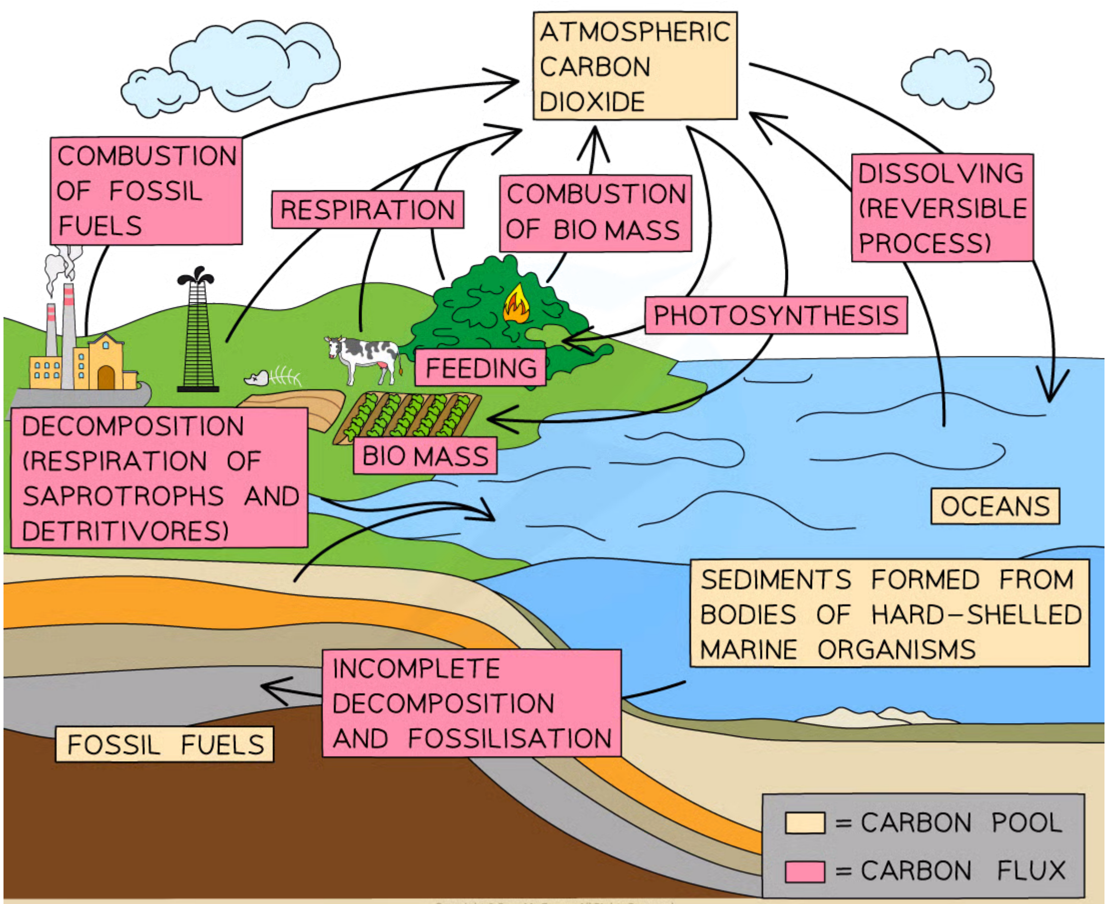
Drawing the Carbon Cycle

- 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



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An illustrated carbon cycle diagram showing both terrestrial and marine cycling

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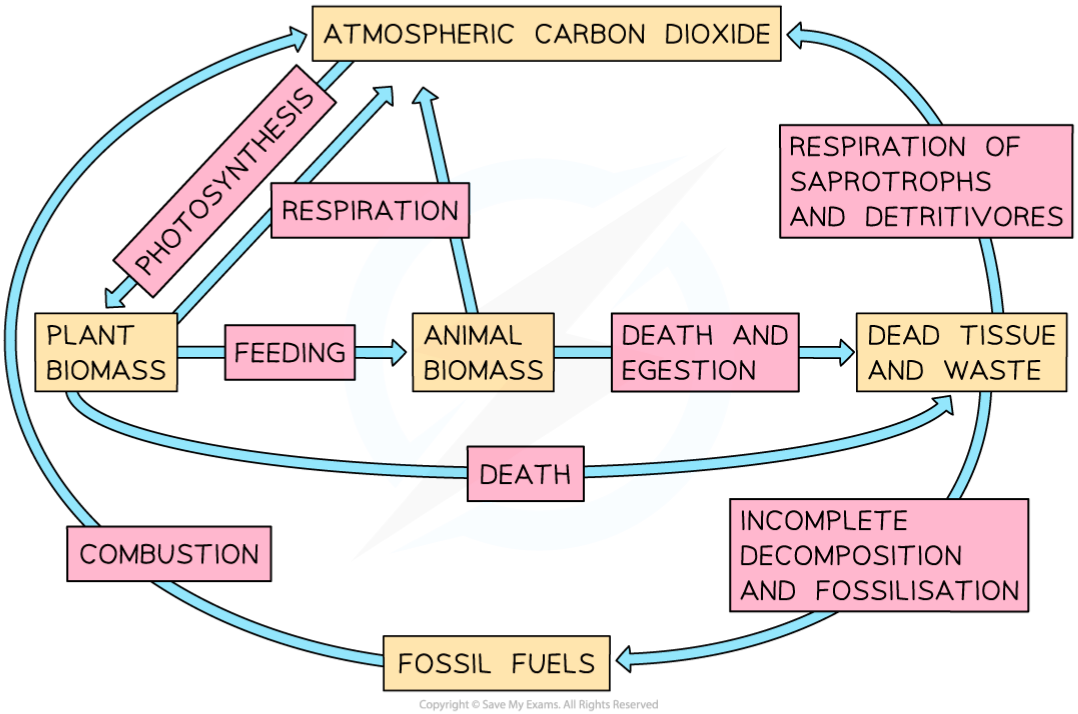

A simple carbon cycle diagram showing terrestrial carbon cycling

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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

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- 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

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