MASTER BIOLOGY

Biology A-level

Module 5: Energy transfers in and between organisms

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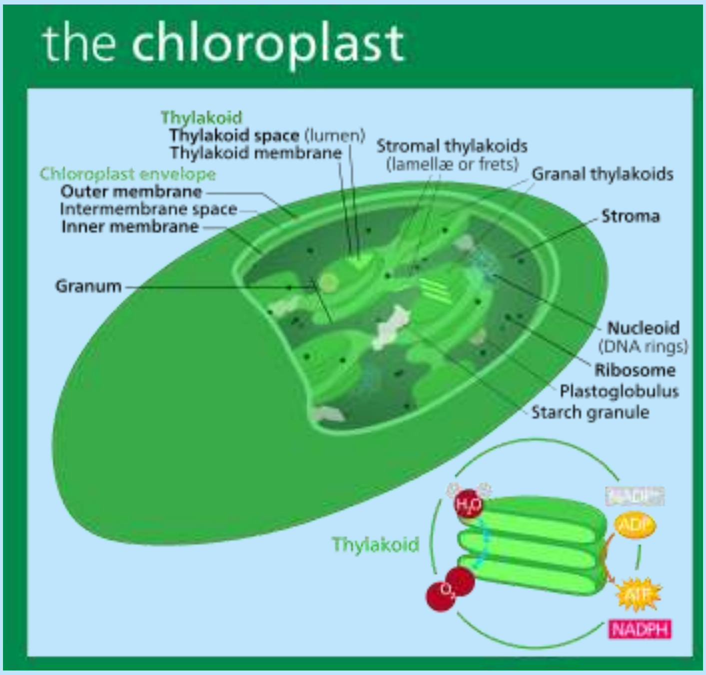
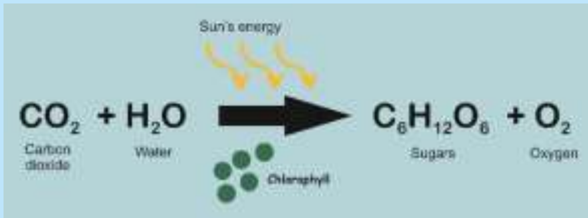
Photosynthesis

Photosynthesis is a reaction in which **light energy is used to produce glucose** in plants. The process requires **water** and **carbon dioxide**, with the products being **glucose** and **oxygen**.

There are two stages of photosynthesis, these are the **light dependent stage** and the **light independent stage**. The rate of photosynthesis is determined by carbon dioxide concentration, light intensity and well as temperature.





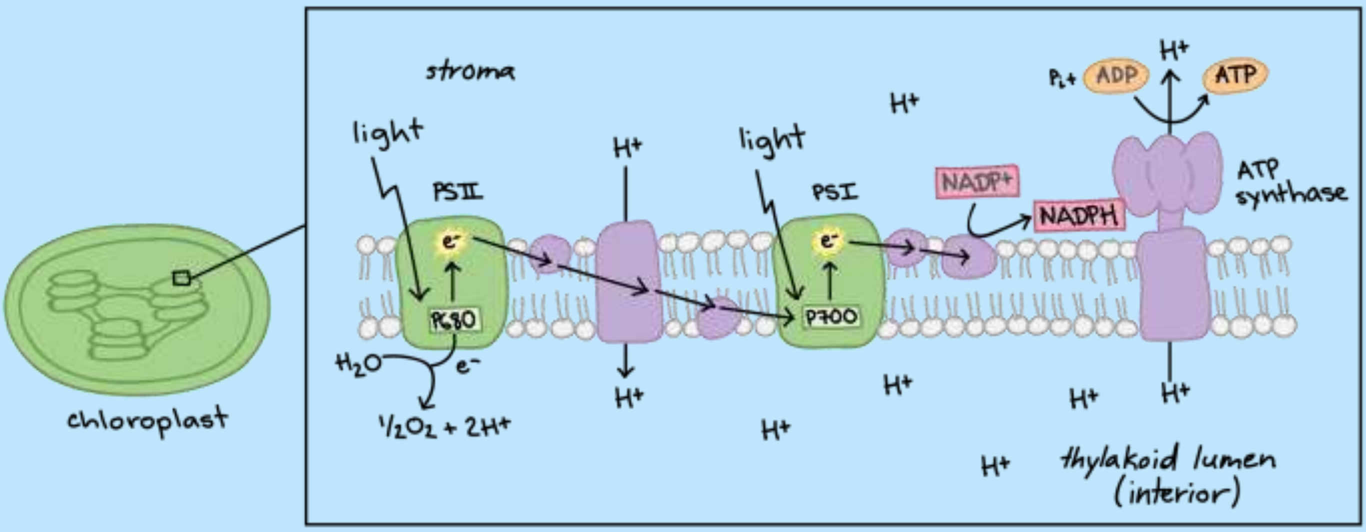
Chloroplasts are the site of photosynthesis and are adapted to photosynthesis in the following ways:

- Contains stacks of **thylakoid** membranes called **grana** which provides a large surface area for the attachment of chlorophyll, electrons and enzymes.
- A network of proteins in the grana hold the chlorophyll in a very specific manner to absorb the maximum amount of light.
- The granal membrane has **ATP synthase channels** embedded allowing ATP to be synthesised as well as being selectively permeable allowing the establishment of a proton gradient
- The grana are suspended in a jelly-like substance much like the cytoplasm in an animal cell
- Chloroplasts contain DNA and ribosomes allowing them to synthesise proteins needed in the light dependent reaction.

Light Dependent Reaction:

1. Photons of light hit chlorophyll molecules in PSII causing the **electrons** to become **excited** to the next energy level and **leave** PSII. This is called **photoionisation**.

2. Light hitting a water molecule in the choroplast causes the splitting of water. This is called **photolysis.** It produces one molecule of oxygen, 4 protons and 4 electrons
3. The oxygen either naturally diffuses out through the stomata or is used in aerobic respiration. The **4 electrons** replace those lost from the chlorophyll
4. The protons move into the stroma, creating a proton gradient.
5. The excited electron from **PSII** then moves down a series of protein complexes through a series of redox reactions. Each complex is at a **lower energy level** than the next. Therefore, energy is released every time an electron passes to the next protein complex
6. The energy from the electron is used to pump 4 protons from photolysis from the **stroma to the thylakoid space**.
7. The electron eventually passes down all the protein complexes and finally moves to **PSI.** Here more photons of light are absorbed, causing the electron to move back up to a high energy level.
8. The electron then moves along the chain to another complex where lastly, the **electron combines with a proton to form a hydrogen atom**. This is then used to reduce NADP, forming reduced NADP (NADPH)
9. The pumping of protons across the thylakoid membrane means that there is now a greater concentration of protons in the thylakoid space than the stroma.
10. As a result a proton gradient forms with a **high concentration in the thylakoid space and a low concentration in the stroma.** The movement of these protons drives the process of photophosphorylation. The enzyme ATP synthase phosphorylates ATP from ADP and Pi.



Light Independent Reaction:

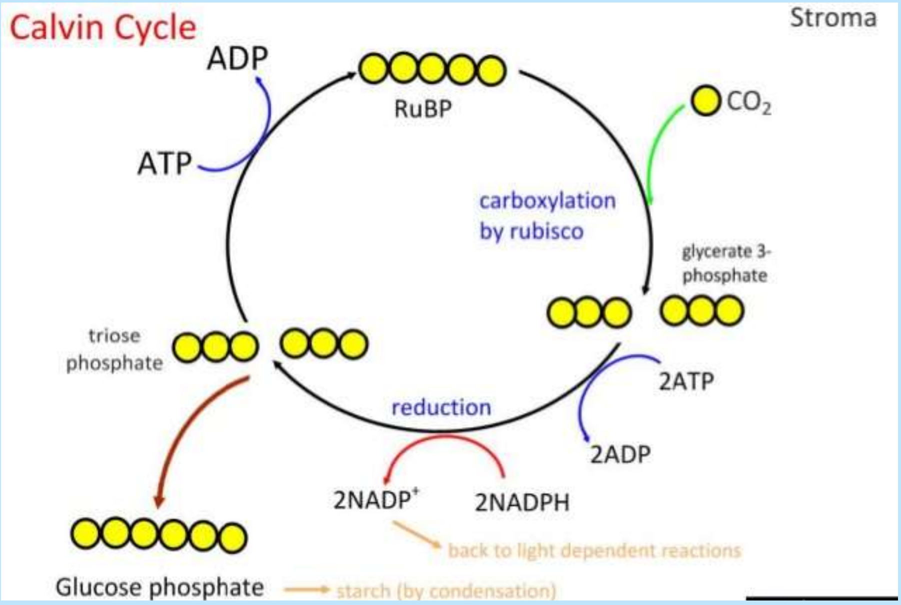
1. Carbon Dioxide Fixation - carbon dioxide that has diffused in through the stomata is fixed with ribulose bisphosphate (RuBP), 5 carbons, in a process known as carboxylation. The enzyme **Rubisco** is needed in order to do this. A **6 carbon sugar** is formed first, however this is very unstable and therefore forms **2 molecules of glycerate-3-phosphate (G3P)**.

2. Reduction Phase - **Reduced NADP** from the light dependent reaction reduces the 2 molecules of G3P, using energy from ATP. This creates 2 molecules of triose phosphate.

3. Regeneration of RuBP - 5 molecules of **triose phosphate** (3 carbons) are used in order to regenerate 3 molecules of **ribulose bisphosphate** (5 carbons). This requires ATP

4. Organic Molecule Production – The spare triose phosphate from this leaves the cycle to help to form molecules of glucose.

6 turns of the Calvin Cycle are required in order to produce 1 molecule of glucose per molecule of CO_2



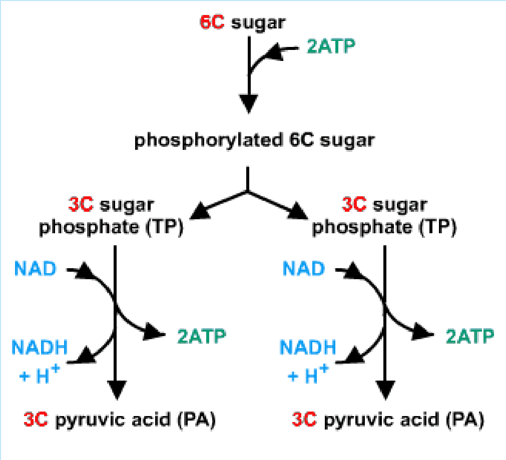
Respiration

Aerobic respiration is the splitting of a respiratory substrate such as **glucose**. This releases carbon dioxide as a waste product. Anaerobic respiration occurs in the absence of oxygen. Respiration is a multi-step process with each step controlled and catalysed by a specific intracellular enzyme. The steps in respiration are detailed below:

Glycolysis

This is the first process of both aerobic and anaerobic respiration. It takes place in the **cytoplasm** of the cell.

1. Glucose is **phosphorylated**, by splitting two molecules of ATP to produce phosphorylated glucose and 2 molecules of ADP
2. Phosphorylated glucose is unstable and splits into two 3 carbon molecules called **triose phosphate**
3. Each molecule of **TP** is then oxidised by giving a proton to NAD to produce NADH (reduced NAD). This will be used later in the Krebs cycle
4. This process also produces two molecules of ATP **per TP molecule**. Ie, 4 ATP molecules in total
5. This produces 2 molecules of pyruvate

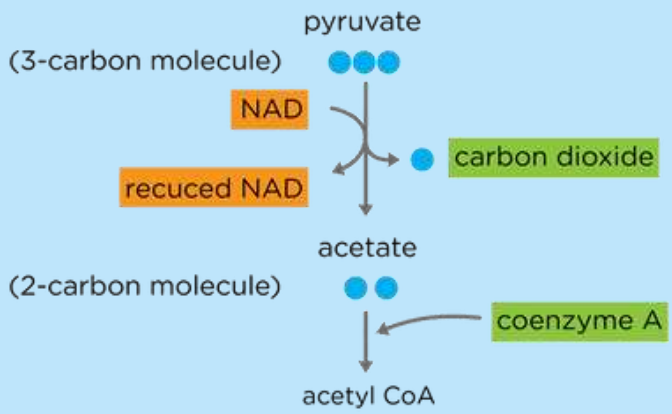


Link Reaction

The 2 molecules of pyruvate are actively transported into the mitochondria where the link reaction takes place.

1. The enzyme decarboxylase then removes a molecule of CO2 from 3 Carbon pyruvate
2. The pyruvate also donates a proton to reduce NAD and produce NADH.
3. The result is a 2 carbon molecule called **acetate**
4. The acetate formed then combines with **coenzyme A** to form a molecule of **acetyl coenzyme A**.

Therefore per glucose molecule 2 molecules of acetyl coenzyme A are formed



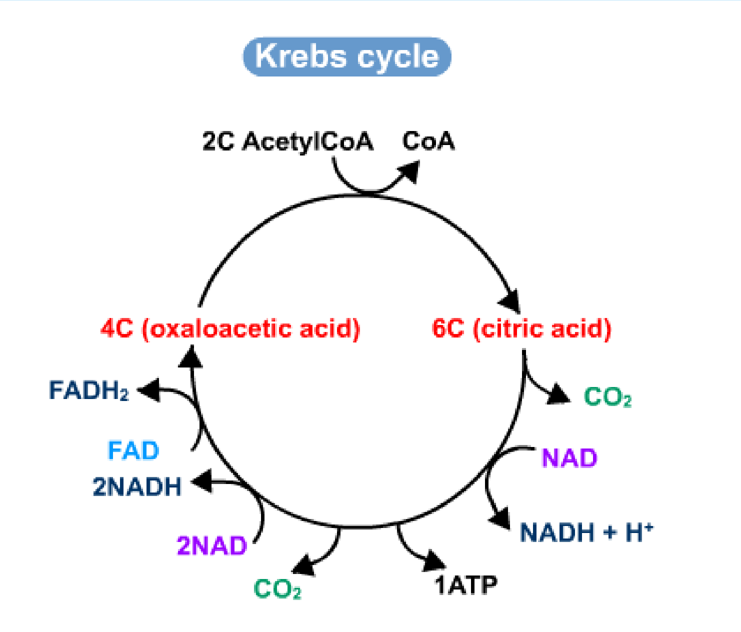
Krebs Cycle

The Krebs cycle occurs in the matrix of the **mitochondria**.

1. The acetyl coenzyme A is added to a 4 carbon molecule already present. This forms a **6 carbon molecule** called citric acid/citrate
2. The 6 carbon molecule that is formed then undergoes a series of reactions:
   a. Loss of 2 carbon dioxide molecules
   b. 3 NADH molecules produced by reduction of NAD
   c. 1 FADH molecule produced by reduction of FAD

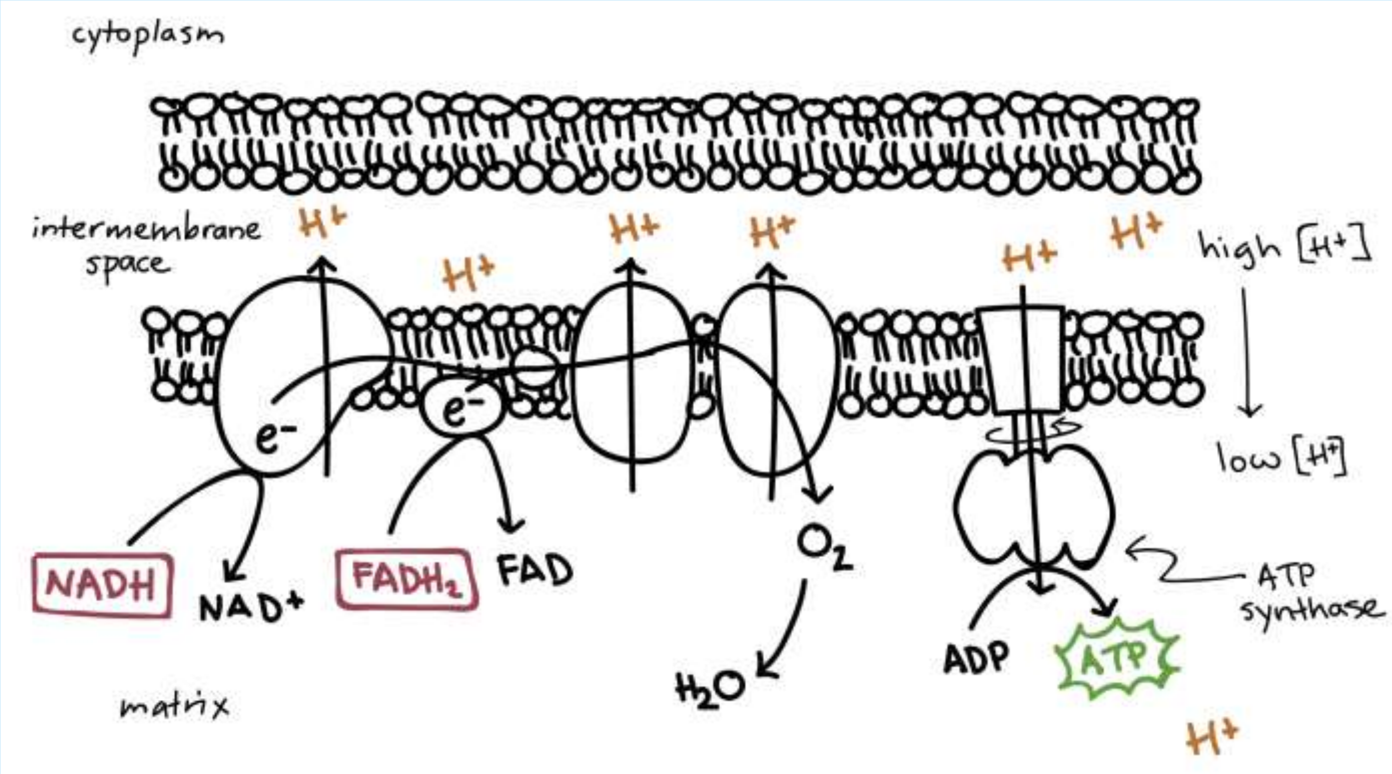
    d. 1 molecule of ATP produced by dephosphorylation of molecules
3. This produces a **4 carbon molecule** which accepts another acetate molecule to begin the cycle again.

The Krebs cycle turns 2 times per molecule of glucose and therefore per molecule of glucose 2 ATP molecules, 6 NADH molecules, 2 FADH molecules and 4 CO2 molecules are produced in the Krebs cycle



Oxidation Phosphorylation

1. The reduced NAD (NADH) from glycolysis, link reaction and Krebs cycle binds to **protein Complex I**. This oxidises NADH back to NAD and releases its hydrogen atoms as protons and electrons. The NAD goes back to the Krebs cycle to be used again
2. Reduced FAD (FADH) binds to **Complex II**. It also releases it hydrogen atoms as protons and electrons and produces FAD again.
3. The electrons released go into an electron chain and pass down it through a series of redox reactions. This releases energy which is used to pump H+ ions (protons) out of the matrix and into the **intermembrane space** against their concentration gradient through protein carriers
4. For each hydrogen released by NADH, 4 protons are pumped across. The protons are pumped into the intermembrane space. This creates a proton gradient where there are more **protons** in the **intermembrane space** than in the matrix
5. The **H^+ ions** then re-enter the matrix of the mitochondria through a special protein carrier which is an ATP synthase. This means that every time a H+ ion passes through it via facilitated diffusion down its concentration gradient, an ATP molecule is created
6. After the electrons have passed through all of the protein complexes and pumped all of the protons across the membrane, they are accepted by the **final electron acceptor, oxygen**.
7. The electrons combine with a **proton** to form a hydrogen atom, which then combines with oxygen to form **water**, a waste product of aerobic respiration



Anaerobic Respiration

1. The only step that goes ahead in anaerobic respiration is **glycolysis**, which takes place in the cytoplasm. The product of this is pyruvate.
2. In anaerobic respiration the pyruvate is further converted into **lactate**
3. The conversion of **pyruvate** to lactate **regenerates NAD from NADH** as NADH donates a H+ to pyruvate to create lactate
4. The NAD that has been regenerated can go back to glycolysis to be reduced again
5. **Lactate** is then **converted back to pyruvate in the liver**. From one molecule of glucose, 2 molecules of ATP (net), 2 molecules of reduced NAD (NADH) and 2 molecules of pyruvate are formed.

Energy and ecosystems

An **ecosystem** includes all the organisms living in a particular area known as the community as well as all the non-living elements of that particular environment. The distribution and abundance of organisms in a habitat is controlled by both **biotic factors** (living) e.g. predators, disease and **abiotic factors** (non-living) such as light levels and temperature. Each species has a particular role in its habitat called its **niche**. This consists of all of that species' biotic and abiotic interactions with the environment.

The Sun is the source of all energy in ecosystems with photosynthetic organisms using this to produce their own food. These can be termed **autotrophs** and are **producers**. Those organisms that cannot synthesise their own food are called **heterotrophs**. All animals are heterotrophs. Only around 10% of chemical food energy is passed on between organisms in the food chain. The other 90% is lost to the surroundings as:

- **uneaten parts** e.g. the bones.

- **decay** of dead material e.g. bacteria may decay some material.
- **excretion** e.g. energy is lost in faeces
- exothermic reactions e.g. heat lost in **respiration**.

The **efficiency** of energy transfer between the trophic levels is worked out using the formula:

$$\text{Percentage efficiency} \quad \frac{\text{energy available after the transfer}}{\text{energy available before the transfer}} = \times 100$$

The **biomass** can be measured in terms of **mass of carbon** or **dry mass of tissue per given area per given time.** The dry mass is used as the **wet mass** can **vary** too much. The chemical energy stored in dry biomass can be estimated using **calorimetry**. This is carried out in a bomb calorimeter in which a sample of known mass is burnt in pure oxygen. The bomb calorimeter is submerged in water and therefore the change in water temperature can be used to calculate the energy in the sample.

- **Net primary productivity (NPP)** – The chemical energy store in plant biomass after respiratory losses to the environment have been taken into account
- **Gross primary productivity (GPP)** – The chemical energy store in plant biomass, in a given area or volume, in a given time before respiratory losses have been taken into account

$$\text{NPP} = \text{GPP} - \text{Respiratory Losses}$$

- The net primary production is available for plant growth and reproduction as well as to other trophic levels in the ecosystem such as **decomposers** and **herbivores**
- The net production of consumers (N) such as animals can be calculated by:

$$N = I - (F+R)$$

- I = the chemical energy store in ingested food
- F represents the chemical energy lost to the environment in faeces and urine
- R represents the respiratory losses to the environment.

Nutrient cycles

Nutrients are recycled within natural ecosystems, as shown by the nitrogen cycle and the phosphorous cycle.

The Nitrogen Cycle

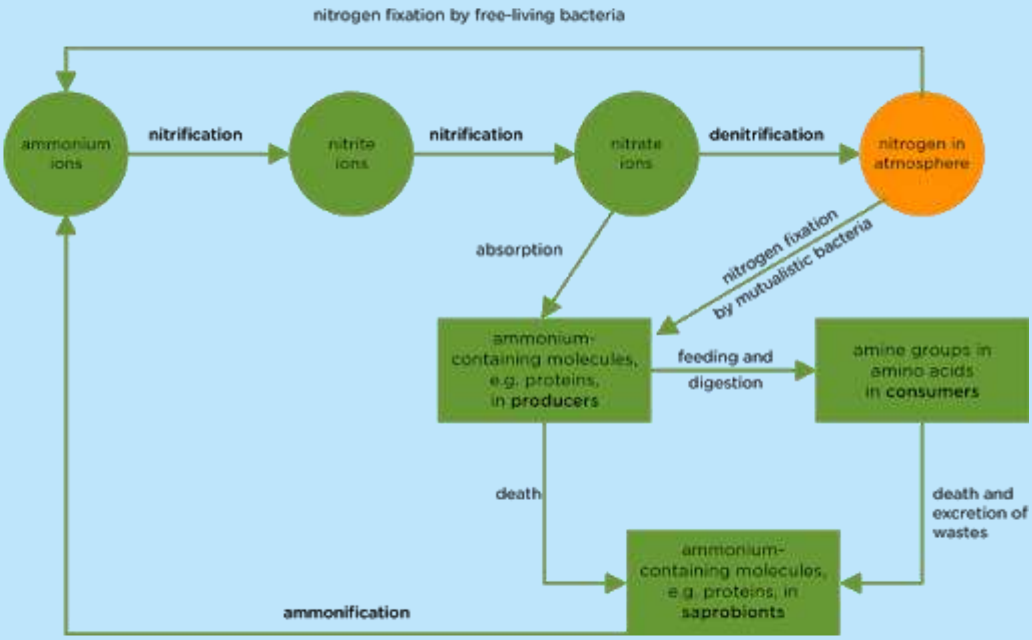
Nitrogen is an element used in many biological molecules. There is a limited amount of nitrogen on earth. Due to this it must be recycled from dead organisms and waste products. Most of this is carried out by bacteria in the soil. There are four stages of the nitrogen cycle, these are detailed below:

- Ammonification where microbes known as **saprobionts** break down organic matter to ammonia in a two stage process. Firstly, proteins are broken down into amino acids with the use of extracellular protease enzymes. These are then subsequently broken down further to remove amino groups with the use of deaminase enzymes. Saprobionts use the products of decomposition for respiration.

- Nitrification where nitrifying bacteria convert ammonia to nitrite ions, NO_{2-}, in an oxidation reaction, with a nitrate ion, NO_{3-}, intermediate. Most plants can take in nitrate ions through their roots.

- Dentrification where nitrate ions, NO_{3-}, are converted to nitrogen gas, N_2, by the denitryfing bacteria. This process is wasteful and can be prevented from occurring by soil being well drained and aerated.

- Nitrogen fixation where nitrogen gas is fixed into other compounds by bacteria with nitrogen fixing ability. They do so by reducing nitrogen gas to ammonia which subsequently dissolves to form ammonium ions. Nitrogen fixing bacteria live in root nodules of **leguminous** plants. The relationship between nitrogen fixing bacteria and the plant is known as mutualistic, as it is beneficial to both organisms.



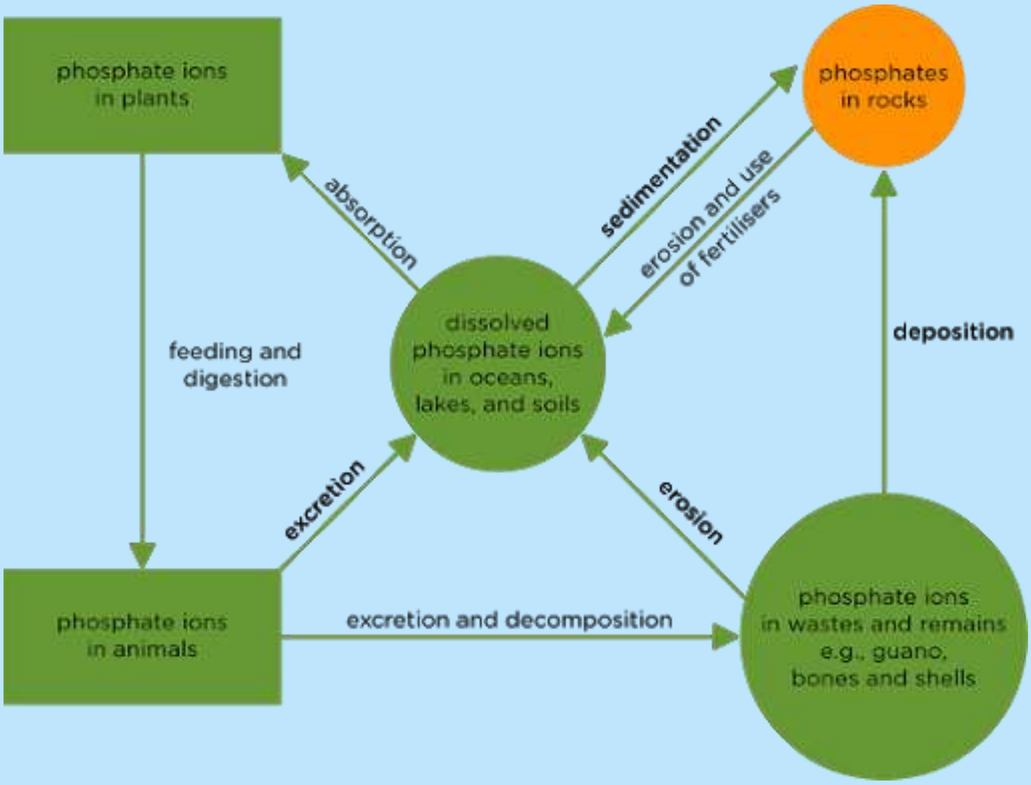
The Phosphorus Cycle

Phosphorus like nitrogen is another element found in many biological molecules that needs to be recycled. Plants can take in phosphate ions, PO_{43-}, from soil. Phosphate is released from sedimentary rocks as a result of weathering, as well as through the decay of bones, shells and the excreta of some birds.

Mycorrhizae are important in facilitating the uptake of water and inorganic ions by plants. These are associations between certain types of fungi and the roots of the vast majority of plants. They increase the surface area and act as a sponge holding water and minerals. As a result a plant can better resist drought and take up inorganic ions more easily.

Natural and artificial fertilisers are used to replace the nitrates and phosphates lost by harvesting plants and removing livestock.

Nitrogen fertilisers greatly increase crop yields and therefore can help to deal with the demands of a growing human population. However they have negative effects on the environment which include reducing biodiversity, leaching and eutrophication.



Leaching

Leaching is the process by which mineral ions, such as nitrate, dissolve in rainwater and are carried from the soil to end up in rivers and lakes. As a result of this eutrophication occurs. This provides algae in waterways with enough nitrate ions to grow more rapidly than it otherwise would do. As a result this can block out light from other plants, causing decay and the use of oxygen in the water way. This eventually leads to the death of the ecosystem.