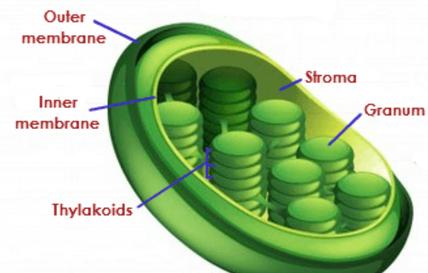
AQA Biology A-level

Topic 5: Energy transfers in and between organisms

Notes

Photosynthesis



Chloroplast diagram

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.
- 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. This is called photoionisation. The charge separation from this drives the process of photolysis.

2. Photolysis is the splitting of water with light. One molecule of water requires 4 photons of light to split. When water is split it produces 1 molecule of oxygen, 4 protons and 4 electrons. The oxygen either naturally diffuses out through the stomata or is used in respiration. The 4 electrons replace those lost from the chlorophyll, whilst the protons move into the stroma, later creating a proton gradient.

3. The excited electron then moves down a series of protein complexes. At one of the complexes the energy from the electron is used to pump 4 protons from the stroma to the thylakoid space.

4. The electron then moves down the chain further to PSI. Here more photons of light are absorbed causing the electron to move back up to a high energy level.

5. The electron then moves along the chain to another complex where the electron combines with a proton to form a hydrogen atom. This is then used to reduce NADP, forming reduced NADP.

6. The pumping of protons across the membrane means that there is now a greater concentration of protons in the thylakoid space than the stroma. As a result a proton gradient forms with a high concentration in the thylakoid space and a low concentration in the stroma. The protons move across the membrane by diffusion through a protein known as a stalked particle. 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) 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.

2. REDUCTION PHASE - The 2 molecules of glycerate-3-phosphate contain a -COOH group and is therefore an acid. The reducing power of reduced NADP therefore reduces the glycerate-3-phosphate, with energy being provided by ATP. This therefore forms 2 molecule of triose phosphate. All of the NADP from the light dependent reaction has now been used with only some of the ATP being used.

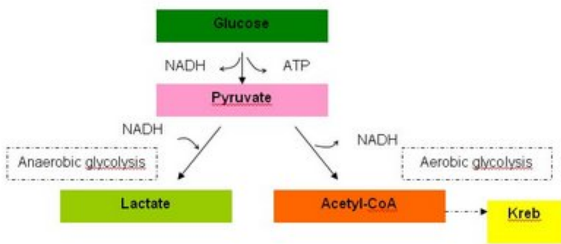
3. REGENERATION OF RuBP - 5 molecules of triose phosphate are used in order to regenerate 3 molecules of ribulose bisphosphate. The remaining amount of ATP from the light dependent stage is now used.

4. ORGANIC MOLECULE PRODUCTION - 2 molecules of triose phosphate can combine to form the intermediate hexose sugar fructose 1,6 bisphosphate where after it forms molecules of glucose.

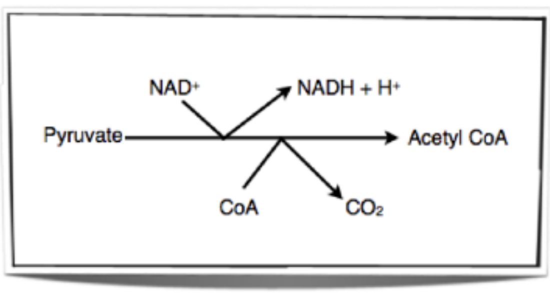
6 turns of the Calvin Cycle are required in order to produce 1 molecule of glucose per molecule of CO_2

Respiration

Aerobic respiration is the splitting of a respiratory substrate, to release carbon dioxide as a waste product. Hydrogen is reunited with atmospheric oxygen with the release of a large amount of energy. 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:



1. Glycolysis - this is the first process of both aerobic and anaerobic respiration. It takes place in the cytoplasm of the cell. Glucose is phosphorylated to produce 2 molecules of pyruvate, 2 molecules of ATP and 2 molecules of NADH. In anaerobic respiration the pyruvate is further converted into lactate with the help of NADH. 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.

2. **Link Reaction** - in the link reaction the 2 molecules of pyruvate are **actively transported into the mitochondria**. The enzyme **decarboxylase** then removes a molecule of CO2 with a hydrogen also being lost, going on to reduce NAD. The **acetate** formed then combines with coenzyme A to form a molecule of **acetyl coenzyme A**. **Per glucose molecule 2 molecules of acetyl coenzyme A are formed and 0 ATP**

3. **Krebs Cycle** - The Krebs cycle occurs in the **matrix of the mitochondria**. To being with the acetyl coenzyme A gives the 2 carbon acetate to a 4 carbon molecule already present. The **6 carbon molecule** that is formed then undergoes a series of reactions. Eventually the starting 4 carbon molecule is regenerated to accept another acetate molecule. **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.**

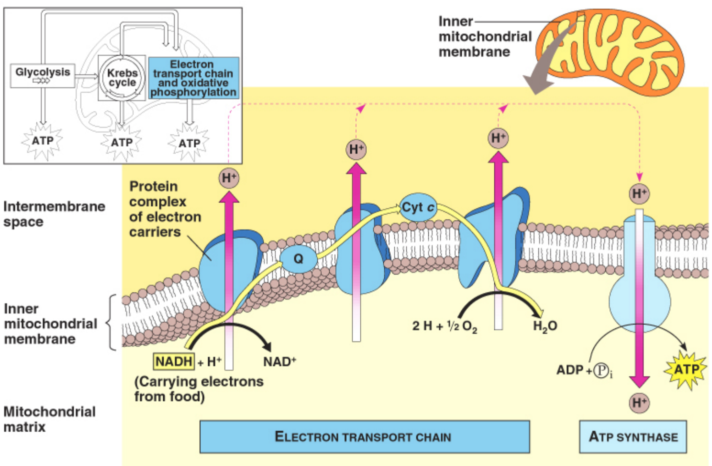
4. **Oxidation Phosphorylation** - the process of oxidative phosphorylation occurs as follows:

    1. The reduced NAD (NADH) from the Krebs cycle binds to protein Complex I, releasing its **hydrogen atoms as protons and electrons**. The NAD hydrogen carrier then goes back to the Krebs cycle to be used again. Reduced FAD (FADH) binds to Complex II. It also releases it hydrogen atoms as protons and electrons. The **protons move into the mitochondrial matrix** whilst the electrons released go into the **electron chain**.

    2. The electrons are then passed down a chain of protein complexes (Complex I to IV) each having a **higher affinity than the previous**. In **Complexes I, III and IV** the energy from the electron is used to pump across protons. For each hydrogen released by NADH **4 protons are pumped across**. The protons are pumped into the **intermembrane space**.

    3. After the electrons have pumped across the protons they are **accepted by the final acceptor oxygen**. The electrons combine with a proton to form a hydrogen atom, which then combines with oxygen to form **water**.

    4. The pumping of the protons from the mitochondrial matrix to the intermembrane space creates a **proton gradient**. The protons therefore move across the membrane through protein channel called a **stalked particle**. The proton motive force provides energy for **ATP synthase** to produce **ATP**.



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 factor (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 which consists of its 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 with all animals being these. 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:

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

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 rate at which energy is transferred into the organic molecules that make up new plant biomass, that is the chemical energy store in plant biomass after respiratory losses to the environment have been taken into account
- Gross primary productivity (GPP) - the rate at which energy is incorporated into organic molecule in the plants in photosynthesis, that is the chemical energy store in plant biomass, in a given area or volume, in a given time
- Therefore, NPP = GPP - R
- 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) where I represents the chemical energy store in ingested food, F represents the chemical energy lost to the environment in faeces and urine and 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 of which there is a finite amount 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 nitrate ions, NO_3^-, in an oxidation reaction, with a nitrite ion, NO_2^-, 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_4^{3-}, 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 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**.