Chapter 8 —> Metabolisms, Cell respiration & photosynthesis

8.1 Metabolism

Metabolic pathways:

- Metabolism —> the sum of all reactions that occur within an organism
- Allow fro a greater level of regulation of the chemical changes
- Organised in chains (Glycolysis, …) or in cycles (Krebs, Calvin, …)

Activation energy:

- Every chemical reaction requires a certain amount of energy in order to proceed
- Enzymes binding to substrates stresses and destabilises the bonds in the substrate —> reduces the overall energy level needed to convert it into a product —> reaction is also faster
- Exergonic —> if the reactants contain more energy than the products (energy released around)
- Endergonic —> if reactants contain less energy than the products (energy taken from around)

Enzyme inhibition:

- A molecule that disrupts the normal reaction pathway between an enzyme and a substrate —> prevent the formation of an enzyme-substrate complex —> prevent formation of a product
- Can be either competitive or non-competitive

Competitive inhibition:
- Involves a molecule (not the substrate), binding to the enzyme's active site
- The molecule is both structurally and chemically similar to the substrate
- As the active site is occupied the substrate can't binds to it
- Effects of inhibitor can be reduced by increasing substrate concentration
- Relenza —> synthetic drug to treat individuals infected by influenza virus
  —> competitively binds to the neuraminidase (virus) active site and prevents binding

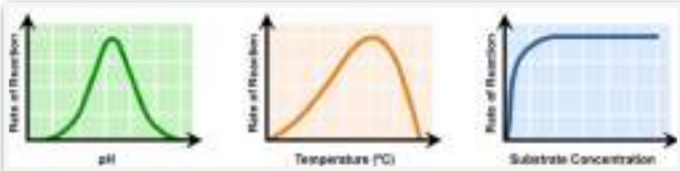
Non-competitive inhibition:
- Involves a molecule binding to a site other than the active site —> allosteric site
- The binding causes a conformational change to the enzyme's active site —> does not match any more with the substrate, so can't bind
- Increasing substrate levels cannot mitigate the inhibitor's effect
- Cyanide —> a poison which prevents ATP production via aerobic respiration —> death
  —> it binds to an allosteric site on cytochrome oxidase —> the electron transport chain cannot continue to function anymore

Feedback inhibition:

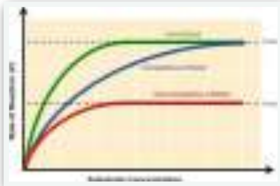
- A form of negative feedback by which metabolic pathways can be controlled
- The final product in a series of reactions inhibits an enzyme from an earlier step (non-comp)
- The enzyme cannot function —> the reaction sequence is stopped —> lower production rate
- Needed to ensure levels of an essential product are always tightly regulated
- Isoleucine —> an essential amino acid (not synthesised by humans) (eggs, fish, cheese, …)
  —> plants and bacteria use threonine to synthesise it (5 steps)

—> firstly threonine is converted into an intermediate compound by an enzyme
—> then isoleucine can bind to an allosteric site on this enzyme and be a non-comp
—> ensures that isoleucine production does not cannibalise stocks of threonine

Enzyme kinetics:



- Rate of reaction (s^{-1}) = 1 / time taken (s)
- Factors affecting enzyme activity include:
- Competitive inhibitors —> exist in direct competition with the substrate —> maximum rate can still be achieved but with a higher substrate concentration
- Non-competitive inhibitors —> are not in direct competition with the substrate so increasing substrate concentrations won't change anything so max. rate is reduced



Rational drug design and malaria:

- Malaria —> a disease caused by parasitic protozoans of the genus plasmodium
- The parasite requires both a human and mosquito host —> hence mosquito bites needed
- Anti-malarian drugs target the specific enzymes malaria uses and inhibits them
- Computer modelling techniques can be used to invent compounds that will function as inhibitors

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8.2 Cell respiration

ATP:

- A high energy molecule that functions as an immediate power source for cells
- The three covalently bonded phosphate groups store potential energy in their bonds
- When ATP is hydrolyse (forms ADP+Pi) —> energy is released for use by the cell
- Two functions —> the energy currency of the cell
  —> the released phosphate group may be given to other molecules
- ATP is synthesised from ADP by:
  —> solar energy —> photosynthesis converts light energy into chemical
  —> oxidative processes —> cell respiration breaks down molecules to release ATP

Cell respiration:

- The controlled release of energy from organic compounds to produce ATP
- Anaerobic respiration —> the incomplete breakdown of molecules for few ATP (no oxygen use)
- Aerobic respiration —> the complete breakdown of molecules for a lot of ATP (oxygen needed)
- The breakdown occurs via a number of linked processes —> less energy required

	Oxidation	Reduction
Electrons	Loss	Gain
Hydrogen	Loss	Gain
Oxygen	Gain	Loss

Reduction and Oxidation:

-Energy stored in the molecules is transferred with the protons and electrons to carrier molecules
-$NAD^+ + 2H^+ + 2e^-$ —> $NADH + H^+$
-$FAD + 2H^+ + 2e^-$ —> $FADH_2$

Glycolysis —> Link reaction —> Krebs Cycle —> Electron transport chain —> Chemiosmosis
$C_6 H_4 O_6 + 6\ O_2$ ——> $6\ CO_2 + 6\ H_2O$

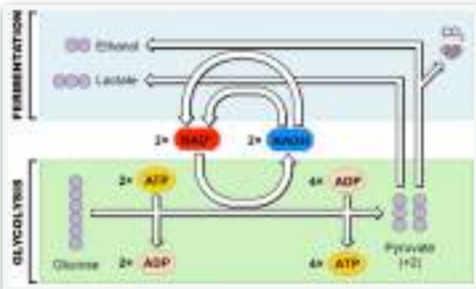
Glycolysis:

- Occurs in the cytosol of the cell —> a hexose sugar (6C) is broken down in two pyruvate (3C)
- It is an anaerobic process
- Glucose —> main organic compound used in cell respiration (lipids and proteins can be used)
- Lipids —> not preferentially used as they are harder to transport and digest
- Proteins —> not preferentially used as they release potentially toxic nitrogenous compounds

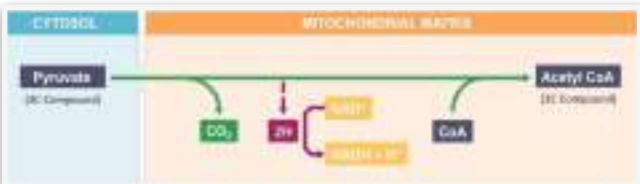
1) Phosphorylation —> hexose sugar is phosphorylated by two ATP (forms hexose biphosphate)
   —> makes the molecule less stable and more reactive + no diffusion out of cell
2) Lysis —> the hexose biphosphate (6C sugar) is split into two triode phosphates (3C sugars)
3) Oxidation —> hydrogen atoms are removed from the 3C sugars to reduce NAD^+ to $NADH + H^+$
   —> two molecules of NADH are produced in total
4) ATP formation —> some energy released from the sugars is used to directly synthesise ATP
   —> called substate level phosphorylation
   —> 4 molecules of ATP are generated during glycolysis (2ATP per 3C sugar)

Aerobic respiration:
- If oxygen is present the pyruvate is transported to the mitochondria for further breakdown
- The further oxidation generates large numbers of reduced hydrogen carriers (NAD e FAD)
- In the presence of oxygen, the reduced hydrogen carriers can release their stored energy to synthesise more ATP
- Link reaction, Krebs cycle and electron transport chain are the next processes

Anaerobic respiration (fermentation):
- If oxygen is not present the pyruvate is not broken down further and no more ATP is produced
- The pyruvate remains in the cytosol and becomes lactic acid (animal) or ethanol and CO_2 (plants)
- This conversion is reversible

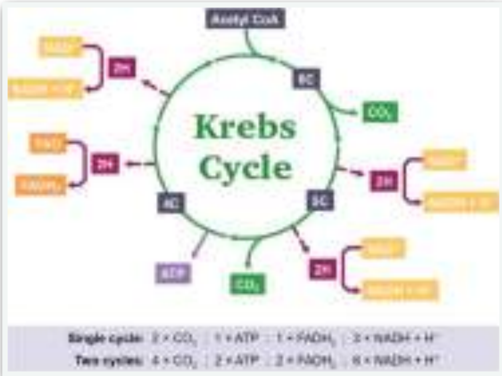


Link reaction:



- It links the products of glycolysis with the aerobic processes of the mitochondria
1) pyruvate is moved from the cytosol to the mitochondrial matrix by carrier proteins
2) The pyruvate loses a carbon atom (decarboxylation) —> it forms a CO_2 molecule
3) The 2C compound forms an acetyl group when it loses hydrogen atoms via oxidation
4) The acetyl compound combines with coenzyme A to form acetyl CoA
- The link reaction occurs twice per molecule of glucose (2 pyruvate received)

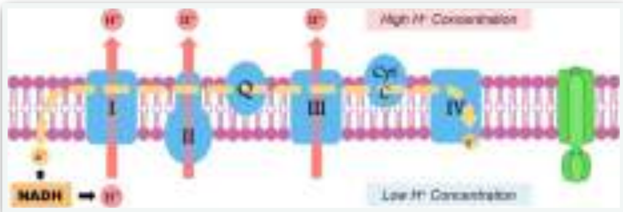
Krebs cycle:



- Occurs in the matrix of the mitochondria
- Acetyl CoA transfers its acetyl group to a 4C compound to make a 6C compound —> then it is released and returns to the link reaction
- Two carbon atoms are released via decarboxylation to form 2 CO_2 molecules
- Multiple oxidation reactions —> reduction of hydrogen carriers
- One molecule of ATP is produced directly via substrate level phosphorylation
- Krebs cycle occurs twice (one per each acetyl CoA)

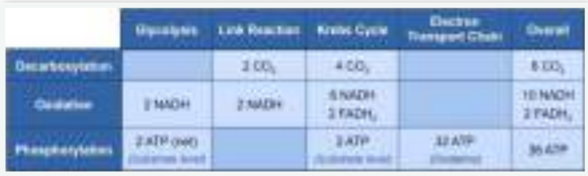
Oxidative phosphorylation:

Electron transport chain:



1) hydrogen carriers are oxidised and release high energy electrons and protons
2) The electrons are transferred to the electron transport chain
3) As electrons pass the chain they lose energy —> used to pump protons (H^+) from the matrix
4) The accumulation of H^+ ions in the inter membrane space created an electrochemical gradient

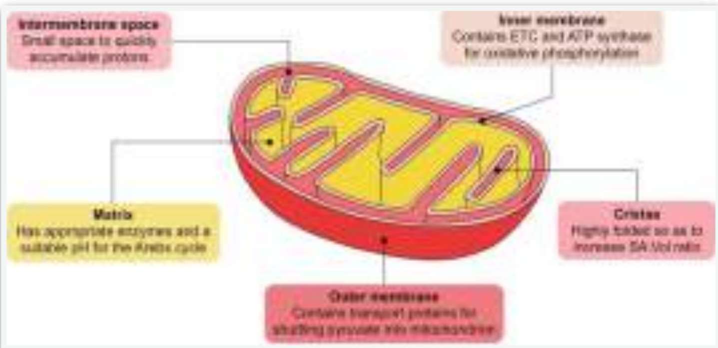
Chemiosmosis:



	Glycolysis	Link Reaction	Krebs Cycle	Electron Transport Chain	Overall
Decarboxylation		2 CO_2	4 CO_2		6 CO_2
Oxidation	2 NADH	2 NADH	6 NADH 2 $FADH_2$		10 NADH 2 $FADH_2$
Phosphorylation	2 ATP (net) (Substrate level)		2 ATP (Substrate level)	32 ATP (Oxidative)	36 ATP

1) the electrochemical gradient will cause H^+ ions to diffuse back into the matrix
2) This diffusion is facilitated by the transmembrane enzyme ATP synthase
3) H^+ ions move through ATP synthase —> cause molecular rotation of the enzyme, synth. ATP
4) Oxygen acts as the final electron acceptor —> removes the de-energised electrons to prevent the chain from becoming blocked —> it also binds to H^+ ions to form H_2O

Mitochondria:



8.3 Photosynthesis

- The process by which cells synthesis organic molecules from inorganic molecules using light
- It can only occur in certain organisms and requires photosynthetic pigments
- Two step process —> Light independent rxn —> convert light energy into chemical (ATP)
  —> Light independent rxn —> use chemical energy to synthesise compounds

$6\ CO_2 + 12\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$

Light dependent reactions:

- Use photosynthetic pigments to convert light energy into chemical energy (ATP and NADPH)
- These reactions occur in the thylakoids
- Photophosphorylation —> light provided is the initial energy source for ATP production

1) Excitation of photosystems by light energy

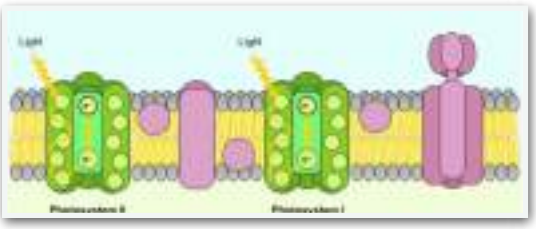
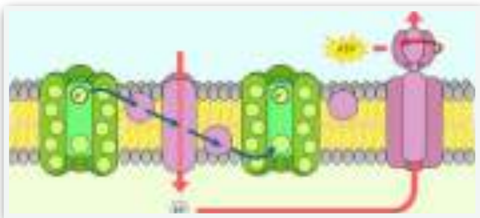
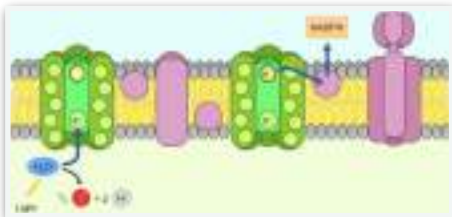
—> photosystems —> groups of photosynthetic pigments in the thylakoid membrane
—> PS I (700 nm) is before PS II (680 nm)
—> when a photosystem absorbs light energy, it energises delocalised electrons
—> the exited electrons are transferred to carrier molecules within the thylakoid membrane
—> the electrons lost are replaced by electrons released from water via photolysis

2) Production of ATP via electron transport chain

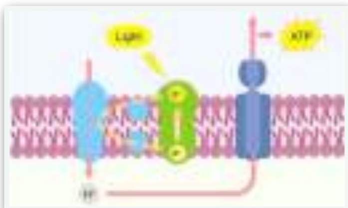
—> electrons from PS II are transferred to an electron transport chain
—> electrons lose energy in the process —> used to translocate H^+ ions into the thylakoid creating an electrochemical gradient
—> The H^+ ions return to the Stroma via ATP synthase (chemiosmosis) —> used to catalyse the synthesis of ATP from ADP + Pi
—> the de-energised electrons are taken up by PS I

3) Reduction of $NADP^+$ and the photolysis of water

—> PS I energises the electrons again
—> electrons transferred to carrier molecule and reduce $NADP^+$ to form NADPH (by ferrodoxin)
—> water is split by light energy into H^+ ions (for chemiosmosis) and oxygen

Photophosphorylation:



Cyclic photophosphorylation:

- Only uses the PS I and there is no reduction of $NADP^+$
- The de-energised electron returns to the photosystem after having entered the electron transport chain to produce ATP
- $NADP^+$ is not reduced + water is not needed to replenish electron supply

Non-Cyclic photophosphorylation:

- Involves both photosystems and reduces $NADP^+$
- The process explained in Light dependent reactions

Light independent reactions:

- Use the chemical energy from LD reactions to form organic molecules
- Occur in Stroma, the fluid-filled space of the chloroplast
- Calvin cycle —> light independent reactions

1) **Carbon fixation**
   —> The Calvin cycle beings with a 5C compound (Ribulose biphosphate)
   —> enzyme rubisco catalyses the attachment of a CO_2 molecule to RuBP —> 6C
   —> the 6C are unstable so break down into two 3C compounds (Glycerate-3-phosphate)
   —> one cycle takes three molecules of RuBP with three CO_2 to make six G3P

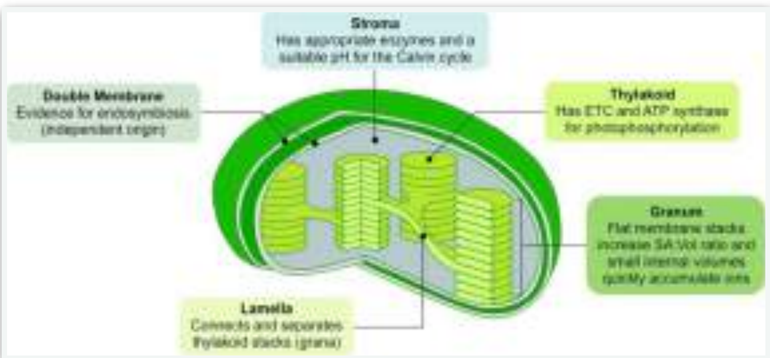
2) **Reduction of Glycerate-3-phosphate**
   —> G3P is converted into triode phosphate using NADPH and ATP
   —> the reduction by NADPH transfers H atoms to the compound
   —> the hydrolysis of ATP provides the necessary energy

3) **Regeneration of RuBP**
   —> out of 6, just one triose phosphate molecule can be used to form half a sugar molecule
   —> other five TP molecules are recombined to regenerate stock of RuBP (5 x 3C = 3 x 5C)
   —> the energy to regenerate RuBP is derived from the hydrolysis of ATP

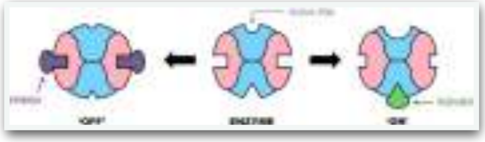
Lollipop Experiment:

1) Radioactive carbon-14 is added to a lollipop apparatus containing Chlorella algae
2) Light is given to the plant to induce photosynthesis
3) After different periods of time the algae is killed with heated alcohol (stops cell metabolism)
4) Dead algal samples are analysed using 2D chromatography —> to see different carbon comp.
5) Radioactive carbon compounds on the chromatogram were identified by autoradiography
6) By comparing different periods of light exposure, the order in which carbon comp. generate was determined —> Calvin cycle

Chloroplasts:



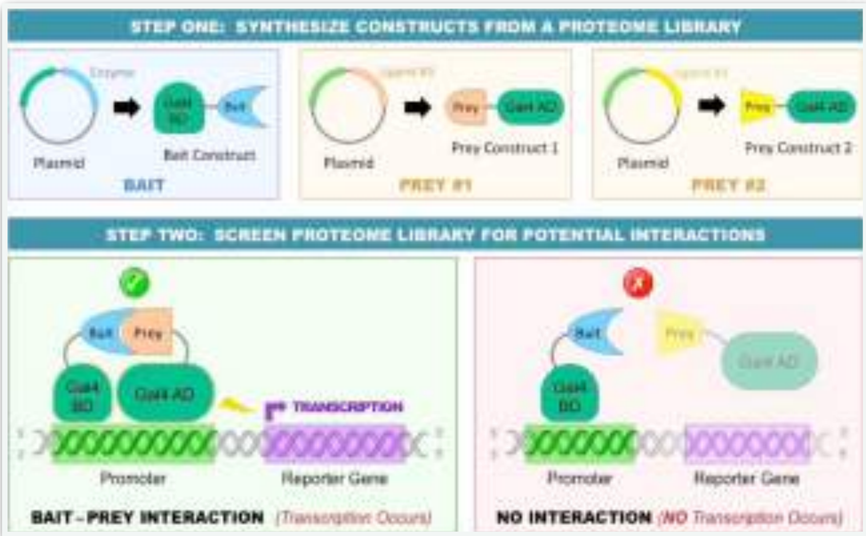
Extra:



Allosterism:

- Is the modulation of an enzyme's activity via the binding of an effector molecule (ligand) to a site other than the enzyme's active site (allosteric site)
- Positive al. —> the binding of oxygen molecules to haemoglobin
  —> haemoglobin can bind to four oxygen molecules (HbO_8)
  —> as each molecule binds it changes conformation of Hb and increases capability
  —> this ensures that Hb will transport the max amount of oxygen
- Negative al. —> any example of non-competitive inhibition

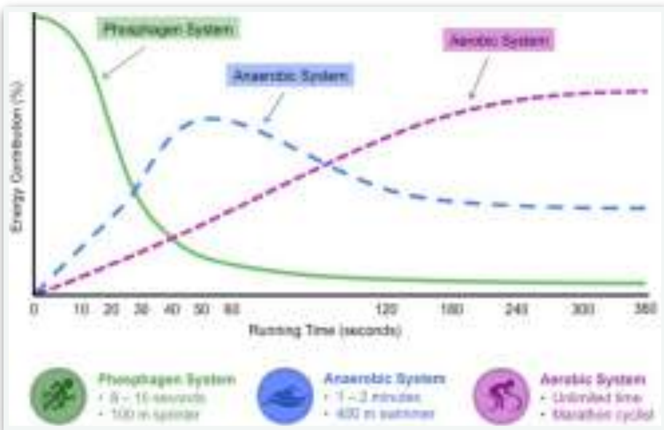
Yeast-2-Hybrid system:



- A simple scientific technique used to screen a library of proteins for potential interactions
- Bait —> eg. enzymes
- Prey —> eg. different ligands
- Simple technique —> has a relatively high rate of false positives (partial interactions)

Phosphagen system:

- Phosphagens —> energy storing compounds that are chiefly found in muscle and nervous tissue
- They function as an immediate access reserve of high energy phosphates that can make ATP
- Are found in tissues that experience rapidly changing energy needs
- Phosphocreatine —> common example used by animals
  —> at rest, ATP hydrolysed to ADP and phosph. used to make phosphocreatine
  —> this occurs in the mitochondria where ATP levels are high
  —> during exercise phosphocreatine is hydrolysed and the phosphate released to make ATP from ADP
  —> this occurs in the muscles, where ADP levels will be high
- Phosphocreatine synthesises a pool of ATP more rapidly than cell resp. but reserves don't last
- The phosphagen system will be used for the first 10-12 seconds of intense exercise
- Anaerobic respiration provides a more sustained pool of ATP but produces lactic acid
- Anaerobic respiration will be used for the first 1-2 minutes of exercise
- Aerobic respiration requires a constant supply of oxygen but can produce a large yield of ATP
- Will be used for long-distance and less intense exercise activities



Photosynthesis vs Respiration:

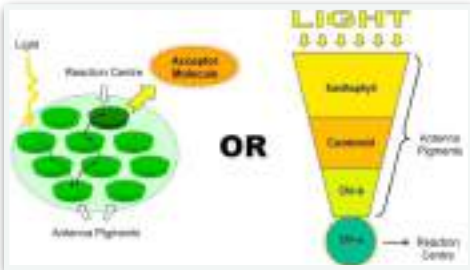
Similarities:

- Both involve the production of chemical energy (ATP)
- In photosynthesis ATP is produced via light energy (photophosphorylation)
- Cell respiration ATP produced by breaking down organic molecules (oxidative phosphorylation)
- In both cases the production of ATP involves an electron transport chain and chemiosmosis
  —> photosynthesis —> electrons are donated by chlorophyll and protons accumulate within the lumen of the thylakoid
  —> cell respiration —> electrons are donated by hydrogen carriers and protons accumulate in the intermembrane space

Differences:

- Photosynthesis is an anabolic process while cell respiration is a catabolic process
- Photosynthesis —> water is broken down to oxygen to release electrons for ETC
  —> electrons from the ETC are taken up by hydrogen carriers (NADPH)
  —> uses the Calvin cycle to synthesise glucose (requires CO_2 and H carriers)
- Cell respiration —> uses the Krebs cycle to break down glucose (releases H carriers and CO_2)
  —> H carriers release electrons for the ETC (NADH and $FADH_2$ specifically)
  —> electrons from the ETC are taken up by oxygen to form water

Accessory pigments:



- Photosynthetic organisms do not rely on a single pigment to absorb light, but instead on a combined action of many
- These photosynthetic pigments are grouped into photosystems (absorb and funnel light energy)
- In this way the cell maximises its light absorption
- When a pigment is energised by light it releases high energy electrons (ionisation)
- Antenna pigments —> transfer energised electrons to a central reaction centre —> than electrons are passed on to an acceptor molecule in an ETC to synthesise ATP
- Accessory pigments presence explains why not all leaves are green
  —> other pigments may produce different colours than green
  —> deciduous trees change colour when leaves stop producing chlorophyll in winter

C3, C4 and CAM plants

- C3 plants —> plants that fix carbon dioxide directly from the air
- Rubisco can also use oxygen as an alternative substrate —> photorespiration
- Photorespiration reduces levels of photosynthesis by up to 25% in C3 plants
- Oxygen act as a competitive inhibitor for rubisco
- In hot and arid conditions plants have evolved to limit exposure of rubisco to oxygen
- C4 and CAM plants use the enzyme PEP carboxylase to combine CO_2 to a 3C compound
- PEP carboxylase has a higher affinity for CO_2 than rubisco and doesn't bind to oxygen
- C4 pathway —> CO_2 is physically separated from oxygen to improve the binding to Rubisco
  —> it is brought to a deeper tissue layer and is released (less oxygen present)
- CAM pathway —> CO_2 reserves are created to improve binding to Rubisco
  —> the CO_2 reserves created during the night are used during the day when stomata must remain closed to avoid water loss

GAP project:

- Global Artificial Photosynthesis Project —> an international venture aimed at copying the natural process of photosynthesis in order to develop more efficient solar energy harvesting tech.
- Artificial photosynthesis —> aimed to produce clean energy with heat the only product released
    —> involves constructing systems that will undertake three key steps:
        —> harvest light energy
        —> transduce this energy to electrons
        —> use redox reaction to generate chemical fuel resources