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PHOTOSYNTHESIS

IN HIGHER PLANTS

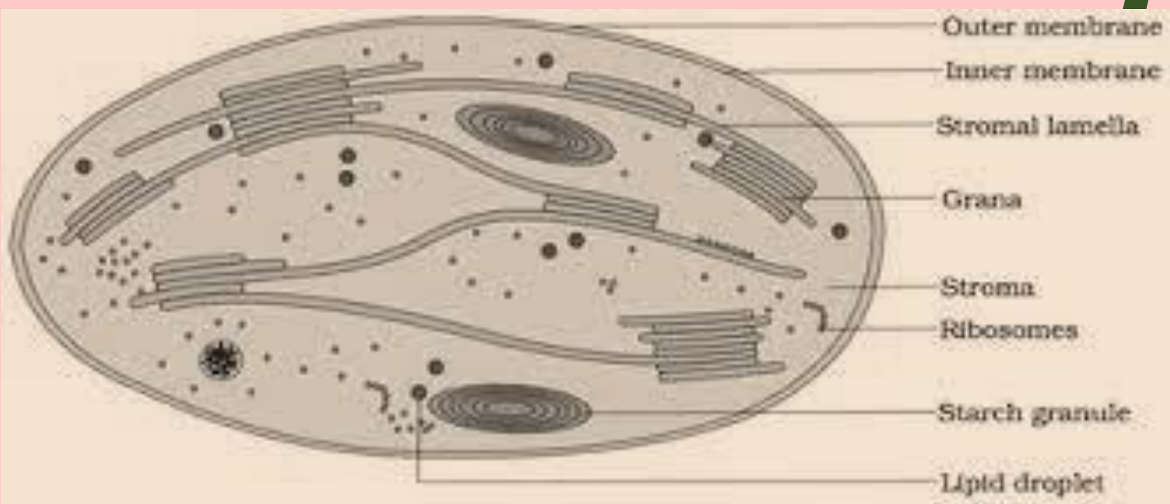
WHERE DOES PHOTOSYNTHESIS TAKE PLACE?

Photosynthesis does take place in the green leaves of plants but it does so also in other green parts of the plants. the mesophyll cells in the leaves, have a large number of chloroplasts.

chloroplast there is membranous system consisting of grana, the stroma lamellae, and the matrix stroma.

The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH. In stroma, enzymatic reactions synthesise sugar, which in turn forms starch.

The former set of reactions, since they are directly light driven are called light reactions (photochemical reactions). The latter are not directly light driven but are dependent on the products of light reactions (ATP and NADPH) they are called, as dark reactions (carbon reactions).



HOW MANY TYPES OF PIGMENTS ARE INVOLVED IN PHOTOSYNTHESIS?

According to chromatographic separation of the leaf pigments shows that the colour that we see in leaves is not due to a single pigment but due to four pigments:

Chlorophyll a (bright or blue green in the chromatogram)

chlorophyll b (yellow green)

xanthophylls (yellow)

carotenoids (yellow to yellow-orange)

Though chlorophyll is the major pigment responsible for trapping light, other thylakoid pigments like chlorophyll b, xanthophylls and carotenoids, which are called accessory pigments, also absorb light and transfer the energy to chlorophyll a. Indeed, they not only enable a wider range of wavelength of incoming light to be utilised for photosynthesis but also protect chlorophyll a from photo-oxidation.

WHAT IS LIGHT REACTION?

Light reactions or the 'Photochemical' phase include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH.

protein complexes are involved in the process. The pigments are organised into two discrete photochemical light harvesting complexes (LHC) within the Photosystem I (PS I) and Photosystem II (PS II).

The LHC are made up of hundreds of pigment molecules bound to proteins. Each photosystem has all the pigments forming a light harvesting system also called antennae. These pigments help to make photosynthesis more efficient by absorbing different wavelengths of light. The single chlorophyll a molecule forms the reaction centre.

THE ELECTRON TRANSPORT

In PS II the reaction centre chlorophyll a absorbs 680 nm wavelength of red-light causing electrons to become excited and jump into an orbit farther from the atomic nucleus.

These electrons are picked up by an electron acceptor which passes them to an electrons transport system consisting of cytochromes.

The electrons are not used up as they pass through the electron transport chain, but are passed on to the pigments of photosystem PS I.

Same as electrons in the reaction centre of PS I are also excited when they receive red light of wavelength 700 nm and are transferred to another accepter molecule that has a greater redox potential.

These electrons then are moved downhill again, this time to a molecule of energy-rich NADP+ . The addition of these electrons reduces NADP+ to NADPH + H+ .

This whole scheme of transfer of electrons, starting from the PS II, uphill to the acceptor, down the electron transport chain to PS I, excitation of electrons, transfer to another acceptor, and finally downhill to NADP+ reducing it to NADPH + H+ is called the Z scheme.

Splitting of Water

The splitting of water is associated with the PS II; water is split into 2H+ , [O] and electrons. This creates oxygen, one of the net products of photosynthesis. The electrons needed to replace those removed from photosystem I are provided by photosystem II.

$$2H_2o \longrightarrow 4H^+ + o_2 + 4e^-$$

Cyclic and Non-cyclic Photo-phosphorylation

Non-cyclic photo-phosphorylation

The process through which ATP is synthesised by cells is named phosphorylation. Photophosphorylation is the synthesis of ATP from ADP and inorganic phosphate in the presence of light. When the two photosystems work in a series, first PS II and then the PS I, a process called non-cyclic photo-phosphorylation.

Cyclic photophosphorylation

When only PS I is functional, the electron is circulated within the photosystem and the phosphorylation occurs due to cyclic flow of electrons.

Cyclic photophosphorylation also occurs when only light of wavelengths beyond 680 nm are available for excitation.

Chemiosmotic Hypothesis

The biological process by which ATP synthase produces ATP molecules is known as this process. An explanation

of how energy molecules (ATP: Adenosine triphosphate) are produced during photosynthesis is provided by the Chemiosmotic theory.

Chemiosmosis requires a membrane, a proton pump, a proton gradient, and ATP synthase. Energy is used to pump protons across a membrane, to create a gradient or a high concentration of protons within the thylakoid lumen.

ATP synthase has a channel that allows diffusion of protons back across the membrane; this releases enough energy to activate ATP synthase enzyme that catalyses the formation of ATP. Along with the NADPH produced by the movement of electrons, the ATP will be used immediately in the biosynthetic reaction taking place in the stroma, responsible for fixing CO_2, and synthesis of sugars.

WHERE ARE THE ATP AND NADPH USED?

The Primary Acceptor of CO2

the first product was a C3 acid, the primary acceptor would be a 2-carbon compound; they spent many years trying to identify a 2-carbon compound before they discovered the 5-carbon RuBP.

The Calvin Cycle

The Calvin cycle proceeds in three stages:

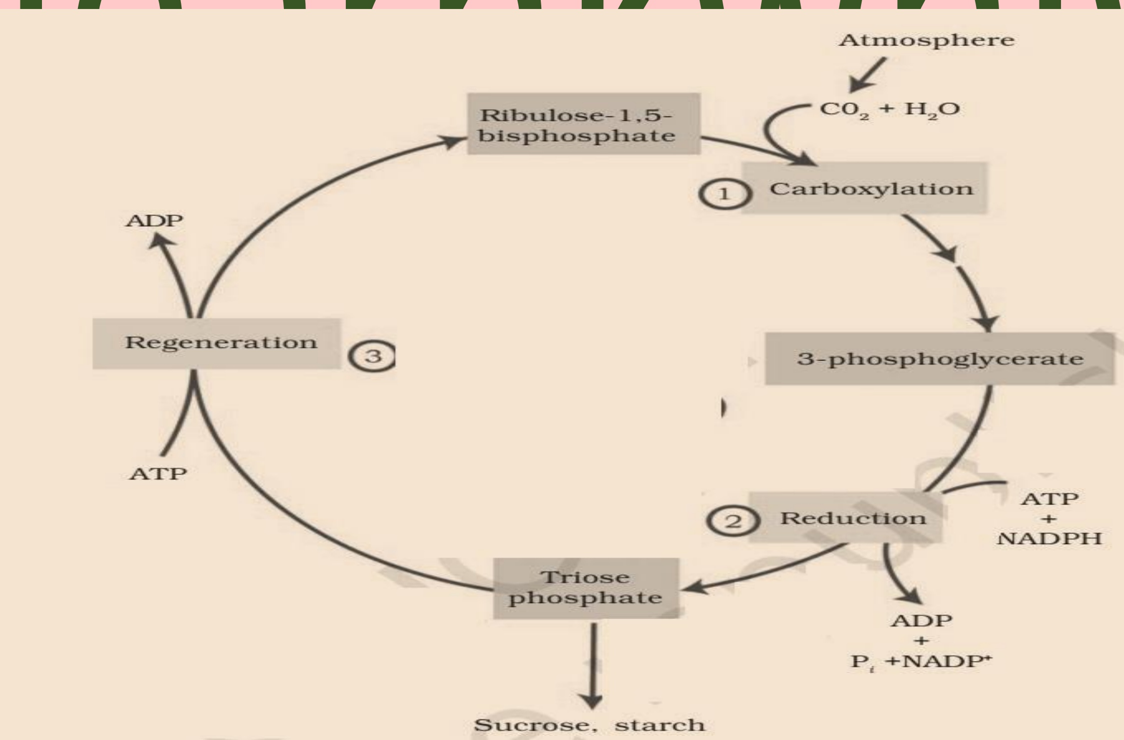
(1) carboxylation, during which CO_2 combines with ribulose-1,5-bisphosphate

(2) reduction, during which carbohydrate is formed at the expense of the photochemically made ATP and NADPH

(3) regeneration during which the CO_2 acceptor ribulose-1,5-bisphosphate is formed again.

Carboxylation

Carboxylation is the most crucial step of the Calvin cycle where CO_2 is utilised for the carboxylation of RuBP. This reaction is catalysed by the enzyme RuBP carboxylase which results in the formation of two molecules of 3-PGA.



Reduction

The steps involve utilisation of 2 molecules of ATP for phosphorylation and two of NADPH for reduction per CO_2

molecule fixed. The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the formation of one molecule of glucose from the pathway.

<u>Regeneration</u>

The regeneration steps require one ATP for phosphorylation to form RuBP.

<u>THE C4 PATHWAY</u>

C4 plants are special: They have a special type of leaf anatomy, they tolerate higher temperatures, they show a response to high light intensities, they lack a process called photorespiration and have greater productivity of biomass.

The particularly large cells around the vascular bundles of the C4 plants are called bundle sheath cells, and the leaves which have such anatomy are said to have 'Kranz' anatomy.

The bundle sheath cells may form several layers around the vascular bundles; they are characterised by having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.

This pathway that has been named the Hatch and Slack Pathway.

The primary CO_2 acceptor is a 3-carbon molecule phosphoenol pyruvate (PEP) and is present in the mesophyll cells.

The enzyme responsible for this fixation is PEP carboxylase or PEP case.

The C4 acid OAA is formed in the mesophyll cells. It then forms other 4-carbon compounds like malic acid or aspartic acid in the mesophyll cells itself, which are transported to the bundle sheath cells.

In the bundle sheath cells these C4 acids are broken down to release CO_2 and a 3-carbon molecule.

The 3-carbon molecule is transported back to the mesophyll where it is converted to PEP again, thus, completing the cycle.

The CO_2 released in the bundle sheath cells enters the C3 or the Calvin pathway. The bundle sheath cells are rich in an enzyme Ribulose bisphosphate carboxylase-oxygenas, but lack PEP case.

PHOTORESPIRATION

Photorespiration involves a complex network of enzyme reactions that exchange metabolites between chloroplasts, leaf peroxisomes and mitochondria.

In C3 plants some O_2 does bind to RuBisCO, and hence CO_2 fixation is decreased. Here the RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule of phosphoglycerate and phosphoglycerate (2 Carbon) in a pathway called photorespiration.

In the photorespiratory pathway, there is neither synthesis of sugars, nor of ATP. Rather it results in the release of CO_2 with the utilisation of ATP. In the photorespiratory pathway there is no synthesis of ATP or NADPH.

In C4 plants photorespiration does not occur. This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site.

FACTORS AFFECTING PHOTOSYNTHESIS

Photosynthesis is under the influence of several factors, both internal (plant) and external. The plant factors include the number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO_2 concentration and the amount of chlorophyll.

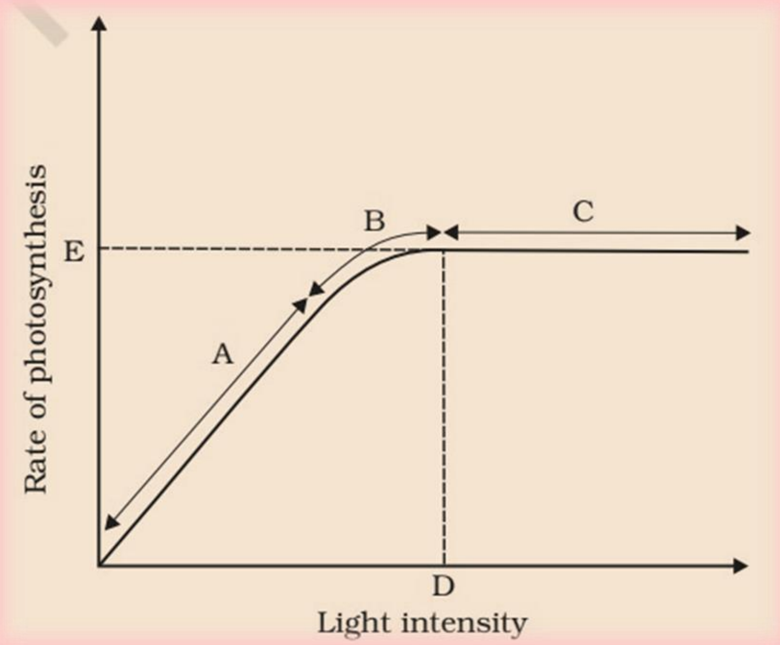
The plant or internal factors are dependent on the genetic predisposition and the growth of the plant. The external factors would include the availability of sunlight, temperature, CO_2 concentration and water.

Law of Limiting Factors

If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed.

Light

There is a linear relationship between incident light and CO_2 fixation rates at low light intensities. At higher light intensities, gradually the rate does not show further increase as other factors become limiting.



Carbon dioxide Concentration

The C3 and C4 plants respond differently to CO2 concentrations. At low light conditions neither group responds to high CO2 conditions. At high light intensities, both C3 and C4 plants show increase in the rates of photosynthesis.

Temperature

The dark reactions being enzymatic are temperature controlled. Though the light reactions are also temperature sensitive they are affected to a much lesser extent. The C4 plants respond to higher temperatures and show higher rate of photosynthesis while C3 plants have a much lower temperature optimum.

Water

Even though water is one of the reactants in the light reaction, the effect of water as a factor is more through its effect on the plant, rather than directly on photosynthesis. Water stress causes the stomata to close hence reducing the CO_2 availability.