AUTOTROPHIC NUTRITION

Animals depend on plants because the food materials which animals eat are manufactured by plants. Thus, animals feed, and can only feed on complex organic matter, plants however, can feed on simple inorganic materials, building these up into complex organic molecules. The type of nutrition employed by plants is called **autotrophic nutrition**. It also occurs in certain protists like algae, euglena and bacteria such as cyanobacteria.

It involves the synthesis of organic compounds from inorganic raw materials and is sometimes called holophytic nutrition. The raw materials are majorly carbondioxide and water, in the presence of some kind of energy.

Organisms that feed through this way are called **autotrophs or autotrophic organisms**.

TYPES OF AUTOTROPHIC NUTRITION:

There are two methods employed in autotrophic organisms, of synthesizing organic from inorganic materials: Photosynthesis and chemosynthesis.

Photosynthesis: This is the method used all green plants, some protists and bacteria. It is the synthesis of organic compounds, primarily sugars from carbondioxide and water using sunlight as the source of energy and chlorophyll or some other closely related pigments for trapping the light energy. These organisms are called **photoautotrophs**.

Chemosynthesis: Used by certain bacteria, this is the synthesis of organic compounds from carbon dioxide and water but the energy, instead of coming from light is supplied by special methods of respiration involving the oxidation of various inorganic materials such as hydrogen sulphide, ammonia and iron (II). Organisms are Chemoautotrophs

CHEMOSYNTHESIS:
This is the chemical process in which inorganic chemicals are oxidized to provide energy to living organisms for the synthesis of organic compounds.

Table below shows examples of chemosynthetic bacteria, their substrate, the main products of their oxidation and their habitats:

Chemosynthetic bacteria	Substrate	Main Product	Habitat
Nitrosomonas & Nitrococcus	Ammonium (NH_4^+)	Nitrites (NO_2^-)	Soil
Nitrobacter	Nitrites (NO_2^-)	Nitrates (NO_3^-)	Soil
Thiobacillus or colourless sulphur bacteria	Hydrogen sulphide (H_2S)	~~Sulphate~~ H_2O and ~~(SO_4^{2-})~~ S	Decaying organic matter
Ferrobacillus or Iron bacteria	Ferrous (Fe^{2+})	Ferric (Fe^{3+})	streams flowing over iron rocks
Hydrogenomonas	Hydrogen (H_2)	Water (H_2O)	Soil.

Mechanism of chemosynthesis in some bacteria:
Lets consider an important group of chemosynthetic organisms such as the nitrifying bacteria found in the soil. Through their metabolic activities, they enrich the soil in available nitrogen i.e nitrogen in a form obtainable by plants.

Some of these bacteria namely Nitrosomonas and Nitrococcus, obtain energy by oxidizing ammonia (formed from breakdown of animal and plant proteins during decay) to nitrite. The conversion involves several steps. As soon as it is liberated into the soil, the ammonia combines with carbon dioxide to form ammonium carbonate. This is then converted to nitrous acid under the influence of the bacteria above:

$$(NH_4)_2CO_3 + 3O_2 \xrightarrow{\text{Nitrococcus}} 2HNO_2 + CO_2 + 3H_2O + \text{Energy}.$$

The nitrous acid immediately combines with, forexample calcium or magnesium salts to form the appropriate nitrite. Another nitrifying bacterium, Nitrobacter, oxidizes nitrites to nitrates.

$$Ca(NO_2)_2 + O_2 \xrightarrow{\text{Nitrobacter}} Ca(NO_3)_2 + \text{Energy}.$$

In all these cases, the energy released is used for the synthesis of organic compounds as below

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

Note:

Certain bacteria convert nitrates, to nitrites, ammonia or even nitrogen. Although many plants can absorb ammonium compounds, nitrites and nitrogen cannot be used, since nitrites are toxic to most plants.

As these bacteria deprive the soil of available nitrogen compounds they are known as denitrifying bacteria. They do this because they tend to live in conditions of oxygen shortage such as water logged areas, and in order to correct this deficiency, they reduce nitrates to nitrites, ammonia or nitrogen, thereby liberating oxygen. The oxygen is then used for the aerobic breakdown of sugar, and the energy released is used for the synthesis of organic compounds.

Importance of chemosynthesis:

The chemical activities of the organisms involved bring about nutrient cycling, e.g. Nitrosomonas and Nitrobacter bacteria are involved in nitrification in plants. Thiobacillus catalyse the conversion of sulphur containing compounds to sulphates which are directly useful to plants. ~~t~~

However, some denitrifying bacteria reduce nitrates in the soil hence affecting plant growth

PHOTOSYNTHESIS

Green plants obtain their energy from sunlight. The process whereby green plants use solar energy to produce organic molecules is called photosynthesis. Carbon dioxide and water are the raw-materials for the process, which can be summarized in the equation below:

$$energy + CO_2 + H_2O \longrightarrow (CH_2O) + O_2$$

complex organic molecules

Importance of photosynthesis:

- It is the main way through which sun's energy is captured by plants for use by all organisms.
- It provides a source of complex sugar or organic molecules for heterotrophic organisms.
- It releases oxygen for use by aerobic organisms
- It reduces on gaseous carbon-dioxide, which would be toxic if accumulated in the atmosphere to cause green house effect.
- Humans depend on photosynthesis for energy containing fuel, which have developed over millions of years such as oil, coal and others.

THE LEAF STRUCTURE

The leaf is the main photosynthetic structure of a plant, although stems, sepals and other parts may also photosynthesize.

Leaves have different adaptations to bring together the 3 raw materials, water, carbon dioxide and light and to remove the products oxygen and glucose.

Leaves may carry out the same process, however, they show a wide range of form. This range of form is often due to different environmental conditions.

~~GENE~~

The internal structure of a leaf (dicot type)

Leaves are generally thin and flat and collectively present a large surface area to the light.

Internally, the leaf is covered by a layer of cuticularised epidermal cells, the cuticle being generally thicker on the upper surface than the lower.

The inside of the leaf is filled with cells which contain chloroplasts. These cells are of two types. Those immediately beneath the upper epidermis called the palisade cells, are elongated ~~form~~ with their long axes perpendicular to the surface. They are separated from each other by narrow air spaces and are densely packed with chloroplasts. ~~They also~~ The chloroplasts tend to arrange themselves in the part of the cell which receives maximum illumination, usually the upper part.

The palisade cells collectively form the palisade mesophyll layer which may be one or several cells in thickness.

Filling the leaf between the palisade layer and the lower epidermis are the spongy mesophyll cells. Irregular in shape and arrangements, they also contain chloroplasts but fewer than the palisade cells. Their cellulose walls are thin and permanently saturated with moisture. Between the spongy mesophyll cells are large air spaces which communicate with each other and with those between the palisade cells. This system of air spaces allows gases to diffuse freely between the cells.

The lower epidermis is pierced by numerous pores or stomata (singular. stoma). The upper epidermis may have some too but they are usually fewer than in the lower epidermis. Each connects with the intercellular air spaces described above. Bordered by guard cells which can open and close the pore, the stomata regulate the passage of carbon-dioxide, oxygen and water vapour across the surface of the leaf.

The leaf also contains central midrib as well as ~~two~~ smaller veins. These consist of conducting tissue specialized for transporting materials to and from the leaf. The **Xylem** brings water and mineral salts from the roots in elongated conducting tubes called vessels. The **phloem** removes soluble food materials from the leaf in specialized rows of cells called sieve tubes. Xylem and phloem together constitute a vascular bundle.

— Diagram — 1 —

Check Tooles pg 270-275 or Dongo notes

General adaptations of leaves for photosynthesis

1. For obtaining and removing gases:
2. For obtaining sunlight
3. For obtaining and removing water.

The leaf as an organ of photosynthesis:

Carbon dioxide from the atmosphere diffuses through the stomata into the sub-stomatal air chambers and hence via the intercellular air spaces to the chloroplasts in the mesophyll and palisade cells.

Water drawn up to the leaves from the soil via the conducting tissues of the roots and stem, passes out of the xylem elements in the veins to the surrounding cells. With the water come mineral salts (nitrates, sulphates and phosphates) required for the synthesis of proteins.

Oxygen and excess water vapour diffuse out of the leaf via the intercellular air spaces and stomata. Sugar and other products of photosynthesis are moved to other parts of the plant in the sieve tubes.

The leaves of mesophytic plants are broad, thin, flattened structures. They thus have a relatively large surface area through which light can pass. The thinness of leaves means that light passes over a short distance to the mesophyll tissue, where chloroplasts are mainly located.

Penetration of light to the mesophyll tissue is helped by the transparency of the leaf epidermis.

THE RAW MATERIALS OF PHOTOSYNTHESIS

The raw-materials of photosynthesis are carbon dioxide and water.

Carbon dioxide is the only form in which a plant can take in carbon, though some aquatic plants may obtain it from hydrogen-carbonate ions in the water.

~~Eq~~ Equally, water is the only source of hydrogen for reducing the carbon dioxide, the first step in the building up of carbohydrates.

Mineral salts (sulphates, phosphates and nitrates) are also required, not for the formation of carbohydrates but for their further conversion into proteins. Other ions are needed for making other products like magnesium is required for chlorophyll, and iron for the cytochromes involved in metabolism.

THE PRODUCTS OF PHOTOSYNTHESIS

The main product of photosynthesis is monosaccharide sugar (glucose). This can be converted into proteins for growth, broken down into carbon dioxide and water for energy production, or built up into starch for storage, depending on the plant.

The other product of photosynthesis is oxygen. This is demonstrated by collecting the gas given off by a water plant such as the pondweed (Elodea) and tested for oxygen. The plant is set up under a funnel as shown below. Gas is collected in a test tube and tested for oxygen with a glowing splint.

— Diagram - 2 —

Some idea of the rate of photosynthesis can be obtained by counting the number of bubbles given off per unit time.

However, another way of estimating the rate of photosynthesis is shown below. In this case, the amount of gas evolved by the water plant is measured. This apparatus is useful to compare the rate of photosynthesis in different conditions i.e. light intensity

- Diagram - 3 -

Observations and Explanations:

Colourless gas which relights a glowing splint evolves from the cut end of the plant. The gas is oxygen released from photosynthetic reactions.

The rate of gas evolved is directly proportional to light intensity up to a certain illumination i.e the closer the light source is to the plant, the more oxygen bubbles evolve up to a certain light intensity then remains relatively constant and may decrease. This is because of the increased light intensity which provides more energy for photo-activation of electron flow. Increased illumination may not cause any further evolution of oxygen because of light saturation and other factors limiting the process. Increased illumination may cause a decrease in bubbles evolution because chlorophyll gets bleached with increased illumination

Note:

Detecting for formation of starch establishes whether or not a land plant has been carrying out photosynthesis.

The plant is first de-starched by placing it in the dark for above 12 hours. This prevents photosynthesis from taking place so the plant has to draw upon its starch reserves. After de-starching one of the leaves should be tested for starch to check that none is present. The plant is now returned to the light, and after a period of time one of the leaves is re-tested for starch. Its presence indicates that photosynthesis has been going on.

The test for starch is as follows: the leaf is boiled gently in water until flaccid and immersed in warm 90% alcohol (ethanol or methanol) until decolourized. When placed in dilute iodine, any parts of the leaf containing starch turn dark blue.

THE CONDITIONS REQUIRED FOR PHOTOSYNTHESIS:
For photosynthesis to take place, a plant requires carbon dioxide, water, light, a suitable temperature and chlorophyll. To demonstrate their necessity, simple experiments either on whole plants or single leaves involving first de-starching by putting it in the dark for a period of time and the necessary controls setup are carried out.

Carbon dioxide:
The necessity for CO_2 can be tested by the arrangement below. One of the green leaves of a well-watered potted plant is deprived of CO_2 by enclosing it in a flask containing a small volume of potassium hydroxide (caustic potash), which absorbs the CO_2 from the air in the flask. A second leaf, enclosed in a separate flask containing water, serves as a control. The plant is placed in a well lit place for several hours after which the two leaves are removed and tested for starch. The control leaf is usually found to have formed a significant quantity of starch, the other leaf little or none.

— Diagram - 4 —

Carbon dioxide provides carbon atom that builds up the structural skeleton of organic molecules such as carbohydrates, proteins and lipids.

Water
The experimental determination of its necessity is to

trace what happens to ~~the~~ water ~~plant~~ after it has been taken into the plant, by supplying a plant with the heavy isotope of water $H_2^{18}O$. The role of water in photosynthesis is to provide hydrogen for reducing the carbon dioxide to form organic substances. Water also provides electrons after photolysis, which neutralize the electrons lost from photo~~synthesis~~system (II) of chloroplasts.

Light

De-starching the plant by putting it in the dark indicates that light is necessary for photosynthesis. The importance of light can be further demonstrated by covering part of a previously de-starched leaf with a strip of opaque paper and then exposing it to light for several hours. On testing the leaf for starch with iodine, the dark colour is confined to the illuminated parts of the leaf. The covered part remains colourless, indicating the failure of this part of the leaf to form starch.

– Diagram – 5 –.

Note:

Not all the wavelength of light i.e colours are absorbed by chlorophyll. This can be shown by projecting a beam of light through a solution of extracted chlorophyll and then through a prism which separates it into its different wavelengths. After passing through the prism, the light is projected onto a screen and any colour absent from the normal spectrum are those that have been absorbed by the chlorophyll. This gives an **absorption spectrum** for chlorophyll. A graph of the relative absorption of different wavelengths of light by a pigment like chlorophyll. It is measured by a spectrophotometer.

· On the same graph, an **action spectrum** is also represented. This is a graph of the effectiveness of different wavelengths of light in stimulating the photosynthetic process. It represents the actual rate of photosynthesis in living cells.

— Diagram - 6 —

Explanation of observations:

The red and blue ends of the spectrum disappear showing that light of these colours is absorbed to varying extents by the chlorophyll.

However, the middle part of the spectrum, green light is hardly absorbed at all. Most of it is reflected which is why chlorophyll looks green.

There is non-correspondence of action spectrum of photosynthesis with absorption spectra at point "X". Because it is at X where there is maximum absorption of carotenoids, which are not used in photosynthesis

To show that wavelengths absorbed are used in photosynthesis, the leaves are exposed to different coloured lights and then estimating the amount of carbohydrates formed in each case. This gives an action spectrum for photosynthesis.

From the spectrum, red and blue lights are the most effective wavelengths in photosynthesis. Green is only used to a slight extent.

Therefore, green plants do not use energy from all of the components of white light for photosynthesis. This was demonstrated by H.T. Engelmann. He placed filaments of the green alga, cladophora in a drop of water on a microscope slide. The filaments were illuminated with light of different wavelengths. ~~He~~ then watched the distribution of aerobic bacteria in the water: This is called the **Engelmann's experiment**

— Diagram - 7 —

Explanation of observation:

Bacteria clustered near to the filaments when blue light (450nm) or red light (650nm) was used.

Since the distribution of aerobic bacteria is in response to the concentration of oxygen which is a by-product of photosynthesis, then red and blue lights are the most effective for photosynthesis.

The reason why light from the blue and red parts of the spectrum is effective is that it is absorbed efficiently by the photosynthetic pigments ~~was~~ contained in the chloroplasts of green plants.

Temperature

Photosynthesis proceeds by a series of chemical reactions controlled by enzymes. It can be shown by comparing a plant's rate of photosynthesis at different temperatures that the optimum temperature for photosynthesis in most plants is around 30°C. At lower temperatures, the rate is slowed. If the temperature exceeds about 40°C, the process stops altogether since the enzymes become denatured

Chlorophyll

That chlorophyll is required for photosynthesis can be shown by studying the distribution of starch in a variegated leaf. A variegated leaf is one which lacks chlorophyll, either completely or in patches, giving it a yellow appearance wherever the green pigment is absent e.g. in hibiscus plants

If a variegated plant, previously destarched is exposed to light and one of its leaves is then tested for starch, the dark colour develops only in those parts of the leaf that were green. The distribution of the dark corresponds to the distribution of chlorophyll

- Diagram - 8 -

Chlorophyll is important in photosynthesis because it traps the sunlight energy to form energy in form of ATP.

THE SITE FOR PHOTOSYNTHESIS:

The distribution of starch in a variegated leaf demonstrates that photosynthesis can only take place in the green parts of a plant, and this suggests that the process is closely associated with **chlorophyll**. As chlorophyll is contained within chloroplasts, photosynthesis takes place in or close to the **chloroplasts**.

This was also demonstrated by W. Engelmann. Engelmann chose spirogyra because it has large cells containing a localized chloroplast which is spiral round the edge of cells. He also used the evolution of oxygen as an indication that photosynthesis was proceeding as shown in the set up below.

A filament of spirogyra was mounted on a microscope slide in a drop of water containing numerous bacteria. The slide was first put in darkness which prevented photosynthesis, stopped the evolution of oxygen and immobilized the bacteria. The slide was then exposed to light and viewed under a microscope.

The ~~slide~~ Motile bacteria were seen to cluster round the edge of the cells immediately adjacent to the chloroplast, indicating the evolution of oxygen at that point. Thus the chloroplasts is the site of photosynthesis

— Diagram -9-

Other observations and deduction from the Engelmann's experiments.

- The aerobic bacteria of the slide previously in the dark are immobile but later cluster around the alga filament on exposure to light. Thus, darkness prevents photosynthesis, which stops evolution of oxygen resulting in anaerobic conditions that donot favour aerobic bacterial activity.
- There is hardly any aerobic bacteria in the UV, green and infra-red regions of the spectrum. Thus, light from UV, green and infra-red regions of the spectrum is hardly absorbed by chloroplasts hence least used in photosynthesis, with no/little evolution

of oxygen.

THE CHLOROPLAST PIGMENTS:
Chlorophyll is a mixture of closely related pigments of which chlorophyll is but one. This can be demonstrated by extracting the pigments from leaves with acetone and separating them by paper chromatography. F

Five pigments can be identified: chlorophyll a (blue-green), chlorophyll b (yellow-green), Xanthophylls (yellow) and carotene (orange). The fifth pigment, phaeophytin (grey) is a breakdown of product of chlorophyll. However, chlorophyll a and b are the most common.

Structure of chlorophyll:
Chlorophyll molecule is a tadpole-like structure with a hydrophilic head called porphyrin and a hydrophobic tail made up of long chain alcohol called phytol. The flattened head is made up of four nitrogen containing pyrrole rings (labelled I–IV) which are linked by methine bridges (-CH=). The skeleton of each pyrrole ring is made up of 5 atoms - four carbon and one nitrogen. The nitrogen lies towards the centre. A magnesium atom is held in the centre of porphyrin head by nitrogen atoms of pyrrole rings using two covalent and 2 coordinate bonds. Chlorophyll b differs from chlorophyll a in having the group (-CHO), instead of a methyl group ($-CH_3$) at position R (carbon-3). The phytol tail anchors and orients the chlorophyll molecule in the chloroplast's thylakoid membrane.

- Diagram - 10.

Note:
Chlorophyll a, is a type of chlorophyll common to all plants and the only one found in cyanobacteria,

absorbs light mainly in the red-orange and blue-violet parts of visible light spectrum. Chlorophyll a is the most important pigment in plants because it is the only one that takes a direct part in photosynthesis.
- Instead of chlorophyll a, some photosynthetic bacteria have another type of chlorophyll called bacteriochlorophyll, which contains magnese instead of magnesium.

Structure of carotinoids.
Carotene and xanthophyll are long-chain hydrocarbons. They have two small rings linked by the long-chain. The colour, which ranges from pale yellow through orange to red, depends upon the number of double bonds in the chain. The greater the number of double bonds, the deeper the colour.

— Diagram — 11 —

Note:
Apart from chlorophyll a, there are other photosynthetic pigments in chloroplasts called **accessory pigments**. They donot directly participate in the light stage, but they broaden the range of light that a plant can use.

The pigments absorb light of other wavelengths outside the range of chlorophyll a and convey the energy to chlorophyll a which then uses it in photosynthesis. They do not also absorb well in the green-yellow area of the spectrum around 500-550nm.

They include chlorophylls other than chlorophyll a, carotenoids and phaeophytin.

If the percentage light absorption is plotted against wavelength of light, an absorption spectrum is obtained for each pigment.

— Diagram — 12 —

Observations and explanations.

The action spectrum of photosynthesis corresponds closely to the absorption spectrum of chlorophyll a and b. This indicates that most of the wavelength of light absorbed by chlorophyll are used in photosynthesis.

The wave lengths of about 550nm to 620nm have the lowest absorption and action spectra for all the pigments. The unabsorbed (reflected light) appears green, thus making chlorophyll, the chloroplasts and the leaves that contain it appear green in our eyes.

There are two absorption maxima at 430nm and 662nm wavelengths for chlorophyll a, and 453nm and 642nm for chlorophyll b, but only one maximum for carotenoids at about 510nm. This shows that chlorophyll a and b are the main photosynthetic pigments, however, photosynthesis also occurs in the mid part of light spectrum where carotenoids are active;

Chlorophyll a absorption in red light is about twice that of chlorophyll b and the absorption peak is at a slightly longer wavelength (lower energy). This indicates that chlorophyll a is the most important photosynthetic pigment.

STRUCTURE OF CHLOROPLAST.

Chlorophyll is contained within chloroplasts. A chloroplast of a higher plant is biconvex in shape, about 5μm across in the widest part. The chloroplast is bounded by a double membrane within which are numerous ~~str~~structures called thylakoids. Each thylakoid consists of a pair of membranes close to each other with a narrow space between. The thylakoids can be distinguished into two regions, the granal and intergranal regions. The granal region occurs where the two membranes of each thylakoid are slightly further apart, enclosing in some cases another pair of membranes. In these regions, adjacent thylakoids are neatly aligned, each group constituting a granum. A granum is rather like a stack of coins, being 600nm in diameter. A typical chloroplast contains approximately 60 grana each consisting of about 50 thylakoids. The chlorophyll molecules are laid out as on shelves stacked on top of each other with considerable economy of space. The thylakoids are embedded in a watery matrix, the stroma. This contains numerous enzymes responsible for the reduction of carbon dioxide and numerous starch granules, end-products of photosynthesis

- Diagram - 13 -

Adaptations of chloroplasts for their functions:

- Outer membrane is semi-permeable to regulate entry and exist of substances for maintaining internal chloroplast environment
- Abundant light trapping pigments for photosynthesis
- Abundant enzymes catalyse photosynthetic reactions in the stroma.
- Extensive network of thylakoids membranes increase surface area for photosynthesis.
- Narrow intermembrane space enables H^+ ions concentration gradient to be rapidly established for chemiosmosis to occur
- Inner membrane contains molecules for electron transport pathway for ATP synthesis.
- DNA presence codes for protein synthesis, including enzymes.
- Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm.
- Outer membrane is permeable to gases like carbon dioxide which is a raw-material for photosynthesis.
- The thylakoids membranes hold the chlorophyll molecules in a suitable position for trapping the maximum amount of light.

- The chlorophyll molecules are stacked on top of each other in small space. This provides a large surface area without taking up too much room or space.
- Numerous starch granules store manufactured foods for the plant.

The arrangement of pigments in the chloroplast:
The photosynthetic pigment molecules are clustered in the thylakoid membranes. Each cluster is called an <u>antenna complex</u>. The molecules in the complex are arranged so as to channel light energy to just one molecule of chlorophyll a, the only molecule that donates an electron to the primary acceptor molecule. Chlorophyll a and the primary acceptor molecule make up the <u>reaction centre</u>. The reaction centre and all the other light-gathering molecules combine to form a <u>photosystem</u>, the light-harvesting unit in chloroplasts.
There are two types of photosystems: Photosystem I and photosystem II. In photosystem I, the reaction centre is called P700 because its chlorophyll a has a maximum absorption at a wavelength of 700nm (red light). Photosystem II has a reaction centre called P680 because its chlorophyll a has a maximum absorption at 680nm ~~bec~~ (a more orange-red). The two photosystems usually act together in the light stage of photosynthesis.
- A photosystem structure - M.Kent - Pg. 79.

THE CHEMISTRY OF PHOTOSYNTHESIS:
In the process of photosynthesis, energy from sunlight is trapped by chlorophyll and used in the manufacture of carbohydrate from carbon dioxide and water.

How chlorophyll harnesses energy from sunlight?
When sunlight is absorb by a photosynthetic [redacted]

Each photon of light contains a fixed amount of energy called a quantum corresponding to a particular wavelength of light.

The shorter the wavelength, the larger the quantum.

When a chlorophyll molecule absorbs a photon of light, one of the pigment's electrons gain energy. its ~~energy~~ energy level is raised from the lowest most stable level (the ground state) to a higher level called the excited state. In pure chlorophyll, the excess energy at chlorophyll is released quickly as heat and light, and the electrons revert to their ground state immediately. However, in a chloroplast, the excited electron is passed onto another molecule called a primary acceptor molecule. This molecule is reduced (it gains an electron) as the chlorophyll is oxidised (it loses an electron) at photosystems.

Reduction of the primary acceptor molecule is the first stage of the light-dependent reaction.

~~Stage~~ THE LIGHT-DEPENDENT STAGE:

This stage involves the splitting of water by light, a process called photolysis of water. In the process, ADP is converted to ATP. This addition of phosphorus is termed phosphorylation and as light is involved it is called photophosphorylation.

Photolysis:

This is the process by which water molecules are split with the aid of light energy absorbed by chlorophyll a. When the chlorophyll a absorbs light, it loses an electron and becomes positively charge (electron-deficient), and it needs to replace electrons before it reacts again.

The enzymes extracts electron from water to replace each electron lost from chlorophyll a. It is this reaction which results in water molecules being split during the light stage of photosynthesis. In addition to electrons, protons and oxygen are also produced.

$$2H_2O \longrightarrow 4H^+ + 4e^- + O_2.$$

The protons (H^+) are used to reduce $NADP^+$ and the oxygen is given off as a waste gas or used in respiration.

The function of the light stage is therefore twofold; by the photochemical splitting of water, it provides hydrogen atoms for the reduction of carbon dioxide; and by producing ATP, it provides a source of energy for the ~~subsequence~~ subsequent synthesis of carbohydrates.

Photophosphorylation.

This is the formation of energy (ATP molecules) using light energy. These processes occur in two photochemical systems: Non-cyclic pathway and the cyclic pathway.

Non-cyclic photophosphorylation.

Here, the same electrons that leave the chlorophyll photosystems are not recycled back into the chlorophyll. It is called the **Z-scheme** because the zig-zag route of the electrons in the diagram resembles a Z on its side.

In the Z-scheme, light energy is trapped in photosystem II and boosts electrons to a higher energy level. The electrons are ~~passed~~ received ~~from~~ by the electron acceptor called plastoquinone.

The electrons are passed from the electron acceptor along a series of electrons carriers to photosystem I. The energy lost by the electrons is captured by converting ADP to ATP. Light energy has thereby been converted to chemical energy.

Light energy absorbed by photosystem I boosts the electrons to an even higher energy level. The electrons are received by another electron acceptor called ferredoxin.

The electrons which have been removed from the chlorophyll are replaced by pulling in other electrons from a water molecule in photosystem II. The loss of electrons from the water molecule causes it to dissociate into protons and oxygen gas.

The protons from the water molecule combine with the electrons from the second electron acceptor and these reduce nicotinamide adenine dinucleotide phosphate ($NADPH_2$ or reduced $NADP^+$).

~~Some electrons from the second acceptor may pass~~ ~~ba~~

— Diagram - 14 -

The cyclic pathway:

Here, excited electrons from photosystem I are recycled back to ~~the~~ oxidize chlorophyll in the same system by electron carriers, mainly cytochromes. For each molecule of ATP formed by the cyclic route, two are generated in non-cyclic pathway.

Cyclic pathway occurs in green plants when ~~light~~ there is sufficient ADP and inorganic phosphate available. Cyclic photophosphorylation involves only photosystem I. The energy from the excited electrons is used to make ATP, it is not used to reduce $NADP^+$.

— Diagram - 15 —

Note:

Plastoquinone and ferredoxin molecules are iron-containing proteins, that act as primary electron acceptors from photosystem II and I respectively. Cytochromes are redox-active proteins containing a haem with a central iron atom at its core, as a cofactor. They are involved in the electron transport chain.

Compare cyclic and non-cyclic pathway.

Similarities:

In both: there is flow of electrons through several electron ~~carriers~~ carriers. There are pigment systems which accept and lose electrons. ATP is formed. Pigment system I ~~and~~ is involved. Electron movement is located in the thylakoid membrane. Protons are moved outwards of the thylakoids. Protons are actively pumped from stroma into thylakoid space. There is photo-excitation of electrons in the photosystems

Differences:
Non-cyclic pathway involves both photosystems I and II whereas cyclic pathway involves only PSI. In non-cyclic pathway, electrons flow unidirectionally (non-cyclically) while in cyclic pathway, electrons flow cyclically. The first electron donor in non-cyclic pathway is water and in cyclic pathway, the first electron donor is photosystem I. The last electron acceptor is photosystem I in cyclic pathway but $NADP^+$ is the last electron acceptor in the non-cyclic pathway. Non-cyclic pathway produces ATP, $NADPH_2$ and oxygen, however only ATP is produced by ~~the~~ cyclic pathway. There is photolysis of water in non-cyclic pathway and no photolysis in cyclic pathway occurs.

In summary, the main products of light stage of photosynthesis are thus ATP, $NADPH_2$ and oxygen. Oxygen is given as a by-product of photosynthesis. ATP and $NADPH_2$ are used in the dark stage.

ATP is a source of energy required for the dark reactions, and NADPH reduces substances in the dark stage.

THE LIGHT INDEPENDENT STAGE:
The light-independent stage used to be known as the "dark stage" because the reactions can take place in the dark if sufficient ATP and NADPH are available.

During the light-independent stage of photosynthesis, carbon-dioxide is **fixed**. It is assimilated into a plant by being converted into biochemical products in the plant. The overall reaction is the reduction of carbon-dioxide to glucose.

Enzymes convert carbon-dioxide to glucose in a series of reactions discovered by Melvin Calvin using his "lollipop apparatus". The reactions used ATP and NADPH, the products of the light dependent stage.

The lollipop apparatus:

M. Calvin used this apparatus to study the light-independent reactions of photosynthesis. Algae were cultured in the thin transparent vessel (the lollipop) into which hydrogen-carbonate labelled with radioactive ^{14}C was injected. The metabolic pathway of the light-independent stage was traced by analysing the radioactive compounds formed at different times after injection of the hydrogen carbonate using paper chromatography and autoradiography.

– Diagram – 16 –

The calvin cycle (C_3 pathway)

This is called C_3 pathway because the first stable product in the cycle contains 3 carbon atoms. Hence plants which carry out this mechanism are called C_3 plants. It is all green plants.

The calvin cycle is divided into three phases namely: carbon fixation, reduction and regeneration of the carbon dioxide acceptor.

<u>Carbon fixation:</u>

The calvin cycle incorporates each carbon dioxide molecule, one at a time by attaching it to a 5-carbon sugar named ribulose bisphosphate (RuBP). The enzyme that catalyzes this first step is <u>RuBP carboxylase</u> or <u>rubisco</u>. (This is the most abundant protein in chloroplasts and is also said to be the most abundant protein on earth). The product of the reaction is a six-carbon intermediate so unstable that it immediately splits in half, forming two molecules of 3-phosphoglycerate (PGA) or glycerate phosphate (GP) for each CO_2 fixed

Reduction and phosphorylation
Each molecule of GP receives an additional phosphate group from ATP, becoming 1,3-bisphosphoglycerate. Next, a pair of electrons donated from NADPH reduces 1,3-bisphosphoglycerate, which also loses a phosphate group becoming phosphoglyceraldehyde (PGAL) or glyceraldehyde phosphate (GALP). Some molecules of PGAL undergo isomerization and several reactions to form hexose sugar, hence sucrose or starch for storage are made by polymerization

Regeneration of the CO_2 acceptor (RuBP)
Most of the PGAL regenerate the original carbon dioxide acceptor, RuBP. More of the ATP from the light dependent stage is needed to provide the energy for this conversion. 7

This is important because only by ensuring a supply of RuBP can the continued fixation of carbon dioxide take place.

- Diagram - 17 -

Note:
PGA is the first stable 3-carbon compound hence the C_3 pathway. However, PGAL is the first stable triose sugar to be formed in Photosynthesis.

Fate of photosynthetic products:
Glucose from photosynthesis can be converted into other carbohydrates, like sucrose, starch and cellulose, amino acids, fatty acids or glycerol.

Synthesis of other carbohydrates.
The triose phosphate in the calvin cycle can be synthesized into hexose sugars such as glucose

and fructose. Glucose and fructose may be combined to give the disaccharide sucrose which is transported throughout the plant in the phloem. The glucose may, on the other hand, be polymerized into starch for storage, or polymerized into cellulose, this makes up over 50% of plant cell walls.

Synthesis of lipids:
Lipids are mostly esters of fatty acids and glycerol. GP may be converted to acetyl coenzyme A, which in turn is used to synthesize a variety of fatty acids. Triose phosphate is easily converted to glycerol. Lipids are storage substances in seeds, constituents of cell membranes, and their waxy derivatives make up the waterproofing cuticle. Fatty acids provide some flower scents, which are used to attract insects for pollination.

Synthesis of proteins:
Conversion of GP into acetyl coenzyme A is the starting point for amino acid synthesis. The acetyl CoA enters the Krebs cycle and from its intermediates a wide variety of amino acids can be made by transamination reactions. The amino acids are polymerized into proteins.
Proteins are essential for growth and development and make up a major structural component of the cell especially the cell membrane. All enzymes are proteins, and they may also be used as storage material.

THE EXACT SITES OF THE LIGHT AND DARK STAGES:
Soluble stroma material, separated from the rest of chloroplast structures, is incapable of photochemical reactions but contains the enzyme necessary for reducing carbon dioxide and will do so if supplied with ATP and reduced NADP. Thus the dark reactions occur in the stroma.

Tiny fragments of thylakoid membrane show that they can perform the light reactions. Thus, the light reactions are associated with the thylakoid membranes. It is in these membranes that ATP and NADPH is formed by chemiosmosis

The chemiosmotic theory in chloroplasts:
Chemiosmosis is the movement of ions across a selectively permeable membrane down an electrochemical gradient. These movements of ions were first studied by P.D. Mitchell, and are described as P. Mitchell hypothesis.

It involves the active transport of protons from the stroma across a thylakoid membrane into the thylakoid compartment. This so-called proton pump is driven by the energy released from excited electrons as they pass down an electron transport system. Protons accumulate in the thylakoid compartment forming a concentration gradient.

They can diffuse back across the membrane into the stroma, but only through channels called chemiosmotic channels. These channels are formed by an enzyme complex called ATP synthase or ATPase.

As protons pass through the channels, the enzyme complex converts ADP and inorganic phosphate into ATP.

— Diagrams – Campell Pg197 & Kent – Pg90 17 –

Note:
There are 3 steps in the light reactions contribute to the proton gradient namely: Water is split by photosystem II on the side of the membrane facing the thylakoid space. As plastoquinone, a mobile carrier, transfers electrons to the cytochrome complex, four protons are translocated across the membrane into the thylakoid space, and a hydrogen

ion is removed from the stroma when it is taken up by $NADP^+$

PHOTOSYNTHESIS IN DIFFERENT CLIMATES AND ALTERNATIVE MECHANISMS OF CARBON FIXATION

Green plants thrive in environments ranging from hot and dry regions to freezing-cold polar regions. Their success depends on their adaptability. These adaptations include ways of fixing CO_2.

C3 PLANTS.

C_3 plants fix CO_2 directly into the calvin cycle as the 3-carbon compound glycerate 3-phosphate (GP). C_3 plants are common and widely distributed, they include some of the most important crop plants such as wheat, soya beans and rice.

C_3 plants function efficiently in temperate conditions, however, they suffer two major disadvantages in hot, dry environments.

First, to obtain sufficient CO_2, C_3 plants must open their stomata. Unfortunately, when stomata are open, they not only allow CO_2 to enter the plant, but also allow water to escape. So in hot dry conditions, C_3 plants have to either cease photosynthesising or run the risk of wilting and dying. Secondly, C_3 plants suffer from a problem of high partial pressures of Oxygen at low altitudes.

C4 PLANTS: THE HATCH-SLACK PATHWAY.

These are plants that exhibit the C4 photosynthesis. C4 photosynthesis is a mechanism of photosynthesis in which the first stable compound of CO_2 fixation is a four carbon compound called **oxaloacetic acid (OAA)**, inside mesophyll cells, which is later reduced and exported into bundle sheath cells for further metabolism.

The C4 system is efficient at high temperatures and regions of high partial pressures of oxygen.

C4 plants include maize, sorghum, amaranthus, sugar canes, paspalum and others. C4 plants represent only 3% of the world's vascular plants yet they contribute about 20% to the global primary productivity because of their high productivity.

The leaves of C4 plants have a special arrangement of mesophyll cells, called Kranz anatomy

The Kranz Anatomy:

There are two distinct types of photosynthetic cells namely bundle-sheath cells and mesophyll cells. Bundle-sheath cells are arranged into tightly packed sheaths around the veins of the leaf. Between the bundle sheath and the leaf surface are the more loosely arranged mesophyll cells. The calvin cycle is confined to the chloroplasts of the bundle-sheath cells, however, the cycle is preceded by incorporation of CO_2 into organic compounds in the mesophyll cells.

— Diagram —18—

Note:

Mesophyll chloroplasts are randomly distributed distributed along cell walls, where as bundle sheath chloroplasts are located close to the vascular tissue or mesophyll cells depending on the plant species.

Only mesophyll chloroplasts can change their positions in response to environmental stresses.

Bundle sheath cells have large agranal chloroplasts but the thin walled mesophyll cells have grana in the chloroplasts.

Bundle sheath ~~cells~~ chloroplasts have large starch granules while mesophyll chloroplasts lack starch grains.

The C_4 mechanism.

They do not use ribulose biphosphate (RuBP) to fix CO_2 directly into the Calvin cycle. Instead, they use a 3-carbon phosphoenolpyruvate (PEP) to fix carbon dioxide as a four-carbon compound called <u>oxaloacetic acid</u>. The reaction ~~of~~ is catalyzed by <u>PEP carboxylase</u>. This enzyme cannot combine with oxygen, hence C_4 plants continue to fix CO_2 even when its concentration is very low. This initial fixation of CO_2 occurs in the <u>mesophyll cells</u>.

Then the OAA is converted to malate, another 4-carbon compound. Malate is transported or shunted into the bundle sheath cells via the <u>plasmodesmata</u>, where it releases carbon dioxide. ~~Malate is also oxidized by~~ oxidized NADP

Once released, the carbon dioxide is reassimilated by RuBP and enters the Calvin cycle as described for C_3 plants.

As a result of this pathway, the concentration of CO_2 in the bundle sheath cells is 20 to 120 times higher than normal.

In the bundle sheath cells, malate is dehydrogenated by NADP to form pyruvic and and NADPH. The pyruvate produced returns to mesophyll cells for phosphorylation by ATP to regenerate PEP, the CO_2 acceptor.

- Diagram - 19 -

Advantages of C_4 pathway over C_3 pathway:

C_4 plants photosynthesize at very low CO_2 concentration eg. in dense tropical vegetation) because PEP carboxylase enzyme has a very hight affinity for CO_2.

The CO_2 fixing enzyme in C_4 plants are more active at hot temperature and high illumination, therefore photosynthesis occurs rapidly at low altitude, hot and brightly lit tropical conditions than in C_3 plants.

The productivity of C_4 almost is 4 times greater than in C_3 plants. This is because; of the increased rate of CO_2 uptake. The bundle sheath cells have a large photosynthetic surface area, large chloroplasts, in which dark reaction occur. The palisade cells have large grana to increase the photosynthetic surface area for light reactions.

Disadvantage of C_4 pathway to C_3 plants:
The CO_2 fixing enzymes in C_4 plants are less active at cool, moist and low illumination conditions, therefore photosynthesis occurs slowly at high altitude with cool temperature and in low light intensity of temperate conditions.

Qn:
Inspite of the higher productivity of C_4 pathway, which is almost 4 times greater than in C_3 plants, majority of plants perform C_3 photosynthesis. Explain this statement.

CO_2 concentration is a major factor determining the pathway of CO_2 fixation. While C_4 plants are more productive at low CO_2 concentrations, C_3 plants form the dominant plantlife because they are effective at high CO_2 whose concentration is high in most environments and steadily increases due to increasing combustion of fossil fuels.

Also considering that C_4 photosynthesis is more complex, it involves many reactions both in bundle sheath cells and in mesophyll cells, and requires a specialized Kranz anatomy, most plants have simpler structures.

Therefore, unless water loss is a significant issue, C_3 dominate since C_3 photosynthesis is more effective.

PHOTORESPIRATION:
This is process by which the enzymes of photosynthesis in the presence of light combine with oxygen at its high concentration rather than CO_2, and produces CO_2 in the process.

However, unlike normal cellular respiration, photorespiration generates no ATP, and in fact it photorespiration consumes ATP.

And unlike photosynthesis, photorespiration produces no sugar and thus decreases photosynthetic output by siphoning organic material from the Calvin cycle and releasing CO_2 that would otherwise be fixed.

When C_3 plants are exposed to low CO_2 concentration or high Oxygen concentration e.g when stomata close to reduce water loss, RuBP carboxylase catalyses the reaction between RuBP and oxygen to form a 2-carbon compound called phosphoglycolate, which is oxidized to release CO_2.

Photorespiration which inhibits growth in C_3 plants is avoided or reduced in C_4 plants because; the CO_2 fixing enzyme PEP carboxylase does not accept oxygen. RUBISCO enzyme inside the bundle sheath cells is shielded from high oxygen concentration by the ring of palisade mesophyll cells. Also due to lack of grana in the bundle sheath cells on which Oxygen would be produced reduces photorespiration.

Qn: Compare C_3 plants and C_4 plants.

CAM PLANTS:

These are a group of plants that have evolved a third type of CO_2 fixation which enables them to survive in very hot and dry climates like deserts, where a plant would lose to much water when stomata open during day.

CAM is an abbreviation for Crassulacean acid metabolism, a type of metabolism observed in the family of plants called crassulaceae. Such plants include cacti, sisal, Bryophyllum, Vanilla, pineapples.

In CAM plants, stomata open at night and close during day, hence they change the stomatal rhythm to conserve water efficiently in deserts. But they do not photosynthesize very efficiently. Most are very slow growing and where there is very much water, CAM plants cannot compete well with C_3 or C_4 plants.

The CAM mechanism:

At night when stomata open, nocturnal CO_2 fixation mediated by PEP carboxylase accumulates organic acids (Malate) within the vacuoles of mesophyll cells until morning, when the stomata close.

During the day, when the light reactions can supply ATP and NADPH for the calvin cycle, CO_2 is released from the organic acids made in the night before to become incorporated into sugar in the chloroplasts.

FACTORS AFFECTING PHOTOSYNTHESIS:

Photosynthesis is affected by many factors, both external (in the environment). and internal (inside the plant). External factors include light intensity, CO_2 concentrations, temperature, wind velocity, water and mineral supplies. Internal factors include type and concentration of photosynthetic pigments, enzyme and water content, and leaf structure and position.

Temperature:

Photosynthesis involves both light stage and dark stages, however the photochemical reactions of photosynthesis is unaffected by temperature, but that the light independent stage is temperature dependent.

An optimum temperature ranging from 25°C to 35°C is required. At temperatures around 0°C, the enzymes stop working and at very high temperatures, the enzymes are denatured.

The effect of temperature on photosynthesis at high and low light intensities.

-20-

- Diagram ~~-~~ Advanced - Pg. 253 -

Explanation:

At high intensity of light or when light is not

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a limiting factor, the rate of photosynthesis is affected as described above. However, increasing the temperature has no effect on the rate of photosynthesis at low light intensity.

This is because at low light intensity, there is less energy to run the photochemical reactions.

Effect of temperature on C_3 and C_4 plants:

- Diagram - Handout - Pg 16 - 21 -

Explanation:

Below 10°C, C_3 rate of photosynthesis is higher than in C_4 above 10°C. Because C_4 photosynthetic enzymes are less active in the cold but become more active with increase in temperature.

The maximum rate of photosynthesis attained in C_4 is much higher than in C_3, because the optimum temperature for enzymes involved in the C_4 cycle is higher than in the C_3 cycle.

At 45°C, the rate of photosynthesis decreases because ~~light intensity~~ enzymes controlling photosynthesis are denatured.

There is an initial decrease in photosynthetic rate to a maximum at about 40-42°C, inspite of further increase in temperature, because light intensity becomes a limiting factor in each of the 3 cases.

There is increase in the rate of photosynthesis with increase in temperature until up to 40°C, because increase in temperature activates enzymes to a level beyond which enzyme denaturation occurs.

Carbon dioxide concentration

On a warm sunny day, the concentration of CO_2 in the air is probably the factor which limits photosynthesis more than any other

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On average, the amount of CO_2 in the atmosphere is 0.03% and this concentration is controlled mainly by respiration by organisms and fossil fuel combustion by man.

– Diagram – 22 – ~~Handout Pg 16~~ Advanced Pg ~~243~~ 247

Explanation:

Generally, the rate of photosynthesis increases rapidly with increasing CO_2 concentration to a maximum and thereafter remains constant.

This is because, CO_2 is a raw-material for photosynthesis. RuBISCO attaches CO_2 molecules to form PGA in the calvin cycle, so the more the concentration of CO_2, the higher the rate of photosynthesis.

At further CO_2 concentrations, other factors become limiting, and the enzyme molecules become saturated by the CO_2 molecules hence the rate of photosynthesis levels off.

Effect of CO_2 concentration on C_3 & C_4 plants.

– Diagram – 23 – Handout – Pg 16 –

Explanation:

The rate of photosynthesis is faster in C_4 than C_3, because PEPcarboxylase of C_4 has a higher affinity for CO_2 than RuBISCO of C_3 and hence acts faster.

The overall photosynthetic products are greater in C_3 than in C_4, because C_4 needs more ATP than C_3 which generally reduces the output of photosynthesis.

The C_4 plants are more efficient at lower CO_2 concentration while C_3 more efficient at higher CO_2, because at lower CO_2 concentration in C_3, photorespiration reduces the photosynthesis efficiency yet PEP carboxylase has a high affinity for CO_2.

C_3 plants have a higher compensation point than C_4, because PEP carboxylase has a high affinity for CO_2.

After attaining the maximum, the rate of photosynthesis remains constant in both, because other factors limit the process like temperature, light intensity, etc.

At the CO_2 concentration of about 70Pa, the rate of photosynthesis is equivalent in both plants.

Light intensity and compensation point:

Low light intensity lowers the rate of photosynthesis. As the light intensity is increased, the rate also increases. At maximum intensity, there is no effect on the rate because other factors limit the process and light saturation occurs. Very high intensity may infact slow down the rate of photosynthesis as it bleaches the chlorophyll.

~~Diagram 24 Advanced~~ Handout p.57.

In darkness, photosynthesis cannot take place, although other metabolic processes such as respiration go on just as they do in day light. In the absence of light, green plants give off CO_2 made in respiration.

When light is available, respiratory CO_2 provides a proportion of a plant's photosynthetic needs. The rest of the CO_2 is absorbed from the surrounding air.

For a plant to grow, it has to synthesise organic materials more rapidly than it oxidises them in respiration. When photosynthesis and respiration occur at rates such that there is no gain or loss of organic matter, a plant is at its compensation point. The time taken for a plant which has been in darkness to reach the compensation point is called the compensation period.

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– Diagram – 24 – Hand out – Pg 17
or Toole's – Pg 282.

Plants under forest canopy (shade plants).

Sun and shade plants use sun and shade leaves respectively. Sun leaves are those that grow on branches exposed to direct sunlight while shade leaves grow on branches exposed to light that has passed through leaves.

In low light, plants need to maximise light absorption for photosynthesis to exceed respiration if they are to survive.

In high light environment, plants maximise their capacity for utilising abundant light energy, while at the same time dealing with excess sunlight which can bleach chlorophyll.

Adaptive Differences between sun plants and shade plants
– Table – 1 –

Photosynthetic pigments in sun leaves and shade leaves ~~of~~ some trees eg beech tree.
– Table – 2 –

The above values/data, are graphically reflected using a bar graph below.
– Bar graph –

Explanation:

The ratio of chlorophyll a, ~~and~~ b is bigger in sun leaves than shade leaves because chlorophyll a is more effective at absorbing the light wavelengths available to sun leaves eg. about 450nm.

Shade leaves contain more chloroplast b than sun leaves because in shade plants, chlorophyll b improves light capturing capacity of the chloroplast.

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Sun leaves contain more carotenoids than shade leaves because carotenoids are accessory pigments that shield chlorophylls from destruction by excessive sunlight.

*1

Why few species of plant can survive under shady habitats?

Less direct light reaches ground via gaps in the canopy hence minimum energy is available for effective photosynthesis.

Of the light that passes through leaves, only a small range of wavelengths reaches the ground, which is not ~~efficient~~ effective for photosynthesis.

Therefore, under shady habitats, little light energy for chlorophyll to absorb is available and hence photosynthesis is insufficient for growth.

Effect of light intensity on CO_2 exchange by sun and shade leaves.

– Diagram - 25 - Advanced - Pg 248

Explanation:

Shade leaves have shorter compensation period or low compensation periods than sun leaves. This is a physiological adaptation which enables shade leaves to make efficient use of light of low intensity.

THE CONCEPT OF LIMITING FACTORS

In 1905, F.F. Blackman, measured the rate of photosynthesis under varying conditions of light and carbon dioxide supply, from which he formulated the principle of limiting factors.

It states that;
At any given ~~amount~~ moment, the rate of a physiological process is limited by the one factor which is in shortest supply, and by that factor alone.

In otherwords, it is the factor which is nearest its minimum value which determines the rate of a reaction. Any change in the level of this factor, called the limiting factor, will affect the rate of the reaction. Changes in the level of other factors cannot affect the reaction

— Diagram — 26 — Toole's Pg 281.
Hand out — Pg 15.

Explanation:
If the amount of light given to a plant is increased, the rate of photosynthesis increases up to a point and then tails off. At this point some other factor, such as CO_2 concentration, is in short supply and so limits the rate.

An increase in CO_2 concentration again increases the amount of photosynthesis until some further factor, eg. temperature, limits the process.

(X1) **Light in a forest:**
The amount of sunlight decreases as light penetrates down the vegetation layers because the amount of leaf area increases. The greater the leaf area over a surface, the lower the quantity of light reaching that surface.
— Graph / diagram — 27 — Hand out — Pg 3.

Explanation:
All the wavelengths of direct light reach the ground because this light passes through gaps left by leaves hence no wavelength is filtered out.

Of the light that passes through leaves, only wavelengths in the range 460nm – 670nm reach the ground because of low or no absorption by chlorophylls in the leaves.

Wavelengths of visible light below 460nm and above 670nm do not reach the ground after passing through leaves because of much absorption by photosynthetic pigments eg chlorophylls.

Of the light that passes through leaves, wavelength 525nm reaches the ground with most energy because it is least absorbed by photosynthetic pigments.

Other factors affecting the rate of photosynthesis

chlorophyll concentration: This affects the rate of reaction as they absorb the light energy ~~the~~ without which the reactions cannot proceed

Water: In response to drying, leaves close their stomates to conserve water being lost as water vapour through them. This reduces the rate of photosynthesis.

Pollution: Soot and dust blocks stomata and reduce the transparency of the leave cuticle. Stomatal blockage reduce CO_2 uptake and the less cuticle transparency reduces light absorption. These reduce photosynthetic rate.

Salinity: This is osmotic ~~s~~ stress or drought stress or water stress. This results in stomata closure in an effort to avoid dessication, reduces photosynthesis because CO_2 uptake reduce

~~Altitude~~ Altitude: This is the height above sea level. This influences or determine the partial pressures of oxygen.

– Diagram – 28 – Hand out – Pg 17 –

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Explanation:

C_3 plants are more abundant at high altitude or elevation, because the decrease in atmospheric pressure at higher altitude decreases the partial pressure of oxygen. enables more productivity since photorespiration reduces.

CAM plants are more abundant at low altitudes, because even when temperature is high, nocturnal opening and closure in day light enables them to reduce ~~lost~~ transpiration. CAM plants that store alot of malate and due to the thus high osmotic value also alot of water, are usually less frost resistant than C_3 plants.

C_4 plants are widely distributed at low altitude and slight elevation, because enzymes are tolerant to high temperatures and the Kranz mesophyll anatomy shields RUBISCO in bundle sheath cells from ~~much~~ O_2 to avoid photorespiration

Inorganic ions: The absence of some ions like nitrogen and magnesium, that are an integral part of the chlorophyll molecule reduces their formation and the leaves become yellow, a condition called chlorosis. Under these circumstances, the rate of photosynthesis is substantially reduced

Qns: Describe how cyanide, and sulphur dioxide affect rate of photosynthesis.

PHOTOSYNTHETIC BACTERIA

Like green plants, these bacteria are able to build up carbon dioxide and water into organic compounds using energy derived from sunlight.

The energy is trapped by a pigment called bacteriochlorophyll which is similar

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to, though simpler than chlorophyll.

They differ from green plants in their source of hydrogen for reducing the CO_2. Instead of obtaining it from water, they get it from hydrogen sulphide, for which reason they are known as sulphur bacteria.

They ~~leave~~ live at the bottom of lakes, ponds and rock pools where hydrogen sulphide is supplied by the metabolism of anaerobic decay bacteria. The residual sulphur resulting from the splitting of hydrogen sulphide is deposited in the bacterial cells.

$$CO_2 + 2H_2S \xrightarrow[\text{Bacteriochlorophyll}]{\text{Light}} CH_2O + 2S + H_2O$$

Bacteriochlorophyll comes in two closely related forms, green and purple, giving the so-called green and purple sulphur bacteria respectively.

FIXATION OF NITROGEN

Nitrogen fixation is carried out by certain prokaryotes. These organisms are able to absorb atmospheric nitrogen and built it up into amino acid, a synthetic feat that commands most plant activities.

The major known nitrogen-fixing organisms are bacteria that live in the roots of leguminous plants such as peas, beans and clover. Such plants are able to thrive in soils deficient in nitrates because they are able to fix nitrogen using the nitrogen-fixing bacteria in their roots.

The bacteria enter the young plant through its root hairs, and they cause the cortical cells of the root to proliferate forming a swelling or root nodule. A vascular strand connects the nodule with the vascular tissues in the main root. In the cells of the nodule, the bacteria multiply rapidly, fixing atmospheric nitrogen and building

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it up into amino acids and proteins.

The association between the bacteria and their host (root nodule) is **mutualistic**, both partners gaining from the relationship. Some of the products of the bacteria's nitrogen fixation pass into the host plant and are utilized by it.

In return, bacteria obtain protection and the host's photosynthesis they obtain carbohydrate which provide a source of carbon for the synthesis of proteins as well as energy for driving the endergonic reactions involved.

Note:

Not all organisms capable of fixing atmospheric nitrogen are found living inside the tissues of another organism. Many free living examples are also known, certain lichens are able because the blue-green cells in them can.