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SENIOR FIVE TERM 2

TOPIC 2: Nutrition in Plants

Competency: The learner evaluates the nutritional strategies of carbon three (C3) and carbon four (C4) plants by analyzing their photosynthetic pathways and adaptation to environmental conditions so as to optimize agricultural productivity and food security under varying climatic conditions.

Contents

Autotrophic Nutrition

This is the synthesis of organic compounds from inorganic sources.

There are two types autotrophic nutrition.

(a) Chemosynthesis: is the synthesis of organic compounds from carbon dioxide and water using energy from oxidation of inorganic materials such as hydrogen sulphide, ammonia and iron II.
(b) Photosynthesis is the synthesis of organic compounds from carbon dioxide and water using energy from light.

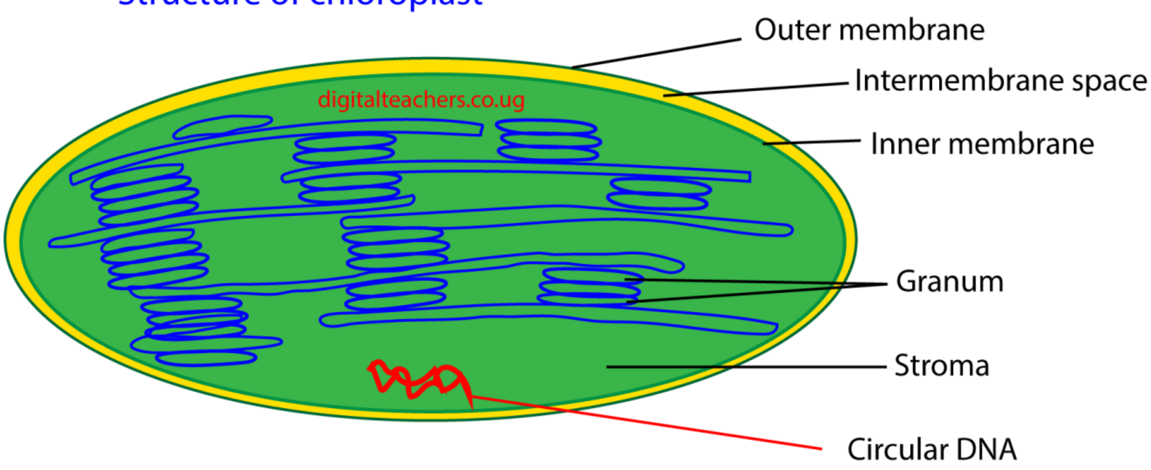
Importance of Autotrophic nutrition

1. Sugars resulting from autotrophic nutrition constitute structures of plants and animals
2. Sugars obtained from autotrophic nutrition are source of energy
3. Human depend on photosynthesis for energy containing fuel, which have developed over millions of years
4. Photosynthesis maintains a constant concentration of carbon dioxide and oxygen in atmosphere. Oxygen is added to atmosphere as a result of photosynthesis while carbon dioxide is removed.

Photosynthesis

The main organelle for photosynthesis is the chloroplast

Structure of chloroplast



Chloroplast is biconcave (to increase the surface area for absorption of light) It is bound by a double membrane within which are numerous structures called thylakoids. Each thylakoid consists of a pair of membrane close to each other with narrow spaces between them. In places, the thylakoid is arranged in a neat stack, rather like a pile of coin called granum (pl. grana). The grana are connected to each other by a less regular arrangement of the inter grana thylakoids. The thylakoid system is embedded in a protein rich matrix called stoma

The parts of chloroplasts and their functions

Outer membrane: acts as protective barrier and regulates the movement of molecules in and out of the chloroplast.
Inner membrane: encloses the stroma and is involved in the transport of materials
Thylakoid membrane: Contains chlorophyll and is the site of light- dependent reactions of photosynthesis.
Stroma: The fluid-filled space where the Calvin Cycle (Light independent reactions) occurs, synthesizing sugars.
Lamellae: Connects thylakoids and helps in organization of thylakoid membrane.
These components work together to facilitate photosynthesis and other metabolic processes in plant cells..

Adaptations of the parts of the chloroplast to their function

Thylakoids and grana: Thylakoids are flattened, disc-shaped sacs where the light-dependent reactions of photosynthesis occur.
Adaptations

(i) Thylakoids are arranged into stacks called grana (singular: granum). This stacking creates a large surface area for the membrane, which is crucial for embedding the maximum number of photosystems (light-harvesttrapping pigments) and ATP synthase enzymes.
(ii) Tthylakoid membranes contain chlorophyll and other light-absorbing pigments organized into photosystems (PSII and PSI). This arrangement maximizes the absorption of light energy. The pigments are arranged in funnel-like structures to efficiently transfer light energy to the reaction center.
(iii) The lumen (the space inside the thylakoid) has a very small volume. This allows a steep proton (H^+) gradient to build up very quickly during chemiosmosis, powering ATP synthase to produce ATP.

Stroma: The stroma is the jelly-like fluid that fills the chloroplast and surrounds the thylakoids. It is where the light-independent reactions (Calvin cycle) occur.
Adaptations

(i) The stroma contains a high concentration of the enzymes needed to catalyze the Calvin cycle, including the enzyme RuBisCO.
(ii) The stroma can store the products of photosynthesis as starch grains and lipid droplets for later use.

(iii) The stroma bathe the grana, allowing the ATP and NADPH produced during the light-dependent reactions to rapidly diffuse to the sites of the Calvin cycle.
(iv) The stroma contains small (70S) ribosomes and a circular loop of DNA (cpDNA), allowing it to synthesize some of its own proteins and enzymes without relying on the nucleus.

Chloroplast envelope (double membrane)

Adaptations

(i) The outer and inner membranes enclose the chloroplast, separating its contents from the rest of the cell. This allows for specific conditions, such as a suitable pH and enzyme concentrations, to be maintained for photosynthesis.
(ii) The inner membrane is less permeable than the outer and contains specific transport proteins. These proteins regulate the passage of molecules, like the G3P product of the Calvin cycle, into and out of the cytoplasm.

General adaptations of chloroplasts to their functions

(i) It is biconcave (to increase the surface area for absorption of light
(ii) Outer membrane is semi- permeable to regulate entry and exit of substances for maintaining internal chloroplast environment.
(iii) Contains chlorophyll to trap light for photosynthesis
(iv) Abundant enzymes catalyse photosynthetic reactions in the stoma
(v) Grana provide large surface area for photosynthetic pigments, electron carriers and ATP synthase enzymes.
(vi) Grana surrounded by the stroma so the products from the light dependent reaction (which occur across the thylakoid membrane which make up the grana) can readily pass into the stroma for the light independent reaction.
(vii) Narrow inter-membrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur
(viii) Inner membrane contains molecules for electron transport pathway
(ix) DNA presence codes for protein synthesis, including enzymes.
(x) Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm
(xi) Outer membrane is permeable to gases like carbon dioxide which is a raw material for photosynthesis

Similarities between a chloroplasts and a mitochondrion

(i) **Double membrane:** Both organelles are enclosed by a double membrane, consisting of a smooth outer membrane and a highly specialized inner membrane.
(ii) **Internal compartments:** The double membrane creates distinct internal compartments. In mitochondria, it is the inner mitochondrial matrix and the intermembrane space. In chloroplasts, it is the stroma, thylakoid lumen, and intermembrane space.
(iii) **Increased surface area:** Both have internal membrane systems with a large surface area. In mitochondria, the inner membrane folds into structures called cristae. In chloroplasts, the inner membrane encloses flattened sacs called thylakoids, which stack into grana. This

increased surface area is vital for embedding the enzymes and protein complexes needed for their metabolic reactions.

(iv) **Circular DNA:** Both contain their own small, circular DNA molecule, much like that found in bacteria. This DNA codes for some of the organelle's proteins.

(v) **Ribosomes:** Both possess their own ribosomes, which are similar in size and structure to bacterial ribosomes (70S). This allows them to synthesize some of their own proteins.

(vi) **Replication by fission:** Both organelles can replicate independently of the cell nucleus through a process similar to prokaryotic binary fission.

Functional similarities

(i) **ATP production:** A central function for both is the synthesis of ATP, the main energy currency of the cell. They both utilize an electron transport chain to generate a proton (H^+) gradient, which is then used by the enzyme ATP synthase to produce ATP through chemiosmosis.

(ii) **Energy conversion:** Both are specialized for energy transformation. Chloroplasts convert light energy into chemical energy stored in glucose, and mitochondria convert the chemical energy stored in glucose into usable ATP.

(iii) **Enzymatic activity:** Both contain a complex system of enzymes and coenzymes to catalyze their specific biochemical pathways.

(iv) **Evolutionary similarities (Endosymbiotic Theory):** The striking similarities between mitochondria, chloroplasts, and bacteria provide strong evidence for the endosymbiotic theory. This theory proposes that both organelles originated from free-living prokaryotic cells that were engulfed by a larger host cell. Mitochondria are thought to have evolved from aerobic bacteria (alpha-proteobacteria)while Chloroplasts are believed to have evolved from photosynthetic cyanobacteria. This shared history explains why they retained their own genetic material, ribosomes, and ability to divide, characteristics not typically found in other eukaryotic organelles.

Differences between a chloroplasts and a mitochondrion

Mitochondria	Chloroplast
Known as the powerhouse of the cell, it is responsible for energy metabolism and cellular respiration	Larger and much more complex than a mitochondrion, it is the site where photosynthesis takes place.
Present in cells of all types of aerobic organisms such as plants and animals.	Present in green plants and green algae
Bean-shaped	Disc-shaped
Colourless organelle	Green in colour
Matrix and Cristae are the two chambers present in a mitochondrion	Stroma and thylakoid are the two chambers of a chloroplast
Consumes oxygen	Releases oxygen
Produce carbon dioxide	Produce carbon dioxide
Do not possess any pigments	Chloroplast is comprised of pigments such as chlorophyll, carotenoids and photosynthetic pigments
Energy is released by breaking down organic food producing carbon dioxide and water	Stores energy and uses carbon dioxide and water to produce glucose

Similarities between cellular respiration and photosynthesis

(i) **Energy Conversion**: Both processes convert energy from one form to another—photosynthesis turns light energy into chemical energy (glucose), while respiration converts chemical energy into usable energy (ATP).

(ii) **Electron Transport Chains**: Each process uses an electron transport chain to move electrons and generate energy-rich molecules (ATP, NADPH in photosynthesis; ATP, NADH, $FADH_2$ in respiration).

(iii) **Enzyme Involvement**: Enzymes catalyze the reactions in both processes, ensuring efficient energy transformation and molecular changes.

(iv) **ATP usage and production**: ATP is central to both processes—photosynthesis produces ATP during the light-dependent reactions, and respiration uses and generates ATP during glycolysis and oxidative phosphorylation.

(v) **Redox Reactions**: Both involve oxidation-reduction (redox) reactions, where electrons are transferred between molecules to facilitate energy flow.

(vi) **Organelles**: Photosynthesis occurs in chloroplasts, while respiration takes place in mitochondria—both specialized organelles in eukaryotic cells.

(vii) **Biochemical Pathways**: Both processes consist of a series of biochemical reactions that are enzyme controlled.

(viii) **Carbon-Based Compounds**: Both processes involve carbon compounds—photosynthesis uses carbon dioxide to make glucose, and respiration breaks down glucose to release carbon dioxide.

(ix) **Interdependence**: The products of one process serve as the reactants for the other. Photosynthesis produces glucose and oxygen, which are used in respiration; respiration produces carbon dioxide and water, which are used in photosynthesis.

Differences between photosynthesis and Respiration

	Photosynthesis	**Respiration**
1	Converts light energy into chemical energy (glucose	Releases energy from glucose for cellular use
2	Occur in chloroplasts	Occur in mitochondria
3.	Use carbon dioxide	Use oxygen
4.	Produce glucose	Breakdown glucose
5.	Require energy (light)	Produce energy (ATP)
6.	Electron carrier NADPH	Electron carriers are NADH and FAD
7.	Anabolic (builds molecules).	Catabolic (breaks down molecules).
8.	Absorb carbon dioxide	Release Oxygen
9.	Produce oxygen	Produce carbon dioxide
10.	Use water	Produce water

Chemistry of photosynthesis

In the process of photosynthesis energy is obtained from sunlight is trapped by chlorophyll and used for the manufacture of carbohydrates from carbon dioxide and water.

The process is summarized by the following equation

$$\text{Carbon dioxide} + \text{water} \xrightarrow{\text{chlorophyll}} \text{Carbohydrates} + \text{oxygen}$$

$$CO_2 \quad\quad H_2O \quad\quad\quad\quad CH_2O \quad\quad O_2$$

Photosynthesis takes place in 3 stages

- Light harvesting
- Electron transport
- Reduction of carbon dioxide

1. Stage 1: Light harvesting

Pigment molecules in thylakoid membrane absorb and collect solar energy and funnel it to special molecules of chlorophyll **a** known as the **reaction centre chlorophyll molecule**. When light energy strikes this molecule, an electron is excited and picked by electron acceptor.

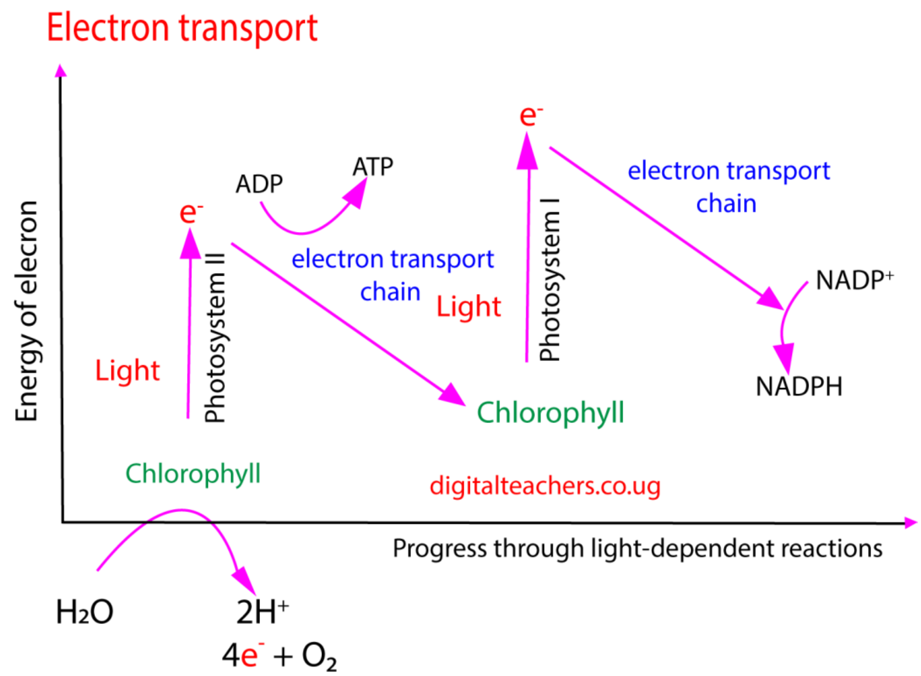
There are **two kinds of reaction centres** in plants called photosystem I (PSI) and photosystem II (PS II) that differ in structure and function. PSI absorbs light at 700nm and PSII at 690nm. Whereas many chlorophyll molecules are involved in collecting energy, only a few make up the reaction centres.

The transport of electrons through the two centres comprises the second state of photosynthesis.

2. Stage 2: electron transport

This stage occurs in thylakoid of the chloroplast and produces **ATP** and reduced nicotinamide adenine phosphate, **(NADPH)** to be used in the reduction of carbon dioxide in the third stage.

The events of electron transport are described in the figure below



(i) Formation of NADPH

When light is absorbed by a chlorophyll molecule PSI an electron is displaced and transferred to an electron acceptor which donates it to a protein ferredoxin. Ferredoxin then passes the electron to NADP which is reduced to NADPH.

The electron lost by PSI is restored from PSII. When PSII absorbs light energy, an electron is displaced from it and passes through electron carrier system which includes cytochromes.

The electron lost from PSII is then restored through photolytic splitting of water (Hill reaction)

(ii) ATP formation

(i) Non cyclic photophosphorylation

The flow of electrons from PSII to PSI in thylakoid membrane causes accumulation of H^+ inside the thylakoid space creating a gradient. The passage of H^+ out of the thylakoid provides energy to synthesize ATP.

(ii) Cyclic photophosphorylation

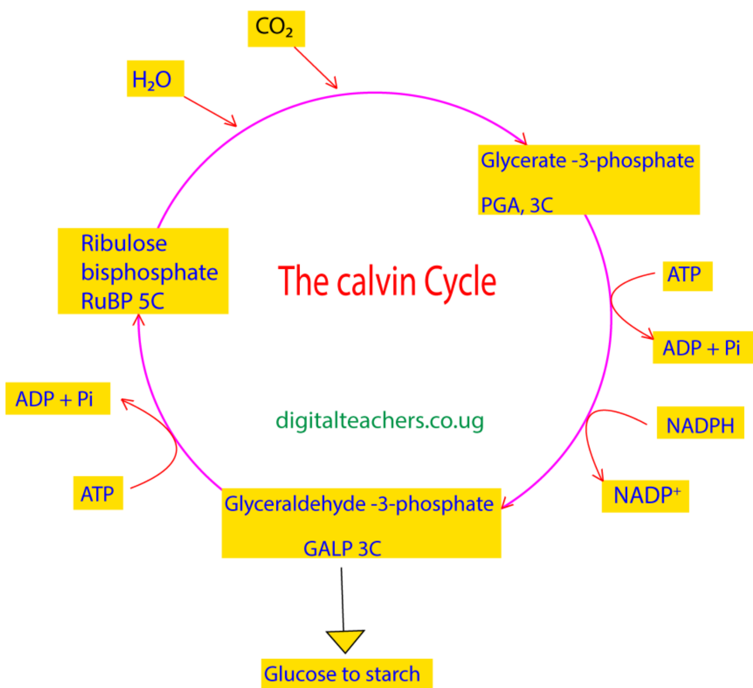
Here when PSI is struck by light, electron is excited, passes through electron carrier system and then returned to PSI; that is PSI is the electron donor and acceptor. H^+ builds up in the thylakoid space creating a gradient. Then the passage of H^+ out of the thylakoid provides energy for synthesizing ATP. It is used to synthesize ATP when synthesis of $NADPH_2$ is not necessary.

Differences between cyclic and non-cyclic photophosphorylation

	Cyclic photophosphorylation	Non-cyclic photophosphorylation
1	It occurs only in PS I	It occurs only in PS I and PS II
2	It involves synthesis of ATP	It involves synthesis of ATP and $NADPH_2$
3	Photolysis of water does not occur	Photolysis occurs and oxygen is liberated
4	Electron motion is cyclic	Electron motion is non-cyclic

3. Reduction of carbon dioxide

This involves a cyclic chain reaction called Calvin cycle. It occurs in the stroma of chloroplast where NADPH and ATP from stage 2 provide reducing power and energy for synthesis of sugars.



1. In the first step, carbon dioxide combines with a 5-carbon organics compound called **ribulose bisphosphate** (RUBP) with the aid of an **enzyme ribulose bisphosphate carboxylase** giving unstable 6-carbon compound.
2. The unstable 6-carbon compound immediately splits into two molecules of 3-carbon compound **glycerate-3-phosphate**, (GP)

3. The GP is reduced to form a 3-carbon sugar, glyceraldehyde-3-phosphate (GALP). The hydrogen for reduction comes from NADPH which also supplies most of the energy, the rest coming from ATP.

4. The 3-carbon sugar is built into a 6-carbon sugar which may be converted into starch for storage.

5. Some of the 3-carbon sugar is used to regenerate ribulose bisphosphate to be used in the Calvin cycle.

Synthesis of proteins using photosynthesis intermediates (ATP, NADPH, G3P)

1. Photosynthesis doesn't produce proteins directly; instead, it provides the essential **carbon skeletons (via G3P)** and **energy (ATP and NADPH)** required for other metabolic pathways to synthesize amino acids.
2. **G**lyceraldehyde-3-phosphate (G3P) is converted into several carbon skeletons for the various amino acids through a series of reactions.
3. Nitrogen (Nitrates) from the soil is combined with the carbon skeletons to form amino acids.
4. Amino acids are assembled into proteins through a process of translationpowered by ATP

The synthesis of lipids using photosynthesis intermediates (ATP, NADPH, G3P)

This transformation lipid from G3P is not a single reaction but a multi-step metabolic pathway that takes place in different cellular compartments, notably the chloroplast and endoplasmic reticulum.

1. G3P produced in the Calvin cycle with the chloroplast is exported to the cytoplasm, processed through parts of glycolysis pathways to pyruvate.
2. The pyruvate is then transported into the plastids, where it is converted into acetyl-CoA, the two-carbon building block for fatty acids. This process is called pyruvate dehydrogenase.
3. The synthesis of fatty acids occurs within the plastids and is a cyclic process catalyzed by the fatty acid synthase (FAS) enzyme complex. This process requires significant amounts of energy (ATP) and reducing power (NADPH) provided by photosynthesis.
4. The FAS complex repeatedly adds two-carbon units (from malonyl-CoA, which is derived from acetyl-CoA) to a growing fatty acid chain. This continues until major fatty acids, such as palmitic acid (C16:0) and oleic acid (C18:1), are formed.
5. The newly synthesized fatty acids are exported from the plastids to the cytoplasm.
6. G3P from the cytoplasm is converted into glycerol-3-phosphate, forming the backbone for glycerolipids.

7. The endoplasmic reticulum, the fatty acids are attached to the glycerol-3-phosphate backbone in a series of steps known as the Kennedy pathway.
8. **Glycerol-3-phosphate acyltransferase (GPAT)** adds the first fatty acid to G3P, forming lysophosphatidic acid (LPA).
9. **Lysophosphatidic acid acyltransferase (LPAAT)** adds the second fatty acid, resulting in phosphatidic acid (PA).
10. **Diacylglycerol acyltransferase (DGAT)** adds the third fatty acid, leading to the final storage lipid, triacylglycerol (TAG).

C3 and C4 plants

In C3 plant such as tomato, and rice, carbon dioxide is fixed by ribulose bisphosphate and the first stable intermediate in production of sugar is a 3-carbon compound**, glycerate-3-phosphate**. However, the C4 plants such as sugar cane and maize fix carbon dioxide using **phosphorenol pyruvic acid (PEP)** and the immediate products of CO_2 fixation is a 4-carbon compound **oxaloacetic** acid.

The oxaloacetic acid formed in C4 plants is subsequently converted into maleic acid from which CO_2 is fed into the Calvin cycle to form carbohydrates.

Advantages of C4 plants over C3 plants

C4 plants have a significant advantage over C3 plants in hot, dry, and high-light environments due to their specialized anatomy and photosynthetic pathway. This adaptation minimizes the **wasteful process of photorespiration and improves water and nitrogen use efficiency.**

1. **C4 plants have reduced carbon dioxide wastage through photorespiration than in C3 plants:** In C3 plants, the enzyme RuBisCO can bind with oxygen instead of carbon dioxide, especially under high temperatures and low CO_2 conditions. This process, called photorespiration, wastes energy and reduces photosynthetic production. In contrast C4 plants use a special enzyme called PEP carboxylase, which has a higher affinity for CO_2 than RuBisCO. They fix carbon dioxide in their mesophyll cells and transport it to specialized bundle sheath cells, where it is released at a high concentration to RuBisCO. This spatially separates the initial CO_2 fixation from the Calvin cycle, effectively suppressing photorespiration.
2. **C4 plants conserve water more efficiently than C3 plants**: In hot, dry conditions, C3 plants must keep their stomata open for longer periods to take in enough CO_2 which also leads to significant water loss through transpiration. Whereas C4 plants can operate with their stomata partially or fully closed for longer periods. Their efficient carbon-concentrating mechanism allows them to continue photosynthesis effectively even at low internal CO_2 levels, dramatically reducing water loss.

3. **C4 plants perform better at higher temperature and light than C3 plants:** In full sunlight, C3 plants reach their maximum photosynthetic rate, or light saturation, well below the available light levels. C4 plants, in contrast, have a very high light saturation point. The energy-intensive C4 pathway works well with abundant sunlight, and their photosynthetic rate continues to increase with higher light intensity.
4. **C4 plants tolerate higher temperatures better than C3 plants:** The C4 pathway gives plants a higher optimal temperature for photosynthesis. This is a major advantage in tropical and subtropical regions where high temperatures would increase photorespiration in C3 plants.
5. **C4 plants use nitrogen more efficiently than C3plants**: Because C4 plants operate at high internal CO_2 concentrations, they can function with much lower levels of RuBisCO. This is significant because RuBisCO is a very nitrogen-rich protein.By reducing the amount of nitrogen invested in RuBisCO, C4 plants can reallocate nitrogen to other metabolic processes or produce more biomass, especially in nitrogen-poor soils.

Disadvantage of C4 plants over C3 plants

While C4 plants are highly adapted for hot, dry, and high-light conditions, they have distinct disadvantages when compared to C3 plants in other environments

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1. **C4 plants use more energy than C3 plants:** The C4 pathway requires extra energy in the form of ATP to function. Specifically, it costs an additional two ATP molecules for every molecule of CO_2 that is fixed compared to the C3 pathway. This extra energy is used to regenerate the CO_2 carrier molecule, PEP (phosphoenolpyruvate), after it releases CO_2 to the Calvin cycle in the bundle sheath cells.
2. **C4 have reduced efficiency in moderate climates:** In cooler, temperate, or high-CO_2 conditions, C4 plants are less energy-efficient than C3 plants. Since photorespiration is naturally suppressed under these conditions, the extra ATP cost of the C4 pathway becomes an unnecessary metabolic burden that reduces overall photosynthetic efficiency.
3. **C4 plants perform poorly in low temperatures and light than C3 plant**: The CO_2 fixing enzymes in C4 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.
4. **Anatomical limitations:** C4 plants require a specialized leaf anatomy (Kranz anatomy) with distinct mesophyll and bundle sheath cells to facilitate the spatial separation of the initial carbon fixation and the Calvin cycle. This more complex anatomy is an evolutionary constraint that limits the range of habitats they can occupy compared to the more widespread and diverse C3 plants

NB: C4 plants grow better under hot, dry conditions when plants must close their stomata to conserve water – with stomata closed, CO_2 levels in the interior of the leaf fall, and O_2 levels rise.

CAM Plant e.g. pineapple

These are C4 plants that live especially in arid environment. Because they are at risk of severe water loss, they have accustomed by opening their stomata at night. Thus as opposed to other C4 plants, in CAM plants, the initial fixation of CO_2 by PEP and the conventional Calvin cycle are separated in time. The stomata are generally closed during the day so there is little loss of water; the CO_2 is fixed during the night when the stomata are open.

Difference between C3, and C4 plant

	C3 pathway	C4 pathway
1	Photosynthesis occurs in mesophyll cells	Photosynthesis occurs in mesophyll cells and bundle sheath cells
2	The CO_2 molecule acceptor is RuBP	The CO_2 acceptor molecule is phosphenol pyruvate
3	The first stable product is a 3C compound Called Glycerate-3-phosphate (PGA)	The first stable product is a 4C compound **oxaloacetic** acid (OAA)
4	Photorespiration rate is high and leads to loss of fixed CO_2. Decrease CO_2 fixation rate	Photorespiration is negligible and is almost absent. Hence high CO_2 fixation rate
5	Optimum temperature is 20^0C to 25^0C	Optimum temperature is 30 to 45^0C.
6	Photosynthetic rate is low	Photosynthetic rate is high
7.	Examples of C3 plants are rice, wheat and tomato	Examples of C4 plants are maize, sugar cane

Differences between C4 and CAM plants

C4	**CAM plant**
Open stomata during day and close them at night	Open stomata at night and close them during day
Do not store CO_2 (carbon dioxide fixation and Calvin cycle is separated by space)	Store CO_2 in form of malate (carbon dioxide fixation and Calvin cycle is separated by time)

Distribution of C4 and C3 plants

The distribution of C3 and C4 plants is primarily driven by their contrasting physiological adaptations to environmental conditions, particularly temperature, water availability, and light intensity. C3 plants dominate cooler, wetter regions, while C4 plants are most successful in hotter, drier, and sunnier climates.

C3 plant distribution

As the most common photosynthetic type, C3 plants are found across nearly all terrestrial environments but dominate in specific climates.

- **Cooler, temperate, and boreal regions:** Because C3 plants are not disadvantaged by photorespiration in these conditions, they are more energy-efficient and competitive than C4 plants. They are the main component of temperate forests, boreal forests, and tundra ecosystems.
- **Higher latitudes and elevations:** As temperature decreases with latitude and altitude, the C3 pathway becomes more favorable. Studies show a clear transition from C4-dominated to C3-dominated vegetation with increasing elevation on mountains.
- **Shaded environments:** In the understory of forests and other low-light environments, the C3 pathway's efficiency at low light intensity gives it a competitive edge.
- **Major C3 crops:** These include wheat, rice, soybeans, and potatoes, which are widely cultivated in temperate and wetter regions.

C4 plant distribution

C4 plants thrive in environments that challenge C3 plants. While a smaller fraction of all plant species, they account for a disproportionately large percentage of global primary production due to their dominance in grasslands and savannas.

- **Hot, dry climates:** C4 plants are most common in tropical and subtropical regions, including grasslands, savannas, and deserts, where their adaptations to high temperatures and water stress are most beneficial.
- **High light intensity:** In full sunlight, the C4 pathway does not reach saturation as quickly as the C3 pathway, allowing for higher productivity.
- **Warm-season grasses:** C4 grasses are often called "warm-season" grasses because they are most active during the warmer months. This leads to temporal separation from C3 grasses in mixed grasslands.
- **High-salinity environments:** The higher water-use efficiency of C4 plants also makes them successful in arid and saline environments, such as salt marshes.
- **Major C4 crops:** Important C4 crops like maize, sugarcane, and sorghum are cultivated extensively in tropical and subtropical regions, as well as warmer temperate zones like the "corn belt" of the central United States.

Factors influencing distribution
The primary climatic factor determining the boundary between C3 and C4 dominance is the **growing season temperature**.

- The "crossover temperature" is the point at which the photosynthetic efficiency of C3 and C4 plants becomes equal. Below this temperature, C3 plants have an advantage; above it, C4 plants are more productive.
- **Water availability** also plays a major role, especially in warmer regions, as C4 plants' superior water-use efficiency allows them to flourish in drier conditions where C3 plants would struggle.
- **Atmospheric CO_2** levels can also affect competition. C3 plants may respond more favorably to elevatedCO_2, but in hot environments, the temperature effect can still give C4 plants an edge.

Definition

Photorespiration (also known as the **oxidative photosynthetic carbon cycle**, or **CO_2 photosynthesis**) refers to a process in plant metabolis where the enzyme RuBisCO oxygenates RuBP, causing some of the energy produced by photosynthesis to be wasted. This process reduces the efficiency of photosynthesis, potentially reducing photosynthetic output by 25% in C3 plants.

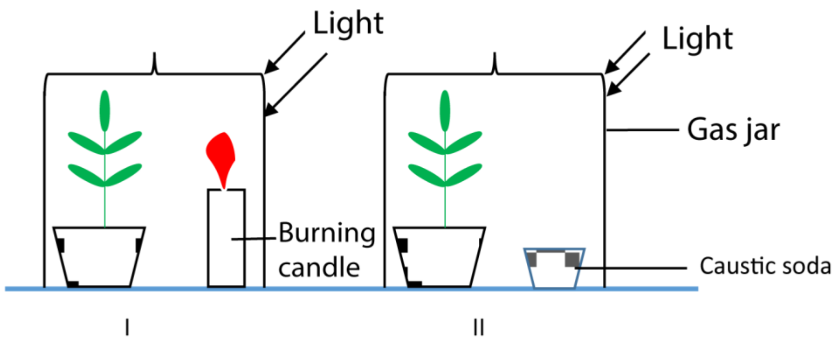
Differences between photorespiration and cellular respiration

Photorespiration	Cellular respiration
Energy is wasted	Energy is formed
substrate is glycolate	Substrate is glucose
Light dependent	Light independent
No photophosphorylation occurs	Photophosphorylation occurs
Requires mitochondria, peroxime, and chloroplast	Requires mitochondria only
Common in C3 plants	Occur in all plants

Conditions necessary for photosynthesis

(a) **Carbon dioxide:** is obtained from the atmosphere and water in case of aquatic plants. It is the source of carbon in carbohydrates.

Experiment to show that carbon dioxide is necessary for photosynthesis



The experiment is set up as shown above

1. Two younger seedling growing in pots are kept in the dark for 3 days (to remove starch) and a leaf from each plant is tested to confirm absence of starch.
2. In experiment I the burning candle supplies carbon dioxide while in experiment II carbon dioxide is absorbed by caustic soda.

3. After 3 hours, a leaf is take from each plant and tested for the presence of starch. Starch is found in the leaf of experiment I which had carbon dioxide.

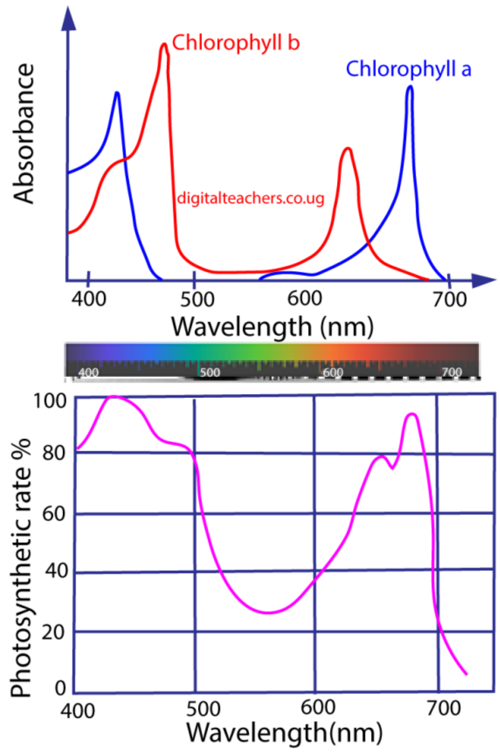
(b) **Water** provides hydrogen for the carbohydrates

(c) **Light** usually from the sun is the source of energy for photosynthesising tissues.

Wave length of light for photosynthesis

An action spectrum is the rate of a physiological activity plotted against wavelength of light. It shows which wavelength of light is most effectively used in a specific chemical reaction. Some reactants are able to use specific wavelengths of light more effectively to complete their reactions.

The action spectrum of chlorophyll is shown in the graph below



From the graph of action spectrum of chlorophyll, it observed that chlorophyll is much more efficient at using blue-violet light (wave length (550-400nm) and orange (600-700nm).

However, Bacteriochlorophyll of purple sulphur bacteria absorb ultraviolet (350nm) and infrared (750nm) part of the spectrum. The difference in wavelengths optimum for photosynthesis both in plants and bacteria enables bacteria to survive under water weeds in the pond. I.e. bacteria find the spectrum useful after the plants have filtered out light for photosynthesis.

(d) **Chlorophyll:** this is a green pigment which helps to trap light energy for photosynthesis.

Experiment to show that chlorophyll is necessary for photosynthesis

When a variegated leaf is picked from a plant on a sunny day and tested for starch. Starch is found only in parts that originally contained chlorophyll.

(e) A **suitable temperature:** photosynthesis proceed by a series of chemical reactions controlled by enzymes which are sensitive to temperature. By comparing the rates of photosynthesis, at different temperatures, optimum temperatures for various plants are obtained.

Limiting factors in respect to photosynthesis

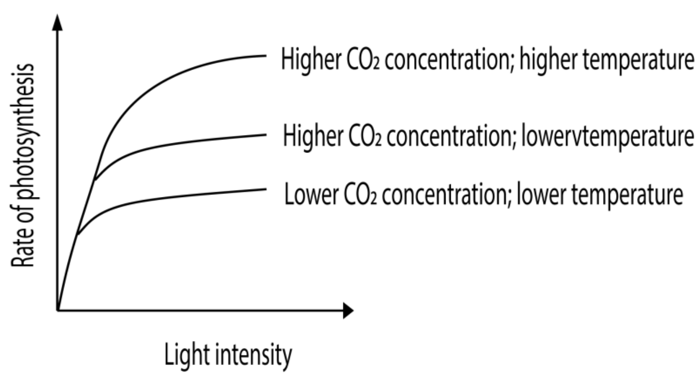
The main **factors** affecting rate of **photosynthesis** are light intensity, carbon dioxide concentration and temperature. In any given situation any one of these may become a **limiting factor**, in other words the **factors** that is in short supply.

In 1905, when investigating the factors affecting the rate of photosynthesis, Blackmann formulated the Law of limiting factors.

This states that the rate of a physiological process will be limited by the factor which is in shortest supply. Any change in the level of a limiting factor will affect the rate of reaction.

For example, the amount of light will affect the rate of photosynthesis. If there is no light, there will be no photosynthesis. As light intensity increases, the rate of photosynthesis will increase as long as other factors are in adequate supply. As the rate increases, eventually another factor will come into short supply.

The graph below shows the effect of low carbon dioxide concentration. It will eventually be insufficient to support a higher rate of photosynthesis, and increasing light intensity will have no effect, so the rate plateaus.



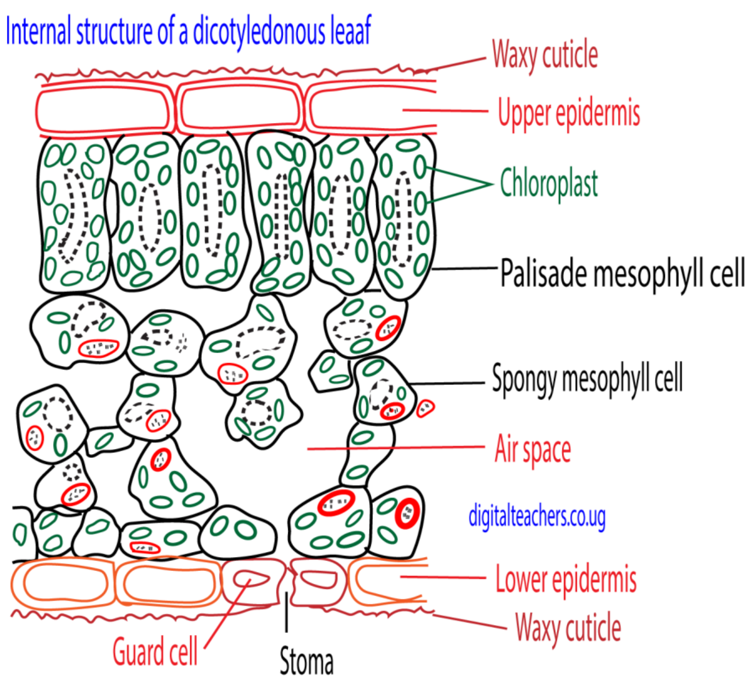
If a higher concentration of carbon dioxide is supplied, light is again a limiting factor and a higher rate can be reached before the rate again plateaus. If carbon dioxide and light levels are high, but temperature is low, increasing temperature will have the greatest effect on reaching a higher rate of photosynthesis.

The leaf

In higher plant the major photo synthetic organ is the leaf.

Functions of the leaves

1. Carry out photosynthesis with subsequent production of organic materials
2. Carry out gaseous exchange through the stomata
3. Transpiration takes place mainly through the leaves resulting in the cooling of plant and absorption of mineral salts and water
4. Some leaves such as those of peas are modified by tendrils for support.
5. Some leaves suck those bryophyllum are modified for storage
6. Some leaves such as for bryophyllum are modified for vegetative reproduction
7. Some leaves possess itching hairs, thorns, spikes and poisonous substances for protection of plant.
8. Some leaves e.g. Venus fly trap are modified for capturing and extracting nitrogen from animals
9. Some produce substances that kill parasites.



Functions of tissues in dicotyledonous leaves

Tissue	Structure	Function
1. Upper and lower epidermis	One cell thick External walls covered with cutin (waxy substance) Contain stomata (pores surrounded by guard cells)	- Protective - Cutin is water proof and reduce water loss from the leaves - Allow gaseous exchange
2. Palisade mesophyll	Column-shaped cells with numerous chlorophyll in thin layer of cytoplasm	- Main photosynthetic tissue. Chloroplast may move towards light
3. Spongy mesophyll	Irregular shaped cells fitting loosely to leave large air space	- Photosynthetic, but fewer chloroplast than palisade cells. Gaseous exchange can occur through the large air space via stomata.
4. Vascular tissue	Extensive finely branching network through leaf	- Conduct water and mineral salts to the leaf in xylem - Remove photosynthetic products through phloem - Provide a supporting skeleton to the lamina, aided by turgidity

Adaptation of leaves to photosynthesis

1. The leaf is only a few cells thick for easy penetration of light and gases.
2. Wax cuticle prevent excessive water loss
3. The palisade cells that contain numerous chloroplasts are well positioned to receive light.
4. Presence of xylem that supply the leaf with water for photosynthesis
5. The spongy mesophyll has many air space. Gases can readily diffuse to all photosynthetic cells
6. They are broad and flat to offer a large surface area exposed to light and air
7. Stomata control passage of gases
8. The arrangement of leaves to the plant is such way that each leaf receives light.

Theories that explain the opening of stomata

Several theories explain how stomata open and close, with the current most accepted model being the **Active Potassium Ion Transport Theory**.

This process is driven by changes in the turgor pressure of the guard cells, which are controlled by light, carbon dioxide levels, water availability, and internal biological rhythms.

Active potassium ion transport theory

This is the modern and most widely accepted theory. It suggests that stomatal opening is primarily driven by the active, energy-requiring influx of potassium (K^+) ions into the guard cells.

Process in light conditions:

1. **Light detection:** Blue light is sensed by phototropins in the guard cell membranes, while red light is used for photosynthesis in the guard cell chloroplasts.
2. **Proton pump activation:** Light detection activates proton pumps (H^+-ATPases) on the guard cell membrane, which use ATP to pump protons out of the cells.
3. **Potassium influx:** The movement of protons creates a negative electrical potential (hyperpolarization) across the guard cell membrane. This potential drives the uptake of positive potassium (K^+) ions into the guard cells through ion channels.
4. **Counter-ion synthesis:** To balance the negative charge created by the proton efflux and the incoming positive K^+ ions, the guard cells produce organic acids like malate from starch. They also take in chloride (Cl^-) ions.
5. **Water influx and turgor:** The increased concentration of malate and other solutes lowers the water potential inside the guard cells. Water enters the guard cells from surrounding cells via osmosis, increasing their turgor pressure.
6. **Stomatal opening:** The guard cells swell and, due to their unique radial microfibril arrangement, they bend outwards, causing the stomatal pore to open.

Role of hormones and CO_2:

- **Low CO_2:** Low concentrations of CO_2 in the leaf's intercellular spaces (due to high photosynthetic activity) also signal the guard cells to open.
- **Abscisic acid (ABA):** The stress hormone ABA causes stomata to close during drought by inhibiting the proton pumps and promoting the efflux of K^+ ions.

Older, less complete theories

Before the details of the active ion transport mechanism were discovered, other theories attempted to explain stomata opening:

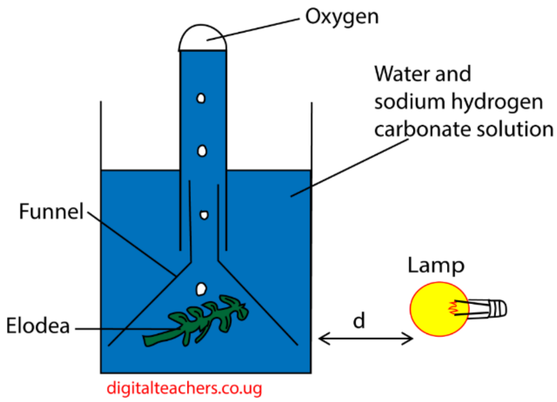
- **Starch-sugar interconversion theory:** This theory proposed that during the day, starch in the guard cells was converted to osmotically active sugars (e.g. glucose). The increased osmotic pressure would cause water to enter, and the stoma would open. At night, sugars would convert back to starch, lowering osmotic pressure and closing the stoma.
    - **Limitations:** This theory could not explain the rapid opening and closing of stomata, which happens too quickly for the starch-sugar conversion to be the sole cause. It also failed to explain stomatal movement in some plants that lack guard cell starch.

- **Photosynthesis in guard cells theory:** This simple theory suggested that photosynthesis in the guard cell chloroplasts produced sugars, increasing the osmotic pressure and causing water influx and opening.
    - **Limitations:** The chloroplasts in guard cells are often poorly developed compared to mesophyll cells. This theory was unable to explain why low CO_2 (a condition not favoring photosynthesis) causes stomata to open, while high CO_2 causes them to close.
- **Glycolate metabolism theory:** This theory suggested that under low CO_2 concentration, glycolate was produced in guard cells. Glycolate could be metabolized to produce sugars or ATP, leading to opening.
    - **Limitations:** This theory does not explain why stomata sometimes close in the presence of glycolate or other factors.

Modification of leaves to their functions

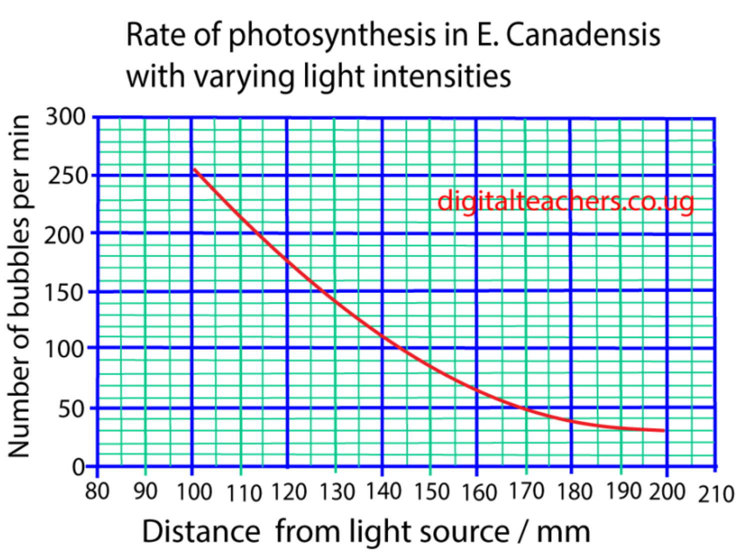
(i) Flattened surface to reduce diffusion distance
(ii) Shiny waxy cuticle to reduce water loss
(iii) Mosaic arrangement to increase light absorption
(iv) modified into tendrils to support weak climbing stems e.g. Gloriosa, peas
(v) Some leaves are modified into spine in order to reduce water loss. Spines also protect the plant from herbivorous animals
(vi) Some leaves are modified into scale leaves (thin, membranous, dry colourless structures) for protection. E.g. onion outer leaves
(vii) **Phyllode :** It is a green, expanded structure formed by the modification of petiole or rachis of leaf. Many xerophytes reduce the size of their leaves to minimize water loss. Such plant develop phyllodes to carry out photosynthesis e.g., *Acacia, Melanoxylon* and *Parkinsonia*.
(viii) Some leaves are flesh to store water and food
(ix) Some leaves develop vegetative bud for reproduction, e.g. bryophyllum
(x) In some rootless, aquatic plants, the submerged leaves are modified into root like structure to absorb water and mineral salts. Such modified leaves are called absorbing leaves. e.g., *Utricularia*.
(xi) Some leaves are brightly coloured to attract insect pollinator, e.g. Bougainville
(xii) Some leaves are modified to trap insects.

Experiment to measure the rate of photosynthesis



Method

a. The apparatus is filled with carbonated water to enrich it with carbon dioxide.
b. The setup is allowed to adjust to light intensity for 2-3 minutes. The rate of bubbling should be adequate such as 10 bubbles per minute.
c. Light intensity is varied by increasing the distance, d, between the light source and the apparatus such as 10, 15, 20, 40 and 45cm. the bigger the distance, d, the lower the light intensity.
d. The rate of formation of bubbles per minute at different distances, d, is an empirical measure of photosynthesis at a given light intensity.
e. Temperature change is buffered by using a beaker of bigger capacity.



Adaptations to photosynthesize in sun and shade

Shade plant	Sun plant
1. Abundant chlorophyll b (low chlorophyll a to chlorophyll b ratio) which gives leaves dark green colour to increase light absorption in the dark;	1. Abundant chlorophyll a (high chlorophyll a to chlorophyll b ratio) to increase light absorption;
2. Palisade/ spongy mesophyll ratio low to allow maximum light penetration;	2. Palisade/ spongy mesophyll ratio high to minimise light penetration;
3. Mesophyll cell surface / leaf area ratio low to maximise light trapping;	3. Mesophyll cell surface / leaf area ratio high to minimize excessive light and transpiration;
4. Leaf orientation horizontal to maximize light trapping;	4. Leaf orientation erect to minimize light trapping;
5. Reddish leaf undersides to enhance reflectance back up through the photosynthetic tissue; giving the plant a second chance to utilize the light.	5. Stomatal density high to avoid over heating;
6. Stomatal density low to avoid over cooling;	6. Much carotenoids to prevent damage to chlorophyll from very bright light.
7. Thin leaves to maximise light penetration;	7. Thick leaves to minimise light penetration;
8. Stomatal size large to allow loss of excess water;	8. Stomatal size small to minimise water loss;
9. Elongated internodes for increased access to light;	Other features (i) RuBISCO and soluble protein content /mass higher (ii) Chlorophyll / soluble protein ratio high (iii) Chloroplast size small

Types of chemosynthetic bacteria

No.	Nutritional type	Source of energy	Source of carbon	Source of hydrogen	examples
1	Autotrophic bacteria are classified according to source energy, carbon and hydrogen				
(a)	Photoautotrophs	Sunlight	CO_2	H_2S	Green sulphurbacteria
(b)	Photoautotrophs	sunlight	CO_2	H_2O	cyanobacteria
(c)	photoheterotroph	Light	Organic compounds	Organic compounds	Purple non sulpur bacteria
(d)	Chemoautotrophs	Inorganic compounds such as NH_3, NO_2, H_2, H_2S	CO_2	H_2O	Nitrifying bacteria, nitrobacter
2	heterotrophs	Organic compound	Organic compounds		Most bacteria

Importance of bacteria

(1) Harmful effects
   (a) Bacteria are agents of disease of animals and plants such as syphilis, cholera, tetanus
   (b) Bacteria cause milk and food deteriorate
   (c) Denitrifying bacteria such as Thiobacillus lead to deterioration of soil fertility.

(2) Useful effects
   (i) Saprotrophic bacteria cause decay of waste materials and lead to formation of humus and recycling of minerals. E.g. Bacteria (Nitrosomonas and nitrobacter) convert organically combined nitrogen (e.g. protein) to nitrate which are absorbed by plants.
   (ii) Nitrogen fixing bacteria e.g. Azobacter fix nitrogen into the soil.
   (iii) Aerobic and anaerobic bacteria are useful in digestion of sewage into harmless substances. Methane gas given off is sometimes used for fuel.
   (iv) Mutualistic bacteria in ruminants' assist ruminants to digest cellulose, and synthesis of vitamin K and B group.
   (v) Some bacteria on the skin of humans enable it to obtain protection again inversion of pathogenic organism
   (vi) Bacteria and fungi are useful for making of cheese.
   (vii) Used for production of useful chemicals in genetic Engineering such as insulin

The significance of chemosynthetic bacteria in an ecosystem

- Chemosynthetic bacteria e.g. Azobacter fix nitrogen into the soil.
- Saprotrophic bacteria cause decay of waste materials and lead to formation of humus and recycling of minerals.
- Chemosynthetic bacteria e.g. Nitrosomonas and nitrobacter convert organically combined nitrogen (e.g. protein) to nitrate which are absorbed by plants.
- They are produce food for other organism in ecosystem

Effects of Light on organisms

Effects light on Plants

(i) **Photosynthesis:** Light is the primary energy source for photosynthesis, the process by which plants, algae, and some bacteria produce food (organic matter) from carbon dioxide and water, releasing oxygen in the process. Chlorophyll pigments primarily absorb blue and red wavelengths of light for maximum efficiency.

(ii) **Light intensity:** Influences stem length (etiolation in low light), leaf size and thickness, and root development.

(iii) **Light quality (color):** Different wavelengths affect specific processes; blue light promotes leaf and root growth, while red light is more efficient at driving flowering and stem elongation.

(iv) **Flowering (Photoperiodism):** The duration of light and darkness (photoperiod) dictates the timing of flowering and fruiting in many plants, ensuring reproduction occurs at the most favorable time of year.

(v) **Stomatal Movement:** Blue light stimulates the opening of stomata (pores on leaves), which is essential for gas exchange (CO_2 uptake and O_2 release) during photosynthesis and for regulating water loss.

(vi) **Phototropism:** Plant grow towards light

Effects light on Animals

(i) **Vision:** Light is essential for vision in most animals, allowing them to perceive their environment, differentiate colors, find food, and avoid predators. Animals have photoreceptor systems ranging from simple eyespots to complex eyes.

(ii) **Circadian Rhythms:** The daily cycle of light and darkness is a primary cue (zeitgeber) that entrains the 24-hour biological clocks of animals, regulating sleep-wake cycles, hormone balance (e.g., melatonin and cortisol), metabolism, and immune function. Disruption of this cycle can lead to various health problems.

(iii) **Reproduction:** Changes in seasonal light duration trigger reproductive cycles and behaviors in many species of insects, fish, birds, and mammals, ensuring offspring are born during favorable conditions.

(iv) **Migration and Behavior:** Light cues are vital for navigation in migrating animals, such as birds and sea turtles, which use moonlight and starlight for orientation. It also influences movement (phototaxis), with some organisms moving towards or away from light sources.

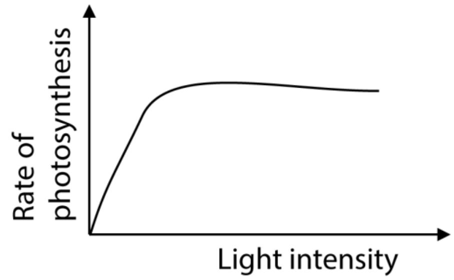
(v) **Pigmentation:** Light exposure is important for skin or plumage coloration and the formation of protective pigments like melanin in the skin of animals, offering protection against harmful UV rays.

(vi) **Vitamin D Synthesis:** In many animals, including humans, UV light exposure in the skin is necessary for the synthesis of Vitamin D, which is essential for bone health.

(vii) **Negative Impacts (Light Pollution):** Artificial light at night can disrupt natural behaviors, navigation, breeding rituals, and food webs, leading to disorientation, habitat loss, and increased mortality for many nocturnal species.

Revision Exercise

1. The figure below shows the rate of photosynthesis against light intensity



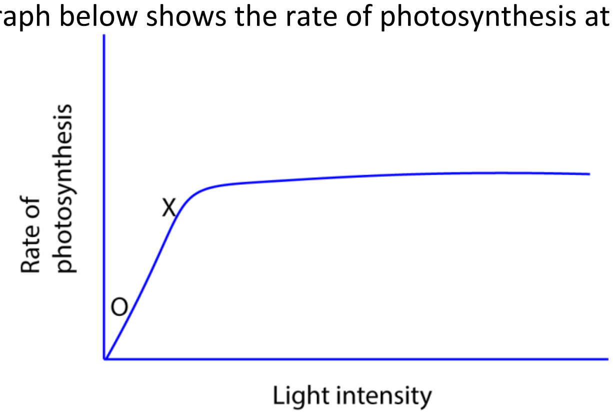
Which one of the following statement is the cause of the flattening of the curve?

A Photosynthetic pigments are saturated
B Too much carbon dioxide is available
C The plant has attained its maximum rate of photosynthesis
D There is a factor other than light which is limiting photosynthesis C

2. Which of the following does not occur during photorespiration?

A Oxygen is used up
B Wasteful loss of carbon as carbon dioxide
C Carbon dioxide is used up
D Wasteful loss of energy C

3. The graph below shows the rate of photosynthesis at different light intensities.



The factor limiting the rate of photosynthesis between O and X is

A Light intensity
B Carbon dioxide.
C Temperature
D Oxygen A
* Increase in light intensity increases the rate of photosynthesis

4. C3 are less efficient than C4 plants in fixing carbon dioxide at low carbon dioxide and high oxygen partial pressure because

A. C3 plants use more energy

B In C3 plants, energy is lost

C RuBP carboxylase is inactivated by high oxygen partial pressure

D PEP carboxylase has high affinity for oxygen. B

5. Photorespiration does not occur in C4 plants because they

A Use phosphenol pyruvic acid for fixing carbon dioxide

B Mainly grow at high altitudes

C Are more abundant in cold region

D Have succulent leaves which lower the internal temperature A

* PEP carboxylase has a very high affinity for CO_2 and, crucially, **does not** bind to oxygen (O_2). This means that even in hot, bright conditions where O2levels are high, this initial step of carbon fixation is not inhibited by oxygen.

6. Photosynthetic bacterial differ from green plants in that

A They lack chlorophyll

B Their source of energy is through oxidation of hydrogen sulphide

C Their source of energy is through oxidation of iron salts

D Their source of hydrogen is hydrogen sulphide D

7. Net primary productivity in C4 plants is higher than in C3 plants because

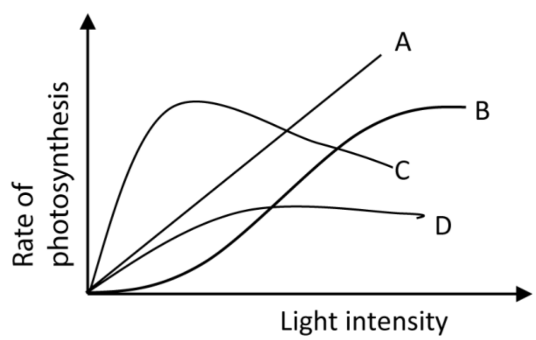
A C4 plants have a higher turn-over rate

B Energy accumulates at a higher rate in C4 plants

C Photophosphorylation occurs in C3 plants

D The rate of respiration is higher in C3 plants B

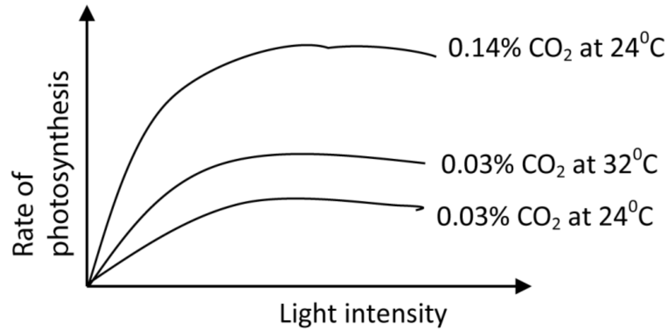
8. Which one of the following curves in the figure below correctly represents plants adapted for low light intensity?



C

C has high rate of photosynthesis at low light intensity

9. Which of the following is illustrated in the figure below?



A With increase in light intensity, the rate of photosynthesis increase until temperature becomes a limiting factor.

B Rate of photosynthesis increases with an increase in the carbon dioxide concentration

C With increase in light intensity, the rate of photosynthesis increases indefinitely

D. Rate of photosynthesis increases with an increase in light intensity until carbon dioxide becomes a limiting factor. D

10. Which of the following is likely to occur if a photosynthesizing plant was suddenly removed from light?

A Reduction in PGA

B Accumulation of PGAL

C Accumulation of PGA

D. No change in amount of PGAL C

* Production of ATP and NADPH stops in the dark, hence PGA accumulates because it is no longer reduced.

11 In which part of the following parts of a chloroplast are water splitting enzymes mostly located?

A Stroma

B. Intergrana

C Cytoplasm

D Grana D

* The water-splitting enzyme complex, also known as the oxygen-evolving complex, is part of Photosystem II. This photosystem is embedded in the thylakoid membranes of the grana, where it uses light energy to split water molecules

12. Etiolation in plants is usually a response to

A Insufficient nutrients

B Low temperature

C Insufficient light

D. Too much water. C

13. In photosynthesis, the major advantage of the C4 pathway is to

A Fix carbon dioxide in the Calvin cycle

B Concentrate carbon dioxide in the cells of leaves

C Fix carbon dioxide from the atmosphere into the leaves

D Store carbon dioxide in form of organic acids B

* **CO_2 concentration mechanism:** The C4 pathway uses a preliminary fixation step with the enzyme PEP carboxylase in mesophyll cells. The fixed carbon is then transported as a 4-carbon compound to the bundle sheath cells, where CO_2 is released. This process effectively creates a much higher concentration of CO_2 around the RuBisCO enzyme than what is available in the atmosphere.

14 During the light stage of photosynthesis, water is important in that it

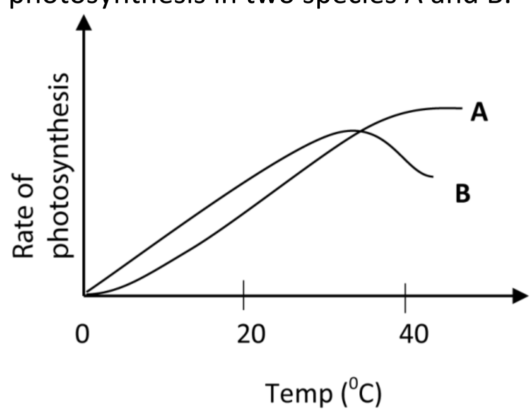
A Gives of oxygen

B Provides hydrogen that reduce NAD

C Reduces carbon dioxide to carbohydrates

D Provides electrons D

15. Figure below shows the relationship between temperature and rate of photosynthesis in two species A and B.



Which one of the following is correct conclusion from the results?

A **B** is a shade plant while **A** is a sun plant

B **A** has a lower compensation point than **B**

C **A** has a higher optimum temperature for photosynthesis than B

D Photorespiration does not occur in **A** but occurs in **B** C

16 Which of the minerals nutrient are constituents of chlorophyll?

A Potassium and sulphur

B Nitrogen and magnesium

C Calcium and phosphorus

D Zinc and copper B

17. Photosynthetic bacteria differ from plants in their nutrition in that the bacteria

A Derive their energy from oxidation of ammonia

B Obtain hydrogen for reduction of carbon dioxide from hydrogen sulphide

C Possess chlorophyll **b** to trap sunlight

D Oxidise hydrogen sulphide to obtain energy B

18. Which one of the following is the role of reduced NADP in the dark stage of photosynthesis?

A Combines with carbon dioxide

B Provide energy

C Provides hydrogen

D Acts as an electron acceptor C

* NADPH donates its hydrogen atoms (which include electrons and protons) to reduce 3-phosphoglycerate (PGA) into glyceraldehyde-3-phosphate (PGAL, or G3P).

19. Which one of the following colours of light are most effective in photosynthesis?

A Green and red

B Blue and red

C Blue and yellow

D Blue and green B

* Chlorophyll pigments absorb light most strongly in the **blue-violet** and **red-orange** regions of the visible light spectrum.

20. Which wavelength from light spectrum is mostly absorbed by green plants?

A brown

B Green

C Blue

D Yellow C

21. Where in the cell does the reduction of carbon dioxide occur during photosynthesis?

A Lamella

B Stroma

C Quatasome

D Grana membrane B

* Stroma contains the enzymes, including RuBisCO, necessary for the light-independent reactions (Calvin cycle) of photosynthesis. Carbon dioxide is "fixed" to a molecule (RuBP) and then reduced to sugar phosphates in the stroma.

22. During what stage of the dark reaction is $NADPH_2$ used? Conversion of

A Ribulose diphosphate to phosphoglyceric acid

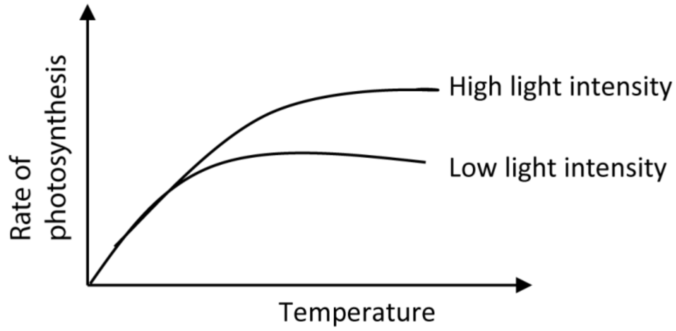
B Phosphoglyceraldehyde to hexose sugar

C Hexose sugar to starch

D. Phosphoglyceric acid to Phosphoglyceraldehyde D

* NADPH donates its hydrogen atoms (which include electrons and protons) to reduce 3-phosphoglycerate (PGA) into glyceraldehyde-3-phosphate (PGAL, or G3P).

23. The figure blow illustrates the phenomenon of limiting factors. What, in this case, is the limiting factor for photosynthesis?



A Chlorophyll content
B Temperature
C Carbon dioxide
D Light D
* Increase in light intensity increases the rateofphotosynthesis

24. Which of the following occurs during the light dependent stage of photosynthesis?
A Formation of ADP
B Formation of $NADPH_2$
C Formation PGAL
D Production of $NAGP^+$ B
* During this stage, light energy is converted into chemical energy, primarily in the form of ATP and **NADPH**.

25. Which of the following pairs of reactants is not required for the light-independent reaction of photosynthesis?
A NADPH and ATP
B ATP and carotenoid
C RuBP and free oxygen
D Carbon dioxide and enzymes A
* **NADPH is** sometimes represented as $NADPH_2$

26. The first carbohydrate made in photosynthesis is
A Ribose sugar
B Ribulose
C Phosphoglyceric acid
D Phosphoglyceraldehyde D

27. In photosynthesis, the major advantage of the C4 pathway is to
A Fix carbon dioxide in the Calvin cycle
B Concentrate carbon dioxide in the cell of leaves
C Fix carbon dioxide from atmosphere into the leaves
D Store carbon dioxide in form of organic acid D

28. During the light stage of photosynthesis, water is an important raw material in that it

A gives off oxygen
B Provide hydrogen that reduces NAD
C Reduce carbon dioxide to carbohydrate
D Provides electron D

29. During water stress, photosynthesis reduces in plant mainly due to shortage of

A carbon dioxide
B mineral salts
C Water
D Sunlight A
* Due to closure of stomata to reduce water loss

30. A close relationship between the action spectrum for photosynthesis and absorption spectrum of the chlorophylls indicate that

A All the light absorbed by the chlorophylls is used in photosynthesis
B Chlorophylls are responsible for absorption of light in photosynthesis
C Photosynthesis proceeds after light absorption
D Light energy is trapped in chlorophylls. B
* **Absorption Spectrum:** This graph shows the wavelengths (colors) of light that a particular pigment (like chlorophyll) absorbs most effectively.

Action Spectrum: This graph shows the overall rate of photosynthesis at different wavelengths of light.

The Correlation: The fact that the peaks of the action spectrum (highest rate of photosynthesis) closely match the peaks of the absorption spectrum (highest light absorption by chlorophyll) demonstrates that the light absorbed specifically by the chlorophyll pigments is the light that is actively driving the process of photosynthesis.

31. The products of light reaction in photosynthesis are

A $NADH_2$, ATP and O_2
B NADP, ATP and O_2
C $NADPH_2$, ADP and O_2
D $NADPH_2$, ATP and H_2 A

32. Which one of the following stages of photosynthesis uses light energy directly?

A Regeneration of ribulose diphosphate
B Production of energy in the form ATP
C Reduction of carbon dioxide
D Formation of phosphoglyceric acid B

33. Which one of the following is the main form of photosynthetic product transported by the phloem?

A Starch

B Amino acids

C Sucrose

D Glucose C

34. The difference between a green plant and the iron bacteria in synthesis of organic compound is that

A Bacteria derive their energy for synthesis from oxidation of inorganic compounds

B Source of hydrogen for the bacteria is not water

C Bacterial have a different kind of chlorophyll

D Bacteria lack enzymes for fixing of carbon dioxide A

35. Which of the following stages of photosynthesis use light energy?

A Regeneration of ribulose diphosphate

B Production of energy in form of ATP

C Reduction of carbon dioxide

D Formation of phosphoglyceric acid B

36. The organism that require only inorganic raw materials from the environment is

A Virus

B Amoeba

C Euglena

D Plasma C

* Euglena requires water, carbon dioxide, and sunlight for photosynthesis

37 If carbon containing radioactive carbon was added to a suspension of photosynthesising algae, in which one of the following compound would the radioactive carbon show first?

A Glucose

B Phosphoglyceric acid

C Ribulose bisphosphate

D Triose phosphate B

38. The table shows the effect of temperature on the rate of apparent photosynthesis and respiration in plants

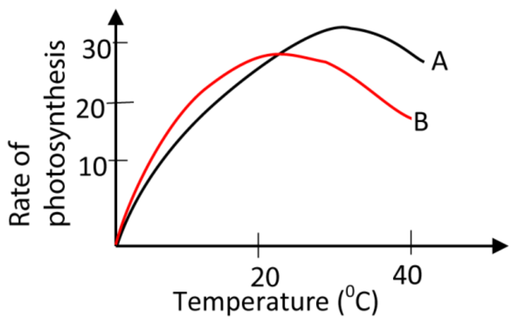
Temperature (^0C)	7	10	15	19	22	28
Rate of apparent photosynthesis ($mgCO_2g^{-1}h^{-1}$)	1.3	2.3	2.8	3.1	2.8	2.5
Rate of respiration ($mgCO_2g^{-1}h^{-1}$)	0.3	0.6	0.7	1.2	1.8	2.1

The temperature in ^0C, at which the plant is least efficient photosynthetically is

A 7
B 10
C 22
D 28 D

* At 28^0C, plant has least net gain in carbon (CO_2)

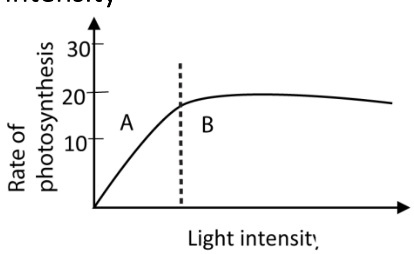
39. The figure below shows the relationship between temperature and the rate of photosynthesis in two plant species A and B.



Which one of the following is the correct conclusion from the result?

A B is a shade plant while A is a sun plant
B A has a lower compensation point than B
C A has a higher optimum temperature for photosynthesis than B
D Photorespiration does not occur in A but occurs in B C

40 The figure below shows the variation of rate of photosynthesis with light intensity



The factor limiting the rate of photosynthesis in region A is

A Light intensity
B Carbon dioxide concentration

C Water

D Temperature A

* Increase in light intensity increases the rate of photosynthesis

41 Which of the following action is most affected by low temperature?

A Absorption of light

B Splitting of water

C. Fixation of carbon dioxide

D Formation of ATP C

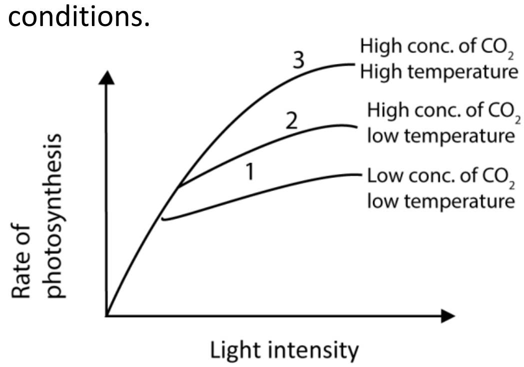
* Photosynthesis is divided into two main stages: the light-dependent reactions and the light-independent reactions (Calvin cycle).

The **light-dependent reactions** (absorption of light, splitting of water, and formation of ATP) are primarily photochemical processes and are not highly sensitive to temperature changes.

The **light-independent reactions** (the Calvin cycle), which includes the fixation of carbon dioxide, are a series of enzymatic reactions. The rate of enzyme-catalyzed reactions is highly dependent on temperature.

Low temperatures significantly slow down the activity of the enzymes involved in the Calvin cycle (such as RuBisCO), thus limiting the rate at which carbon dioxide can be fixed and reduced. Therefore, the fixation of carbon dioxide is the step most affected by low temperature.

42 The figure below shows the rate of photosynthesis of a plant at varying conditions.



Which factor is limiting photosynthesis in curve 2

A Carbon dioxide concentration

B pH

C Light

D Temperature D

* Increasing temperature increase the rate of photosynthesis

43 Which one of the following if increased to an Eldea plant in water at 30^0Cwould lead to a rise in number of bubbles released from the plant

A Light

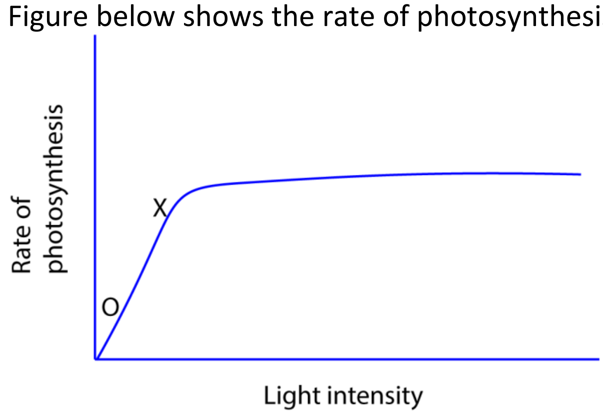
B Temperature

C Wind velocity

D. Humidity A

*
- The bubbles released from an *Elodea* plant during photosynthesis are oxygen (O_2) gas. The rate at which bubbles are produced is a measure of the rate of photosynthesis.
- The plant is already at 30∘, which is likely near or at the optimal temperature for the enzymes involved in photosynthesis.
- **Increasing Light:** If light is a limiting factor, increasing the light intensity will increase the rate of photosynthesis, and thus increase the number of oxygen bubbles produced. In a typical experimental setup under controlled conditions, light is often the limiting factor when other factors are optimal.
- **Increasing Temperature:** Increasing the temperature beyond the optimal 30∘C would likely denature the enzymes and *reduce* the rate of photosynthesis, not increase it.
- **Wind Velocity & Humidity:** Wind velocity and humidity primarily affect transpiration

44 Figure below shows the rate of photosynthesis against light



Which one of the following statements is the cause of flattening of the curve?

A Photosynthetic pigments are saturated with light

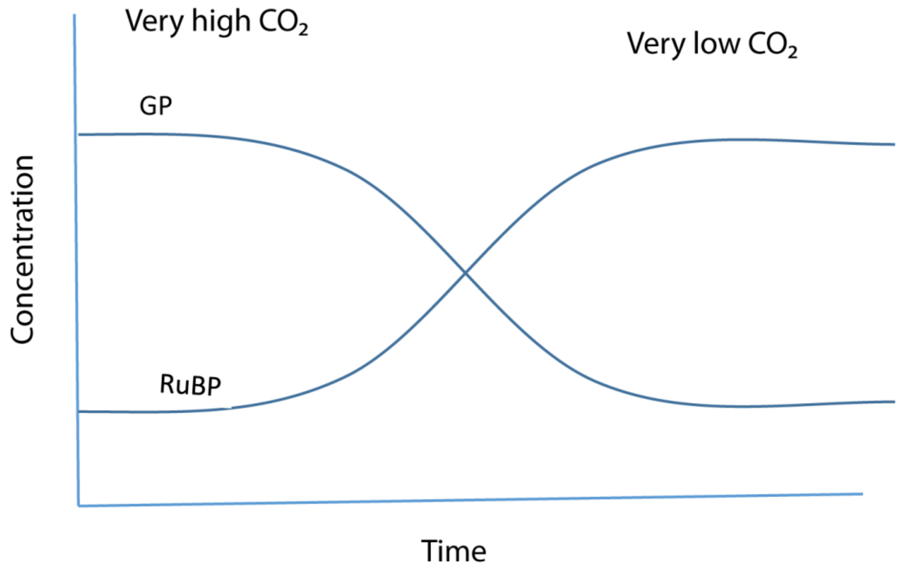
B To much carbon dioxide is available

C Plant has attained maximum rate of photosynthesis

D There is a factor other than light which is limiting the rate of photosynthesis D

Structured questions

45. Figure 7 show the concentration -3 phosphate (GP) and ribulose bisphosphate (RuBP) during an investigation in which a sample of chlorella was allowed to photosynthesis at very low and very high carbon dioxide levels.



(a) Explain the change in concentration of RuBP at

(i) High carbon dioxide levels

The concentration of RuBP is low. This is because RuBP combines with carbon dioxide and water to form glycerate- 3 phosphate (GP).

Note:

$$RuBP + CO_2 + H_2O \xrightarrow{\text{RuBP carboxylase}} 2GP$$

(ii) Very low carbon dioxide levels

The concentration of RuBP is high. This is because RUBP is being regenerated from triose phosphate, but since carbon dioxide concentration is low, RuBP is not being used hence it accumulates

(b) Suggest why the concentration of GP falls when the levels of carbon dioxide is reduced

Carbon dioxide combines with RuBP in the presence of RuBP carboxylase to generate GP. Hence low carbon dioxide levels lead low rate of formation of GP

(c) Name two factors which must have been kept constant in the investigation

Temperature

Light intensity

(d) Give **four** difference between cyclic and noncyclic photophosphorylation

Cyclic photophosphorylation	Non – cyclic photophosphorylation
Involves cyclic pathway of electrons.	Involves non –cyclic pathway of elections.
Photo system 1 is the first electron donor	Water is the first electron donor
Photo system 1 is the last electron acceptor	NADP is the last electron acceptor
Product is ATP only	Products are ATP, reduced NADP and oxygen.
Others Only photo system 1 is involved	Bothe photo system 1 and 11 are involved.

Note: phosphorylation is the process by which ATP is synthesized from ADP and an inorganic phosphate using energy.

In photosynthesis the energy is supplied by light, hence the process is called photophosphorylation. It can be cyclic or non- cyclic

The ATP is formed is formed in the light-dependent stage is used to transfer energy to the light independent stage.

46. (a) What is chemosynthesis? (1mark)

Chemosynthesis is the process by which organic compounds are synthesized from inorganic raw material using energy from oxidation of inorganic compounds.

(b) Outline three ways in which photosynthesis in purple sulphur bacteria differs from that of higher plants (3marks)

Purple sulphur bacteria	Higher plants
Source of hydrogen (reducing power) is hydrogen sulphide.	Source of hydrogen (reducing power) is water
Produce solid globules of sulphur as bi-product.	Produce O_2 as bi-product
Use bacteriochlorophyll as the pigment	Use chlorophyll as the pigment

(c) Explain why it is possible for photosynthetic and chemosynthetic bacteria to co-exist in an oxygen free environment? (3marks)

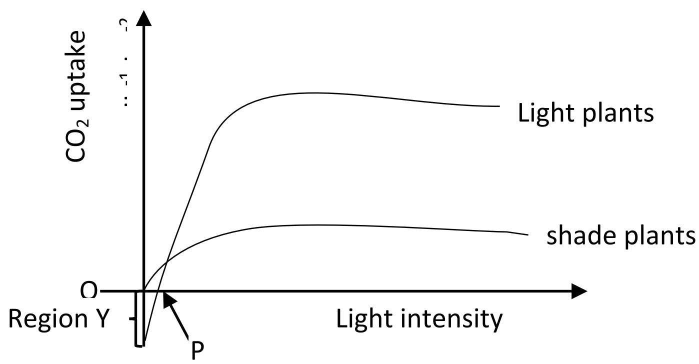
Photosynthetic bacteria release oxygen during photosynthesis, which they both use in respiration. They also produce organic compounds which are used by the chemosynthetic bacteria for metabolism.

Chemosynthetic bacteria produce inorganic substrate like hydrogen sulphide which are used by the photosynthetic bacteria in their metabolism

(d) State the importance of chemosynthetic bacteria in nature. (3marks)

- Chemosynthetic bacteria are important in the decomposition of nitrogenous waste in the environment and thus enrich the soil and water with nutrients.
- They release energy in their metabolism that is used by other organism in synthesis of organic compounds.
- They are producers manufacturing organic compounds that can be utilized by other organism.

47. The figure below shows light saturation curves of photosynthesis for plants of the same species growing under different light intensities.



(a) Compare the effect of intensity on the carbon dioxide uptake in the two types of plants. (4marks)

Similarities

Carbon dioxide uptake increase initially at low light intensities and the decreases gradually at higher intensities, to reach constant valves.

Differences

Light plants	Shade plants
- Initial rate of carbon dioxide uptake is high at low light intensities - Carbon dioxide uptake starts below zero. - reach a constant at a higher light intensity. - higher saturation value	- Initial rate of uptake carbon dioxide is high at low light intensities - Carbon dioxide uptake starts at zero - reach a constant at a lower light intensity. - lower saturation value

(b) Describe the state of the light plants at point P. (2marks)
The plant is in a state of compensation point at point P. Here is no net uptake of carbon dioxide because the rate of photosynthesis equals the rate of respiration.

(c) Explain what happens to the plant biomass in region Y. (2marks)
In region Y the plant biomass decrease

Explanation

The rate of respiration of the plants is higher than photosynthesis. There is more food breakdown than synthesis.

(d) State an environmental factor that affects the shape of the graph other than carbon dioxide (2marks)
Temperature

48. (a) How does the synthesis of organic compounds in photosynthetic bacterial differ from that in

(i) Green plants (2marks)

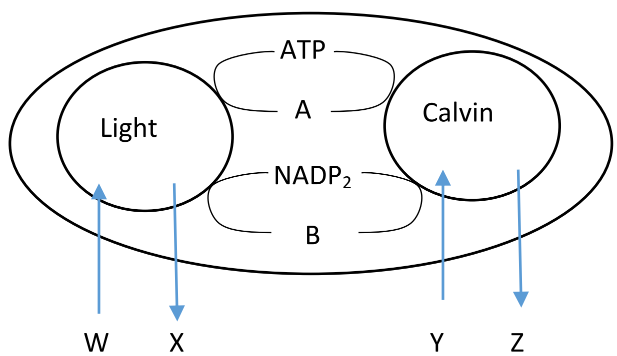
- The hydrogen for reducing carbon dioxide comes from hydrogen sulphide while in green plants, the hydrogen come from water.

- Oxygen is not given off during the synthesis of organic compounds in photosynthetic bacteria as it is in green plants

(ii) Chemosynthetic bacterial? (2marks)

- They obtain energy from sunlight while chemosynthetic bacteria obtain the necessary energy from oxidation of inorganic compounds other than sugar.
- They do not give off any gaseous product during the processes while some chemosynthetic bacteria give off methane gas.

(b) The figure below shows a scheme of reactions occurring in a chroplast during photosynthesis.



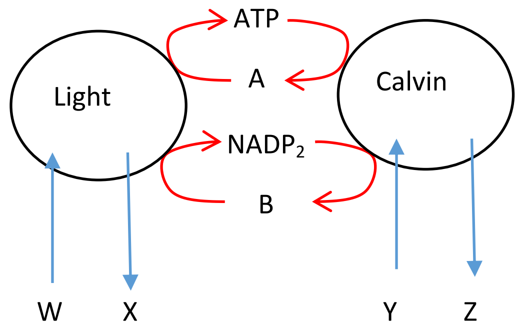
(i) Name the chemical substances represented by letters W, X, Y and Z (2marks)
W-water

X- oxygen

Y – Carbon dioxide

Z- phosphoglyceradehyde (PGAL)/carbohydrate

(ii) Indicate by means of arrows on the diagram, the direction of transfer of substances occurring in cycles A and B (1mark)

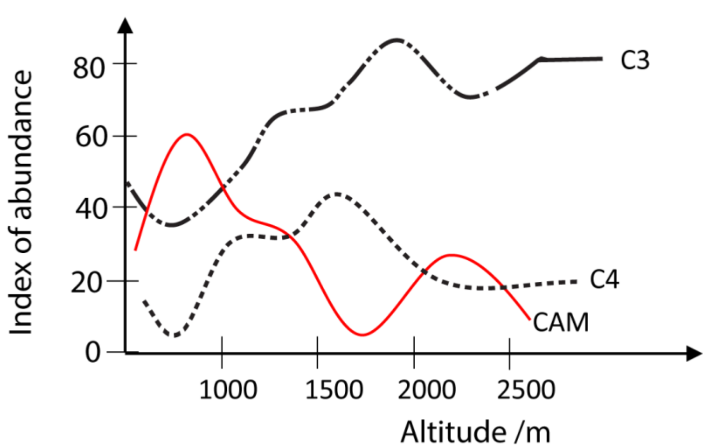


[NB: The candidates should indicate the arrow on the diagram in the question.

(c) State **three** adaptations of a chloroplast for photosynthesis. (3marks)

- It contains chlorophyll molecules which trap sunlight energy for use in the process of photosynthesis.
- it contains thylakoid membranes arranged into coin-like stacks called grana to increase surface area for packaging of chlorophyll molecules
- it contains enzymes necessary for fixation of carbon dioxide.

49. Figure below shows the distribution of C3, C4 and CAM plants at altitudes



(a) Suggest reasons for the trends in the distribution of each of the plants

(i) C3 plants (2marks)

Are more abundant at high altitude.

Reason (s)

At high altitude, the partial pressure of oxygen and temperature are lower. This reduces competition between carbon dioxide and oxygen for RUBP carboxylase enzyme and enhance carbon dioxide fixation. Thus, C3 plants are more abundant at high altitude where they can photosynthesis more efficiently at low temperature

(ii) C4 plants (2marks)

Are more abundant at mid-altitude levels

Reason (s)

due favorable mild temperature

NB PEP carboxylase is not affect by oxygen concentration, temperature is the major limiting factor of photosynthesis in C_4 plants.

(iii) CAM plants (2marks)

Are more abundant at low attitudes

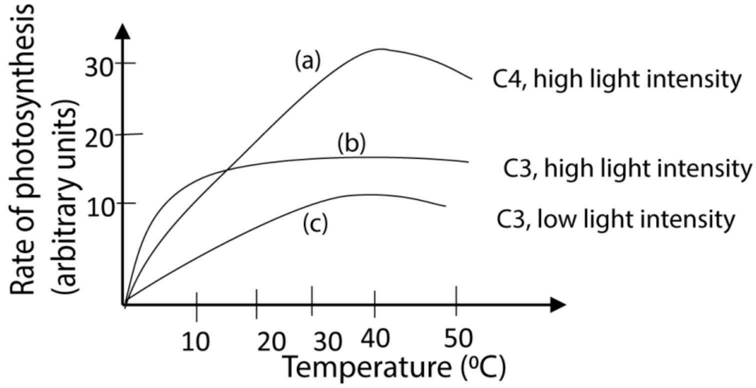
Reason (S)

CAM plants adapted to photosynthesizing more efficiently at higher temperatures. Such temperature can only be experienced at low altitudes, explaining their more abundance there.

(b) State **four** physiologic differences between C3 and C4 plants (4marks)

C_3 plants	C_4 plants
Carbon dioxide acceptor is RUBP	Carbon dioxide acceptor is PEP
First stable product is PGA	First stable product is Oxaloacetic acid (OAA).
Photorespiration occurs	Photorespiration does not occur.
Requires 18 ATP for the synthesis of one glucose molecule	Require 30 ATP for the synthesis of one glucose molecule.

50. The figure below shows the variation of the rate of photosynthesis with temperature in C3 and C4 plants, at different light intensities



(a) Using the figure, state how different temperatures affect the rate of photosynthesis in C3 plants from C4 plants at high light intensity.
(3marks)

C3 plants	C4 plants
Optimum temperature (35^0C) is lower	Optimum temperature (40^0C) is higher
Low maximum rate	High maximum rate
At temperature below 10^0 C, C_3 plants have a higher rate of photosynthesis than C_4 plants	At temperature below 10^0 C, C_3 plants have a lower rate of photosynthesis than C_3 plants
At temperature above 20^0 C, the rate of photosynthesis in C_3 plants is lower than that in C_4 plants.	At temperature above 20^0 C, the rate of photosynthesis in C_4 plants is higher than that in C_3 plants.

(b) Explain the differences in the effect of temperature on the rate of photosynthesis in C3 and C4 plants at high light intensities stated in (a) (03marks)

- In C_3 plants, plants, increase in temperature reduces the affinity of RUBP carboxylase for carbon dioxide but increase its affinity for oxygen. As a result, more CO_2 is lost and less is fixed photosynthesis.
- PEP- carboxylase's affinity for carbon dioxide in C_4 is not affected by temperature. Instead, temperature increases the rate of the enzyme action by increasing the kinetic energy of the reacting molecules and enhances the process of photosynthesis.

(c) Explain the pattern of curve C in the figure above. (04marks)

Rate of photosynthesis increases gradually, until a maximum at about 35^0 C and then decreases rapidly at higher temperature.

Explanation

- The rate of reaction increase with temperature up to 35^0C the optimum temperature because the enzymes are being activated
- The maximum rate attained is low because at high temperature, RUBP carboxylases gives up CO_2 and pick up O_2. CO_2 then lost in photorespiration.
- Above the optimum temperature the rate drops because the enzymes are denatured.

51. (a) Giving examples, differentiate between photosynthetic and chemosynthetic bacteria.

Photosynthetic bacteria manufacture carbohydrates from hydrogen sulphide, carbon dioxide using light energy. Example is cyanobacteria

(H_2S) as electron donor instead of water

$$CO_2 + 2H_2S \longrightarrow C(H_2O) + 2S$$

They do not give off oxygen

Chemosynthetic bacteria manufacture carbohydrates from water and carbon dioxide using energy from oxidation of chemicals such as ammonia. Example is nitosomonas, iron bacteria, hydrogen bacteria

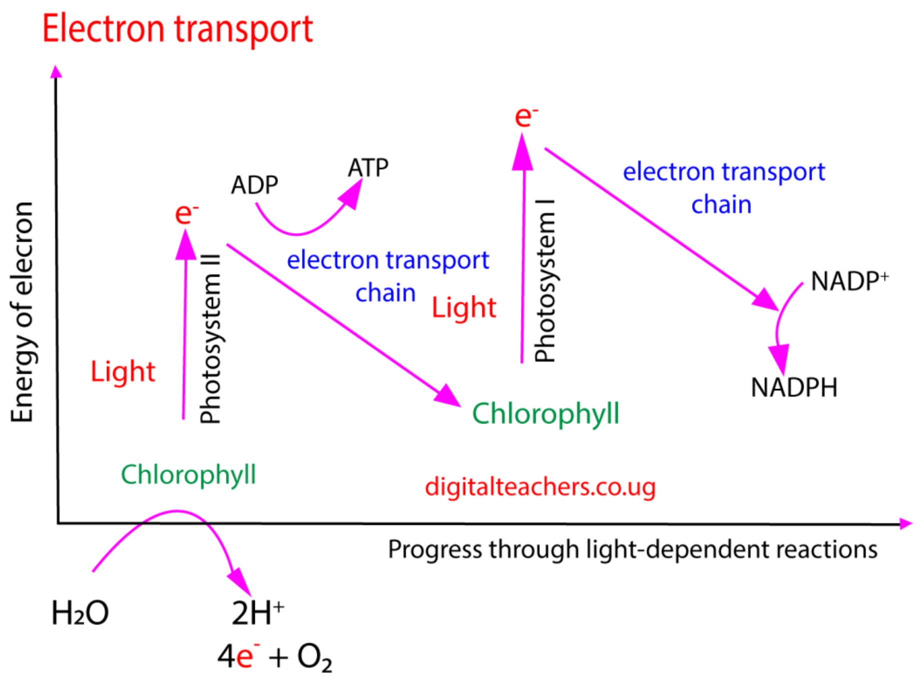
(b) Explain how certain bacteria which require light for photosynthesis, survive under weeds in ponds and rocks

The bacteria chlorophyll absorb light of different wavelengths optimum for photosynthesis from that used by the plants thus, bacteria find the spectrum useful after the plants have filtered out light for photosynthesis. Secondary, the rocks supply hydrogen sulphide.

52. (a) Name the two stages of photosynthesis indicating where, in the chloroplast, they occur.

- light stage occurs in thylakoid membranes
- dark stage occur in stroma

(c) By means of a flow diagram, show the sequence of electron flow during noncyclic photophosphorylation.



Non cyclic photophosphorylation

Chlorophyll molecule PSII is struck by light, an electron is excited and captured by an electron acceptor, passes through an electron carrier system and handed to chlorophyll molecule PSI

The flow of electrons from PSII to PSI in thylakoid membrane causes accumulation of H^+ inside the thylakoid space creating a gradient. The passage of H^+ out of the thylakoid provides energy to synthesise ATP.

53. (a) What is photophosphorylation? (2marks)

Photophosphorylation is the formation of ATP from ADP and inorganic phosphate using sunlight as the source of energy.

(b) Where in the plants cell does cyclic photophosphorylation occur (2mark)
Cyclic photophosphorylation occurs in thylakoid membranes in chloroplast.

(c) Describe the process of cyclic photophosphorylation (5marks)

(i) Light strikes chlorophyll molecule PSI

(ii) an electron is excited, passes through electron carrier system and return to PSI

(iii) in the process, H^+ builds up in the thylakoid space creating a gradient. Then the passage of H^+ out of the thylakoid provides energy for synthesising ATP.

(d) Importance of cyclic photophosphorylation in photosynthesis. (2marks)

Produces ATP when NADPH is not necessary

54. (a) Name the organelle most important in photosynthesis and respiration

(i) Photosynthesis - chloroplast

(ii) Respiration - mitochondria

(b) Give four differences and five similarities between the two organelles

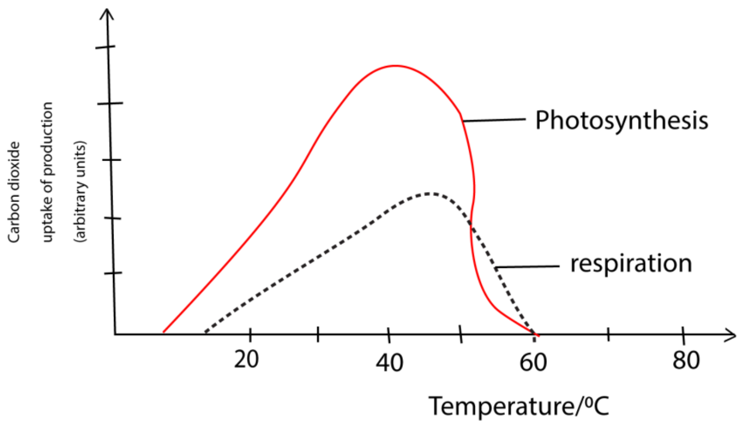
(i) Differences

Mitochondria	chloroplast
Has no chlorophyll	Has chlorophyll
Break down sugars	Synthesise sugars
Inner folding called cristae	Inner folding called thylakoid membranes
colourless	Green
Bean shaped	Disc shaped
Present in plants and animal	Present in plants

(ii) Similarities

- Both have circular DNA
- Both have a double membrane
- Both have extensive membrane system
- Both have a matrix
- Both produce ATP
- Both reproduce by cell division

55. The figure below shows the effect of temperature on the rates of photosynthesis and respiration in well illuminated leaves



(a) Compare the effect of temperature on the rates of photosynthesis and respiration. (04marks)

similarities

- In both photosynthesis and respiration, the rates increase to the maximum and then drop to zero.
- Both have equal CO_2 uptake/production at 50^0C and 60^0C.

Differences

- The rate of photosynthesis starts to rise at a lower temperature than in respiration
- The rate of photosynthesis reaches a maximum at a lower temperature (40^0C) than that of respiration (45^0C).

(b) Explain the shapes of the curves (06marks)

Explanation

- In both, the rate of photosynthesis and respiration increase with temperature to the maximum because the enzymes become more active as temperature increases.
- After the maximum the rates decrease because the enzymes are denatured by high temperature.
- The maximum rate of photosynthesis is reached at lower temperature because the enzymes for photosynthesis have lower optimum temperature.
- Photosynthesis consumes more carbon dioxide than produced by respiration because some sugars are stored and not respired.

Paper 2 revision questions

56. (a) Giving examples in each case, explain what is meant by each of the following

(i) Saprophytes (2½ marks)
Saprophytes are organisms which feed on dead/decaying organic matter. Examples include bacteria, fungi and protists.

(ii) Chemoautotrophs (2½ marks)
Chemoautotrophs are organisms which synthesis organic matter using energy obtained from oxidation of inorganic materials such as ammonia. For example, nitrosomonas and nitrobacter

(b) Compare saprophytes and parasites (10marks)

Similarities

- Both are heterotrophic
- Both produce large number of offspring.
- Both have sexual and asexual phases in their reproductive cycle.
- Both have digestive enzymes.

Differences

Saprophytes	Parasites
Derive energy from decaying organic matter	Derive energy from living organisms
Involve a single adult stage and spores in life cycle	Involve many stages in their life cycle
Use a variety of food sources	Usually very specific to their hosts
Have simple method of nutrition	Have a complex method of feeding
Almost totally bacteria and fungi	Most plant and animal groups have representatives
There are aerobic and anaerobic forms.	Most are aerobic

(c) Explain the importance of saprophytism to human life (5marks)
Saprophytism is important to human life in the following ways;

(i) Recycling of materials by feeding on decaying organic matter, the saprophytes unlock and recycle nutrients which would otherwise have been lost with the dead organisms.

(ii) Decomposition of sewage or waste; saprophytes aid the decomposition of waste produced by human activities. By this the bulk of the waste is reduced and nutrients made available to crops.

(iii) Some saprophytes, especially fungi are used as food by man.

(iv) Physiological processes of saprophytism and as fermentation are useful in brewing and baking.

(v) The production of yoghurt and cheese from milk also employs saprophytic mechanisms.

(vi) Some saprophytes are used in the production of antibiotics.

(vii) Industrial processes such as leather tanning and production of some vitamins make use of saprophytic organisms.

57. (a) How is the chloroplast suited for its function? (08 marks)

- It contains chlorophyll molecules which trap sunlight energy to be used in of photosynthesis.
- It contains thylakoid membranes arranged into coin-like stacks called grana to increased surface area for packaging of chlorophyll molecules.
- It contains enzymes necessary for fixation of carbon dioxide.
- Contain thin membrane for diffusion of gases

(b) Describe the modification of the parenchyma tissue in different parts of a plant, to suit its function. (05marks)

- In roots (e.g., carrots, sweet potatoes), stems (e.g., potatoes, sugarcane), fruits (e.g., apples, pears), and seeds the parenchyma are modified for storage. The cells are large, often lack chloroplasts, and contain a large central vacuole that can store a variety of substances.
- Due to presence of storage granules and intercellular spaces, they absorb water, become turgid and tightly packed and so provide support for the organs in which they form the main means of support.

- In floating plant roots, stems and leaves Parenchyma cells develop large, interconnected **air spaces** (aerenchyma or canals between them) for providing buoyancy.
- A system of air spaces runs from the external environment where they open as stoma (in leaves) or lenticel (in stems). These air spaces run between cells and allow gaseous exchange to take place between living cells and the external environment.
- Parenchyma cells may be flattened to form a one-cell thick layer that covers most parts of the plant as epidermis. This is usually covered with wax and helps to protect the plant from desiccation.
- Photosynthetic parenchyma, also called collenchyma, contains chlorophyll that traps light energy for the process of photosynthesis. It is usually found in the palisade layer of leaves exposed to sunlight.
- Companion cells are specialized parenchyma cells found adjacent to sieve tubes and are vital for the functioning of the latter. They are very active metabolically and how the denser cytoplasm, larger nucleus and smaller vacuoles than normal parenchyma cells denser exposed to sunlight.
- **Secretory Cells:** Some parenchyma cells are modified to produce and secrete substances like nectar, resins, or oils.

(c) Explain the distribution of mechanical tissue in plants. (7marks)

Mechanical tissues in plants constitute the tissues that are responsible for supporting the plant above the ground.

- In the non-woody herbaceous plants, parenchyma serves as the mechanical tissue. It is distributed in the cortex, pith and packing tissue in xylem and phloem. In this position they offer support to the stem when turgid and keep it above the ground.
- In woody plants, mechanical tissue consists of collenchyma and sclerenchyma which has more mechanical strength than parenchyma is located in the cortex,

pith, phloem and xylem at this position, they provide enough tensile and compressional strength that allows the woody plants to withstand the stresses of the atmosphere.

- Sclerenchyma and collenchyma tissue also form mechanical tissue around the vascular bundles. This allows the vascular bundles to remain open in order to continually transport material within the plant.

58. (a) Explain how plants living under the canopy of forest trees are able to survive (15marks)

(i) Some have adopted a parasitic mode of life and are found developing from the stems of tall forest trees as epiphytic feeders.

(ii) Some have climbing stems. This makes them capable of reaching out to light by growing their leaves beyond the forest canopy.

(iii) Some have breathing roots that grow up from the water logged soils to allow for proper gaseous exchange.

(iv) Some plants such as the ferns have tissues that are well adapted to live in the water logged soils of the forest.

(v) Some plants are well adapted to photosynthesize at low light intensities below the forest canopy.

(vi) Some plants form symbiotic relationships with the forest trees and other saprophytic organisms (such as fungi) in order to obtain enough nourishment.

(vii) Some have adopted C_4 photosynthetic pathway, making them more efficient at photosynthesis.

(viii) Most plants have a higher chloroplast density in their leaves compared to the tall forest tress. This makes them efficient at trapping the low light that reaches them below the forest canopy.

(ix) Some plants are more efficient at trapping and utilizing light of different wavelength from that trapped by the tall trees. Thus, they can still be able to receive this after the tall trees have trapped the rest from the light spectrum.

(x) Some of the plants such as the insectivorous plants are heterotrophic feeders and so require a minimum amount of light which they can sufficiently receive even below the forest canopy.

(xi) Most plants possess an extensive surface root system in order to obtain enough aeration in the water logged forest soils.

(xii) Most plants are seasonal with short life cycle, growing only when conditions are favorable especially when deciduous trees lose leaves and allow penetration of light.

(xiii) Some plants are able to adjust the angle of their leaves towards light

(b) Describe how herbaceous plants are supported of the ground. (5marks)

After the absorption of water, the cells in the plant become turgid because of the relatively inelastic cellulose cell wall. This results in a firm tissue which provides mechanical support to the plant. This is supplemented by smaller quantities of mechanical tissues (collenchyma, sclerenchyma and xylem)

59. (a) Compare photosynthesis and aerobic respiration. (9marks)

Similarities

- Both are energy converting processes.
- Both require mechanisms for exchange of carbon dioxide and oxygen.
- Both processes have a reaction pathway in which ATP is formed i.e. photo phosphorylation and oxidation phosphorylation in photosynthesis and respiration respectively.
- Bother processes involve enzyme-controlled reactions.
- Both require special organelles in eukaryotes, chloroplasts for photosynthesis and mitochondria for respiration.
- Both processes are affected by temperature.

Differences

Aerobic respiration	Photosynthesis
A catabolic process (involves breakdown of carbohydrates into simple of sugar) inorganic compounds.	An anabolic process which results in synthesis of carbohydrate molecules from simple inorganic compounds.
Energy is incorporated into ATP for immediate use	Energy is accumulated and stored in carbohydrates
Oxygen is used up	Oxygen is released
Carbon dioxide and water are released	Carbon dioxide and water are used up
Process occurs in decrease in dry mass	Results in increase in dry mass
Process occurs in mitochondria in eukaryotes	Process occurs in chloroplast in eukaryotes
Takes place continuously throughout life and is independent of chlorophyll and light	Occurs only in cells possessing chlorophyll and only in the presence of light.

(b) Explain the effect of low oxygen tension on

(i) C3 plants (3marks)

Low oxygen tensions stimulate photosynthesis in C_3 plants due to reduced competition between oxygen and carbon dioxide for the active site of ribulose -1, 5-biphosphate (RUBP) carboxylase enzyme.

(ii) C4 plants (2marks)

Low oxygen tensions have no effect on the rate of photosynthesis in C_4 plants because the active site of phosphoenol pyruvate (PEP) decarboxylases enzyme does not accept oxygen.

(c) Explain why c4 plants are more efficient in photosynthesis than C3 plants. (06marks)

- In C4 plant PEP carboxylase fix CO_2 and delivers it to the enzyme **RuBisCO** at high concentration resulting in high rate of photosynthesis.

- Photorespiration in C4 plants is negligible because PEP carboxylase does not accept oxygen
- C4 plant are able to photosynthesize at high rates at high temperature because they do not experience photorespiration

60. (a) (i) What are chemotrophic bacteria? (1marks)

Chemoheterophic bacteria are bacteria which use externally obtained chemical substances as their source of food and energy. They are not capable of manufacturing their own food

(ii) Give three groups of bacterial in (a) (i) (3marks)

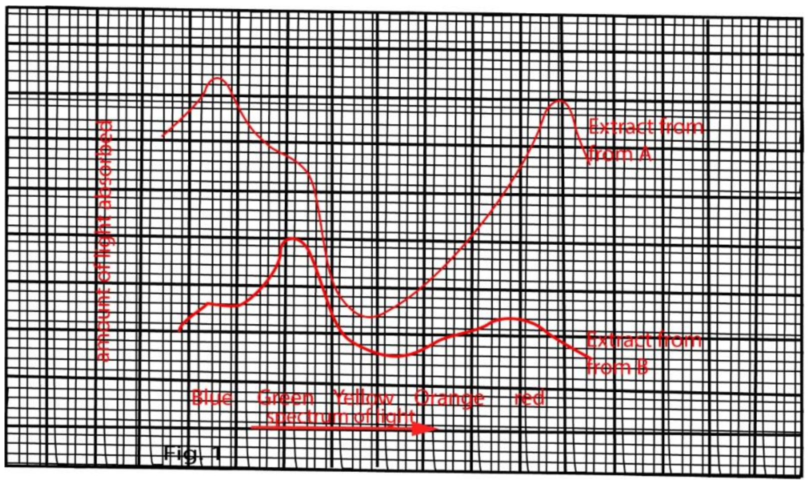
- Saprophytic bacteria
- Parasitic bacteria
- Symbiotic bacteria.

(b) Using examples, explain the ecological importance of each of the groups in (a) (ii) in an ecosystem

- **Saprophytic bacteria** derive organic materials from decomposition of dead and decaying organic matter. Examples include; putrefying bacteria. They decompose dead bodies of plants and animals and covert their complex body building compounds into simpler substances. These are taken up by green plants and used to synthesize new organic compounds. In this way these bacteria help in recycling of materials which would otherwise have been lost from the ecosystem.
- **Parasitic bacteria** are important in causing disease to organisms in the ecosystem. They include cocci and bacilli. They diseases that may lead to death of non- resistant organisms in ecosystem. This leads to population regulation and reduction in competition for resources in the ecosystem. It may also lead to emergency of new species in the ecosystem.
- **Symbiotic bacteria** live in association with other organisms, deriving benefit from the and causing no harm to them. For example, a rhizobium bacterium which lives in association with roots of leguminous plants fixes nitrogen from the atmosphere into nitrates in the soil. These can then be utilized by plants and other organisms in the

ecosystem. Cellulose producing bacteria in the gut of wood eating ants derive shelter from the ants but produce cellulose enzyme that helps the ants to utilize cellulose in their diets. They thus help in recycling of nutrients locked in the cellulose of mood.

61. Two groups of maize seed were germinated and grown in different culture solution. Group A were provided with a complete nutrient solution while group B were provided with a solution lacking magnesium. An extract of photosynthetic pigment was made from leaves of each group of seedlings at the end of three weeks. Fig 1 is the absorption spectrum from the extracts.



In another experiment, six identical shoot of pond weed were placed in separate test tube of pond water in which a dilute solution of sodium hydrogen carbonate had been added. Each test tube was exposed to light which had passed through different coloured filter. The light in all cases was from a 40 watt bulb, placed 40cm from each test tube. The time taken for 20 bubbles to leave the cut end of each shoot was recorded three times and average results were recorded in table 1

Table 1

Colour filter	Average time taken to release 20 bubbles in seconds	Number of bubbles released per minute
Violet	58	
Blue	40	
Blue-green	62	
Green	132	
Yellow	96	
Orange-red	70	

Use the information to answer the questions that follow

(a) Compare the light absorption by extracts from Group A and that of Group B across the light spectrum. (8marks)

Similarities

- Both have two absorption peaks
- Light absorption by extracts from both groups A and B is greater in blue, green and red light and least in yellow light across the spectrum.

Differences

Extract A	Extract B
Across the spectrum, light absorption by extract from group A is greater than that from group B	Across the spectrum, light absorption by extract from group B is lower than that from group A
Peak absorption at blue	Peak absorption at green
the order of absorption is blue > green > orange >> yellow	the order of absorption is green > blue > red > orange > yellow.

(b) Explain the light absorption across the light spectrum for each extract.(9marks)

Extract from group A

Chlorophyll molecules in extract from the group A are well formed because of the adequate amount of nutrients (including magnesium) and therefore capable of absorbing enough light energy for photosynthesis. Being a green molecule, chlorophyll absorbs most of the other colours of the spectrum but reflects green and yellow.

Extract from group B

Extract from group B has inadequate amount of magnesium so that chlorophyll molecules formed are incomplete. Such molecules are less efficient in absorbing light energy for photosynthesis. The photosynthetic pigment formed is yellowish and has a poor absorption capacity for the colour of the light spectrum compared with the green pigment of the extract from group A. however it absorbs other colours of the spectrum better than yellow which is reflected.

(c) How does a coloured filter affect light passing through it? (1mark)
A color filter works by absorbing certain wavelengths of color and transmitting the other wavelengths. For example, a yellow color filter absorbs all colors except yellow, letting only yellow through, so the objects viewed appear to be yellow. If a blue light from a blue filter hits a red object, the blue color is absorbed and the object reflects no light, making it appear to be black.

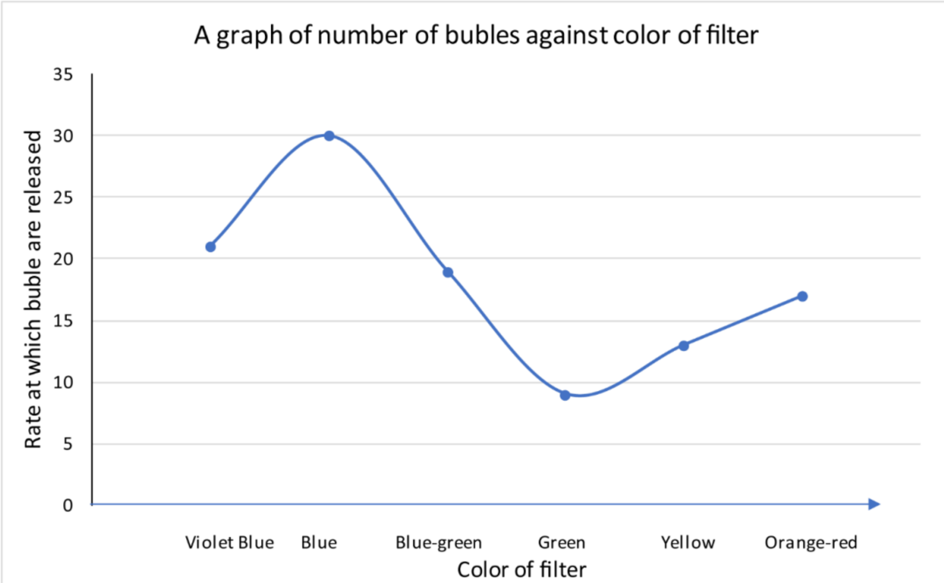
(d) (i) Copy and complete Table 1, by calculating the number of bubbles released by each shoot per minute. (3marks)

1 minute = 60 second
For violet
58 seconds produce 20 bubles
Hence 60 seconds/1minute produce $=\frac{20\times60}{58} = 20.7 \approx 21$

The other values in the table can be determined in the same way,

Colour of filter	Average time taken to release 20 bubble in seconds	Number of bubbles released per minute
Violet	58	21
Blue	40	30
Blue-green	62	19
Green	132	9
Yellow	96	13
Orange red	70	17

(ii) Plot a graph to show the relationship between the colour of the filter and the rate at which bubbles are released. (6marks)



(e) (i) compare your graph with that in figure 1, and state the relationship between the two;

In both graphs, the absorption of light is higher in the violet-blue and orange ranges and minimum in the green-yellow-range of the light spectrum.

(ii) What conclusion can you draw from the relationship? (2marks)

- Violet-blue and orange-red ranges of the spectrum favour the process being investigated better than the other colours.
- Chlorophyll absorbs light well in the violet and orange red regions of the spectrum which energy is used in photosynthesis.

(f) State what would be observed if the distance between the bulb and the test tubes was gradually reduced. Explain your answer. (4marks)
The number of bubbles produced per minute would increase and then reach a maximum and become constant rate due to increased light intensity. A maximum rate is reached when other factor other than light intensity limit the reaction

(g) Explain why
(i) the type of bulb and the distance of the bulb from the test tube were kept constant (1mark)
to maintain a constant temperature and light intensity reaching the test tube.

(ii) a dilute solution of sodium hydrogen carbonate was added to pond water in the test tubes. (2marks)

To produce carbon dioxide that is used by the plants during photosynthesis.

(iii) There were three measurements made on each shoot rather than a single one (1mark)

To minimize statistical errors

(iv) Measuring the rate of photosynthesis by counting bubbles in not accurate (1marks)

- Some oxygen produced could have been used in respiration

62. In an experiment to determine the factors affecting photosynthesis, seedlings of a plant were divided into two groups and grown at a constant high light intensity (25 arbitrary units), another group grown at a constant low light intensity (3 arbitrary units). When the plants were mature, their apparent rates of photosynthesis in milligrams of oxygen released per unit leaf are per hour, were measured over a range of different light intensities

Figure 1 shows the results of the experiment. In addition, some characteristics of the two groups of plants were recorded on table 1

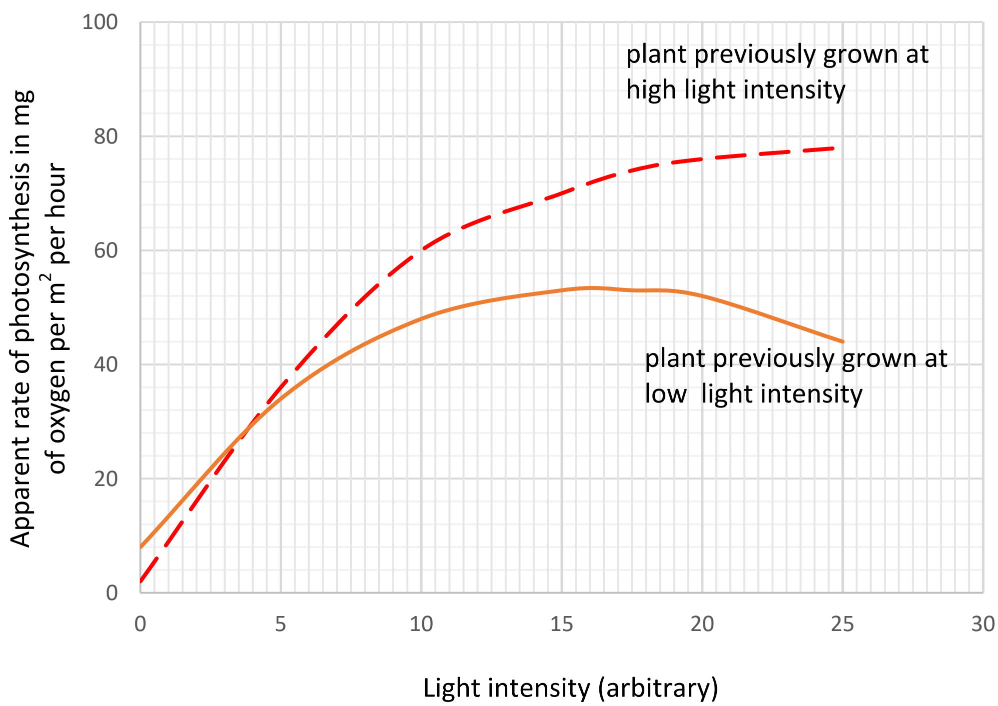


Table 1

Groups of plants	Characteristics
Plants grown at high light intensity	Big, dark green leaves with short internodes
Plants grown at low light intensity	Small, pale yellow leaves with long internodes

(a) From the graph, state

(i) differences in the effect of light intensity on the groups of plants (8marks)

Plants previously grown at low light intensity	Plants grown at high light intensity
Photosynthetic rate is generally lower	Photosynthetic rate is generally high
Photosynthetic rate reduces at high light intensities	Photosynthetic rate increases and peaks at higher light intensities
Optimum light intensity for photosynthesis is lower	Optimum light intensity for photosynthesis is higher
Peak photosynthetic rate lower	Peak photosynthetic rate higher
Photosynthetic rate is higher at lower light intensities.	Photosynthetic rates are lower at low light intensities
Increase in photosynthetic rates with light intensities is gradual	Increase in photosynthetic rate with light intensities is rapid

(ii) similarities in the effect of light intensity on the two groups of plants. (3marks)

- Increase in light intensities cause increase in photosynthetic rate at lower light intensities in both cases
- In both there is optimum light intensity at which photosynthetic rates remain constant called the peak photosynthetic rate.
- In both groups, photosynthetic rate is low at lowlight intensity

(b) Suggest explanation for the differences you have stated in (a) (i). (8marks)

Plants grown previously at high light intensity generally have high rate of photosynthesis at high light intensities because are well adapted to trapping and utilization of light energy for photosynthesis than those previously grown at low light intensity, i.e.

- They have more chloroplasts for trapping sunlight energy.
- Have high stomata density to increase the rate of gaseous exchange and prevent overheating at higher light intensity
- Has much carotenoid to prevent damage to chlorophyll from very bright light.

Plants previously grown at low light intensity have high photosynthetic rate at low light intensities because

- Its enzyme have low optimum temperature
- Has thin leaves to maximize light penetration
- Long internodes exposes each leave to light
- Low stomata density reduces heat low to avoid over cooling.

(c) Explain the pattern of the curve for plants grown in low light intensity. (6marks)

- Initially the of photosynthesis increase with temperature (0.5 -4 unit light intensity), because increase in light intensity increases the rate excitation of electrons from PSI and PSII leading to production of ATP and NADPH for the dark reaction.
- The rate of photosynthesis then slows up because other factors other than light (such as amount of chlorophyll, temperature/carbon dioxide concentration) limit the rate.
- The rate of photosynthesis then drops because at very high light intensity, high temperature denatures the photosynthetic enzymes.

(d) Explain the observed characteristics of the two groups of plants as indicated in table 1. (9marls)

Plants previously grown at low light intensity have

- Have pale leaves because they have low density of chlorophyll
- Have small leaves are due to low rate of photosynthesis producing less nutrient to build structures
- Long internodes to allow increase in length to search for light.

Plants previously grown at high light intensity

- Have dark leaves due to high density of chloroplast
- Have broad leaves due to available nutrients from photosynthesis
- Broad leaves to provide large surface area to trap light

(e) Suggest why:
  (i) Seedlings of the same plant were used in the experiment. (2marks)
  to minimize errors due to genetic composition
  (ii) The rate of release of oxygen was used to measure the rate of photosynthesis. (2marks)
  oxygen is easier to quantify.

(f) Name two factors that may limit the rate of photosynthesis of plants previously grown in high light intensity, if subjected to light intensity above 25 arbitrary units. (2mark)

– temperature
- Chlorophyll
- Carbon dioxide concentration

63. (a) How does a bacteria cell differ from that of a higher plant? (5marks)

Bacterial cell	Plant cell
Independent single celled organism	Is the structural and function unit of plant
Prokaryotic cell	Eukaryotic cell
Cell wall made of murine	Cell wall made of cellulose
Has no membrane bound nucleus	The nucleus is double membrane
Respiration occurs in mesosome	Respiration occurs in mitochondria
DNA single strand	DNA double strand
Ribosome 70S	Ribosome 80S
Lack chlorophyll	Has chlorophyll
Lacks vacuole	Has permanent vacuole
Sexual reproduction by conjugation	Sexual reproduction by fusion of gametes
Small in size	Big in size

(b) Giving Examples, describe the different nutritional groups of bacteria. (5marks)

No.	Nutritional type	Source of energy	Source of carbon	Source of hydrogen	examples
1	Photoautotrophs	Sunlight	CO_2	H_2S	Green sulphurbacteria
2	Photoautotrophs	sunlight	CO_2	H_2O	cyanobacteria
3	photoheterotroph	Light	Organic compounds	Organic compounds	Purple non sulpur bacteria
4	Chemoautotrophs	Inorganic compounds such	CO_2	H_2O	Nitrifying bacteria,

		as NH_3, NO_2, H_2, H_2S			nirobacter
5	heterotrophs	Organic compound	Organic compounds		Most bacteria

(c) Discus the importance of bacterial in nature. (10marks)

A. Harmful effects

(i) Bacteria are agents of disease of animals and plants such as syphilis, cholera, tetanus

(ii) Bacteria cause milk and food deteriorate

(iii) Denitrifying bacteria such as Thiobacillus lead to deterioration of soil fertility.

B. Useful effects

(i) Saprotrophic bacteria cause decay of waste materials and lead to formation of humus and recycling of minerals. E.g. Bacteria (Nitrosomonas and nitrobacter) convert organically combined nitrogen (e.g. protein) to nitrate which are absorbed by plants.

(ii) Nitrogen fixing bacteria e.g. Azobacter fix nitrogen into the soil.

(iii) Aerobic and anaerobic bacteria are useful in digestion of sewage into harmless substances. Methane gas given off is sometimes used for fuel.

(iv) Mutualistic bacteria in ruminants' assist ruminants to digest cellulose, and synthesis of vitamin K and B group.

(v) Some bacteria on the skin of humans enable it to obtain protection again inversion of pathogenic organism

(vi) Bacteria and fungi are useful for making of cheese.

(vii) Used for production of useful chemicals in genetic Engineering such as insulin

64. (a) Distinguish between a bacterium and a plant (6marks)

Differences between bacteria and plant cell

bacterium	Plant
Unicellular organism	Multicellular organism
Nuclear membrane absent	Nuclear membrane present in all cells
DNA is circular and lies free in the cytoplasm	DNA is linear and contained in a nucleus
Membrane bound organelles absent	Membrane bound organelles present

DNA is naked	DNA is associated with proteins to form chromosomes.
Ribosomes are smaller (70S	Ribosomes are larger (80S)
Ribosomes lie free in the cytoplasm	Ribosomes may be attached to endoplasmic reticulum
Mitochondria absent. Respiration carried out by mesosomes	Mitochondria are responsible for aerobic respiration
When present, cell wall is the non-cellulose type, composed of amino sugars and muramic acid.	The cell wall is composed of cellulose

(b) Explain the ecological significance of different nutritional types of bacteria (07marks)

(i) Chemo-heterotrophic bacteria use chemical substance obtained externally as their source of food and energy. They are of vital ecological importance depending on their activities in the ecosystem as illustrated;

- **Saprophytic bacteria**; these derive organic materials from dead decaying organic matter. Examples include, putrefying bacteria. These bacteria are the main organisms to decay. They decompose dead bodies of plants and animals and covert their complex compounds into simpler substances which are taken up by green plants for the synthesis of new complex organic compounds, in this way, these bacteria help in the cycling of matter which would otherwise have been lost from the ecosystem.
- **Symbiotic bacteria;** several bacteria are found in nature in symbiotic relationship with man and other animals. Cellulose-producing bacteria in the gut of wood-eating ants offer the best example. In exchange for shelter provided by the ants, these bacteria help to produce cellulose enzyme that helps these organisms to utilize cellulose in their diet. As a result, they help in recycling of nutrients locked in the

cellulose of wood. Also the bacterium, rhizobium, fixes nitrogen in a symbiotic association with roots of leguminous plants such as peas and beans. This increases the nitrate content of the soil and can be utilized by organisms in the ecosystem.

- **Parasitic bacteria;** these are important in causing disease to organisms in the ecosystem. Examples include; cocci and bacilli. By causing disease, they may lead to death of some non-resistant organisms in the ecosystem leading to population regulation and reducing competition for resources in the ecosystem.

(ii) **Chemo autotrophic bacteria** are more commonly known as chemosynthetic bacteria. They use carbon dioxide as the source of carbon but obtain their energy from chemical reactions. Examples include nitrifying bacteria (nitrosomonas, nitrococcus and nitrobacter), iron bacteria, hydrogen bacteria etc. they enrich the soil with nitrogen through their oxidative reactions.

(iii) **Photo autotrophic bacteria** are also referred to as photosynthetic bacteria. They use sun light energy as their source of energy and carbon dioxide as the source of carbon. They are important in introducing oxygen to the atmosphere and also providing organic materials for heterotrophic micro-organisms in the environment.

(c) Explain how a leguminous plant and bacteria in nodules benefit from the relationship. (07marks)

The roots of leguminous plants often have nodules in which are numerous rhizobium bacteria. The two organisms live together in mutualistic relations, i.e, both organisms benefit and none is harmed.

- The leguminous plant provides water, shelter, protection and nutrients (organic and inorganic) to the bacteria.
- The rhizobium bacteria have the ability of fixing nitrogen, in the form of nitrates into the soil from the atmosphere. The nitrates are absorbed and utilized by the leguminous plant.

65. (a) How are leaves modified to perform its function?

Modification of leaves to their functions

(i) Flattened surface to reduce diffusion distance
(ii) Shiny waxy cuticle to reduce water loss
(iii) Mosaic arrangement to increase light absorption
(iv) modified into tendrils to support weak climbing stems e.g. Gloriosa, peas
(v) Some leaves are modified into spine in order to reduce water loss. Spines also protect the plant from herbivorous animals
(vi) Some leaves are modified into scale leaves (thin, membranous, dry colorless structures) for protection. E.g. onion outer leaves
(vii) **Phyllode :** It is a green, expanded structure formed by the modification of petiole or rachis of leaf. Many xerophytes reduce the size of their leaves to minimize water loss. Such plant develop phyllodes to carry out photosynthesis e.g., *Acacia, Melanoxylon* and *Parkinsonia*.
(viii) Some leaves are flesh to store water and food
(ix) Some leaves develop vegetative bud for reproduction, e.g. bryophyllum
(x) In some rootless, aquatic plants, the submerged leaves are modified into root like structure to absorb water and mineral salts. Such modified leaves are called absorbing leaves. e.g., *Utricularia*.
(xi) Some leaves are brightly colored to attract insect pollinator, e.g. Bougainville
(xii) Some leaves are modified to trap insects.

(b) Describe the importance of leaves to the plants.

(i) Carry out photosynthesis with subsequent production of organic materials
(ii) Carry out gaseous exchange through the stomata
(iii) Transpiration takes place mainly through the leaves resulting in the cooling of plant and absorption of mineral salts and water
(iv) Some leaves such as those of peas are modified by tendrils for support.
(v) Some leaves suck those bryophyllum are modified for storage
(vi) Some leaves such as for bryophyllum are modified for vegetative reproduction
(vii) Some leaves possess itching hairs, thorns, spikes and poisonous substances for protection of plant.
(viii) Some leaves e.g. Venus fly trap are modified for capturing and extracting nitrogen from animals
(ix) Some produce substances that kill parasites.

66. (a) Compare photosynthesis and aerobic respiration (9marks)

Similarities

- Both are energy converting processes.
- Both require mechanisms for exchange of carbon dioxide and oxygen.
- Both processes have a reaction pathway in which ATP is formed i.e. photo phosphorylation and oxidation phosphorylation in photosynthesis and respiration respectively.

- Bother processes involve enzyme-controlled reactions.
- Both require special organelles in eukaryotes, chloroplasts for photosynthesis and mitochondria for respiration.
- Both processes are affected by temperature.

Differences

Aerobic respiration	Photosynthesis
A catabolic process (involves breakdown of carbohydrates into simple of sugar) inorganic compounds.	An anabolic process which results in synthesis of carbohydrate molecules from simple inorganic compounds.
Energy is incorporated into ATP for immediate use	Energy is accumulated and stored in carbohydrates
Oxygen is used up	Oxygen is released
Carbon dioxide and water are released	Carbon dioxide and water are used up
Process occurs in decrease in dry mass	Results in increase in dry mass
Process occurs in mitochondria in eukaryotes	Process occurs in chloroplast in eukaryotes
Takes place continuously throughout life and is independent of chlorophyll and light	Occurs only in cells possessing chlorophyll and only in the presence of light.

(b) Explain the effect of low oxygen tension on

(i) C3 plants (3marks)

Low oxygen tensions stimulate photosynthesis in C_3 plants due to reduced competition between oxygen and carbon dioxide for the active site of ribulose -1, 5-biphosphate (RUBP) carboxylase enzyme.

(ii) C4 plants (2marks)

Low oxygen tensions have no effect on the rate of photosynthesis in C_4 plants because the active site of phosphoenol pyruvate (PEP) decarboxylases enzyme does not accept oxygen.

(c) Explain why c4 plants are more efficient in photosynthesis than C3 plants. (06marks)

- In C4 plant PEP carboxylase fix CO_2 and delivers it to the enzyme **RuBisCO** at high concentration resulting in high rate of photosynthesis.
- Photorespiration in C4 plants is negligible because PEP carboxylase does not accept oxygen
- C4 plant are able to photosynthesize at high rates at high temperature because they do not experience photorespiration

Thanks

Dr. Bbosa Science