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NCERT TABLET Biology

for NEET (UG) 2025

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for Faster Revision & Learning

Includes:
- Complete syllabus according to NTA NEET
- Theory and Previous year Qns with NEET PYQs in One-Liner easy to remember format
- Flow Charts for better understanding
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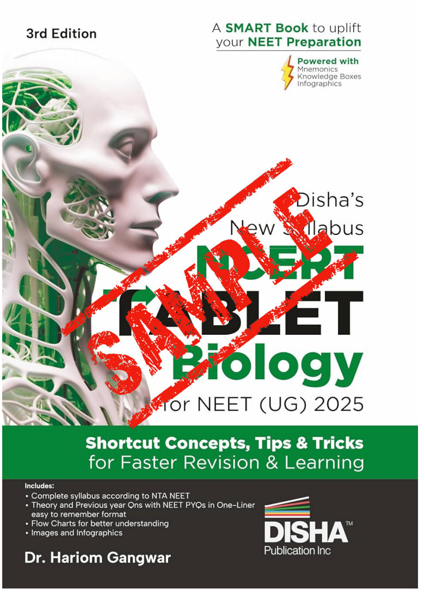

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Unit I

DIVERSITY IN THE LIVING WORLD

Ernst Mayr (1904 – 2004)

Awarded by Triple Crown of Biology

- *Born on 5 July 1904, in Kempten, Germany, ERNST MAYR, the Harvard University evolutionary biologist who has been called* ***'The Darwin of the 20th century'. (NEET 2016)***
- *He was* ***one of the 100 greatest scientists of all time.*** *Mayr joined Harvard's Faculty of Arts and sciences in 1953 and retired in 1975, assuming the title Alexander Agassiz Professor of Zoology Emeritus.*
- *Throughout his nearly 80-year career, his research spanned* ***O****rnithology,* ***T****axonomy,* ***Z****oogeography,* ***E****volution,* ***S****ystematics and the* ***H****istory and philosophy of biology* ***(CODE - HOSTEZ).***
- *He almost single-handedly made the origin of species diversity the central question of evolutionary biology that it is today.*
- *He also pioneered the* ***currently accepted definition of a biological species. (NEET 2016)***
- *Mayr was awarded the three prizes widely regarded as the triple crown of biology* ***(Q. 2015) : the Balzan prize in 1983, the International prize for Biology in 1994, and the Crafoord prize in 1999.***
- *Mayr died at the age of 100 in the year 2004.*
- Biology is the science of life forms and living processes.

CHAPTER 01

The Living World

TOPIC 1. What is Living?

- Growth, reproduction, ability to sense environment and mount a suitable response come to our mind immediately as unique features of living organisms.
- One can add a few more features like metabolism, ability to self-replicate, self-organise, interact and emergence to this list.

Characterstic : 1 Growth

- **All living organisms grow. Increase in mass** and **increase in number** of individuals are twin characteristics of growth.
- A multicellular organism grows by cell division. In plants, this growth by cell division occurs continuously throughout their life span.
- In animals, this growth is seen only up to a certain age. However, cell division occurs in certain tissues to replace lost cells.
- Unicellular organisms multiply by division. One can easily observe this *in vitro* cultures by simply counting the number of cells under the microscope.
- One must remember that increase in body mass is considered as growth.

Characteristics Of Living

Non-defining characterstics	Defining characterstics
• Growth	• Metabolism
• Reproduction	• Cellular Organisation
	• Consciousnes

- Non-living objects also grow if we take increase in body mass as a criterion for growth. **Mountains, boulders and sand mounds do grow**. However, this kind of growth exhibited by non-living objects is by accumulation of material on the surface **(accretion)**.
- **In living organisms, growth is from inside.** Growth, therefore, cannot be taken as a defining property of living organisms.

- Conditions under which it can be observed in all living organisms have to be explained and then we understand that it is a characteristic of living systems. A dead organism does not grow.

Characterstic : 2 Reproduction

- Reproduction, likewise, is a characteristic of living organisms.
- In multicellular organisms, reproduction refers to the production of progeny possessing features more or less similar to those of parents.
- Invariably and implicitly we refer to sexual reproduction. Organisms reproduce by asexual means also.
- Fungi multiply and spread easily due to the millions of asexual spores they produce.
- In lower organisms like **yeast** and ***Hydra***, we observe **budding**.
- In ***Planaria*** (flat worms), we observe **true regeneration**, ***(AIPMT 2014)*** i.e., a fragmented organisms regenerates the lost part of its body and becomes, a new organism.
- **The fungi, the filamentous algae, the protonema of mosses, all easily multiply by fragmentation. *(AIPMT 2012)***
- In majority of higher animals and plants, growth and reproduction are mutually exclusive events.
- When it comes to unicellular organisms like bacteria, unicellular algae or Amoeba, reproduction is synonymous with growth, i.e., increase in cell number or mass. ***(NEET 2016)***
- Hence, we notice that in single-celled organisms, we are not very clear about the usage of these two terms – growth and reproduction.
- Further, there are many organisms which **do not reproduce (mules, sterile worker bees, infertile human couples, etc).**
- Hence, reproduction also cannot be an all-inclusive defining characteristic of living organisms. Of course, no non-living object is capable of reproducing or replicating by itself.

Characteristic : 3 Metabolism

- Another characteristic of life is metabolism. All living organisms are made of chemicals. There are thousands of metabolic reactions occurring simultaneously inside all living organisms, be they unicellular or multicellular.
- The sum total of all the chemical reactions occurring in our body is metabolism.
- **All plants, animals, fungi and microbes exhibits metabolism**. No non-living objects exhibits metabolism.
- Metabolic reactions can be demonstrated outside the body in cell free system.
- An isolated metabolic reaction(s) outside the body of an organism, performed in a test tube is neither living nor non-living.

- **Hence, while metabolism is a defining feature of all living organisms without exception, isolated metabolic reactions in vitro are not living things but surely living reactions.**

Characteristic : 4 Cellular Organisation

- All living organisms are composed of cells and products of cells.
- **Hence, cellular organization of the body is the defining feature of life forms.**

Characteristic : 5 Consciousness

- Perhaps, **the most obvious and technically complicated feature** of all living organisms is this ability to sense their surroundings or environment and respond to these environmental stimuli which could be physical, chemical or biological.
- All organisms, from the **prokaryotes to the most complex eukaryotes** can sense and respond to environmental cues. All organisms handle chemicals entering their bodies.
- All organisms therefore are aware of surroundings. ***(Q. 2011)***
- Plants respond to external factors like light, water, temperature, other organisms, pollutants, etc.
- Photoperiod affects reproduction in seasonal breeders, both plants and animals. ***(NEET 2016)***
- **Human** being is the only organism who is aware of himself, i.e., has **self-consciousness**.
- We sense our environment through our sense organs.
- **Consciousness therefore, becomes the defining property of living organisms.**

Characterstic : 6 Interactions

- All living phenomena are due to underlying interactions.
- **Properties of tissues are not present in the constituent cells.**
- Similarly, properties of cellular organelles are not present in the molecular constituents of the organelle but arise as a result of interactions among the molecular components comprising the organelle.
- These interactions result in emergent properties at a higher level of organization. This phenomenon is true in the hierarchy of organizational complexity at all levels.
- Therefore we can say that living organisms are self-replicating, evolving and self-regulating interactive systems capable of responding to external stimuli.
- **Biology is the story of life on earth.** Biology is the story of evolution of living organisms on earth.

- All living organisms- present, past and future are linked to one another by the sharing of the common genetic material, but to varying degrees.

TOPIC 2. NOMENCLATURE

- Obviously, nomenclature or naming is only possible when the organism is described correctly. This is **identification**.
- Naming or nomenclature of organisms is of two types, vernacular and scientific.
  - **Vernacular or local or common names:** There are millions of plants and animals in the world. We know the plants and animals in our own area by their local names.
- These local names would vary from place to place, even within a country
  - **Scientific or Technical Names:** The scientific names ensure that each organism has only one name. Description of any organism should enable the people (in any part of the world) to arrive at the same name. They also ensure that such a name has not been used for any other known organism.
- In order to facilitate the study, number of scientists have established procedures to assign a scientific name to each known organism. This is acceptable to biologists all over the world.
- **International Code of Biological Nomenclature** is applicable to both plants and animals.
- For plants, scientific names are based on agreed principles and criteria, which are provided in **International Code for Botanical Nomenclature (ICBN).** ***(Q.2014)***
- Animal taxonomists have evolved **International Code of Zoological Nomenclature (ICZN)**.
- The system of providing scientific names is called Binomial nomenclature.

Binomial Nomenclature

- Biologists follow universally accepted principles to provide scientific names to known organisms. Each name has two components – the **Generic name** ***(NEET 2023)*** and the **specific epithet** ***(NEET 2023)***. This system of providing a name with two components is called Binomial nomenclature.
- This naming system given by **Carolus Linnaeus** is being practiced by biologist all over the world This naming using a two word format was found convenient. ***(NEET 2016)***
- The universal rules of nomenclature are as follows:
  - The **first word** in a biological name represents the **genus** while the **second component** denotes the **specific epithet**. ***(NEET 2016)***

- The first word denoting the genus starts with a capital letter while the specific epithet starts with a small letter.
- Both word in a biological name, when **handwritten**, are **separately underlined**, or printed in italics to indicate their Latin origin. ***(NEET 2016)***
- Biological names are generally in Latin (because Latin is a dead language) and **written in italics**. They are Latinised or derived from Latin irrespective of their origen.
- Name of the author appears after the specific epithet, i.e., at the end of the biological name and is written in an abbreviated form, e.g., ***Mangifera indica* Linn**. It indicates that this species was first described by Linnaeus. ***(NEET 2016)***

- The scientific name of mango is written as *Mangifera indica*. In this name *Mangifera represents* the genus while *indica*, is a particular species, or a specific epithet.

TOPIC 3. TAXONOMY

- Taxonomy is not something new. Human beings were, have always been interested in knowing more about the various kinds of organisms, particularly with reference to their own use. In early days, human beings needed to find sources for their basic needs of food, clothing and shelter.
- The **earliest classification** were based on the **uses of various organisms**.
- 'Dogs, cats, mammals, wheat, rice, plants, animals, etc, are convenient categories we use to study organisms. The scientific term for these categories is taxa.
- Taxa can indicate categories at very different levels. Plants – also form a taxa. Wheat is also a taxa. Similarly animals, mammals, dogs, are all taxa – but a dog is a mammal and mammals are animals. Therefore, animals, mammals and dogs represent taxa at different levels.
- External and internal structure, along with structure of cell, development process and ecological information of organisms are essential and form the basis of modern taxonomic studies.
- **There are four processes that are basic to taxonomy:**

  1. Characterisation, 2. Identification,

  3. Classification and 4. Nomenclature
- Human beings were, since long, not only interested in knowing more about different kinds of organisms and their diversities, but also the relationships among them. This branch of study was referred to as systematics. Systematics takes into account evolutionary relationships between organisms.

- The word systematics is derived from the **Latin word** systema which means systematic arrangement of organisms.
- The scope of systematics was later enlarged to include identification, nomenclature and classification.
- **Systema Naturae** were written by **Linnaeus**. Term 'systematics' was also given by 'Carolus Linnaeus'.

- Term 'new systematics' was given by Julian Huxley ***(AIPMT 1988)*** in 1940. New systematics is also called biosystematics.
- Term 'biosystematics' was given by Camp and Gilly (1943). ***(Q.2012)***
- Father of new systematics or neo-taxonomy or biosystematics is Julian Huxley.
- Biosystematics is classification of organism based on their evolutionary history and establishing their phylogeny. ***(AIPMT 2003)***

TOPIC 4. TAXONOMIC CATEGORIES

- Classification is not a single step process but involves hierarchy of steps in which each step represents a rank or category.
- Since the category is a part of overall taxonomic arrangement, it is called the taxonomic category and all categories together constitute the taxonomic hierarchy.
- Each **category, rank** or **taxon** (plural-taxa) referred to as a **unit of classification**.
- Taxon is a taxonomic group of plants and animals with similar traits of any ranking. ***(Q.2013)***

Kingdom	**Code : king**
↑	↑
Phylum or Division	**Plays**
↑	↑
Class	**Chess**
↑	↑
Order	**On**
↑	↑
Family	**Fine**
↑	↑
Genus	**Green**
↑	↑
Species	**Silk**

- These taxonomic groups/categories are distinct biological entities and not merely morphological aggregates. ***(NEET 2022)***
- Insects represent a group of organisms sharing common features like three pairs of jointed legs. It means insects are a rank or category.
- Taxonomical studies of all known organisms have led to the development of common categories such as kingdom, phylum or division (for plants), class, order, family, genus and species.

I. Species

- Taxonomic studies consider a group of individual organisms with fundamental similarities as a species.
- All organisms, including those in plant and animal kingdoms have species as the **lowest category**.

- One should be able to distinguish one species from the other closely related species based on the distinct morphological differences.

II. Genus

- **Genus** comprises a group of related species which has more characters in common in comparison to species of other genera. ***(Q.2013)***
- Let us consider *Mangifera indica*, *Solanum tuberosum* (potato) and *Panthera leo* (lion).
- All the three names, *indica*, *tuberosum* and *leo*, represent the specific epithets, while the first words *Mangifera*, *Solanum* and *Panthera* are genera and represents another higher level of taxon or category.

Genus	Specific epithet	Common name
Solanum	*tuberosum*	Potato
	melongena	Brinjal (egg plant)
	nigrum	Makoi
Panthera	*leo*	Lion
	pardus	Leopard
	tigris	Tiger
Canis	*familaris*	Dog
Felis	*domestica*	Cat
Cocos	*nucifera*	Coconut palm
Nicotiana	*tabacum*	Tobacco

- Each genus may have one or more than one specific epithets representing different organisms, but having morphological similarities.
- Genera are aggregates of closely related species. For example, potato, brinjal and makoi are three different species but belong to the genus *Solanum*.
- Lion (*Panthera leo*), leopard (*P. pardus*) and tiger (*P. tigris*) ***(AIPMT 2011)*** with several common features, are all species of the genus *Panthera*. This genus differs from another genus *Felis* which includes cats.

III. Family

- Family has a group of related genera with still less number of similarities as compared to genus and species. ***(Q.2014)***
- Families are characterised on the basis of both vegetative and reproductive features of plant species. e.g., Among plants three different genera ***Solanum, Petunia*** and ***Datura*** are placed in the family **Solanaceae**. ***(Q.2014)***

  eg.: Among animals genus *Panthera* is put along with genus, *Felis* in the family Felidae. **Cat** and **Dog** are separated into two different families – **Felidae** and **Canidae**, respectively.

IV. Order

- Categories like species, genus and families are based on a number of similar characters. Generally, order and other higher taxonomic categories are identified based on the **aggregates of characters.**
- Order is the assemblage of families which exhibit a few similar characters. The similar characters are less in number as compared to different genera included in a family.

- **Plant families like Convolvulaceae and Solanaceae are included in the order Polymoniales, mainly based on the floral characters.** ***(Q.2014)***
- The animal order, **Carnivora** includes families like Felidae and Canidae. The order of man, monkey, gorilla and gibbon is **primata**.

V. Class

- Class includes related orders. ***(Q.2014)***
- Order Primata (comprising monkey, gorilla and gibbon) is placed in class **Mammalia** along with order Carnivora (includes animals like tiger, cat and dog). Class mammalia has other orders also.

VI. Phylum / Division

- Classes comprising animals like fishes, amphibians, reptiles, birds along with mammals constitute the next higher category called Phylum. All these classes are included in the phylum chordata.
- In case of plants, classes with a few similar characters are assigned to a higher category called Division.

VII. Kingdom

- The **highest category** in taxonomic hierarchy is kingdom.
- All animals belonging to various phyla are assigned to the highest category called Kingdom **Animalia** in the classification system of animals.
- The Kingdom **Plantae** is distinct, and comprises all plants from various divisions.
- As we go higher from species to kingdom, the number of common characteristics goes on decreasing.
- Lower the taxa, more are the characteristics that the members within the taxon share. Higher the category, greater is the difficulty of determining the relationship to other taxa at the same level.

TABLE 1.1 ORGANISMS WITH THEIR TAXONOMIC CATEGORIES

Common Name	Biological Name	Family	Order	Class / Division	Phylum	Kingdom
Man	*Homo sapiens*	Hominidae	Primata	Mammalia	Chordata	Animalia
Housefly	*Musca domestica*	Muscidae	Diptera	Insecta	Arthropoda	Animalia
Mango	*Mangifera indica*	Anacardiaceae	Sapindales	Dicotyledonae	Angiospermae	Plantae
Wheat	*Triticum aestivum*	Poaceae	Poales	Monocotyledonae	Angiospermae	Plantae
Dog	*Canis familiaris*	Canidae	Carnivora	Mammalia	Chordata	Animalia
Cat	*Felis domestica*	Felidae	Carnivora	Mammalia	Chordata	Animalia
Tiger	*Fanthera tigris*	Felidae	Carnivora	Mammalia	Chordata	Animalia
Lion	*Panthera leo*	Felidae	Carnivora	Mammalia	Chordata	Animalia
Leo pard	*Panthera pardus*	Felidae	Carnivora	Mammalia	Chordata	Animalia
Potato	*Solanum tuberosum*	Solanaceae	Polymoniales	Dicotyledonae	Angiospermae	Plantae
Brinjal	*Solanum melongena*	Solanaceae	Polymoniales	Dicotyledonae	Angiospermae	Plantae
Makoi	*Solanum nigrum*	Solanaceae	Polymoniales	Dicotyledonae	Angiospermae	Plantae

Unit IV

PLANT PHYSIOLOGY

- **Calvin** received *Ph.D. in Chemistry.*
- *Calvin along with* **J.A. Bassham** *studied reactions in green plants forming sugar and other substances from* CO_2*,* H_2*, and minerals by labelling the* CO_2*, with* C^{14}*.*
- *Calvin proposed that plants change light energy to chemical energy.*
- *The mapping of the pathway of C assimilation in the PHS earned him Nobel prize in 1961.*
- *The principles of PHS as established by Calvin are at present being used in studies on renewable resources for energy and materials and basic studies in solar energy research.*

Melvin Calvin

CHAPTER 11

Photosynthesis in Higher Plants

- All animals including human beings depend on plants for their food.
- Ultimately, all living forms on earth depend on sunlight for energy.
- The use of energy from sunlight by plants doing photosynthesis is the basis of life on earth.
- Photosynthesis is important due to two reasons : it is the primary source of all food on earth. It is also responsible for the release of oxygen into the atmosphere by green plants.
- **Chlorophyll** (green pigment of the leaf), light, water and CO_2 are required for photosynthesis to occur.
- You may have carried out the experiment to look for starch formation in two leaves – a variegated leaf or a leaf that was partially covered with black paper, and one that was exposed to light.
- On testing these leaves for starch it was clear that photosynthesis occurred only in the green parts of the leaves in the presence of light.
- CO_2 is essential for PHS is demonstrated by Half leaf experiment (By moll's). In this experiment a part of a leaf is inclosed in a test tube containing some KOH soaked cotton (KOH absorbs CO_2) while the other half is exposed to air.
- Chemosynthetic bacteria obtain energy from inorganic chemicals. ***(NCERT EXEMPLAR)***

TOPIC 1. EARLY EXPERIMENTS

I. Joseph priestley

- In **1770** he performed a series of experiments that showed the essential role of air in the growth of green plants
- **Priestey** discovered O_2 in **1774**. He experiment with **mint plant**.
- Priestley observed that a candle burning in a closed space – a bell jar, soon gets extinguished. Similarly, a mouse would soon suffocate in a closed space.
- He concluded that a burning candle or an animal that breathe the air, both somehow, damage the air.
- But when he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn.

- **Priestley hypothesis**- Plants restore to the air whatever breathing animals and burning candles remove.

II. Jan Ingenhousz

- He used similar setup as used by priestly.
- Ingenhousz showed that sunlight is essential to the plant process, that somehow purifies the air fouled by burning candles or breathing animals.
- Ingenhousz experiment with an aquatic plant and showed in bright sunlight small bubbles were formed around the green parts while in the dark they did not. Later he identified these bubbles to be of oxygen.

III. Julius von sachs

- In 1854, Sachs provided evidence for production of glucose when plants grow. Sachs found that the green parts in plants is where glucose is formed and glucose is usually stored as starch.
- His later studies showed that the green substance in plants (chlorophyll as we know it now) is located in special bodies (later called chloroplasts) within plant cells.
- He found that the green parts in plants is where glucose is made, and that the **glucose is usually stored as starch**.

IV. T.W Engelmann

- He split light into its spectral components (VIBGYOR) by using a prism and then illuminated a green alga (***Cladophora***) placed in the suspension of aerobic bacteria.
- Bacteria were used to detect the sites of O_2 evolution.
- Engelmann observed that bacteria accumulated mainly in the region of blue and red light of split spectrum.
- Then first action spectrum of PHS was described. Action spectrum of PHS resembles roughly the **absorption spectra** of Chl-*a* and b.
- By the middle of the nineteenth century the key features of plant photosynthesis were known, namely, that plants could use light energy to make carbohydrates from CO_2 and water.
- Empirical equation of PHS : $CO_2 + H_2O \rightarrow [CH_2O] + O_2$
  $[CH_2O]$ represents a carbohydrate (e.g., Glucose)

V. Van Niel

- He experiment with **purple and green – sulphur bacteria**
- Neil demonstrated that PHS is essentially a light – dependent reaction in which hydrogen from a suitable oxidisable compound reduces CO_2 to carbohydrate, as : $2H_2A + CO_2 \rightarrow 2A + CH_2O + H_2O$
- In green plants H_2O is hydrogen donor and is oxidized to O_2.
- Some organisms do not release 'O_2' during 'PHS'.

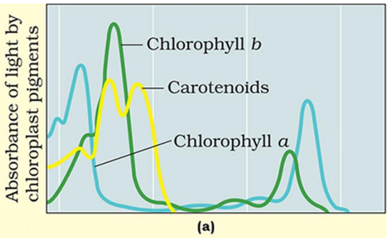
- When H_2S is used as hydrogen donor for purple and green sulphur bacteria, the oxidation product is S (Sulphur) or sulphate (depending on organism) and not O_2.
- Hence, Neil conclude that the O_2 evolved by the green plants comes form H_2O not from CO_2 this was later proved by using **radioisotopic techniques.**
- Correct equation of PHS : $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$.
- Note that this is not a single reaction but description of a **multistep process** called photosynthesis.

TOPIC 2. SITE OF PHS

- **Mesophyll cells** in the leaves have a large number of chloroplasts.
- Chloroplast align (arrange) themselves along the walls of mesophyll cells that they get the optimum quantity of incident light.
- Within the chloroplast there is membranous system consisting of grana, the stroma lamellae, and the matrix stroma. There is a clear division of labour within the chloroplast.
- The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH. In stroma, enzymatic reactions synthesise sugar, which in turn forms starch. The former set of reactions, since they are directly light driven are called light reactions (photochemical reactions).
- The latter are not directly light driven but are dependent on the products of light reactions (ATP and NADPH). Hence, to distinguish the latter they are called, by convention, as dark reactions (carbon reactions). However, this should not be construed to mean that they occur in darkness or that they are not light-dependent.

TOPIC 3. PIGMENTS AND SPECTRUM

- Colour of leaves is not due to a single pigment but due to 4 pigments: (i) Chlorophyll *a* (bright or blue green) ***(NEET 2023)***, (ii) Chl-b (yellow green) ***(NEET 2023)***, (iii) Xanthophylls (Yellow) ***(NEET 2023)*** and (iv) Carotenoides (Yellow to yellow orange). ***(NEET 2023)***
- Leaf pigments are separated by **paper chromatography**.



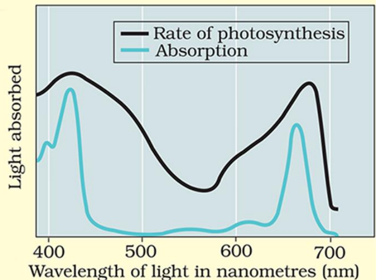
Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids

- Pigments are the substances that have an ability to absorb light at specific wavelengths.
- In blue and red regions of wavelengths chl-a shows maximum absorption.

  Wavelengths at which there is maximum absorption by Chl-*a* i.e. blue and red regions also shows higher rate of photo synthesis.
- Hence it can concluded that chl-*a* is the chief pigment associated with PHS. Chl-*a* is the major pigment responsible for trapping light.
- Most of the PHS takes place in the **blue and red regions** of the spectrum although some PHS also takes place in other wavelengths of the visible spectrum.

(b)

Graph showing action spectrum of photosynthesis



(c)

Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll a

- But other thylakoid pigments like Chl-b, xanthophylls and carotenoids which are called accessory pigments also absorbs light and transfer the energy to Chl-*a*.
- Accessory pigments not only enable a wider range of wavelength of incoming light to be utilized for PHS but also protect Chl-*a* from **photooxidation**.

TOPIC 4. LIGHT REACTION

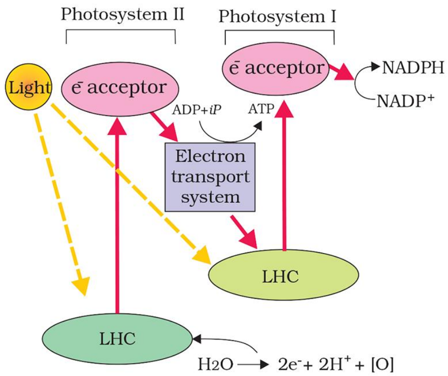
- Photo chemical phase or light reaction includes : (i) Light absorption, (ii) Water splitting, (iii) O_2-release and (iv) Formation of ATP and NADPH (light energy chemical intermediates).
- Several complexes are involved in the process (light reaction).
- Pigments are organized into two discrete (different) photochemical light Harvesting complexes (LHC) within the PSI and PSII.
- Photo systems (PS) are named in the sequence of their discovery and not in the sequence in which they function during the light reaction.
- **LHC** are made up of hundreds of pigment molecules bound to proteins. Each PS have all

  the pigments (except one molecule of Chl-*a*) Forming a light harversing system also called antennae.
- These pigments **(antennae)** help to make PHS more efficient by absorbing different wavelengths of light.

- The single Chl-*a* molecule form the reaction centre.
- Reaction centre is different in both the photo systems.
- In **PSI** the reaction centre Chl-*a* has an absorption peak at 700nm, hence is called P700.
- In **PSII** Chl-*a* has an absorption peak at 680 nm hence called P680. ***(NEET 2023)***

1. Electron Transport

- In PSII the reaction centre (P680) Chl-*a* absorbs 680 nm wavelength of red light causing electrons to becomes excited and Jump into on orbit apart (further) from the atomic nucleus.
- These electrons are picked up by an electron acceptor which passed them to an electron transport system.
- This movement of electrons is downhill in terms of an oxidation reduction or redox potential scale.
- Electrons are not used up as they pass through the electron transport chain, but are passed on to the pigments of PSI.
- Simultaneously, electrons in the reaction centre of PSI are also excited when they receive red light of wavelength 700 nm and are transferred to another acceptor molecule that has a greater redox potential.
- These electrons are then moved downhill again this time to a molecule of energy rich $NADP^+$. The addition of these electrons reduces $NADP^+$ to $NADPH + H^+$.



Z scheme of light reaction

- Whole scheme of transfer of electrons : (i) Strarting from PSII, (ii) Uphill to the acceptor, (iii) Down the electron transport chain to PSI, (iv) Excitation of electrons, (v) Uphill to another acceptor, (vi) Finally downhill to $NADP^+$ is called **Z – scheme**, due to its characterstic shape.
- Z-shape is formed when all the carriers are placed in a sequence on a redox potential scale.
- When the 2 photosystems work in a series, first PSII and then PSI a process called **non-cyclic photo-phosphorylation** occurs.
- These photo system are connected through an electron transport chain (as in Z-scheme).

- Both ATP and $NADH^+ + H^+$ are synthesized by this kind of electron flow (Non-cyclic photo phosphorylations of Z-scheme). ***(NEET 2021)***
- The correct sequence of flow of electrons in the light reaction is PS II, plastoquinone, cytochromes, PS I and ferredoxin. ***(NCERT EXEMPLAR)***
- In light reaction, plastoquinone facilities the transfer of electrons from PS II to Cytb$_6$f complex. ***(NEET 2020)***

2. Splitting of water

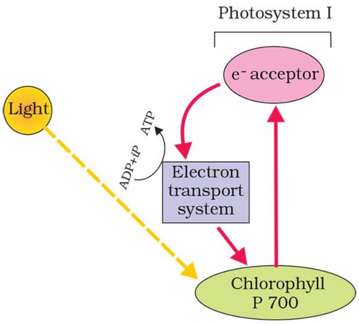
- The electrons that were moved from PSII must be replaced. This is achieved by electrons available due to **splitting of water**. ***(NEET 2020)***
- Splitting of water is associated with PS-II.
- Water is split into $2H^+$, [O] and electrons. This creates O_2, one of the net product of PHS. $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$
- The electrons needed to replace those removed from PSI are provided by PSII.
- Water **splitting complex** is associated with PS-II which itself is physically located on the inner side of membrane of the Thylakoid.
- Protons and O_2 formed likely to be released into the lumen.

3. PHOTO-PHOSPHORYLATION

- Process by which ATP is synthesized by cells (in mitochondria and chloroplasts) is **phosphorylation**.
- Photo phosphorylation is the synthesis of ATP form ADP and inorganic phosphate in **presence of light**.

CYCLIC PHOTOPHORYLATION

- When only PS-I is functional, the electron is circulated within the PSI phosphorylation (ATP formation) occurs due to cyclic flow of electrons.
- A possible location of cyclic photo-phosphorylation is the stroma lamellae.
- Stroma lamellae membrane lacks PSII as well as NADP reductase enzyme while membrane or lamellae of the grana have both PSII and PSI. ***(NEET 2021)***
- The excited electrons does not pass on to $NADP^+$ but is cycled back to the PSI complex through the ETC. Hence the cyclic flow results only in the synthesis of ATP but not of $NADPH+H^+$.



Cyclic photophosphorylation

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

4. CHEMIOSMOTIC HYPOTHESIS

- Chemiosmtic hypothesis has been put forward by Peter Mitchell to explain the mechanism of ATP synthesis in **chloroplast** and **mitochondria**.
- Like in respiration in PHS too, ATP synthesis is linked to development of proton gradient across a membrane.
- Here in the chlorophast these are membranes of thylakoid. In PHS, protons accumulates, towards the inside of the membrane i.e. in the lumen.
- In respiration protons accumulate in the intermembrane space of the mitochondrid ***(NEET 2024)*** when electrons move through the ETS.
- **Cause of proton gradient** across the membrane :

  i. Since splitting of the water molecules takes place on the inner side of the membrane (lumen) the protons that are produced by **splitting of water** accumulate within the lumen of thylakoids. ***(NEET 2022)***

  ii. (a) As electrons move through the photo systems, protons are transported across the membrane.

  (b) This happens because the 1° acceptor of e^- which is located towards the outer side of the membrane transfers its e, not to an e^- carrier but to an H camer.

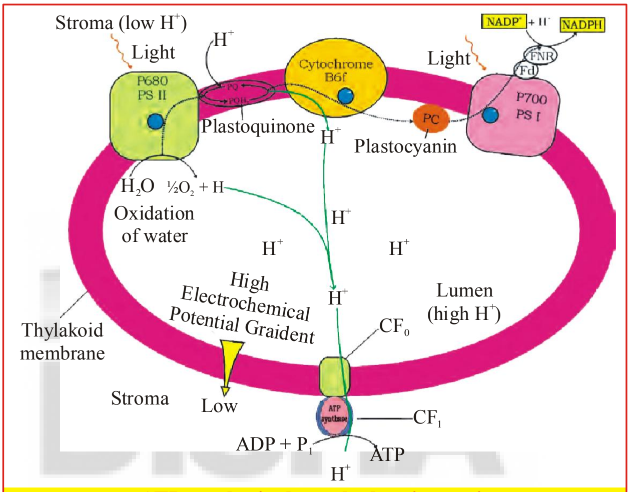
  (c) Hence this molecules removes a protons from the stroma while transporting an e^-.

  (d) When this molecule passes on its e^- to the e^- carrier on the inner side of the membrane the proton is release into the inner side or the lumen side of the membrane.

  iii. (a) **NADP reductase enzyme** is located on the stroma side of the membrane. ***(NEET 2022)***

  (b) Along with e^- that come from the acceptor of electrons of ps I protons are necessary for the reduction of $NADP^+$ to NADPH + H^+. These protons are also removed from the stroma.
- Hence within the chloroplast, protons in the stroma decrease in number ***(NEET 2022)*** while in the lumen there is accumulation of protons ***(NEET 2022)***. This creates a proton gradient across the thylakoid membrane as well as a measurable decrease in pH in the lumen.
- Proton gradient is important because breakdown of this gradient leads to **synthesis of ATP**.
- The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the CF_0 of the ATP synthase.

- The ATP synthase enzyme consists of two parts: one called the CF_0 is embedded in the thylakoid membrane and forms a transmembrane channel that carries out facilitated diffusion of protons across the membrane.
- The other portion is called CF_1 and protrudes on the outer surface of the thylakoid membrane on the side that faces the stroma. The break down of the gradient provides enough energy to cause a conformational change in the CF_1 particle of the ATP synthase, which makes the enzyme synthesise several molecules of energypacked ATP.



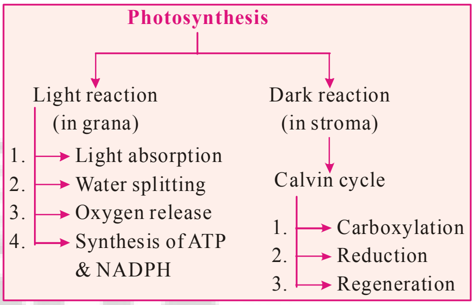
ATP synthesis through chemiosmosis

- Chemiosmosis requires : (i) A membrane, (ii) A proton pump, (iii) A proton gradient and (iv) ATPase enzyme.***(NEET 2023)***
- Energy is use to pump protons across a membrane to create a gradient or a high concentration of protons within the thylaloid lumen.
- ATPase has a channel that allows diffusion of protons across the membrane this releases enough energy to activate ATPase enzyme. That catalyses the formation of ATP.
- Along with NADPH produced by the movement of electrons, the ATP will be used immediately in the biosynthetic or dark reaction taking place in stroma, responsible for fixing CO_2 and synthesis of sugars.
- During light reaction in photosynthesis ATP, O_2 and hydrogen donor (NADPH) are formed. ***(NCERT EXEMPLAR)***

TOPIC 5. BIOSYNTHETIC PHASE OF DARK REACTION

- Products of light reaction are ATP, NADPH and O_2.
- Of these O_2 diffuse out the chloroplast while ATP and NADPH are used for the synthesis of sugar. This called **biosynthetic phase of PHS**.

- Biosynthetic phase does not directly depend on the presence of light but is dependent on the product of the light reaction (i.e., ATP and NADPH), besides CO_2 and H_2O. ***(NEET 2024)***
- Immediately after light becomes unavailable, the biosynthetic process continues for some time and then stops. If then, light is made available the synthesis starts again.
- **Melvin calvin** uses radioactive C^{14} in algal PHS led to the discovery that first CO_2 fixation product was 3-carbon organic acid.
- The **first product** identified was 3-PGA (3-phosphoglyceric acid).
- Calvin contributed to working out the complete biosynthetic pathway, hence it is called Calvin cycle.
- CO_2 assimilation during PHS was said to be of two main types :
  i. Those plants in which first product of CO_2 fixation is C_3 acid (PGA) is called C_3 pathway.
  ii. Those plants in which first product was a C_4 acid (OAA) is called C_4 pathway.



5.1 Calvin Cycle (C_3 pathway)

- Calvin pathway occurs in all biosynthetic plants, it does not matter whether they have C_3 or C_4 (or any other) pathways.
- First CO_2 acceptor molecule is 5- carbon ketose sugar (RUBP-Ribulose bisphosphate)
- Calvin worked out whole pathway and showed that the pathway operated in a cyclic manner and RUBP is regenerated.
- Calvin cycle described into three stages-CRR : (i) **Carboxylation**, (ii) **Reduction** and (iii) **Regeneration.**

I. Carboxylation

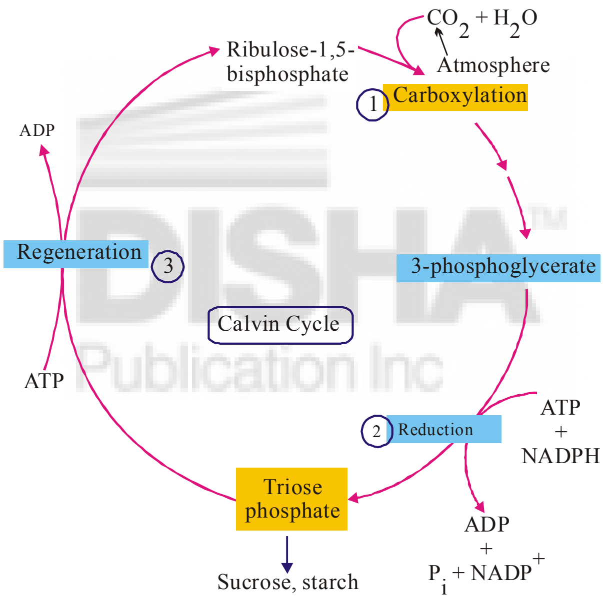
- Carboxylation is the fixation of CO_2 into a stable organic intermediate.
- Carboxylation is the most crucial step of the calvin cycle where CO_2 is utilized for the carboxylation of RUBP.
- This reaction is catalysed by the **enzyme RUBPcarboxylase** RuBisCo which results in the formation of two molecules of 3- PGA.
- RUBP carboxylase enzyme also has an oxygenation activity it would be more correct to call it **RUBP carboxylase- oxygenase or RUBisCo**.
- RuBiCO is a bifunctional enzyme. ***(NEET 2020)***

II. Reduction

- These are a series of reactions that lead to the formation of glucose.
- Reduction involves utilization of two molecules of ATP for phosphorylation and two of NAD PH for reduction per CO_2 molecule fixed.
- The fixation of 6 molecules of CO_2 and 6 turns of the cycle are required for the removal of one molecule of glucose from the pathway.

III. Regeneration

- Regeneration of the CO_2 acceptor molecule RUBP is crucial if the cycle is to continue uninterrupted
- The reqeneration step **requires 1 ATP** for phosphorylation to form RUBP.
- Hence for every CO_2 molecule entering the Calvin cycle 3 molecules of ATP and 2 of NADPH are required. ***(NEET 2024)***

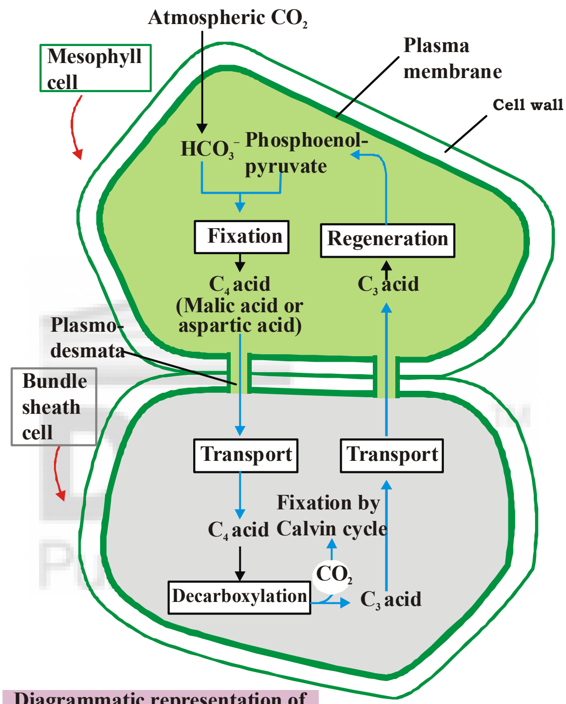


The Calvin cycle proceeds in three stages : (1) carboxylation, during which CO_2 combines with ribulose-1, 5-bisphosphate; (2) reduction, during which carbohydrate is formed at the expense of the photo-chemically made ATP and NADPH; and (3) regeneration during which the CO_2 acceptor ribulose-1,5-bisphosphate is formed again so that the cycle continues

- It is probably to meet this difference in number of ATP and NADPH used in the dark reaction that the cyclic phosphorylation takes place.
- To make one molecule of glucose 6 turns of cycle is required and then 6 CO_2, 12 NADPH and 18 ATP is required. ***(NEET 2023)***

5.2 C_4 pathway or Hatch and Slack Pathway

- C_4 pathway occure in the plants that are adapted **to dry tropical regions.**
- Even though C_4 plants have C_4 OAA is the first CO_2 fixation product they use the C_3 pathway or Calvin cycle as the main biosynthetic **pathway**. ***(NEET 2021)***
- 1° CO_2 acceptor in C_4 plants is a 3-C molecule PEP (phosphoenol pyruvate) and is present in the **mesophyll cells**. ***(NEET 2022)***



Diagrammatic representation of the Hatch and Slack Pathway

- The enzyme responsible for the fixation is PEPcase (PEP carboxylase- Activator is Mg^{2+}) is found only in mesophyll cells.
- Bundle sheath lack **PEPcase enzyme**. ***(NEET 2023)***
- C_4 acid (OAA) is formed by carboxylation is mesophyll cells therefore initial carboxylation reaction occurs in mesophyll cells, (also in C_3 pathway).
- OAA the forms other 4-C compounds like malic acid or aspartic acid in the mesophyll cells it self, which are transported to the bundle sheath cells.
- In the bundle sheath cells these C_4 acids are broken down to release CO_2 and a 3-C molecule.
- The 3-C molecule is transported back to mesophyll where is is converted to PEP again thus completing the cycle.

- CO_2 released in the bundle sheath cells enters the C_3 or the calvin pathway a pathway common to all plants. The **bundle sheath** cells are rich in RuBisCo enzyme (necessary for the C_3 or the calvin cyclc), but lack PEP case. ***(NEET 2020)***
- Calvin pathway in C_4 plants takes place only in bundle sheath cells (because RuBisCo is present) but does not takes place in the mesophyll cells because lack of RuBisCo enzyme in mesophyll cells of C_4 plants like **maize** and **sorghum**. ***(NEET 2022)***

TOPIC 6. PHOTORESPIRATION

- Photorespiration creates an important difference between C_3 and C_4 plants.
- In Calvin cycle the first CO_2 fixation step (RuBP combines with CO_2 to forms two molecules of 3PGA) is catalysed by RuBisCo.

S.No.	Characterstics	C_3 Plants	C_4 Plants
1.	1° CO_2 acceptor	RuBP	PEP
2.	Number of carbons in 1° CO_2 acceptor	5	3
3.	1° CO_2 fixation product	PGA	OAA
4.	Number of carbons in 1° CO_2 fixation product	3	4
5.	Calvin cycle takes place in	Mesophyll	Bundle sheath
6.	Initial carboxylation reaction occurs in	Mesphyll	Mesophyll
7.	Number of cell type that fix CO_2	One (mesophyll)	Two (Meso & B.S.)
8.	PEP Case is	Absent	Present
9.	RuBis CO is	Present	Present
10.	RuBis CO is present in	Mesophyll	Bundle sheath
11.	Kranz anatomy	Absent	Present

- RuBisCo is characterized by the fact that its active site can bind to both CO_2 and O_2 (hence named carboxylase oxygenase).
- **RuBisCO** has a much greater affinity for CO_2 than for O_2, when $CO_2 : O_2$ is nearly equal.
- This binding is competitive. It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme.
- In C_3 plants some O_2 does bind to RuBisCO, and hence CO_2 fixation is decreased. ***(NEET 2024)***

- Here the RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule of phosphoglycerate and phosphoglycolate (2 Carbon) in a pathway called photorespiration. ***(NEET 2020)***
- In the photorespiratory pathway, there is neither synthesis of sugars, nor of ATP. Rather it results in the release of CO_2 with the utilisation of ATP.
- In the photorespiratory pathway there is no synthesis of ATP or NADPH. The biological function of photorespiration is not known yet. ***(NCERT Correction-2019-20)***
- In C_4 plants photorespiration does not occur. ***(NEET 2023, 2024)***
- This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site.
- This takes place when the C_4 acid from the mesophyll is broken down in the bundle sheath cells to release CO_2. This results in the increasing intracellular concn. of CO_2.
- In turn, this ensures that the RuBisCo functions as a carboxylase minimizing the oxygenase activity.
- Due to the lack of photorespiration in **C_4 yields are better** in addition these plants (C_4) show tolerance to higher temperatures.
- C_4 plants are special as : (i) They have a special type of leaf anatomy, (ii) They tolerate higher temperatures, (iii) They show a response to high light intensities, (iv) They lack photorespiration and (v) They have greater productivity of biomass.
- The particularly large cells around the vascular bundles of the C_4 plants ***(NCERT Correction-2019-20)*** are called bundle sheath cells, and the leaves which have such anatomy are said to have **Kranz anatomy** (Kranz means wreath and is a reflection of arrangement of cells).
- The bundle sheath cells may form several layers around the vascular bundles. Bundle sheath cells are characterized by : (i) Large number of chloroplasts, (ii) Thick walls impervious to gaseous exchange and (iii) No intercellular spaces.
- Organelles having enzymes involved in photorespiration are mitochondria, peroxisomes and chloroplasts. ***(AIPMT 2012)***

TOPIC 7. FACTORS AFFECTING PHS

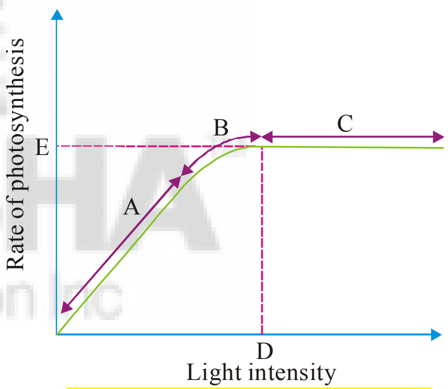
- PHS is under the influence of both external and internal (plant) factors.
- Plant factors include the number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO_2 concentration and amount of Chl.
- Plant factors are dependent on the genetic predisposition and the growth of the plant.
- External factors would include the a variability of sunlight, temperature, CO_2 concentration and water. As a plant photosynthesises all these factors will simultaneously affects its rate.

- Hence, though several factors interact and simultaneously affect PHS, usually one factor is the major cause or is the one that limits the rate.
- Hence at any point the rate will be determined by the factor available at sub-optimal levels.
- When several factors affect any biochemical process, **Blackmans (1905)** law of limiting factors comes into effect.
- This states- "If a Chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value, it is the factor which directly affects the process if its quantity is changed."
- For example despite the presence of a green leaf, optimal light and CO_2 conditions the plant may not photosynthesise if the temp is very low. This leaf, if given the optimal temp will start photosynthesizing.

I. Light

- At low light intensities there is a linear relationship between incident light and CO_2 fixation rate.
- At higher light intensities gradually the rate does not show further increase as other factors become limiting.
- **Light saturation** occurs at 10% of the full sunlight.
- Hence, except for plants in shade or in dense forests, light is rarely a limiting factor in nature.
- Increase in incident light beyond a point cause the break down of chl (solarisation) and a decrease in PHS.
- Green light range is least effective in photosynthesis.

(NCERT EXEMPLAR)



Graph of light intensity on the rate of photosynthesis

II. CO_2 Concentration

- CO_2 is the major limiting factor for PHS.
- The atmospheric concn. of CO_2 is **very low (between 0.03 and 0.04 %)**.
- Increase in concn. upto 0.05% can cause increase in PHS. Beyond this the levels can become damaging over longer periods.

- C_3 and C_4 plants respond differently to CO_2 cocentrations. At low light intensities neither group responds to high CO_2 conditions.
- At high light intensities both C_3 and C_4 plants show increase in the rates of PHS.
- C_4 plants show saturation at about **360 μlL^{-1} (0.036%)**.
- C_3 plants show saturation beyond 450 μlL^{-1} (0.045%) and responds to increased CO_2 concentration. Thus, current availability of CO_2 levels is limiting to the C_3 plants.
- The fact that C_3 plants respond to higher CO_2 concn. by showing increased rates of PHS leading to higher productivity has been used for green house crops like **tomatoes** and **bell pepper**.
- They are allowed to grow in CO_2 enriched atm that leads to higher yields.

III. Temperature

- **Dark reaction** are enzymatic hence **temperature controlled.**
- Though the light reactions are also temperature sensitive they are affected to a much lesser extent.
- C_4 plants respond to higher temp and show higher rate of PHS while C_3 plants have a much lower temp optimum.
- Tropical plants have a higher temp. optimum than plants adapted to temperate climates.

IV. Water

- Water is one of the **reactants** in the light reaction. Effect of water is more through its effect on the plant, rather than directly on PHS.
- Water stress cause the stomata to close hence reducing the CO_2 availability. Water stress also makes leaves wilt, thus reducing the surface area of the leaves and their metabolic activity.

NOTE: A few normal seedlings of tomato were kept in a dark room. After a few days they were found to have become white-coloured like albinos. This condition is called etiolation. ***(AIPMT 2014)***