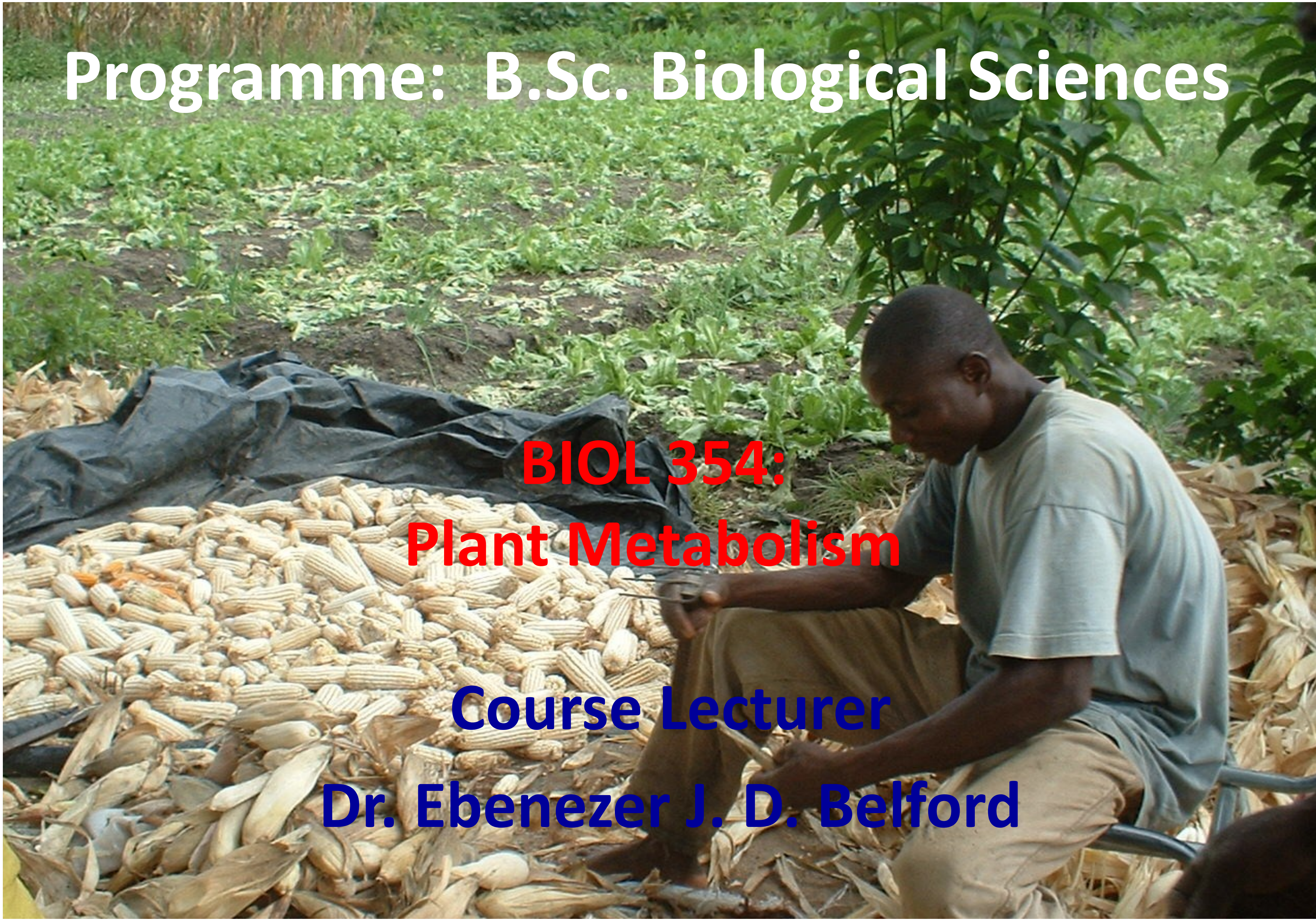


Programme: B.Sc. Biological Sciences

BIOL 354: Plant Metabolism

Course Lecturer

Dr. Ebenezer J. D. Belford

BIOL 354: Plant Metabolism

Year Three - Semester Two

- Three (3) Credit hours
- Two (2) hours - Theory
- Three (3) hours - Practical

Assessment Requirements

- ✓ **Quiz**
- ✓ **Mid Semester Examination**
- ✓ **Practical Assignments – Weekly**
- ✓ **Theoretical Assignments**
- ✓ **Attendance**

Continuous Assessment 30%

- ✓ **End Semester Examination 70%**

LECTURE TOPICS

1. PHOTSYNTHESIS

a) Discovery
b) Overview
c) The Reactants – CO_2, Water, Solar energy, Chlorophyll
d) Evidence: The Mechanism of Process
- The Light Reaction – Light dependent reactions
- The Dark Reaction – Light independent reactions

e) Factors affecting photosynthesis

2. RESPIRATION

a) Glycolysis

b) The Krebs Cycle – (Citric acid cycle)

c) The Electron Transport System

LECTURE TOPICS *contd.*

3. NITROGEN METABOLISM

a) Forms of Nitrogen available to Plants

b) Nitrate Reduction

c) Relationship of Nitrate Reduction to:-

- Respiration and Photosynthesis

d) Conversion of Ammonia to Amino acids

4. MINERAL NUTRITION

a) Water Culture

b) Role of Mineral Nutrients in Plant Metabolism

c) Symptoms of Mineral Deficiency and Toxicity

Recommended texts for further reading

1. Geoffrey M Cooper and Robert E. Hausman (2004). The Cell. A Molecular Approach. 3rd Edition.
2. D. O. Hall and K. K. Rao (1981). Photosynthesis.
3. Conn, E. E. Stumpf, P. K., Bruening, G. and Doi, R. H. (1987). Outlines of Biochemistry.
4. Goodwin, T. W. and Mercer, E. I. (1972). Introduction to Plant Biochemistry.
5. Stern, K. (2003). Introductory Plant Biology.
6. Taiz, Lincoln and Zeiger, Eduardo (2002). Plant Physiology. 3rd Edition.
7. **Any advance Biology Text**.

Requirements for Practical Classes

- ✓ A Laboratory (practical) file is essential. Any **hard cover file with A4 paper** to fit will be appropriate. In it you should record all protocols, diagrams, observations and results on practical assignments.

- ✓ Diagrams must be drawn with a **pencil**. Use pencils with soft lead, preferably HB. Label and rule lines in pencil, as this will facilitate correction.

- ✓ Protective garment. **Lab coat**, designed to protect you from direct exposure to dangerous chemicals and infectious materials.

Objectives of the course

Plant Metabolism is a sub-discipline of Botany concern with photosynthesis and mineral nutrition of plants.

At the end of the course, you should be able to:

- **Define and explain with examples the various concepts in Plant Metabolism.**
- **Understand the role of photosynthesis on earth and recognize the site of photosynthesis in a plant.**
- **Identify and distinguish between the multistage processes of photosynthesis.**
- **Distinguish between photosynthesis and respiration.**
- **Get an insight to process of nitrogen metabolism and the role of mineral nutrition in plant.**

1.0 PHOTOSYNTHESIS

1.1 Discovery

- ***Introduction***
- ***Is Water the Source of Energy in Plants?***
- ***The Interaction of Plants with Air***
- ***Plants and Light***

1.0 Photosynthesis *contd.*

1.2 Overview

- **Plant:** a living thing which grows on earth, in water or on other plants and usually has a stem, leaves, roots and flowers and produces seeds.

- **Metabolism:**
  - is the chemical processes occurring within a living cell, especially those that cause food to be used for energy and growth.
  - is the sum of the chemical reactions within a cell.
  - process where some substances are broken down to yield energy while other substances are synthesized.

1.0 Photosynthesis *contd.*

1.2 Overview *contd.*

- **The synthesis of complex substances (e.g. living tissue) from simpler ones together with the storage of energy is referred to as *Anabolism or Constructive metabolism*.**

- **The breakdown of more complex substances into simpler ones together with the release of energy is referred to as *Catabolism or destructive metabolism or dissimilation*.**

1.0 Photosynthesis *contd.*

1.2 Overview *contd.*

- **Metabolic Pathways help to organize metabolism: each pathway is a series of reactions organized such that the products of one reaction become substrates for the next.**

- **The reactants are the initial substrate for the metabolic pathway.**

- **The end products are compounds which the cell can use, store or secrete.**

1.0 Photosynthesis *contd.*

1.2 Overview *contd* – Definition of Photosynthesis

What is Photosynthesis?

- **The process by which plants manufacture their food. Food here, being the product of Photosynthesis.**

- **Photosynthesis, generally, is the synthesis of sugar from light, carbon dioxide and water, with oxygen as a waste product.**

- **Photosynthesis is the process that changes light energy into the energy of chemical bonds. It synthesizes glucose. This process occurs in the chloroplast of plants.**

1.0 Photosynthesis *contd.*

1.2 Overview *contd* – Definition of Photosynthesis

What is Photosynthesis contd.?

- **The molecular process by which plants, algae (aquatic, photosynthesizing organisms), and certain bacteria convert light energy into chemical energy in making food (sugar molecules) from simple chemicals (carbon dioxide, CO_2 and water, H_2O) in the presence of chlorophyll.**

The word photosynthesis means "putting together with light" in order for a cell to obtain usable energy, the radiant energy of light must be converted through a series of complex chemical reactions.

1.0 Photosynthesis *contd.*

1.2 Overview *contd* – Definition of Photosynthesis

What is Photosynthesis contd.?

Photosynthesis is a chemical reaction and so can be written as a word equation:

$$6\ CO_2 + 6H_2O + \text{solar energy è} \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

The overall equation for photosynthesis is:

$$6CO_2 + 12H_2O + \text{solar energy è} \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

1.0 Photosynthesis *contd.*

1.2 Overview *contd.*

What is Photosynthesis contd.?

- ✓ **All life on earth depends on photosynthesis for food and oxygen. Energy is needed for all living cells to function.**
- ✓ **It is needed for food digestion, growth, molecule formation, and reproduction.**
- ✓ **Everything would shut down without sunlight (include us humans), it is the original source of all this energy.**

1.0 Photosynthesis *contd.*

1.2 Overview *contd*

What is Photosynthesis contd.?

- ✓ **In photosynthesis, green plants use the energy of sunlight to convert carbon dioxide into hydrocarbons that promote plant growth while generating oxygen from water and releasing the oxygen to the atmosphere.**
- ✓ **All animals including humans depend either directly or indirectly on this source of food and oxygen. Consequently, photosynthesis is considered the most important chemical process on earth.**

1.0 Photosynthesis *contd.*

1.2 Overview *contd*

What is Photosynthesis contd.?

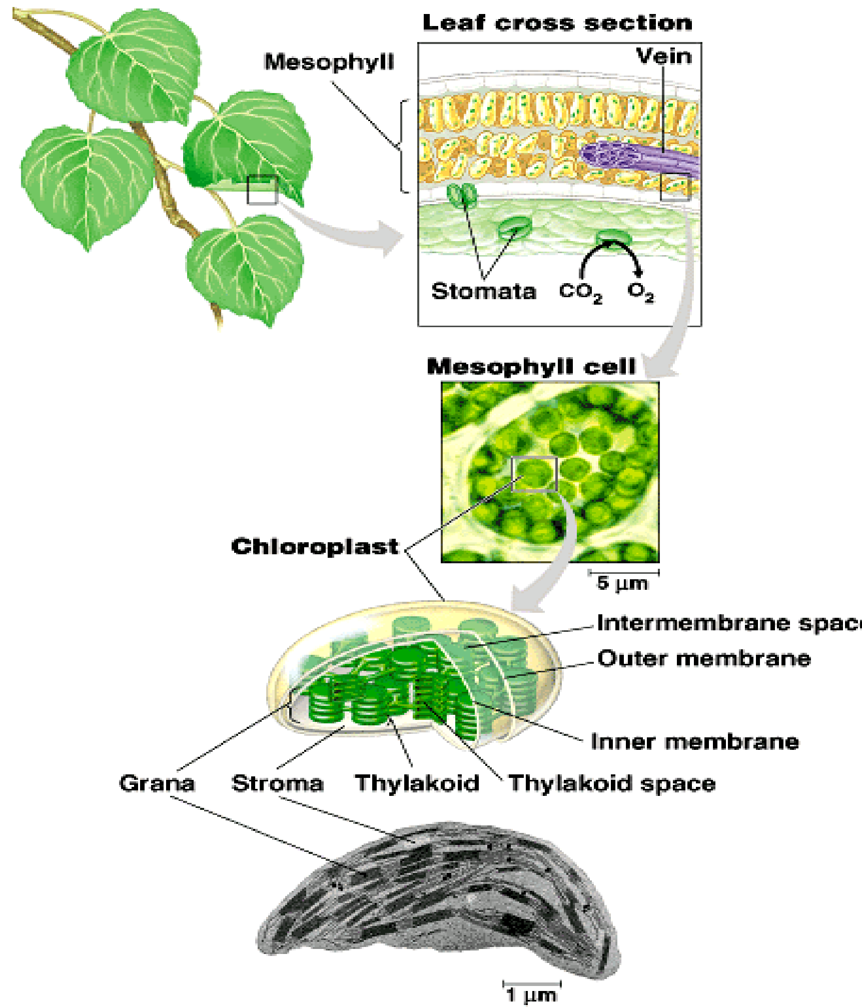
- Photosynthesis is the process that changes light energy into the energy of chemical bonds.
- It synthesizes glucose.
- The process occurs in the chloroplast of plants.
- The overall equation for photosynthesis is:

$$6CO_2 + 12H_2O + \text{solar energy è} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

1.0 Photosynthesis *contd.*

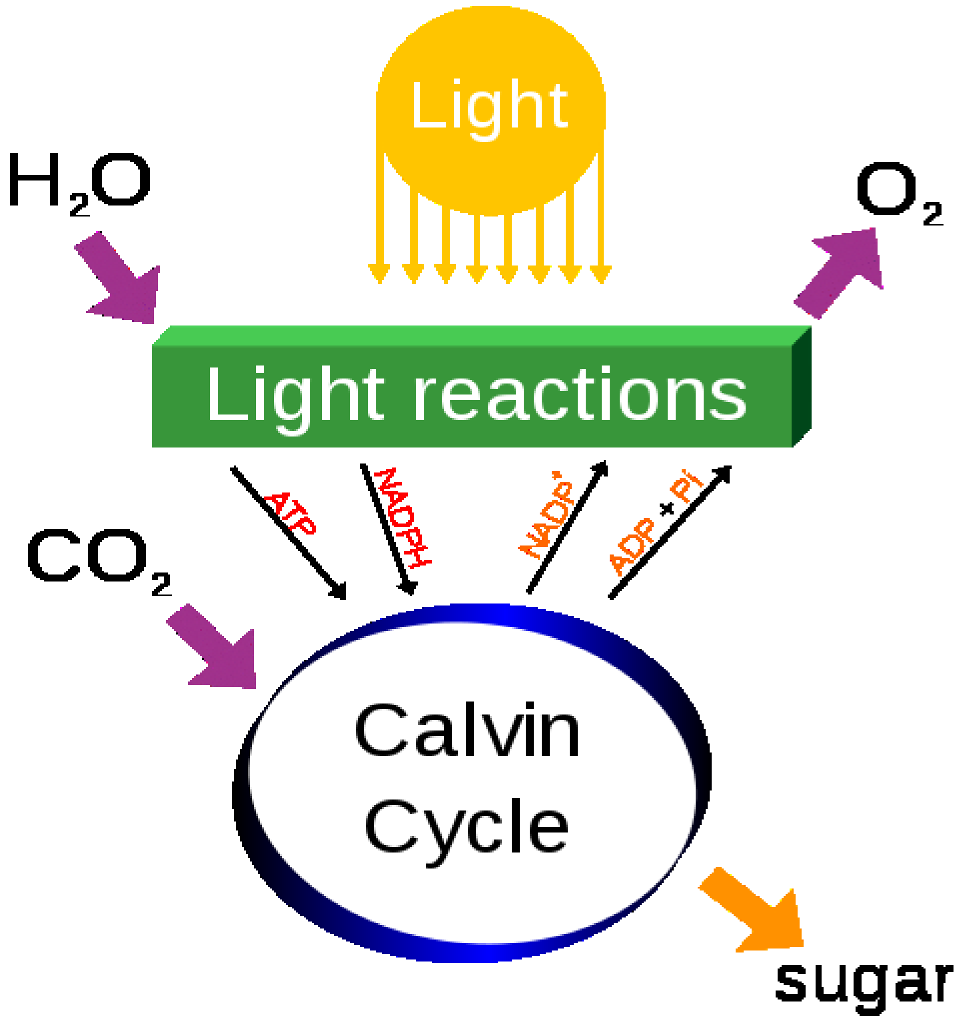
1.2 Overview *contd.*

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



1.0 Photosynthesis *contd.*

1.2 Overview *contd.*



$6\ CO_2 + 6\ H_2O \rightarrow C_6$I

1.0 Photosynthesis *contd.*

1.3 The Reactants

CO_2, Water, Solar energy, Chlorophyll

- ***Carbon gets into the leaf through minute pores in leaves called stomata and***
- ***Water goes into the plant through its roots***
- ***Solar energy from sunlight***
- ***Chlorophyll located in chloroplast in plants***

Oxygen is a by-product; it gets out of the cell through the stomata.

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Carbon dioxide (CO_2)

- The earth's atmosphere contains approximately 79% nitrogen, 20% oxygen and the remaining 1% is a mixture of less common gases-including 0.039% carbon dioxide.
- Carbon dioxide in the atmosphere is coming from fossil fuels, deforestation and human activities.
- The oceans hold a large reservoir of carbon dioxide, which keeps the atmospheric levels essentially constant.

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Carbon dioxide (CO_2)

- **Carbon dioxide in the atmosphere reaches plant mesophyll via the stomata.**
- **The carbon dioxide dissolves on the thin film of water that covers the outside of cells.**
- **The carbon dioxide then diffuses through the cell wall into the cytoplasm in order to reach the chloroplasts.**
- **Photosynthesis is enhance by carbon dioxide.**

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Water (H_2O)

- **Water is plentiful on earth, however, it may or may not be plentiful at the location of each individual plant.**
- **Therefore, plants will close their stomata, if need be, which reduces the CO_2 supply to the mesophyll.**
- **Less than 1% of the water that is absorbed by plants is used in photosynthesis, the remainder is either transpired or incorporated into protoplasm, vacuoles or other cell materials.**
- **The water utilized in photosynthesis is the source of oxygen released as a photosynthetic byproduct.**

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Light

- **The energy from the sun comes to earth in various wavelengths, the longest being radio waves and the shortest are gamma rays.**
- **Approximately 40% of the radiant energy the earth receives from the sun is visible light.**
- **Visible light ranges from red, 780 nanometers to violet, 390 nanometers.**
- **The violet to blue and red to orange ranges are the most often used in photosynthesis.**
- **Most light in the green range is reflected.**

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Light

- Of the visible light that reaches a leaf, approximately 80% is absorbed.
- Light intensity varies widely with time of day, temperature, season of year, altitude, latitude and other atmospheric conditions.
- High intensity light isn't necessarily a beneficial thing for plants.
- In high intensity light, photorespiration may occur, which is a type of respiration that uses oxygen and releases carbon dioxide but differs from standard aerobic respiration in the pathways that it utilizes.

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Chlorophyll

- There are more than one type of chlorophyll, however, they all have one atom of magnesium in the center.
- In some ways the chlorophyll is quite analogous to the heme structure in hemoglobin (the iron containing pigment that carries oxygen in blood).
- Chlorophyll has a long lipid tail that anchors the molecule in the lipid layers of the thylakoid membranes - recall that thylakoids are coin-like discs in stacks of grana within the stroma of the chloroplasts.
- The chloroplasts of most plants contain two main types of chlorophyll imbedded in the thylakoid membranes.

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Chlorophyll

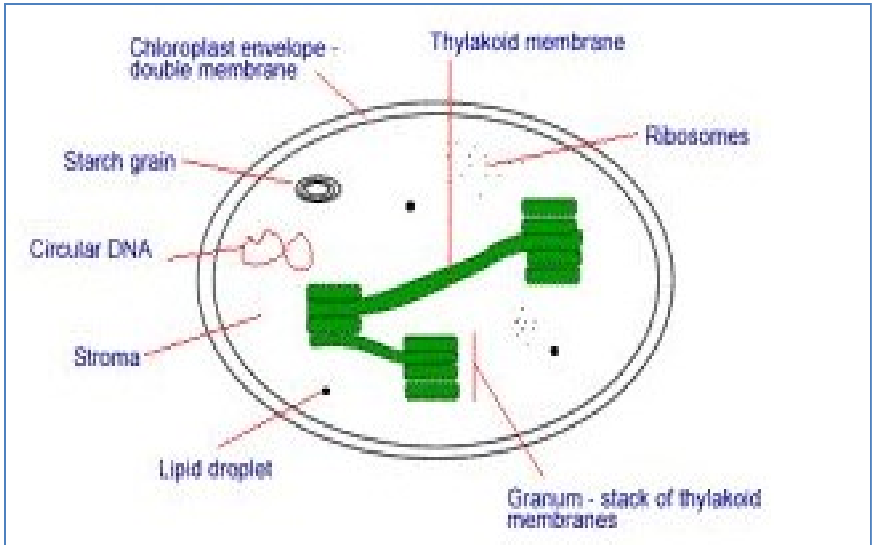
- The formula for bluish-green chlorophyll a is $C_{55}H_{72}MgN_4O_5$ and the formula for yellow-green chlorophyll b is $C_{55}H_{70}MgN_4O_6$.
- In general, most chloroplast has about three times as much chlorophyll a than b. The main role of chlorophyll b is to broaden the spectrum of light available for photosynthesis: chlorophyll b absorbs light energy and transfers the energy to a chlorophyll a molecule.
- Other pigments are contained in chlorophyll c, d, and e and take the place for chlorophyll b in some cases.
- Note that all the chlorophyll molecules are related to each other and differ only slightly in molecular structure.

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*

Chlorophyll

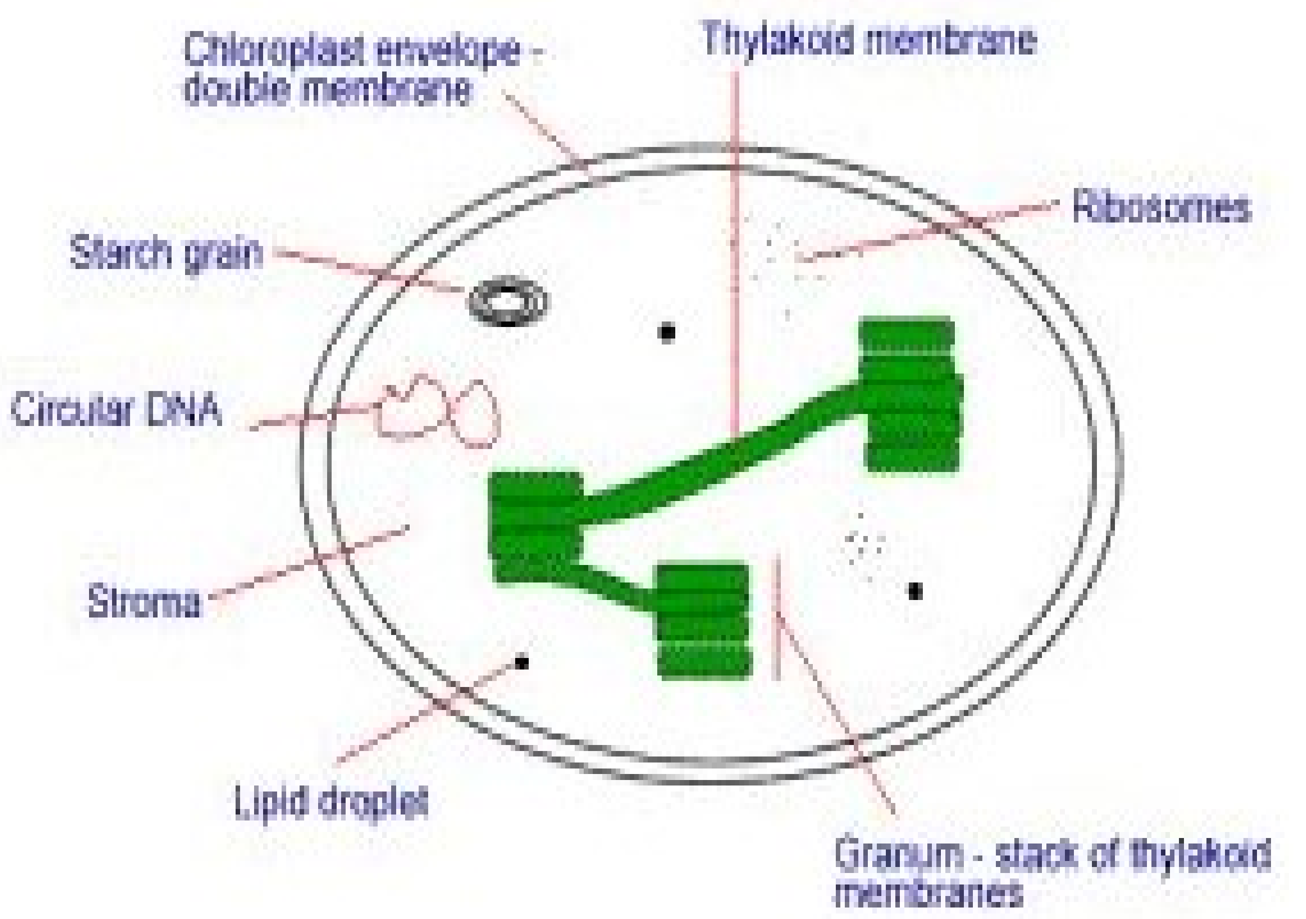
- **Light-harvesting complexes contain 250 to 400 pigment molecules and are referred to as a photosynthetic unit.**
- **There are countless numbers of these units spread throughout the grana of a chloroplast.**
- **In the chloroplasts of green plants, two types of these harvesting units operate together in order to bring about the first phase of photosynthesis.**



Chloroplast

1.0 Photosynthesis *contd.*

1.3 Reactants *contd.*



Chloroplast

1.3 Reactants – Energy source

Autotrophic nutrition

- **Living organism are grouped on the basis of their carbon and energy source.**
- **Organisms which have an inorganic source of carbon namely carbon dioxide, are described as autotrophic ('self-feeding').**
- **The term also defines organisms which are able to use external sources of energy in the synthesis of their organic food materials.**
- **Plants are of this group, using light via photosynthesis, they are therefore photo-autotrophs.**
- **In a food chain, autotrophs are described as primary producers.**

1.0 Photosynthesis *contd.*

1.3 Reactants – Energy source

Chemotrophic nutrition

Some prokaryotes obtain energy from the oxidation of simple inorganic substances and use this energy to build up organic molecules. These organisms are chemosynthetic and include the nitrifying bacteria which are important in the nitrogen cycle.

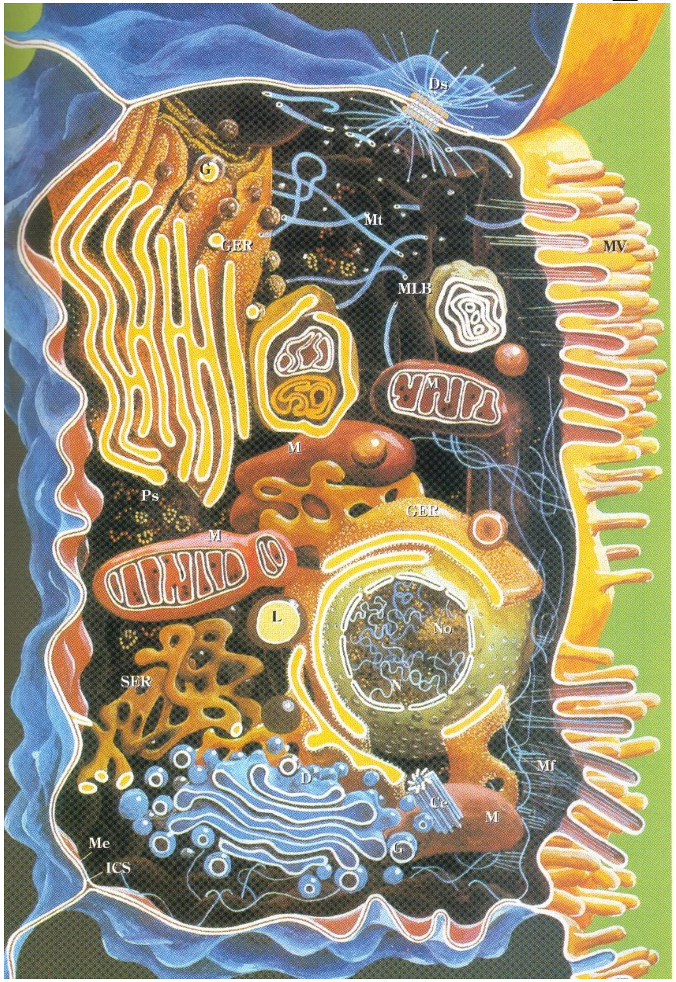
Heterotrophic nutrition

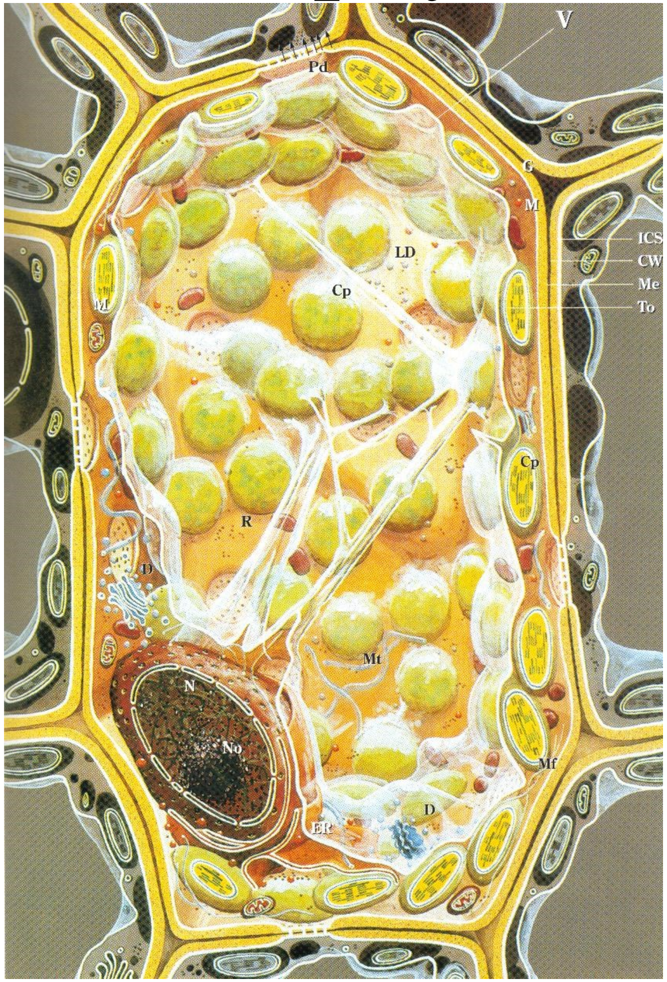
- **Organisms which have an organic source of carbon namely carbohydrates, are described as heterotrophic ('other-feeding').**
- **The term also defines organisms which obtain their energy by breaking down substances obtained from the bodies of other organisms.**
- **In a food chain, the heterotrophs are described as secondary producers.**

1.0 Photosynthesis *contd.*

1.3 Reactants – Energy source

Heterotrophy vs. Autotrophy



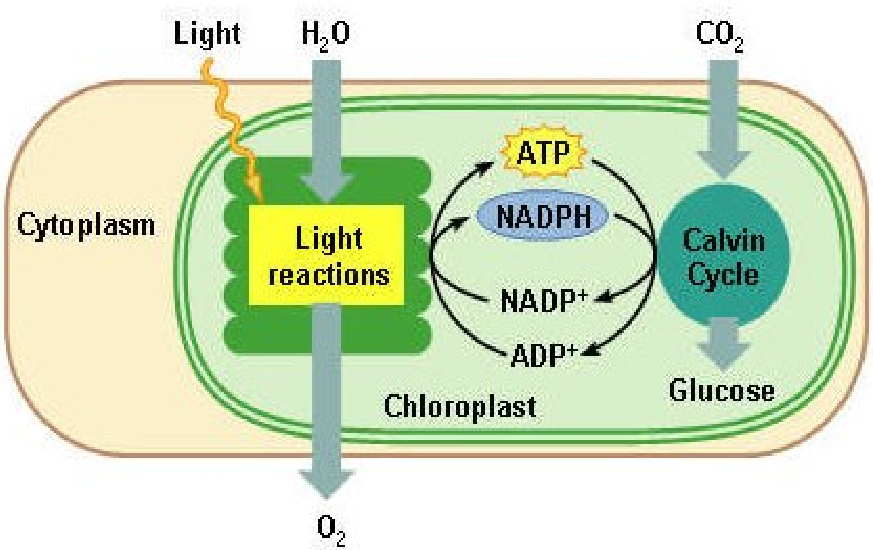


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis

- **Photosynthesis is essentially an oxidation-reduction process by which hydrogen is transferred from water to carbon dioxide through a carrier substance.**



- **In the process of photosynthesis energy from sunlight is absorb by chlorophyll and converted into chemical energy, stored in two compounds namely:**
  - Adenosine triphosphate (ATP) and
  - reduced Nicotinamide adenine dinucleotide phosphate ($NADP.H_2$).

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis - Light

- **Light is made up of wavelengths and particles.**
- **Wavelength is denoted by the Greek letter λ (Lamda) which is the distance between successive wave crests.**
- **The number of wave crests that is observed at a given time is known as the frequency and is denoted by nu (ν).**
- **Lamda (λ) and nu (ν) are related by $C = \lambda\nu$. Where C is the speed of wave.**
- **The speed of light is $3.0 \times 10^8 ms^{-1}$ (300,000 km/s).**
- **The order of colors is determined by the wavelength of light.**

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis - Light

- A **particle** of light is also referred to as a **photon**.
- Each photon contains an amount of energy that is called a **quantum** (plural, **quanta**).
- The **energy** (E) of a photon is delivered in discrete packets, depending on the frequency of light according to Planck's law: $E = h\nu$. Where **h** is the Planck's constant (6.626×10^{-34} Js).
- A pigment molecule can absorb only one photon at a time and any photon absorbed could initiate a photochemical reaction.

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **Pigments are chemical compounds by which the energy of sunlight is captured for photosynthesis.**
- **The pigments have the ability to absorb and reflect certain wavelengths of visible light. This makes them appear "colorful".**
- **However, since each pigment reacts with only a narrow range of the light spectrum, there is usually a need to produce several kinds of pigments, each of a different color, to capture more of the sun's energy.**

1.0 Photosynthesis *contd.*

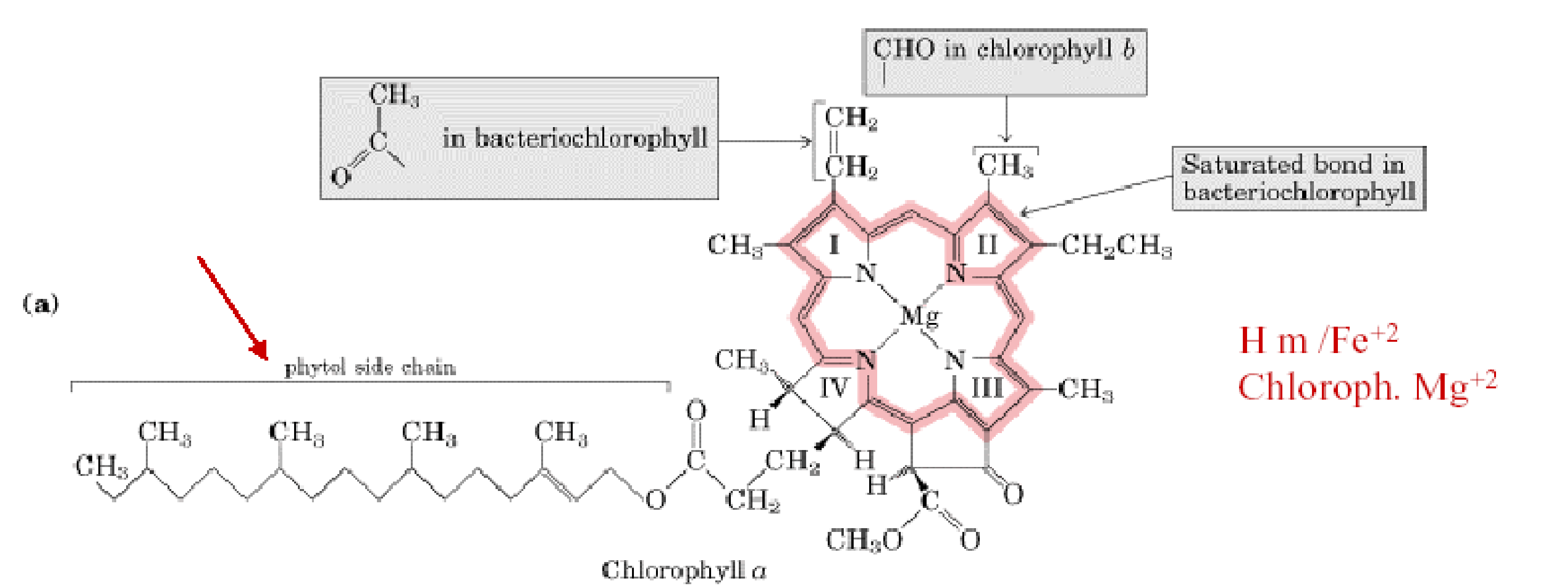
1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

There are three basic classes of pigments.

Chlorophylls are greenish pigments which contain a porphyrin ring.

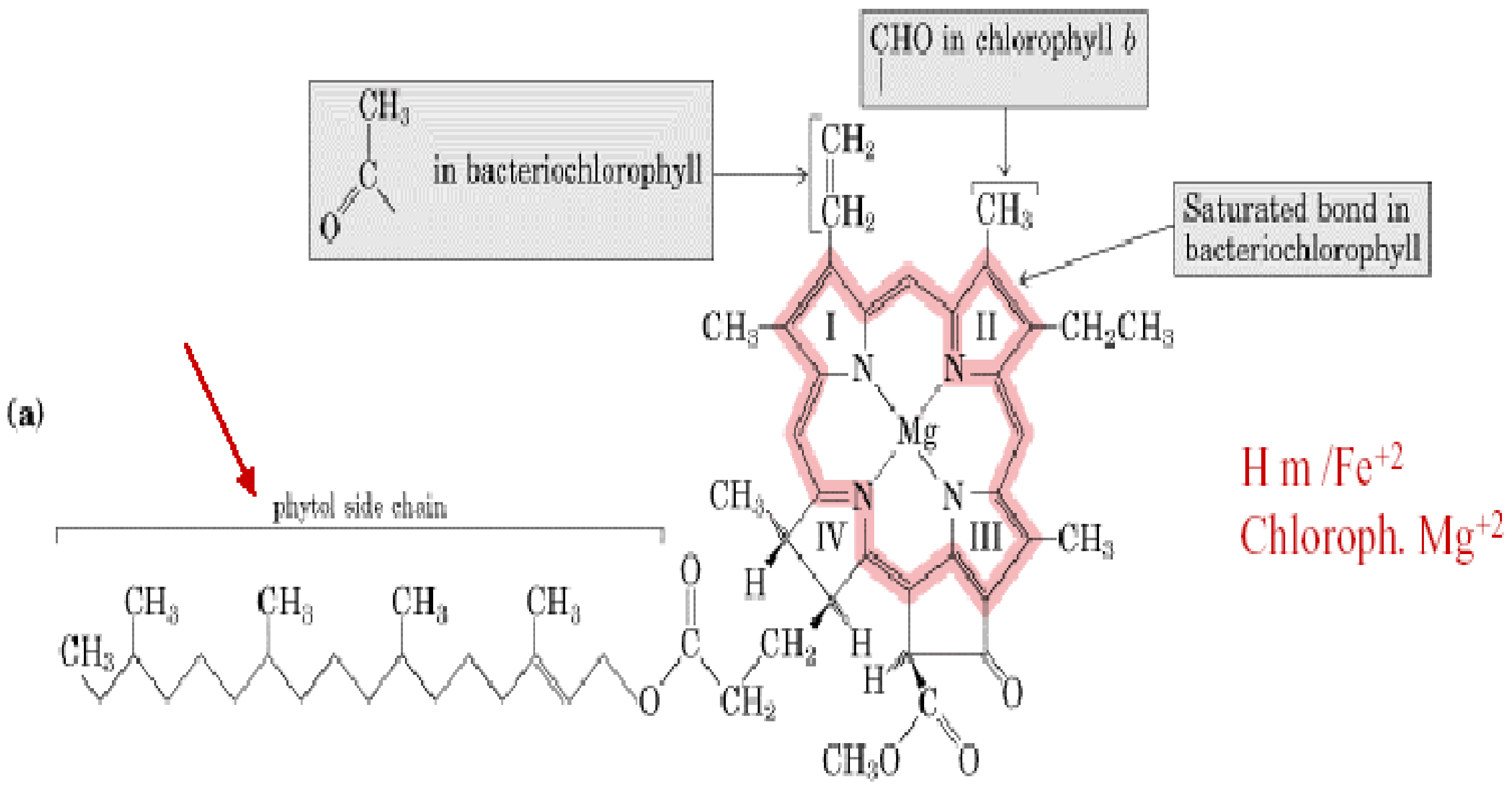
- **This is a stable ring-shaped molecule around which electrons are free to migrate.**



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments



Chlorophyll *a*

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **Because the electrons move freely, the ring has the potential to gain or lose electrons easily, and thus the potential to provide energized electrons to other molecules.**

- **This is the fundamental process by which chlorophyll "captures" the energy of sunlight.**

Carotenoids are usually red, orange, or yellow pigments.

- **They include the familiar compound carotene, which gives carrots their color.**
- **Carotenoids cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass their absorbed energy to chlorophyll. For this reason, they are called accessory pigments.**

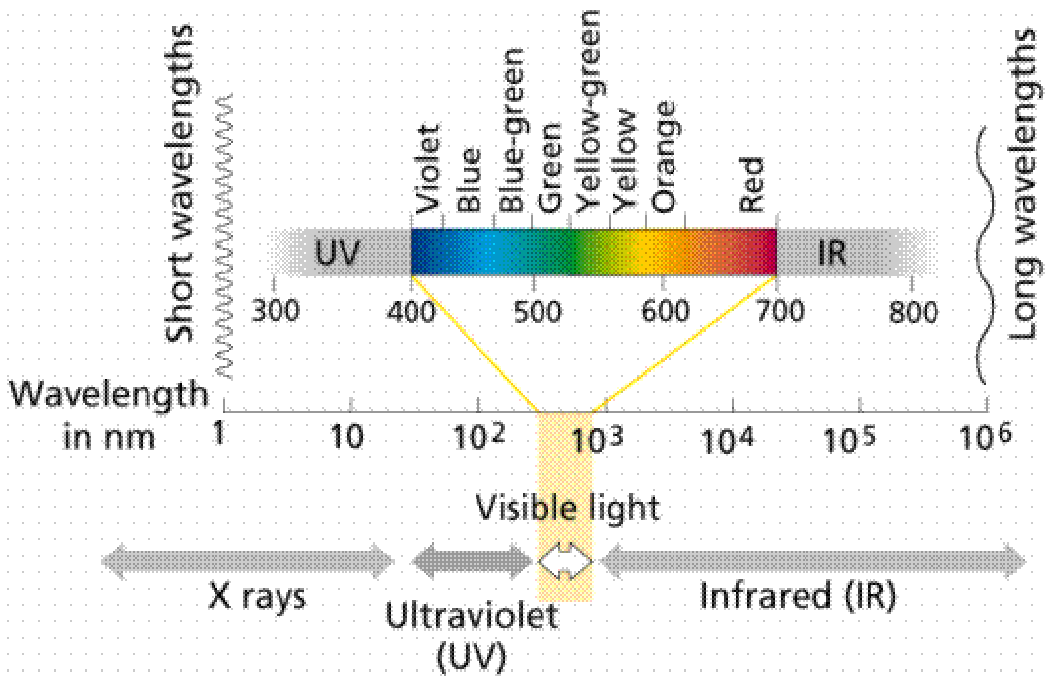
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **Light energy is available in discrete packets called quanta.**
- **The longer the wavelength of radiation, the less energy that radiation contains.**
- **Visible light is one small part of the electromagnetic spectrum, from about 400 nm (blue) to 700 nm (red).**

- **The longer the wavelength of visible light, the more red the color.**
- **Likewise the shorter wavelengths are towards the violet side of the spectrum.**
- **Wavelengths longer than red are referred to as infrared, while those shorter than violet are ultraviolet.**



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

Phycobilins (blue pigments) are water-soluble pigments.

- **They occur only in Cyanobacteria and Rhodophyta.**
- **They are found in the cytoplasm, or in the stroma of the chloroplast.**
- **They are also accessory pigments.**

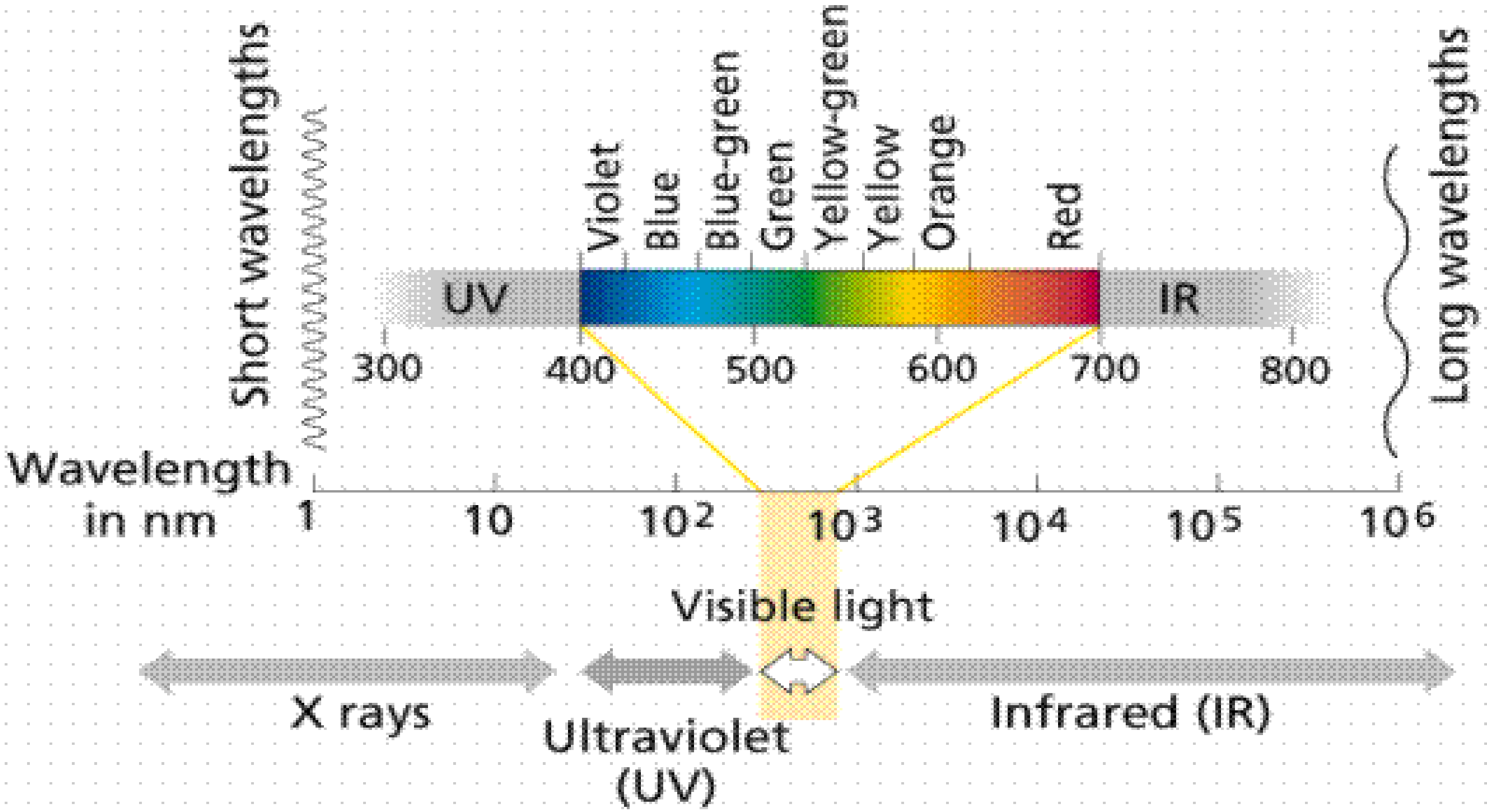
A photosynthetic pigment (accessory pigment; chloroplast pigment; antenna pigment) is a pigment present in chloroplasts or photosynthetic bacteria that captures the light energy necessary for photosynthesis.

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **Visible light is one small part of the electromagnetic spectrum, from about 400 nm (blue) to 700 nm (red).**



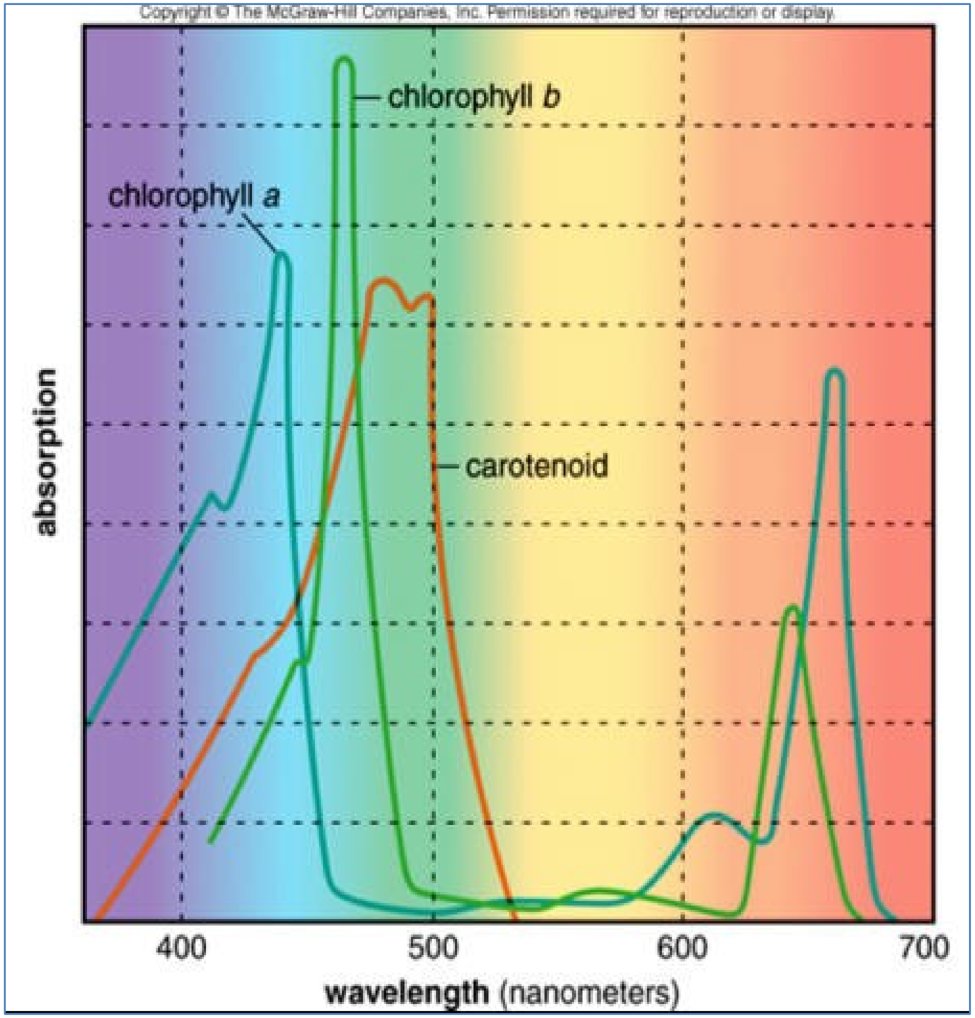
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **When the pigments involved in photosynthesis are subjected to different wavelengths of light, they absorb some wavelengths more than others.**

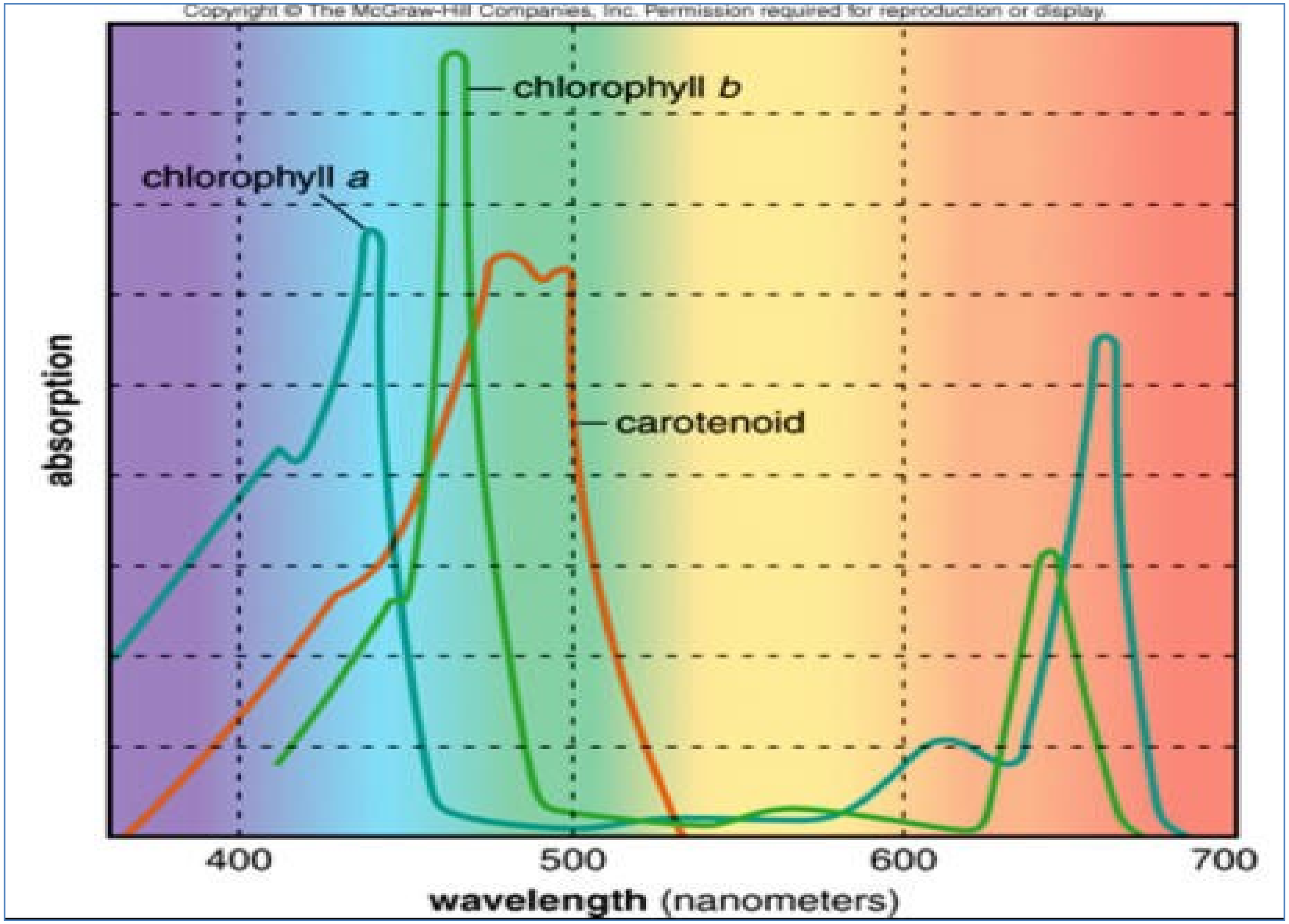
- **A graph showing the degree of absorption of light by a pigment is referred to as the absorption spectrum for that pigment.**



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

Absorption Spectrum of Pigments

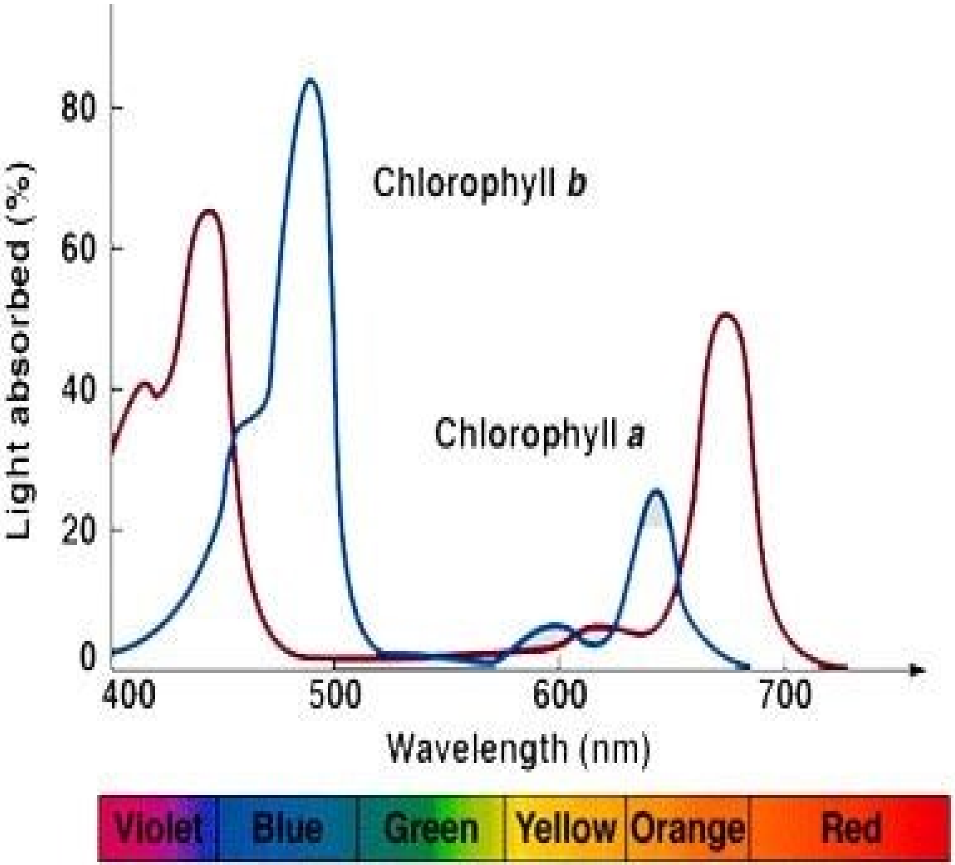


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- **Chlorophylls absorb strongly in the blue-violet and red regions of the spectrum (and not in the green region, hence leaves containing chlorophyll appear green), while carotenoids absorb in the blue and green regions.**
- **The colour of the carotenoids (yellow to orange and red) is usually masked by that of the chlorophylls, which are present in larger quantities.**

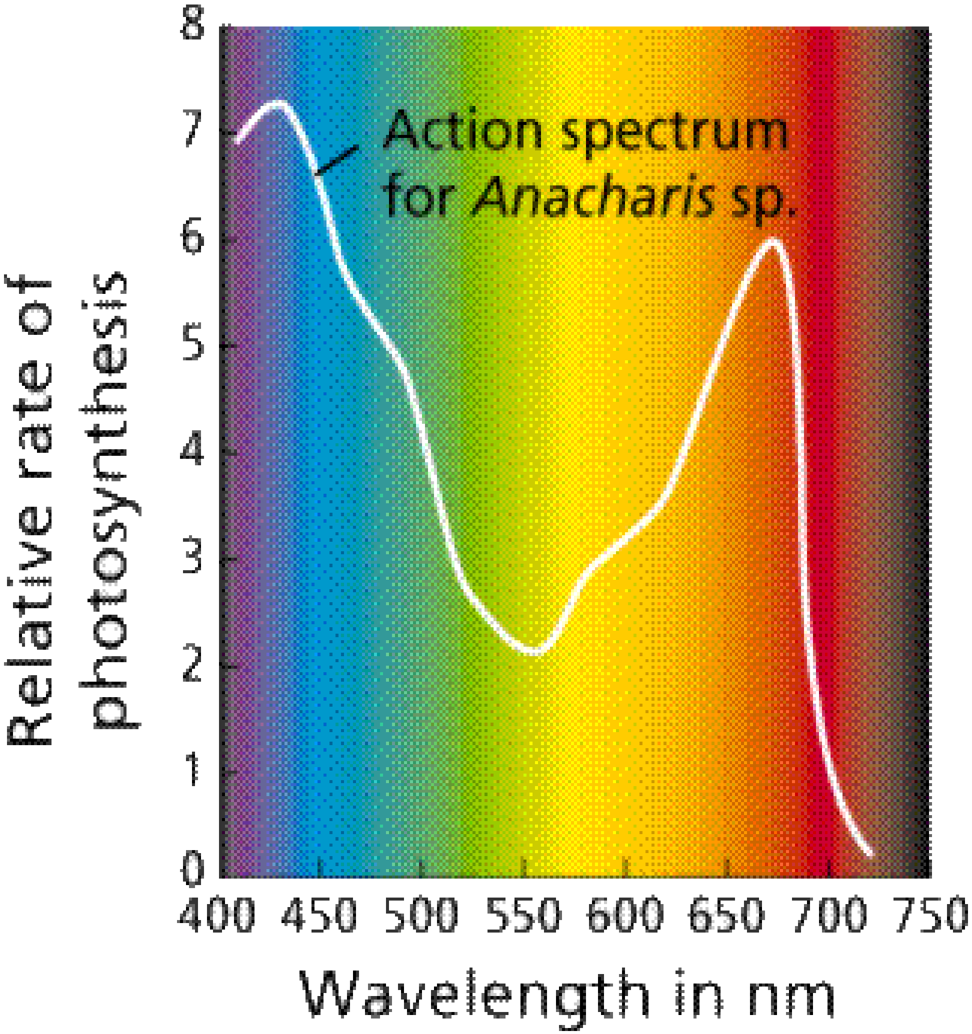


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The Chemistry of Photosynthesis – The Photosynthetic Pigments

- A graph showing the degree to which different wavelengths affect photosynthesis is called the action spectrum for photosynthesis.
- The action spectrum for photosynthesis is closely correlated with the action spectra for chlorophylls a and b and the carotenoids.
- This suggests that these are the main pigments involved in harvesting light in photosynthesis.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

Photosynthesis – A Multi Stage Process

- **The photosynthetic process occurs in two successive processes: the light reactions and the dark (carbon-fixing) reactions each consisting of many steps.**
- **The light stage results in a product that is fed into the dark stage.**

The light reactions (light-dependent reactions):

Cyclic photophosphorylation	Non-cyclic photophosphorylation:
✓ Photosystem 1: Reaction centre P_{700} ✓ ATP: Adenosine triphosphate	✓ Photolysis: splitting of water molecules ✓ Photosystem 1: Reaction centre P_{700} ✓ Photosystem 11: Reaction centre P_{680} ✓ ATP and $NADPH_2$

The Dark reactions (light-independent reactions):

➢ Calvin cycle	➢ Carbon-fixing reactions

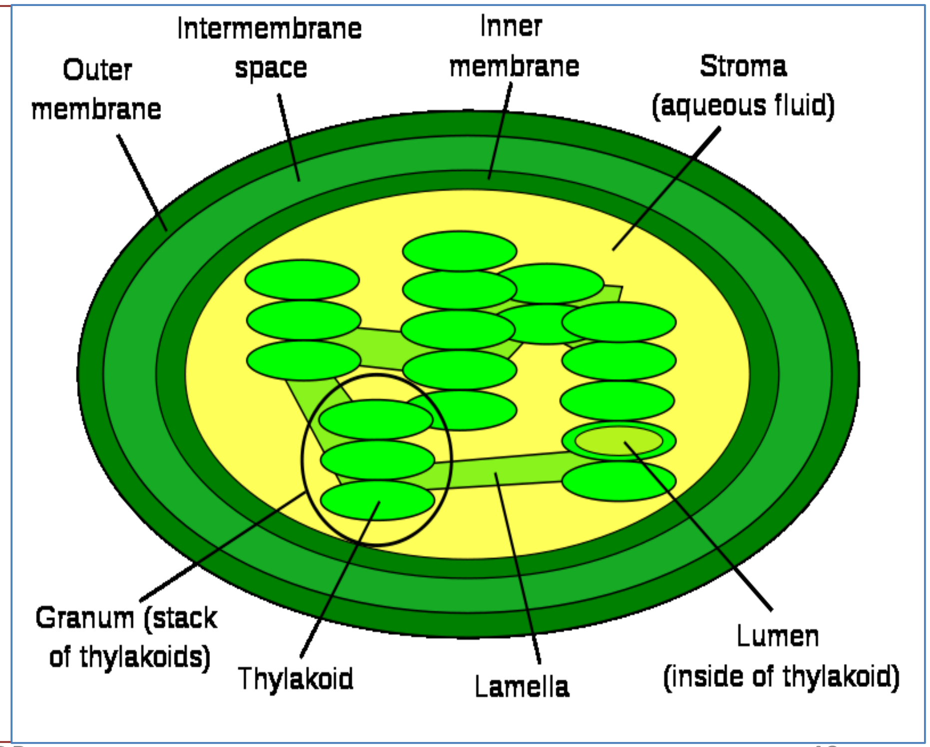
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

- The **light-dependent reactions**, or **light reactions**, are the first stage of photosynthesis.
- In this process light energy is converted into chemical energy, in the form of the energy-carriers ATP and $NADPH_2$.

- The light-dependent reactions take place on the **thylakoid membrane** inside a chloroplast.
- Stacks of thylakoids are known as **grana**.
- The inside of the thylakoid membrane is called the **lumen**, and outside the thylakoid membrane is the **stroma**, where the light-independent reactions take place.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

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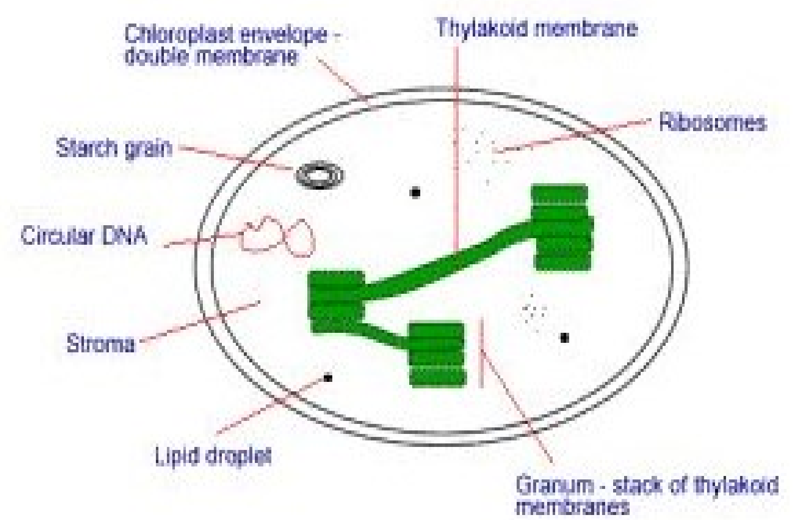


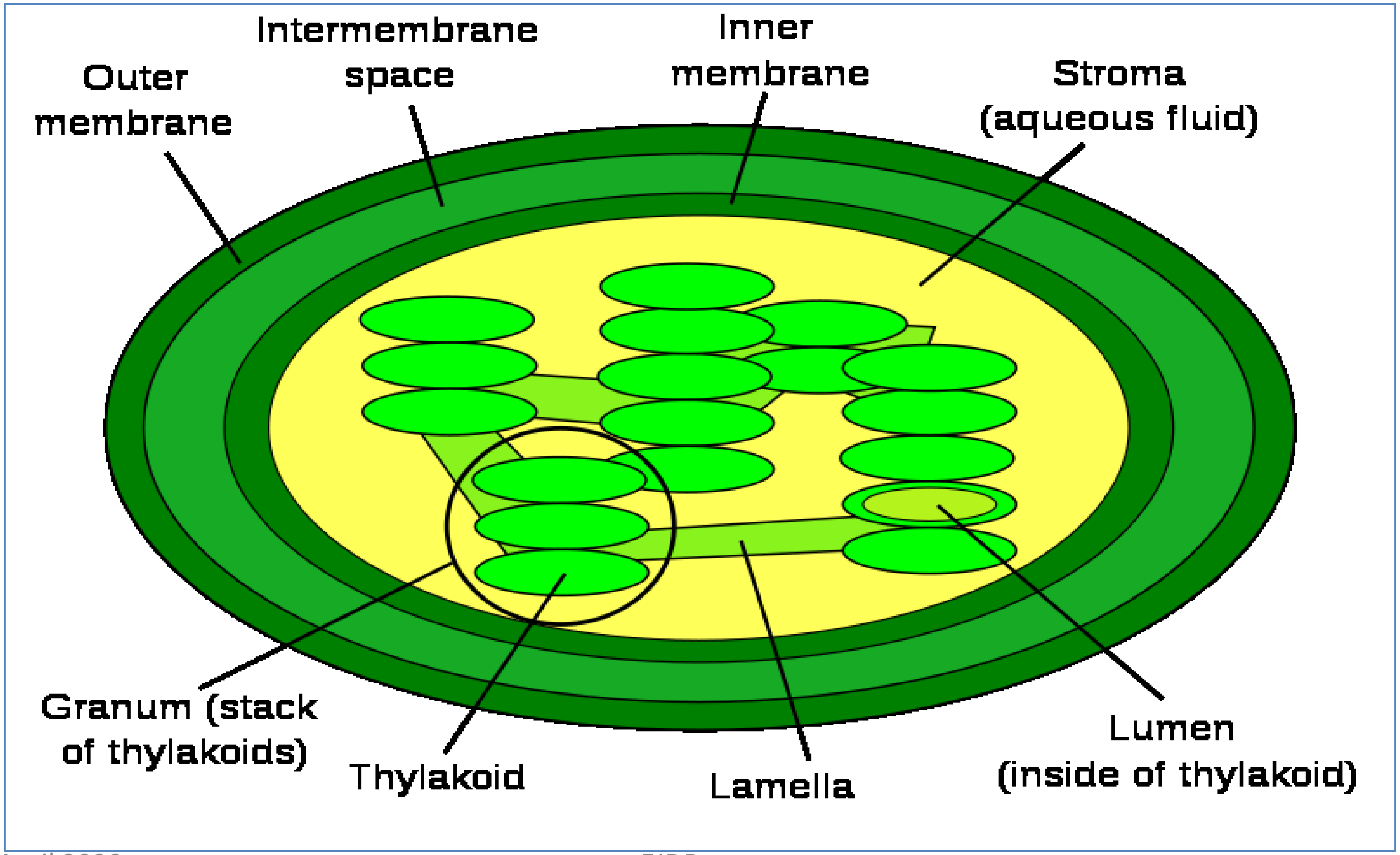
Chloroplast

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

- The light-dependent reactions take place on the **thylakoid membrane** inside a chloroplast.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

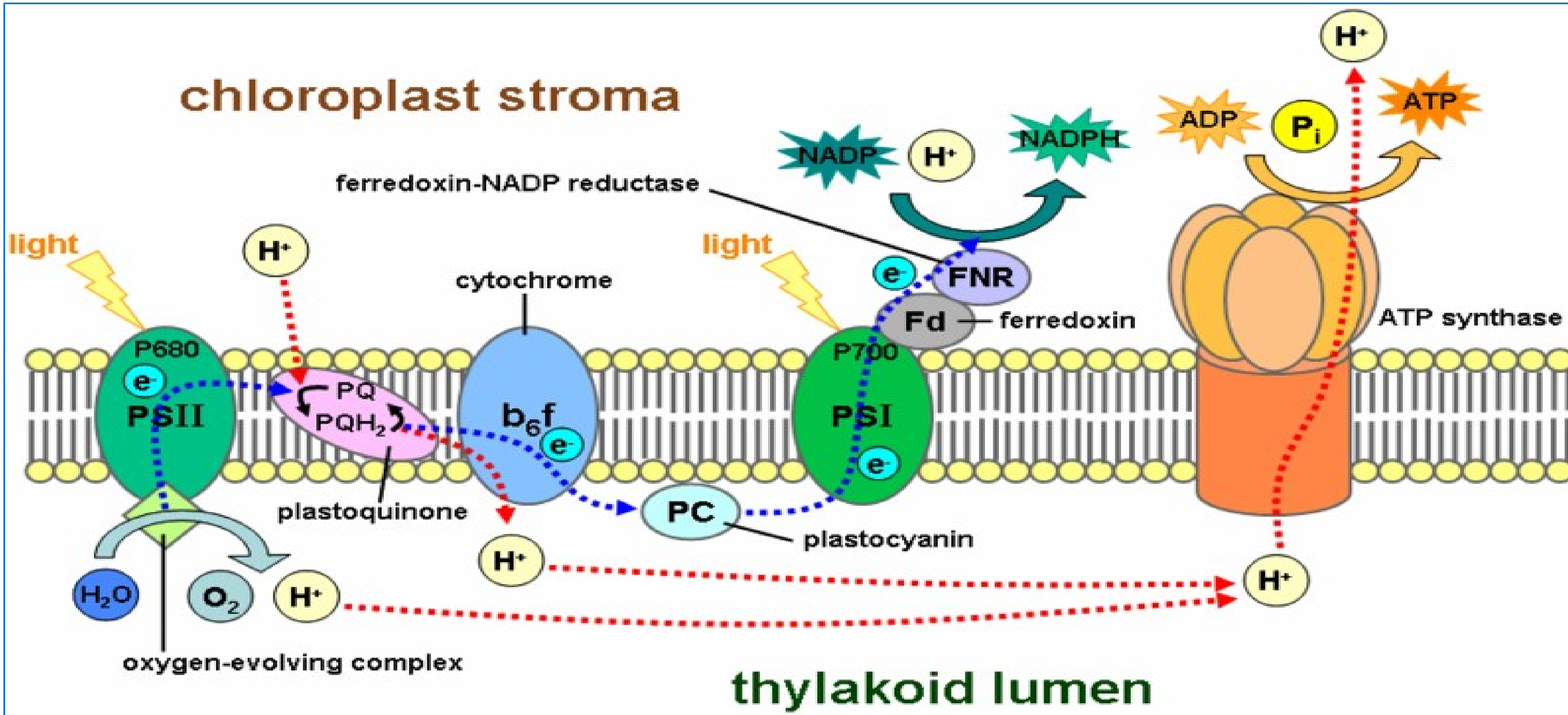
- **The thylakoid membrane contains some integral membrane protein complexes which catalyze the light reactions.**
- **There are four major protein complexes in the thylakoid membrane:**
  - ✓ **Photosystem 1 (PSI),**
  - ✓ **Photosystem 11 (PSII),**
  - ✓ **Cytochrome b6f complex and**
  - ✓ **ATP synthase.**
- **These four complexes work together to ultimately create the products ATP and NADPH.**

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

Four major protein complexes in the thylakoid membrane: Photosystem 1 (PSI), Photosystem 11 (PSII), Cytochrome b6f complex and ATP synthase.



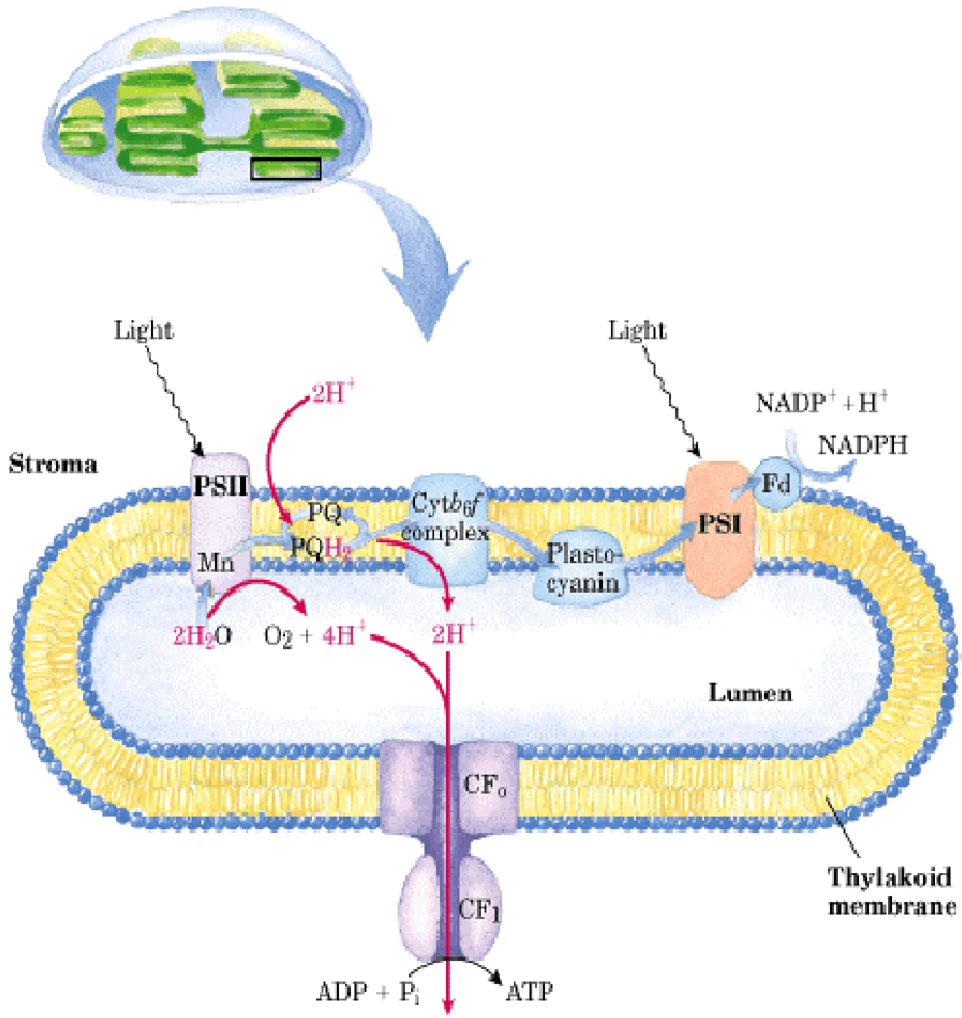
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

Four major protein complexes in the thylakoid membrane:

Photosystem 1 (PSI), Photosystem 11 (PSII), Cytochrome b6f complex and ATP synthase.



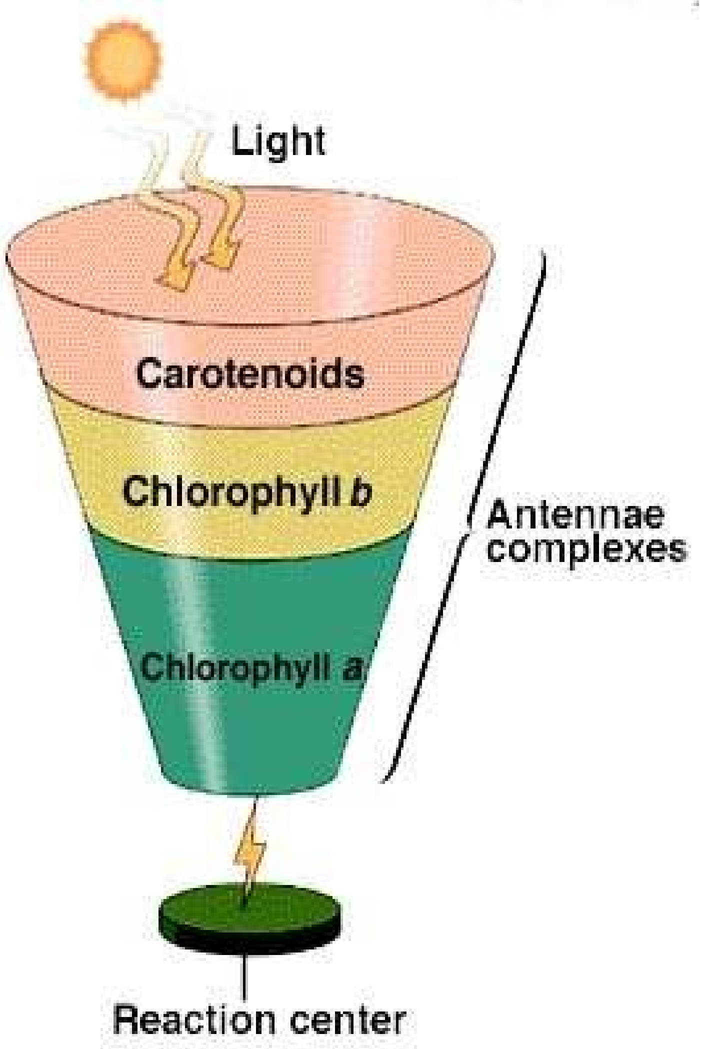
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

❖ Light harvesting complex

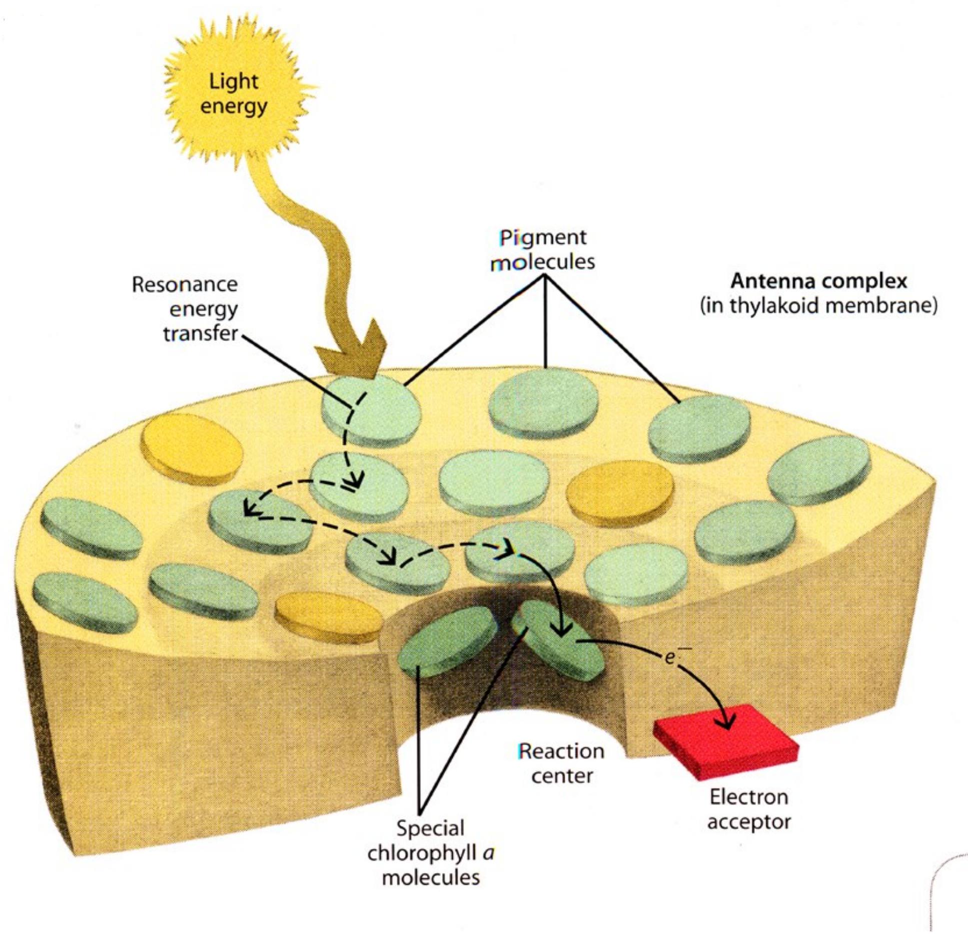
- The chlorophyll and accessory pigments are located in two types of photosystems known as Photosystem 1 and 11 (PS1and PS11).
- Each contains an antenna complex or light-harvesting complex of pigment molecules and a reaction centre.
- The light-harvesting complex or photosynthetic unit contains about 200-450 pigment molecules required to collect and convert light energy.



1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

❖ **Energy transfer in light harvesting complexes**



When a pigment absorbs light energy, one of three things will occur.

- ✓ **Energy is dissipated as heat.**
- ✓ **The energy may be emitted immediately as a longer wavelength, a phenomenon known as fluorescence.**
- ✓ **Energy may trigger a chemical reaction, as in photosynthesis.**

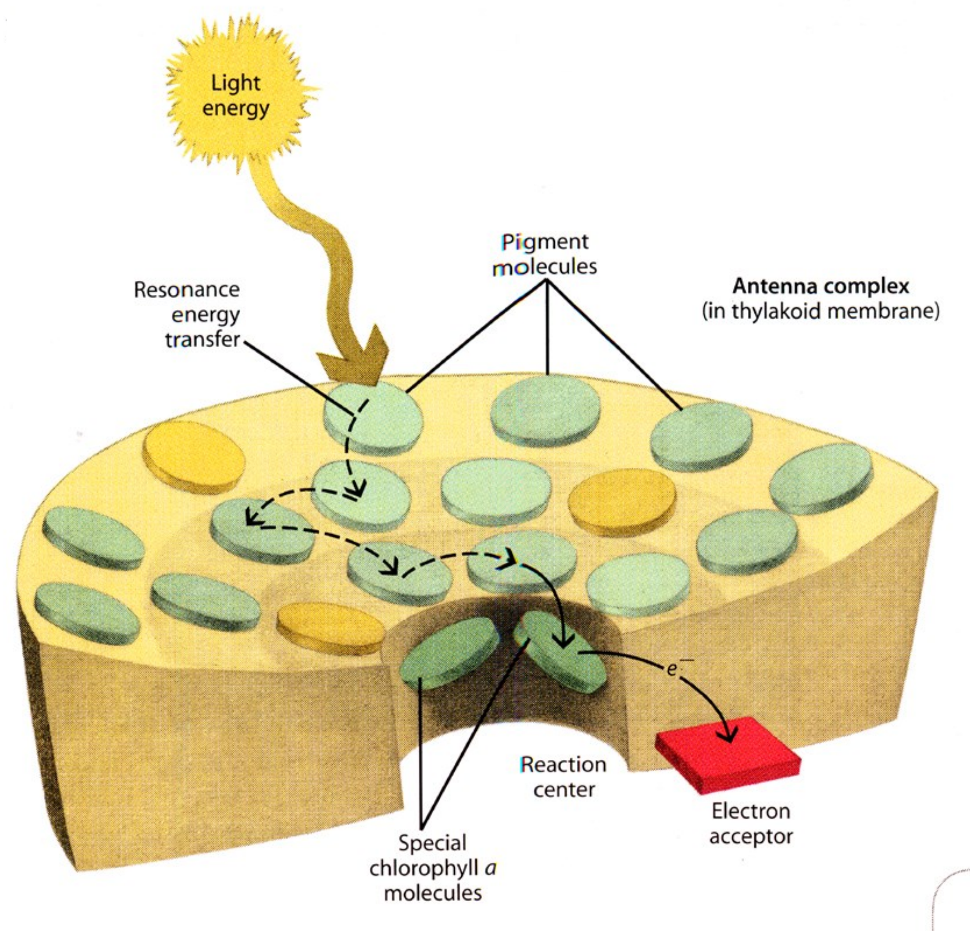
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

❖ **Energy transfer in light harvesting complexes**

- **Light is absorbed by individual pigments in the light-harvesting complexes.**
- **Energy is transferred from one pigment to another via Resonance Energy Transfer.**
- **This means that when a photon strikes the pigment molecule it becomes excited, an electron is lifted to a higher energy level.**
- **Different pigments collects light of different wavelengths, making the process more efficient.**



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process

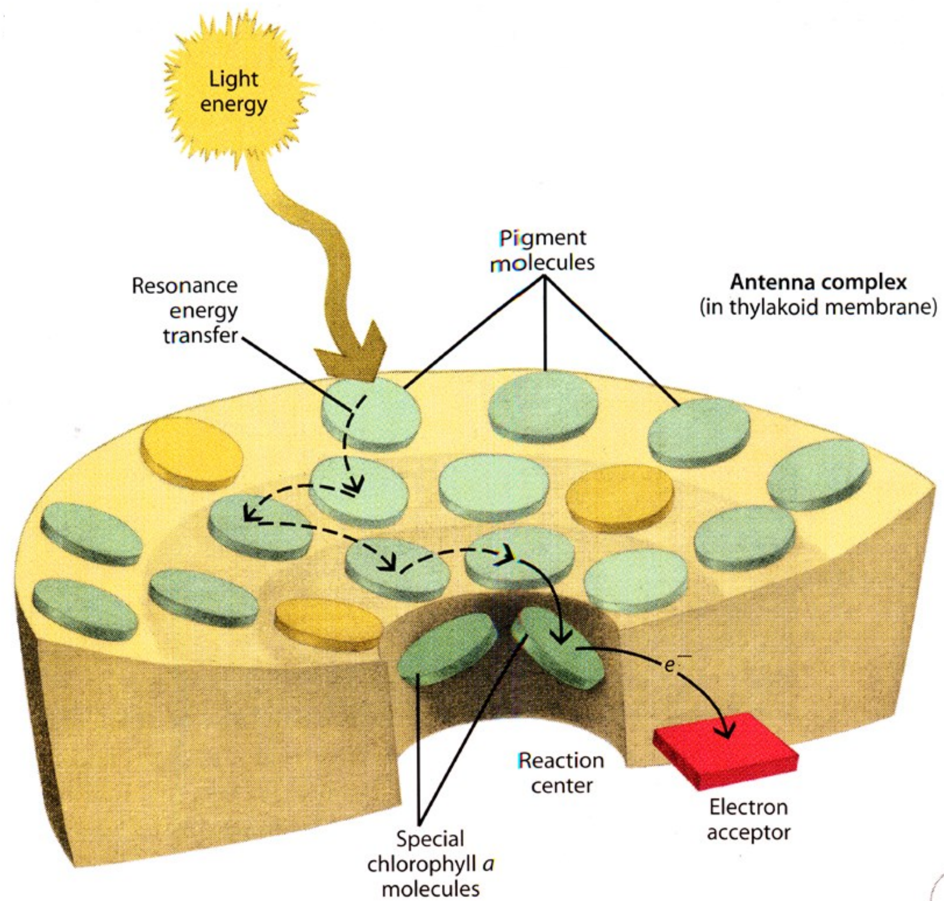
The light reactions - Light-dependent reactions

❖Energy transfer in light harvesting complexes

- The energy transferred from one pigment to another is funneled to a **reaction centre**, a specialized form of chlorophyll-**a**.

- The **reaction centre** is known as **P700** in PS1 and **P680** in PS11, where electron transfer starts. **P** here stands for pigment.

- The pathway followed by the electron can be **cyclic**, returning to where it began, or **non-cyclic** ending at NADP.



1.0 Photosynthesis *contd.*

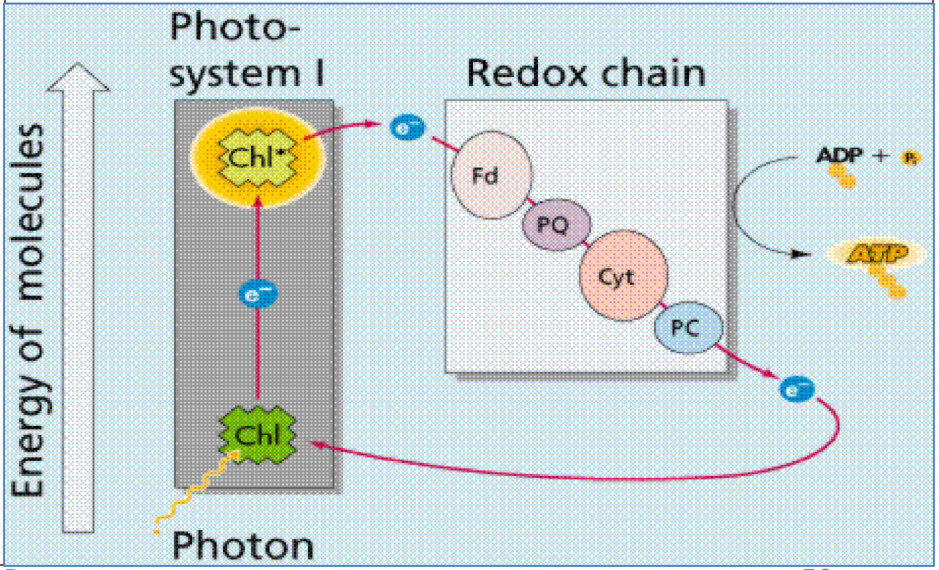
1.4 The Mechanism of the Process

The light reactions - Light-dependent reactions

Photophosphorylation is the process of converting energy from a light-excited electron into the pyrophosphate bond of an ADP molecule.

Cyclic photophosphorylation

- Cyclic photophosphorylation or Cyclic Electron Flow occurs **less commonly in plants** than noncyclic photophosphorylation.
- It is seen in some eukaryotes and primitive photosynthetic bacteria.
- It occurs when cells require additional ATP, or when there is no NADP+ to reduce to NADPH.
- It involves only Photosystem I and generates **ATP but not NADPH**.
- As the electrons from the reaction centre of Photosystem I are picked up by the electron transport chain, they are transported back to the reaction centre chlorophyll.



1.0 Photosynthesis *contd.*

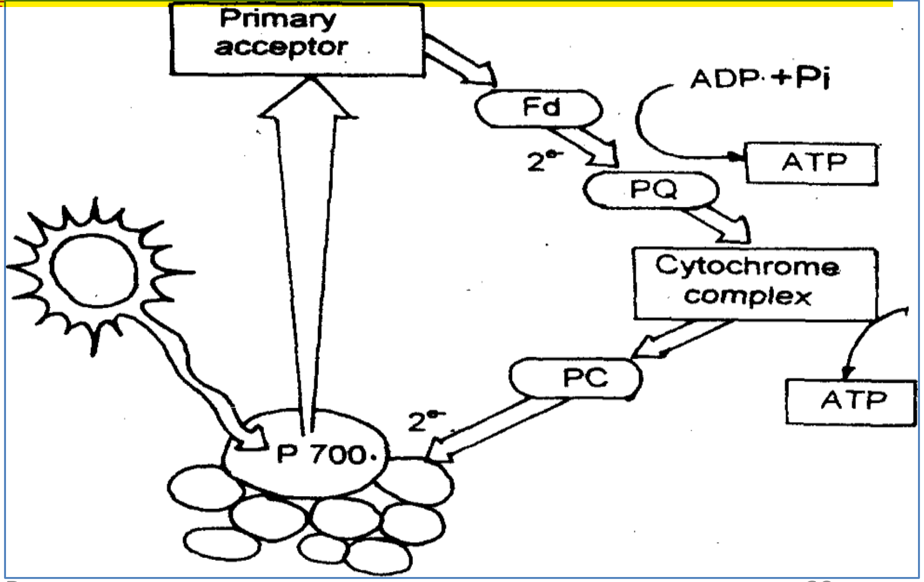
1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions - Cyclic photophosphorylation *contd.*

- Electron expelled by P700 in PS1 is picked up by an electron carrier **ferredoxin** Fd (an iron containing co-enzyme in the chloroplast).
- The electron travels from one electron acceptor to another in a series of redox reactions.
- From ferredoxin the electron passes through other electron carriers, such as **plastoquinone** (PQ) **cytochrome** (Cyt) and **plastocyanin** (PC).

- During the transfer of the electron from one carrier to another the high energy is utilized for the addition of phosphate radical to ADP to form ATP

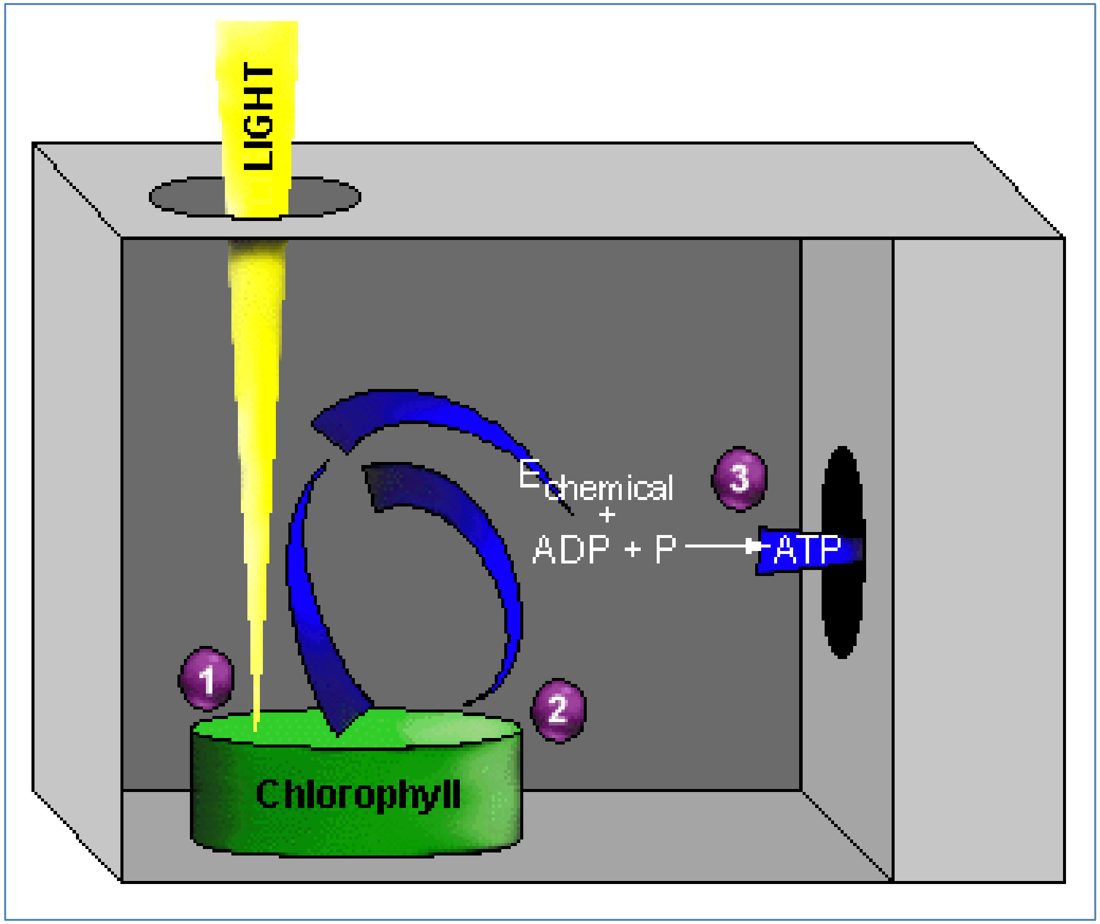
- Two ATP molecules are formed per electron transfer from reaction centre chlorophyll.
- Finally the excited electron is returned to the chlorophyll. The chlorophyll gets back the same electron.
- This close circuit flow of electron is known as **cyclic photophosphorylation**.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions - Cyclic photophosphorylation *contd.*

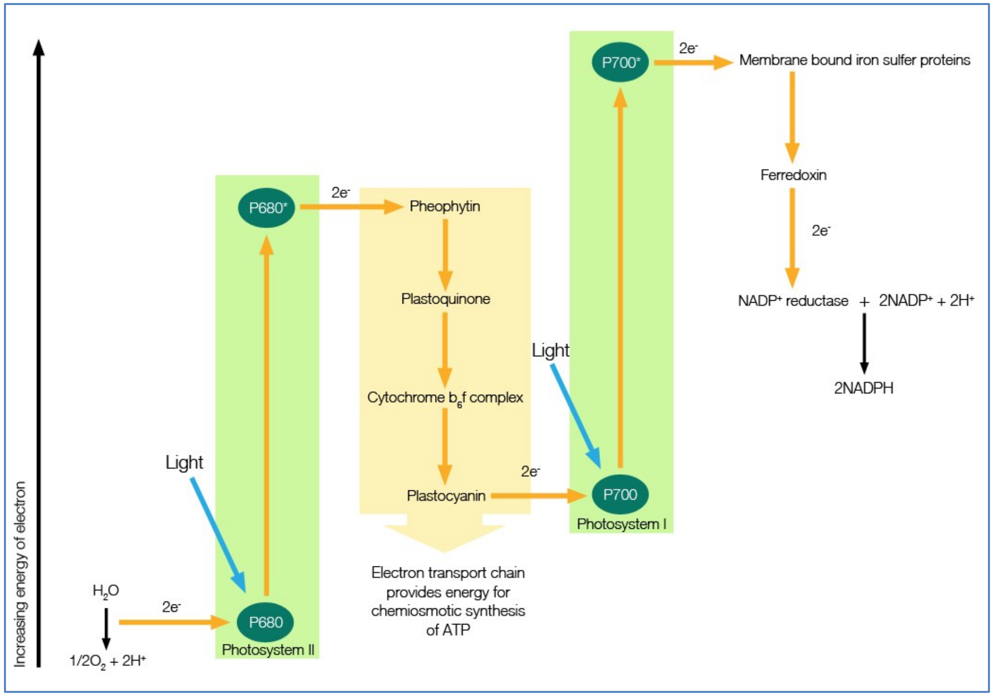


1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

- The second way that ATP is formed during photosynthesis is called **noncyclic photophosphorylation** which also includes the **photolysis** of water. **It occurs mainly in green plants**.
- The process involves two photosystems, **PS1** and **PS11**. Light is absorbed by **two different pigment systems**.

- **PS11** absorbs light and energy which causes the P680 molecule to excite its electron and pass it onto **plastoquinone** through **pheophytin**.
- Plastoquinone passes the electron through the **cytochrome** onto **plastocyanin**.
- Plastocyanin then transfers the electron to **PS1**



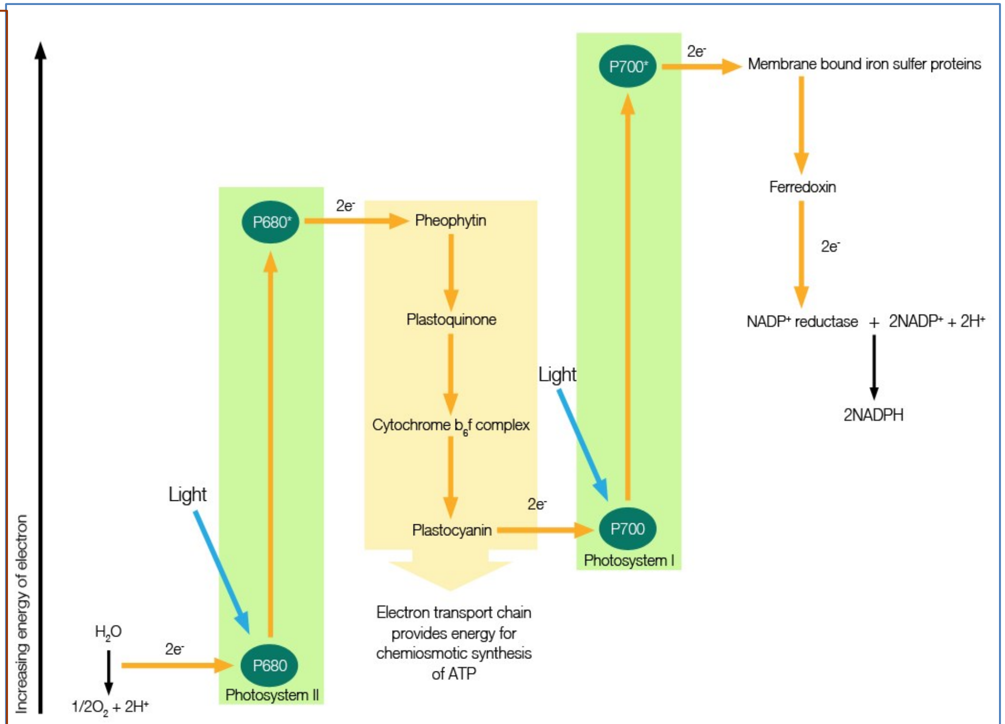
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

- During the transfer of electrons from PS11 through electron carriers **energy is utilized for the formation of ATP molecules**.
- The PS11 electron carriers finally transfers the electrons to the chlorophyll molecules of PS1.

- The electron deficiency in PS11 is filled by **Photolysis**, the splitting or dissociation of water spontaneously into oxygen (O_2) and hydrogen (2H).
- Oxygen escapes to the atmosphere, **while hydrogen combines with reducing agent NADP** in the chloroplast to form NADPH.



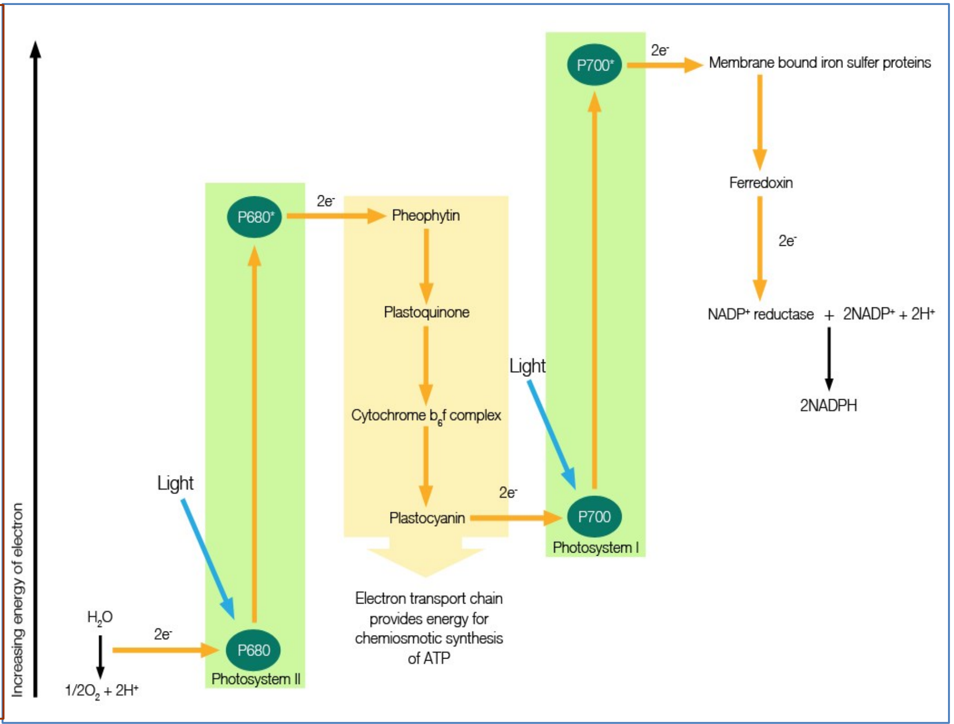
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

- PS1 accepts energy from light and then an electron from P700 is excited and passed on to an electron acceptor called FeS.
- FeS (Iron Sulfide) then passes its electron to Ferredoxin. Ferredoxin then donates its electron to $NADP^+$ reductase.

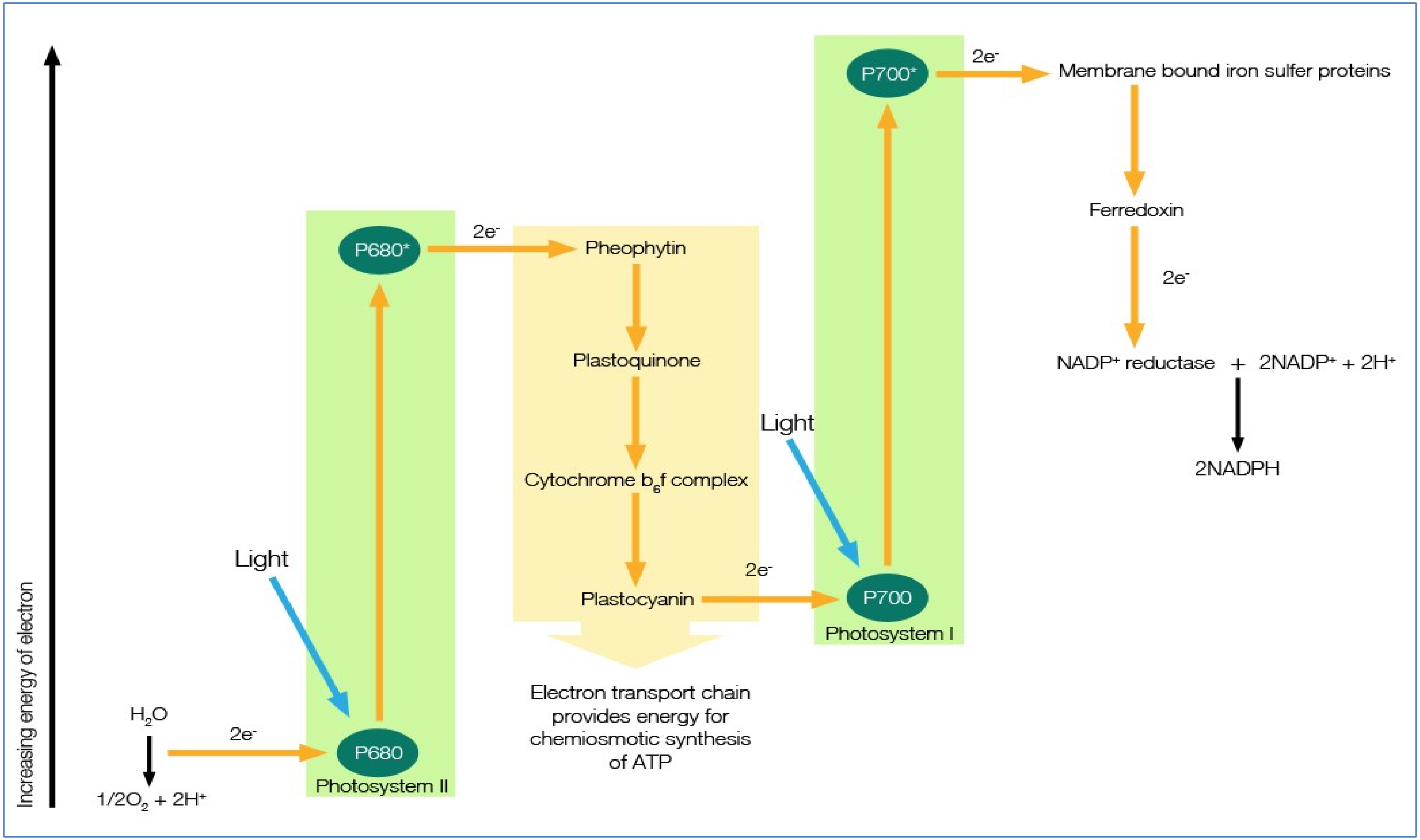
- $NADP^+$ reductase donates the electron to a molecule of $NADP^+$ making it negatively charged.
- It is stabilize by the addition of a proton (H^+ ion) from water to form NADPH.
- This NADPH is then released into the stroma where it becomes part of the dark reactions of biosynthesis.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

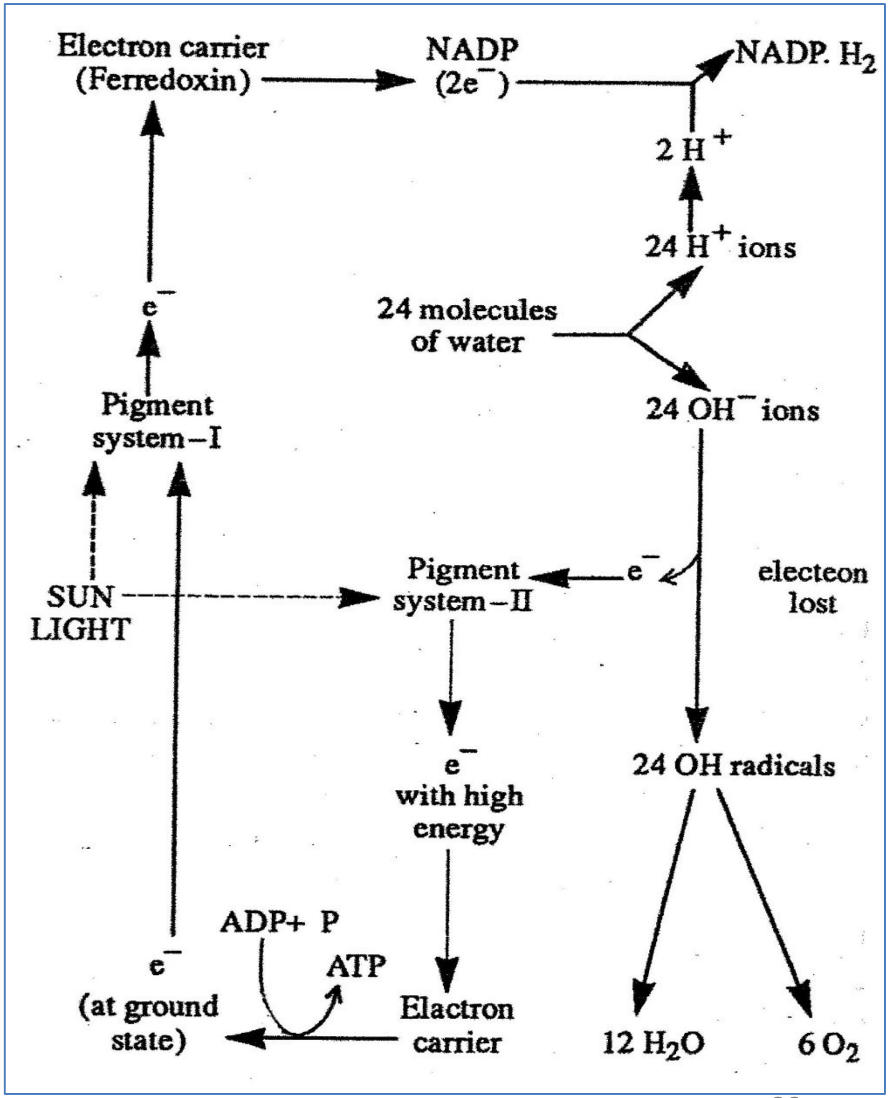


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

- The chlorophyll of PS1 does not get back the electron it expel and thus the system is not a closed circuit flow of electrons.
- The NADP molecules continue to receive electrons and develop an affinity for hydrogen ions from water, and more water gets ionized into hydrogen (H^+) ions and hydroxyl ions (OH^-).
- Two of these hydrogen ions combines with a molecule of negatively charged NADP to form $NADPH_2$

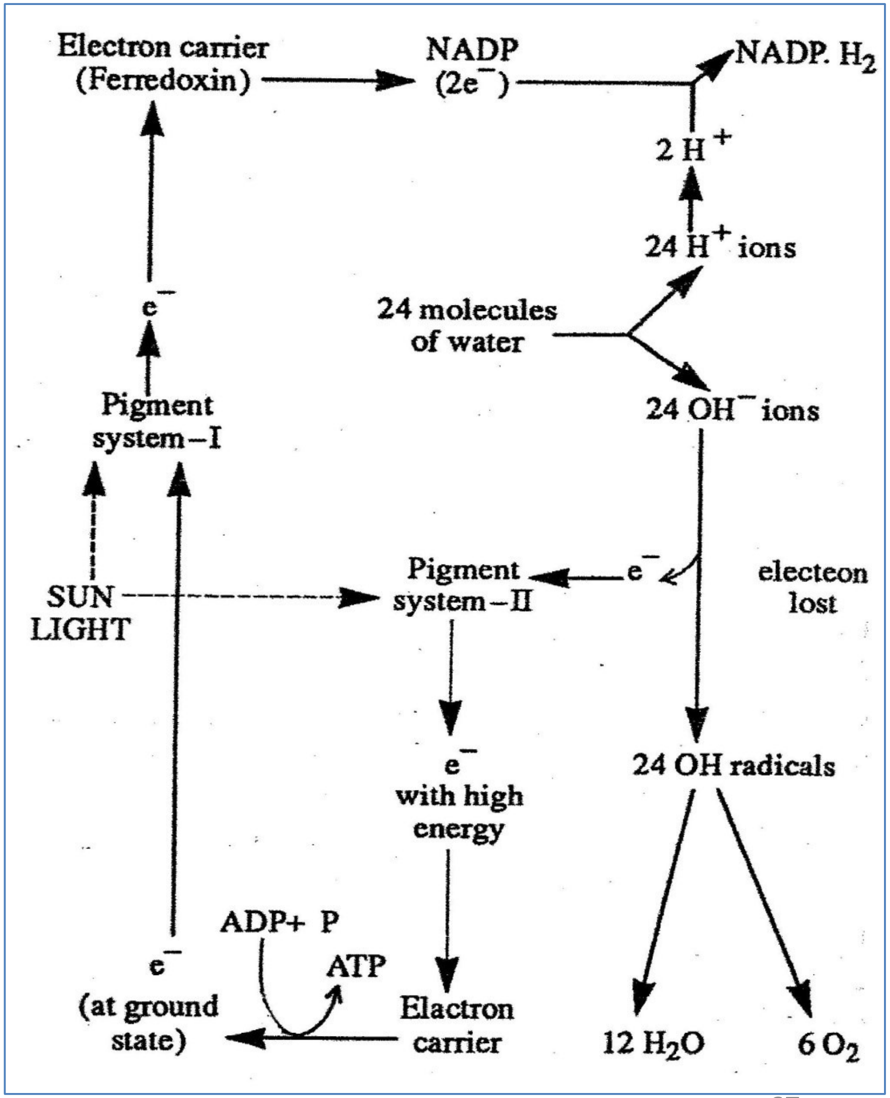


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

- During this process 24 molecules of water undergo ionization for the production of 12 molecules of $NADPH_2$.
- Each of the 24 (OH^-) ions formed loses an electron to become an OH radical.
- The 24 OH radicals combine to give rise to 12 molecules of water and 6 molecules of oxygen (O_2).
- The electrons lost by the hydroxyl ions replace the electrons expelled by PS11.



1.4 The Mechanism of the Process - The light reactions

Non-Cyclic photophosphorylation - Photolysis

The general reaction of **photosynthetic photolysis** can be given as:

- **H_2A + 2 photons (light) → 2e- + $2H^+$ + A**
- **The chemical nature of "A" depends on the type of organism. In purple sulfur bacteria, hydrogen sulfide (H_2S) is oxidized to sulfur (S).**
- **In photosynthesis, in chloroplasts of green algae and plants, water (H_2O) serves as a substrate for photolysis resulting in the generation of free oxygen (O_2).**
  H_2O + 2 photons (light) → 2e- + $2H^+$ + O.
- **This is the process which returns oxygen to earth's atmosphere.**
- **Photolysis of water occurs in the thylakoids of cyanobacteria and the chloroplasts of green algae and plants.**

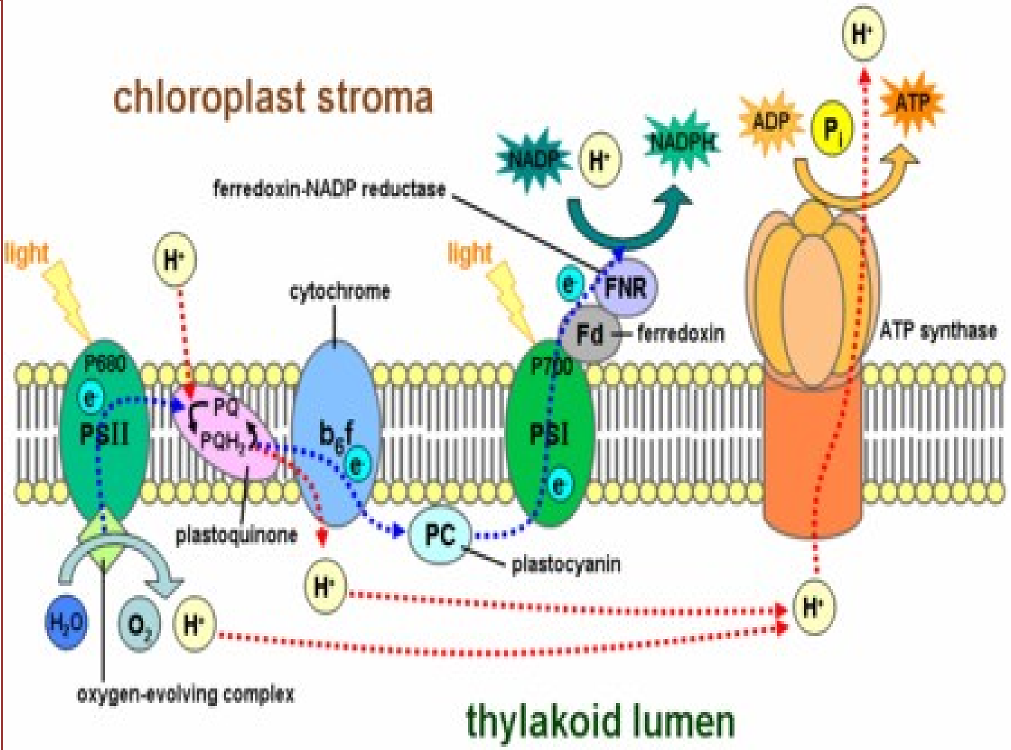
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Non-Cyclic photophosphorylation - Chemiosmosis

- **The enzyme necessary for mediation of the splitting of water molecules is on the inside of the thylakoid membrane.**
- **As a result of this, a proton gradient forms across the membrane and the movement of these protons is thought to be a source of energy for generating ATP.**

- The process is similar to molecular movement during osmosis and has hence been termed **chemiosmosis**.
- Protons move across the membrane, and are assisted in crossing by **protein channels called ATPase**.
- As a result of the proton movement, **ADP and phosphate combine and produces ATP**.

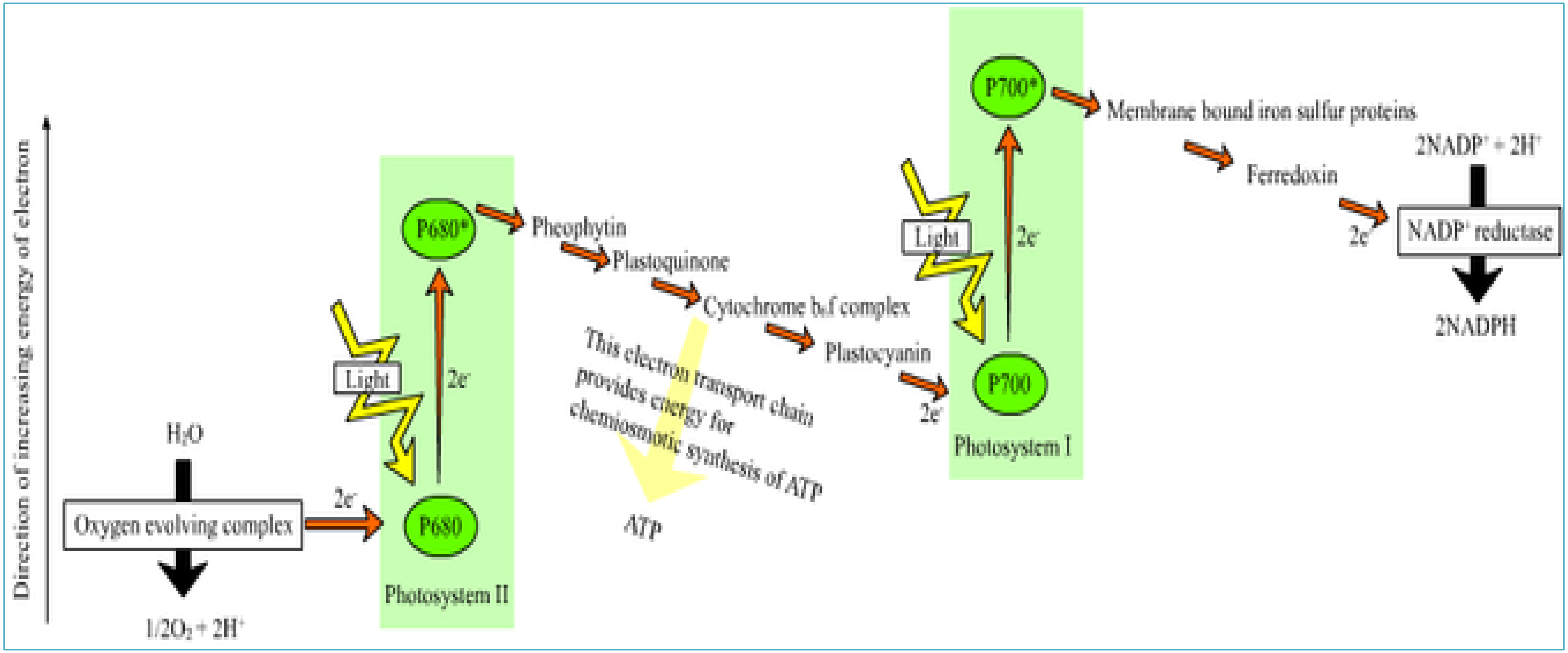


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

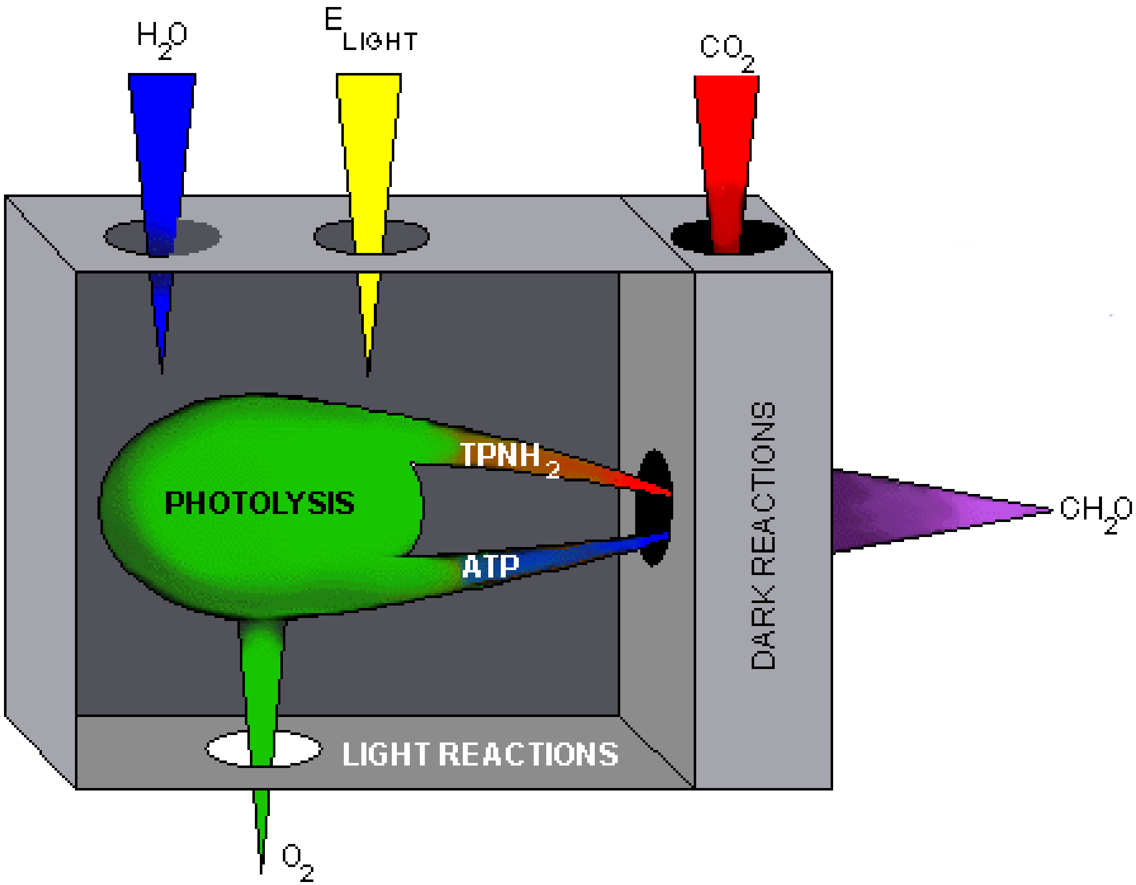
- The electrons lost by the hydroxyl ions replace the electrons expelled by PS11. The electrons are taken through the electron transport chain, the so called Z-scheme.



1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

Black Box…



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-dependent reactions – Non-Cyclic photophosphorylation

Comparism of cyclic and non-cyclic photophosphorylation

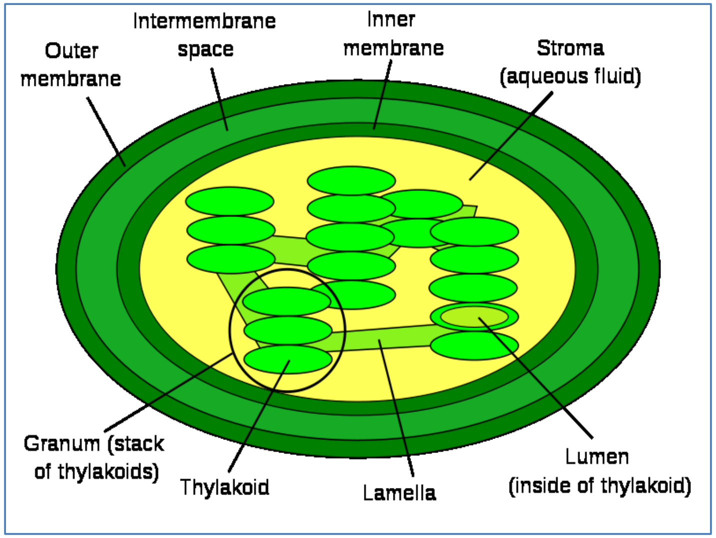
	Non-Cyclic	**Cyclic**
Pathway of electrons	Non-Cyclic	Cyclic
First electron donor (source of electrons)	Water	Photosystem I (P700)
Last electron acceptor (destination of electrons)	NADP	Photosystem I (P 700)
Products	Useful: ATP, Useful: NADPH, By product: O_2	Useful: ATP only
Photosystem involved	I and II	1 only

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – Dark reactions

- The light independent (or dark, or carbon fixing) reactions of photosynthesis, which takes place in the stroma of the chloroplast, outside of the thylakoid membranes, do not require light, although they take place during daylight hours.



- They use ATP and NADPH produced by the light dependent reactions to convert CO_2 into the organic molecules needed to build new cells e.g. glucose ($C_6H_{12}O_6$).

- The reactions are controlled by enzymes and their sequence was determined by Melvin Calvin, James Bassham and Andrew Benson at the University of California, USA, during the period 1946 – 1953.

1.0 Photosynthesis *contd*.

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – Dark reactions

- There are three phases to the light-independent reactions:
  - carbon fixation,
  - reduction reactions, and
  - ribulose 1,5-bisphosphate(RuBP) regeneration.

- There are three known mechanisms through which CO_2 is converted to carbohydrates during the carbon fixing reactions.
- The most widespread or common is the 3-Carbon Pathway or Calvin Cycle or C_3 Cycle.

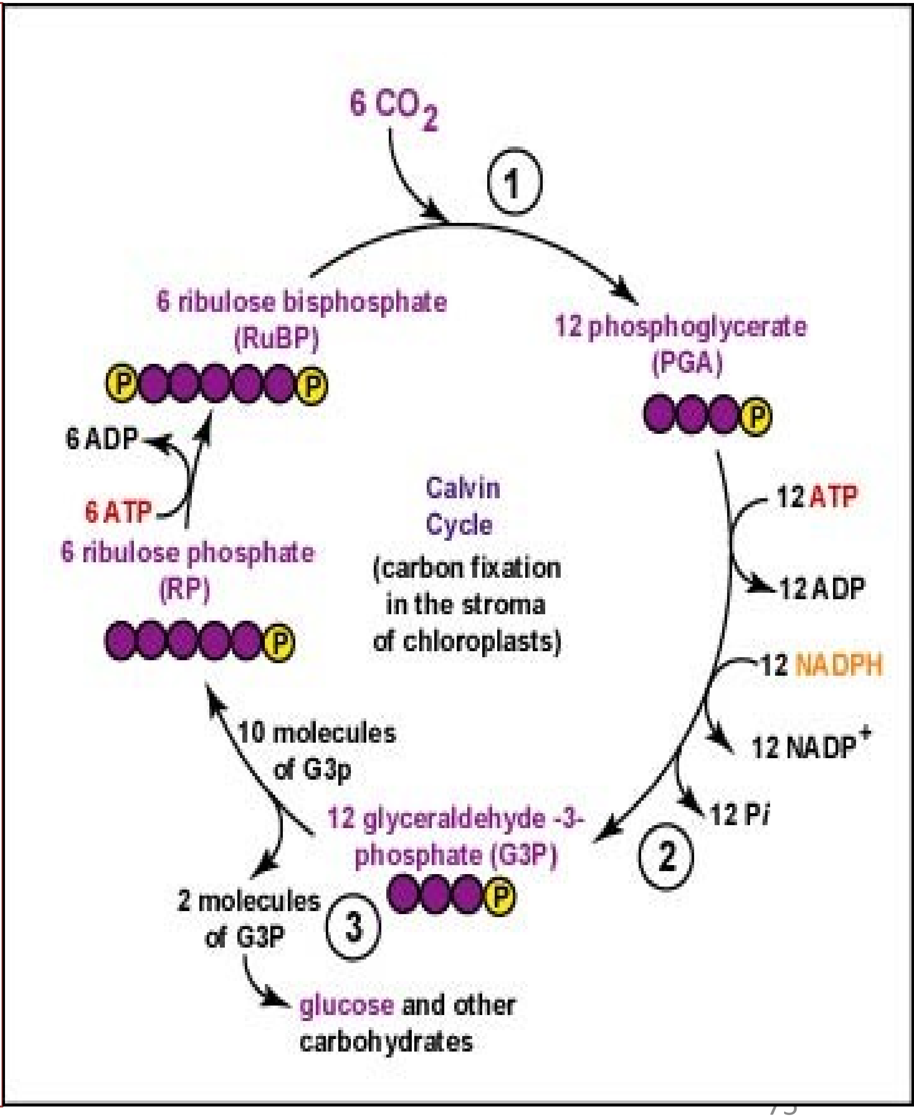
- In the 3-carbon pathway C_3 plants use the Calvin cycle for the initial steps that incorporate CO_2 into organic matter, forming a 3-carbon compound as the first stable intermediate.
- Most broadleaf plants and plants in the temperate zones are C_3.

1.0 Photosynthesis *contd*.

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 3-Carbon Pathway

- During the Calvin cycle a **five-carbon sugar molecule** called **ribulose bisphosphate**, or **RuBP**, is the **acceptor that binds CO_2 dissolved in the stroma**.
- This process, called CO_2 fixation, is **catalyzed** by the enzyme **RuBP carboxylase/oxygenase (Rubisco)**, forming **an unstable six-carbon molecule**.
- This molecule quickly breaks down to give two molecules of the **three-carbon 3-phosphoglycerate** (3PG), also called **phospho-glyceric acid** (PGA).



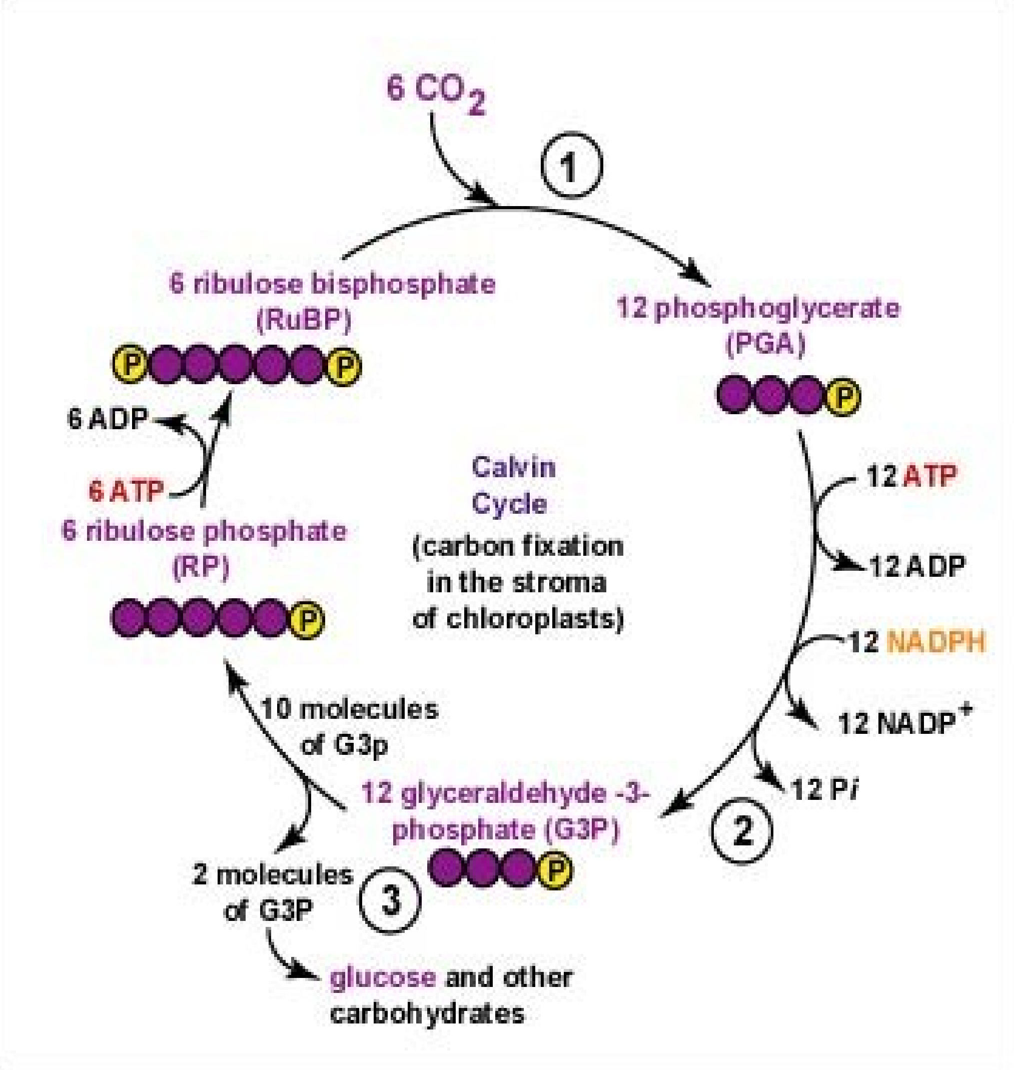
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 3-Carbon Pathway

- ATP and NADPH from the light-reactions, **supply the energy and reducing power required** to convert the **3PGA** to 12 molecules of **glyceraldehydes 3-phosphate** (GA3P), which is a 3-carbon sugar phosphate complex.

- *For every **6 molecules of CO_2** entering the cycle, **12 molecules of GA3P** are produced.*

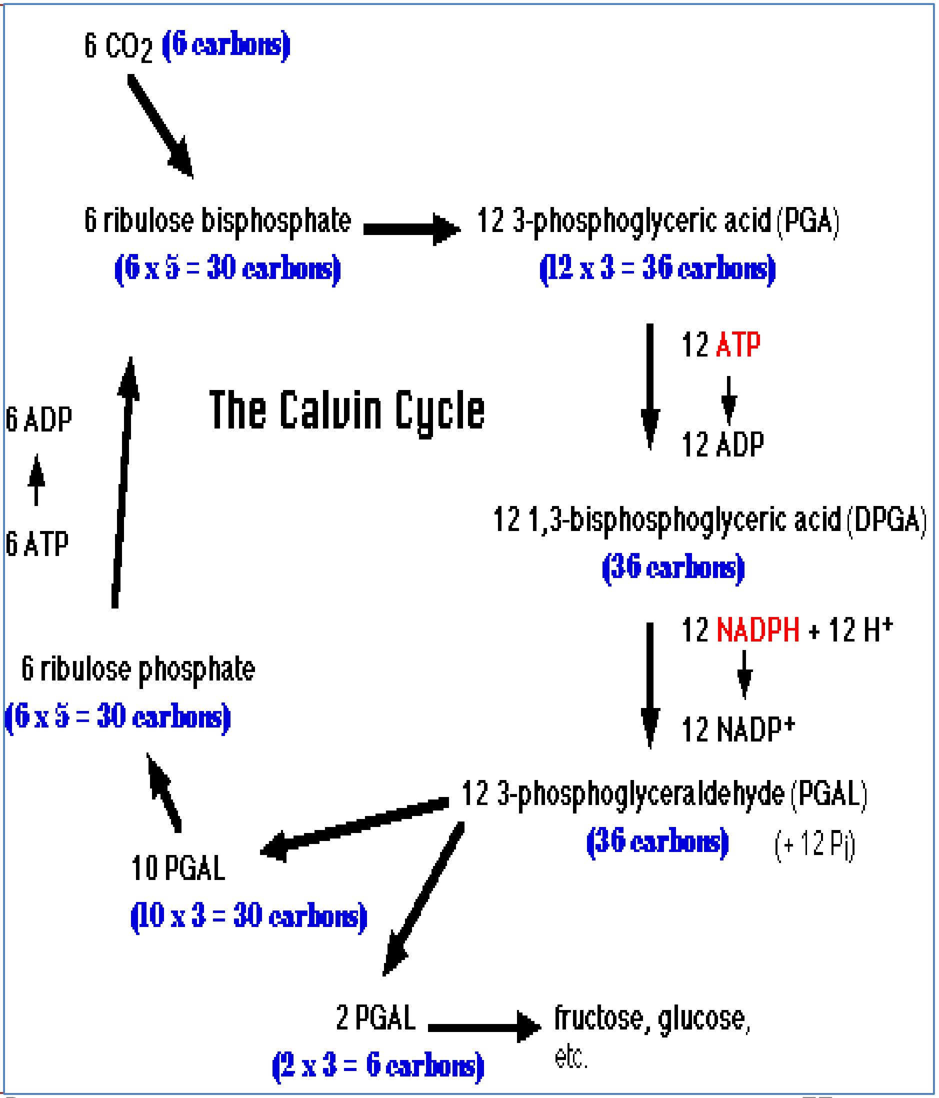


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 3-Carbon Pathway

- Finally, of the 12 molecules of GA3P formed; **10 are restructured into six 5-carbon molecules of RuBP** (the sugar that started the process).
- The other two are removed from the circle and **converted into glucose**, or **other molecules such as starch, lipid or protein**.
- This pathway is called **C3 carbon fixation** because the **first stable product formed** is a **3-carbon** compound.



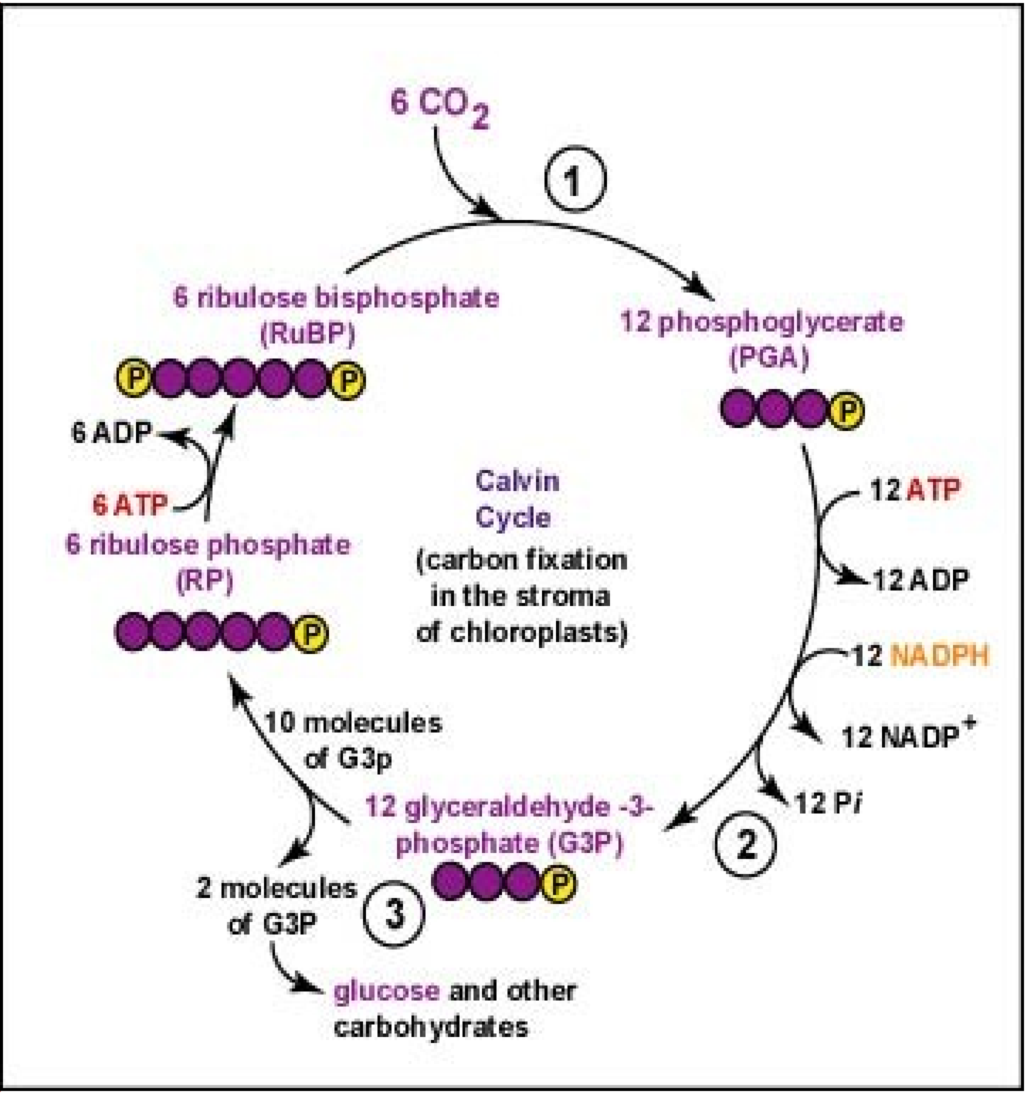
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 3-Carbon Pathway

- 12 ATP and 12 NADPH from the light-reactions, **supply the energy and reducing power required** to convert the **3PGA** to 12 molecules of **glyceraldehydes 3-phosphate** (GA3P).

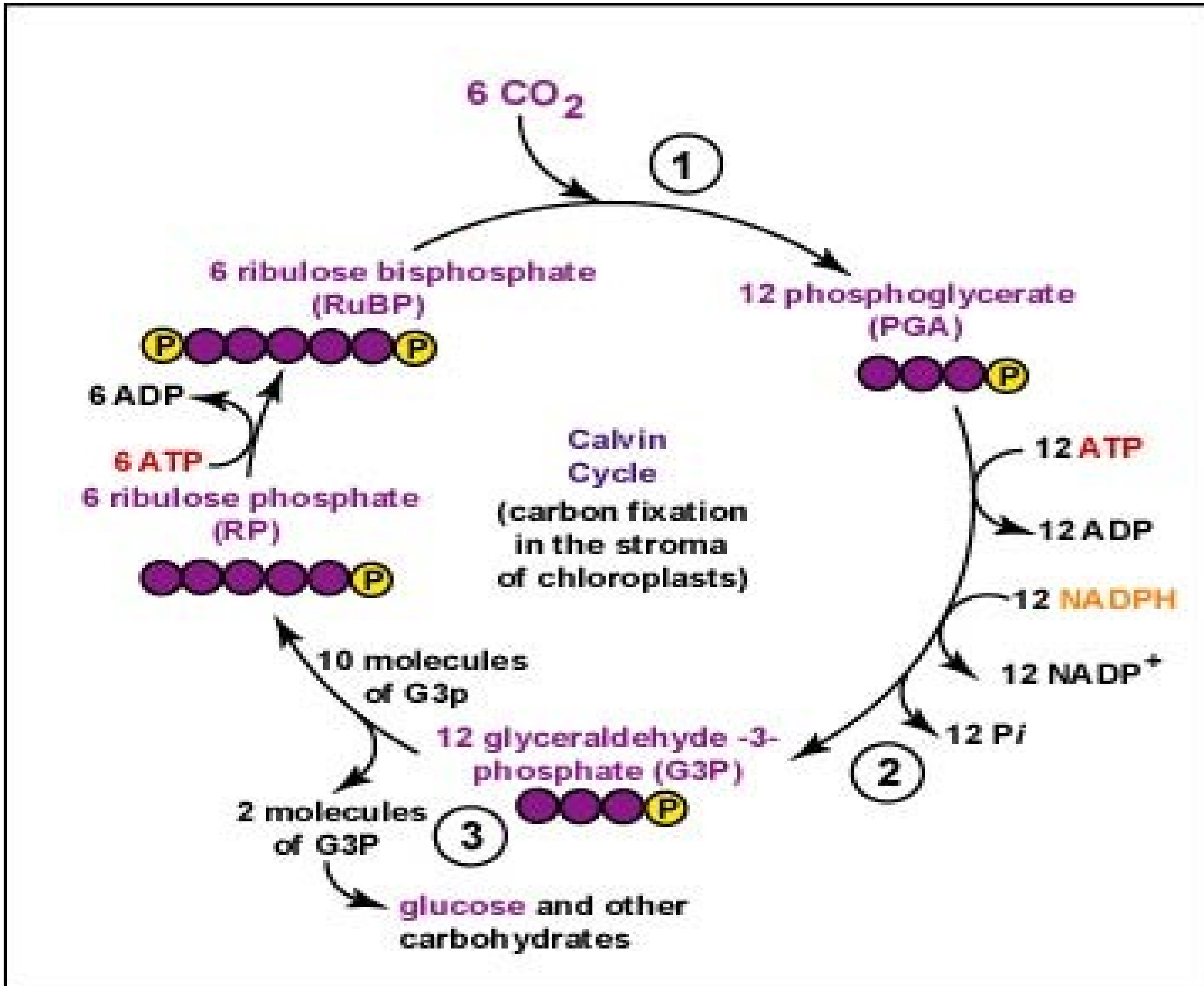
- 6 ATP **supply the energy for the** conversion of 6 ribulose phosphate (RuP) to 6 ribulose bisphosphate (RuBP).



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 3-Carbon Pathway

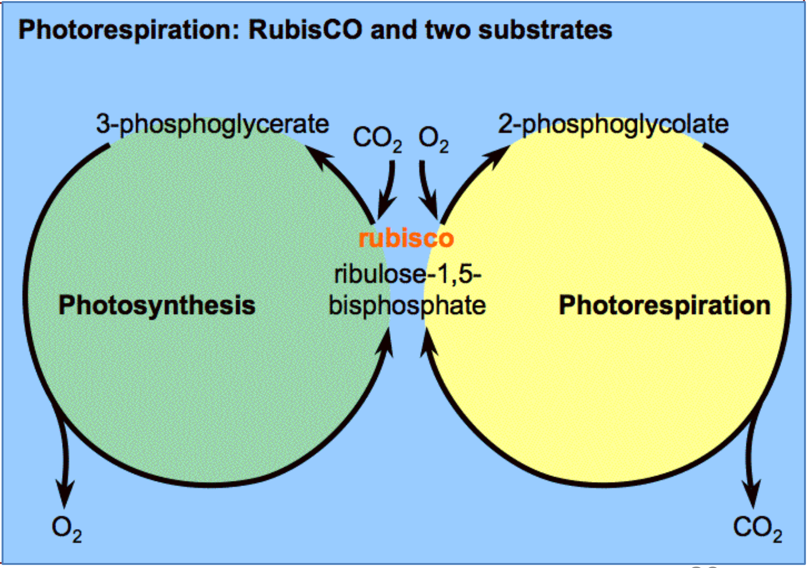


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – Photorespiration

- In C3 metabolism, **when carbon dioxide levels are low**; for example, when the **stomata are closed to prevent water loss** on hot dry days or during drought, **O_2 ratio in the leaf increase relative to CO_2 concentrations**.
- As a result **rubisco** starts fixing **O_2** instead of **CO_2**.
- This **oxygenase activity** of rubisco is referred to as **Photorespiration**.
- It **inhibits** the Calvin Cycle and **reduce the net productivity** of the plant.
- The net result of this is that instead of producing **2**, 3C PGA molecules, **only 1 molecule of PGA** is produced and a toxic 2C molecule called **phosphoglycolate** is produced. CO_2 is also released.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – Photorespiration

- To prevent this process of photorespiration, two specialized biochemical metabolism have been evolved in the plant world: **C4** and **CAM** metabolism.

- They use a **supplementary method** of CO_2 uptake which forms a **4-carbon** molecule instead of the two 3-carbon molecules of the Calvin cycle.

- C4 plants have **structural changes in their leaf anatomy** so that their **C4 and C3 pathways are separated in different parts of the leaf**.

- CAM plants — separate their **C3 and C4** cycles **by time**.

1.0 Photosynthesis *contd.*

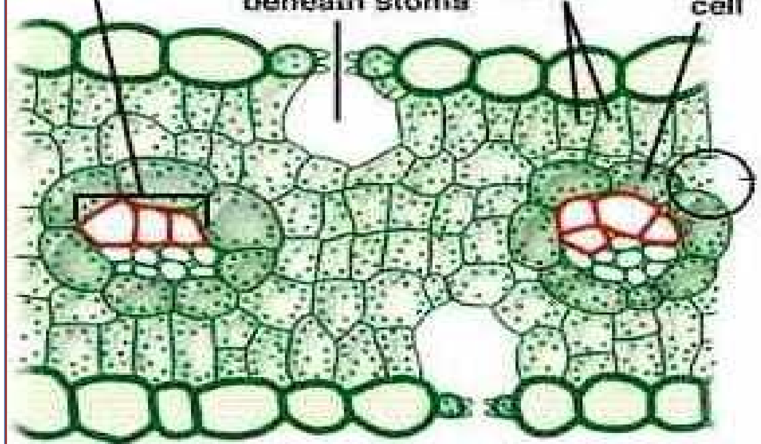
1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

C4 Pathway

- Plants of at least 100 genera that occur primarily in the tropics (e.g. maize, sorghum, millet, sugarcane) have a mechanism by which they can **keep the carbon dioxide concentration in the chloroplasts very high** and thus prevent photorespiration.

- They have a **specialized leaf anatomy** called **Kranz anatomy** in which their **vascular bundles are surrounded by two rings of cells**; the **bundle sheath** cells and the **mesophyll** cells



PORTION OF A CROSS SECTION OF A LEAF WITH C_4 PHOTOSYNTHESIS

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

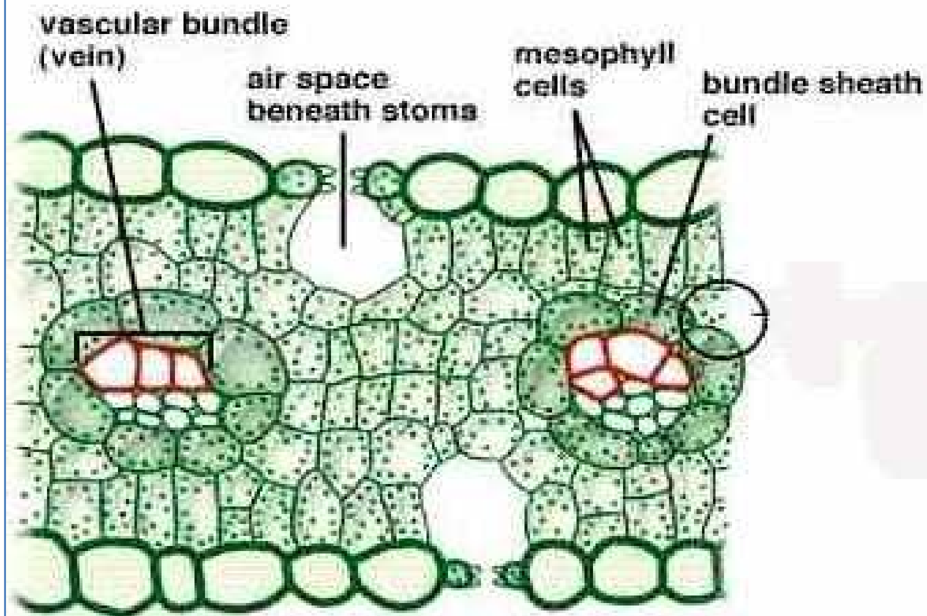
Light-independent reactions – 4-Carbon Pathway

C4 Pathway

- The inner ring, **called bundle sheath cells**, contain large and conspicuous **starch rich chloroplasts lacking grana** or have only **poorly developed types**.

- The mesophyll cells present as the outer ring, have **chloroplast containing chlorophyll** bearing internal membranous structures called grana.

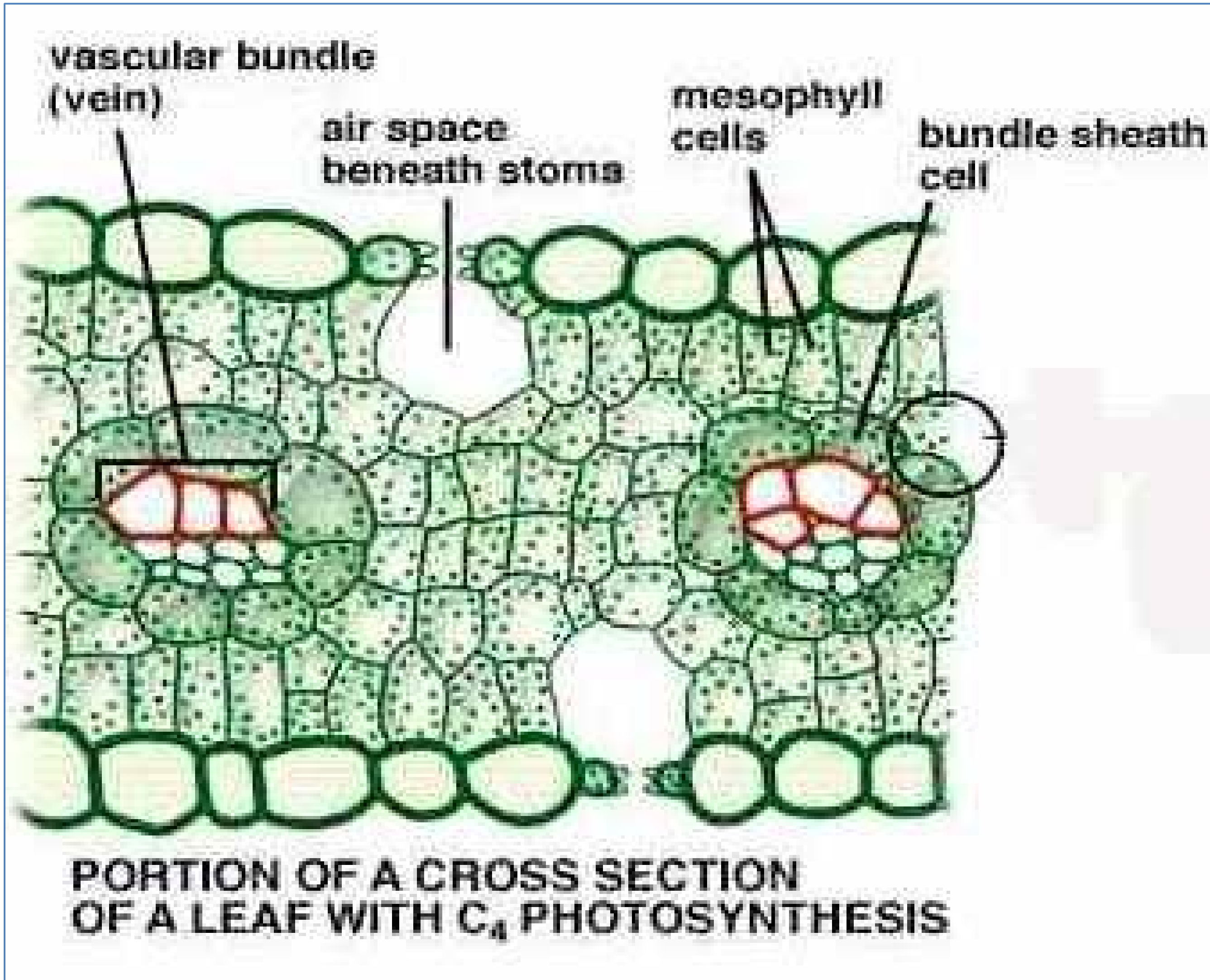
- The chloroplasts are said to be **dimorphic**.



PORTION OF A CROSS SECTION OF A LEAF WITH C_4 PHOTOSYNTHESIS

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway



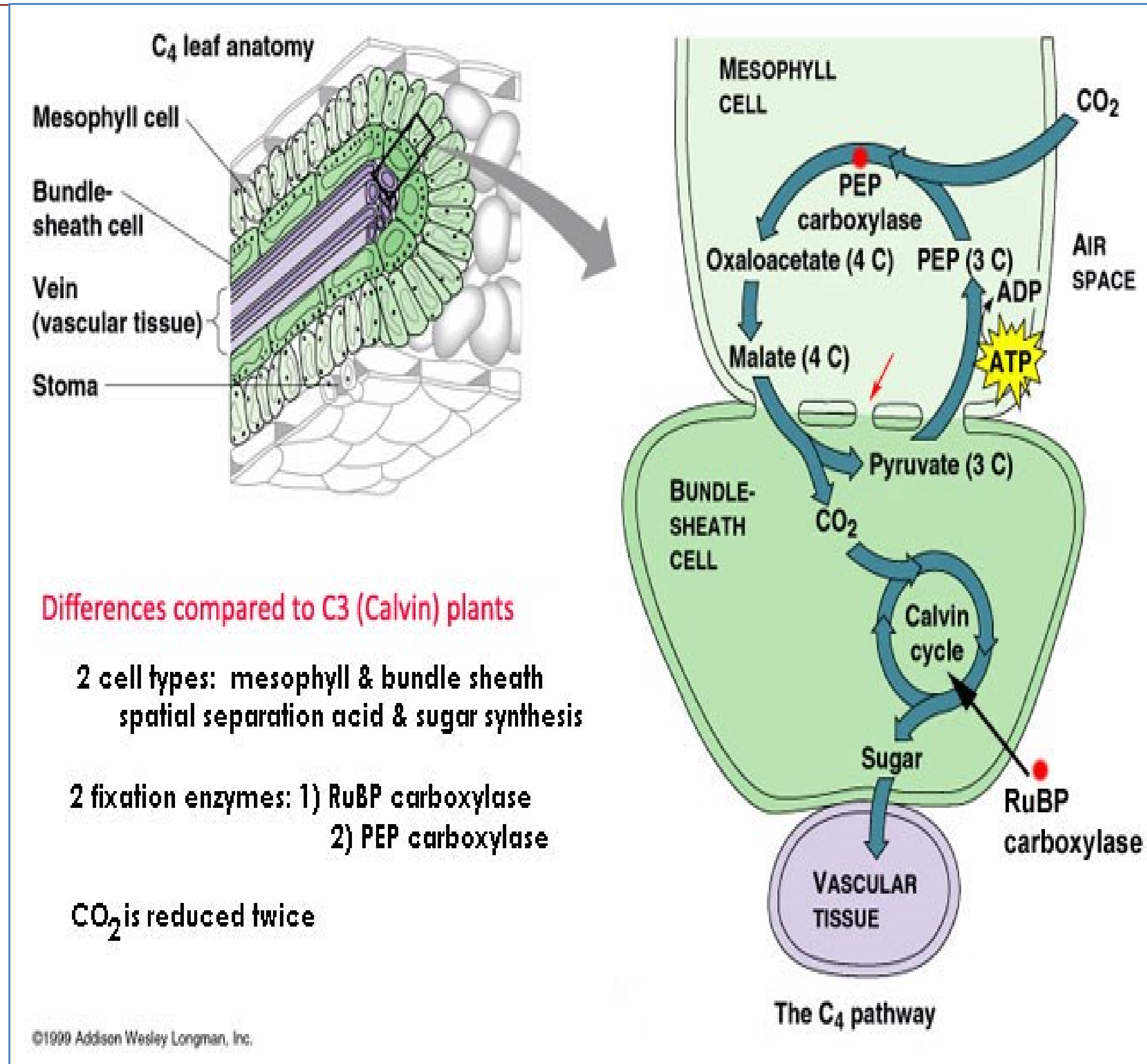
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

The Hatch-Slack Pathway

- The first metabolite containing the added CO_2 is a **4 carbon compound** discovered by Hatch and Slack, two Australian biochemists.
- Hence its also referred to as the ***Hatch-Slack pathway***.



1.0 Photosynthesis *contd.*

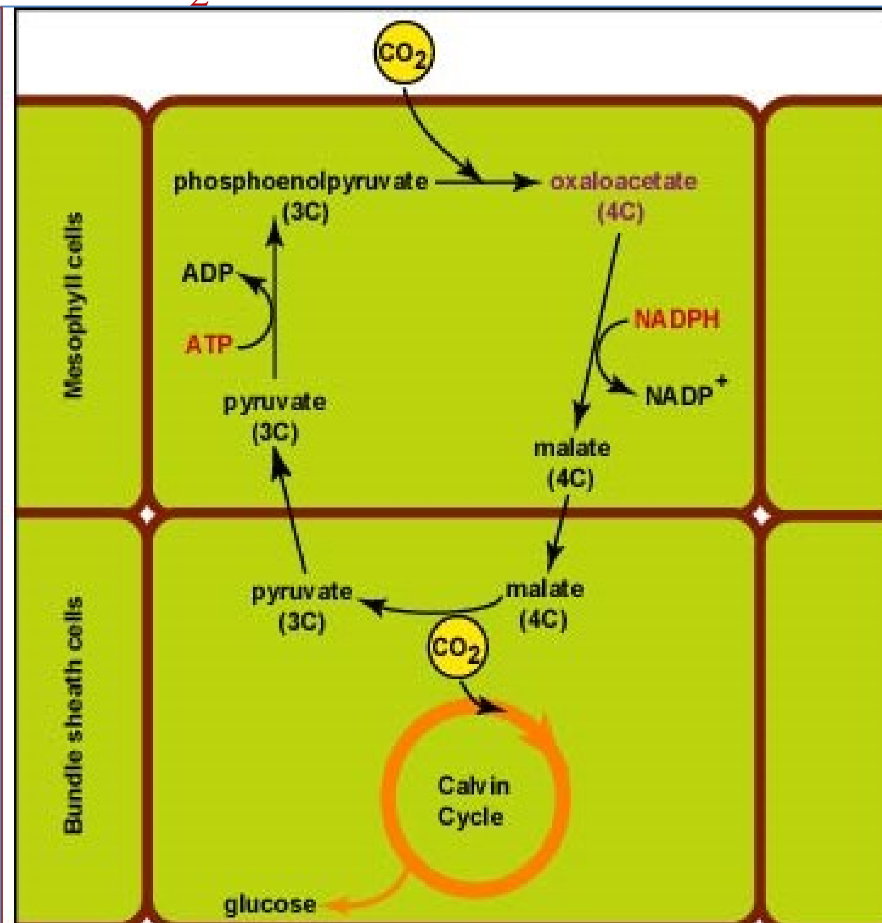
1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

The Hatch-Slack Pathway

C4 pathway is designed to efficiently fix CO_2 at low concentrations.

- CO_2 is fixed to a three-carbon compound called **phosphoenol-pyruvate** **(PEP)** to produce the four-carbon compound **oxaloace-tate (oxaloacetic acid)**.
- The enzyme catalyzing this reaction, **PEP carboxylase**, fixes CO_2 very efficiently so the C4 plants don't need to have their stomata open as much.
- This occurs in cells called mesophyll cells.



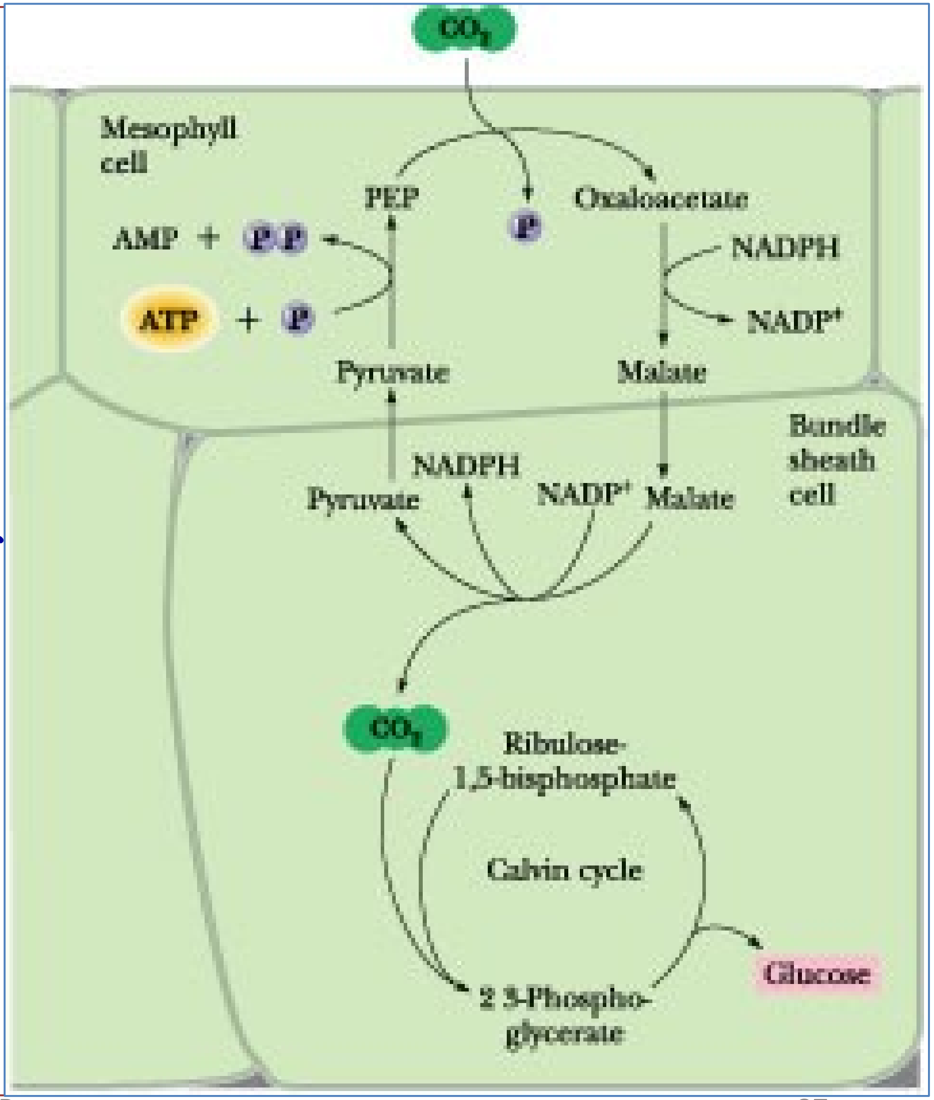
1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

- Depending on the plant species the oxaloacetate is then converted to another four-carbon compound called malate (malic acid) or aspartate (aspartic acid) in a step requiring the reducing power of NADPH.

- The malate then exits the mesophyll cells and enters the chloroplasts of specialized cells called bundle sheath cells.

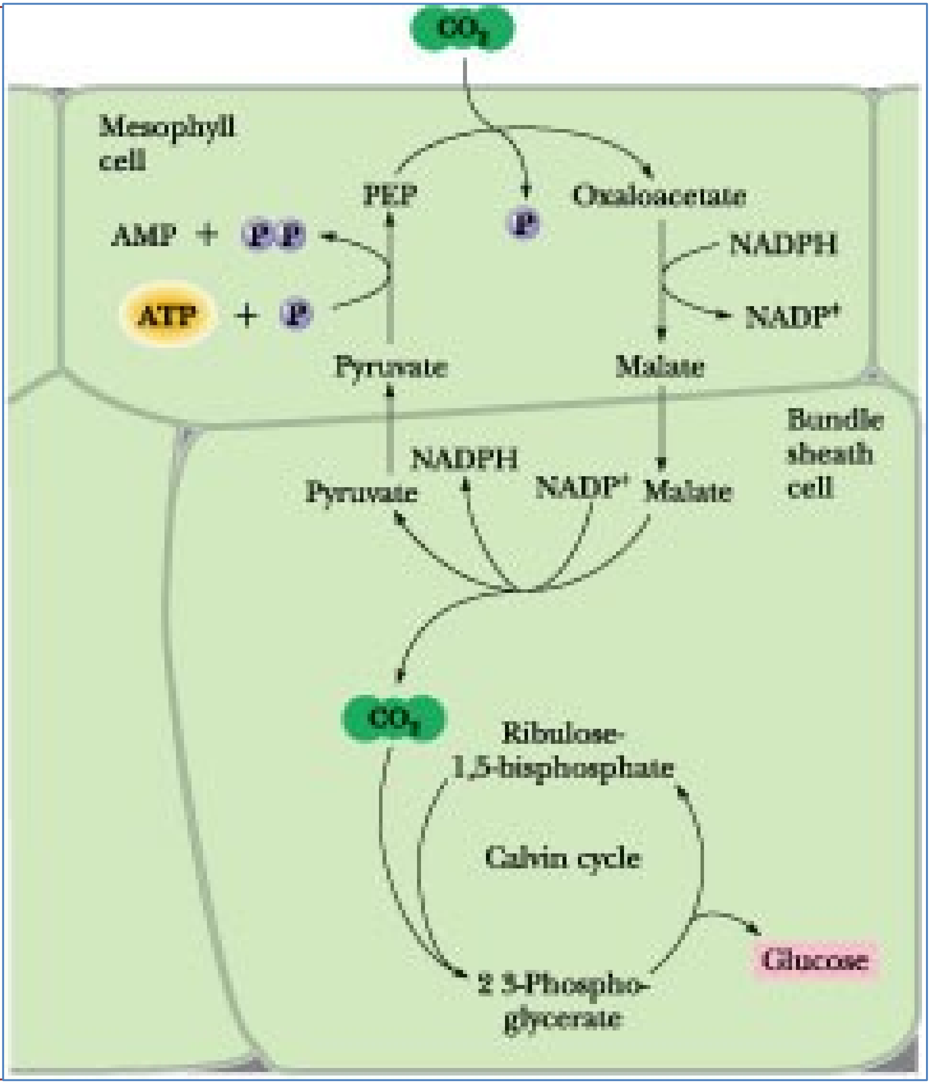


1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

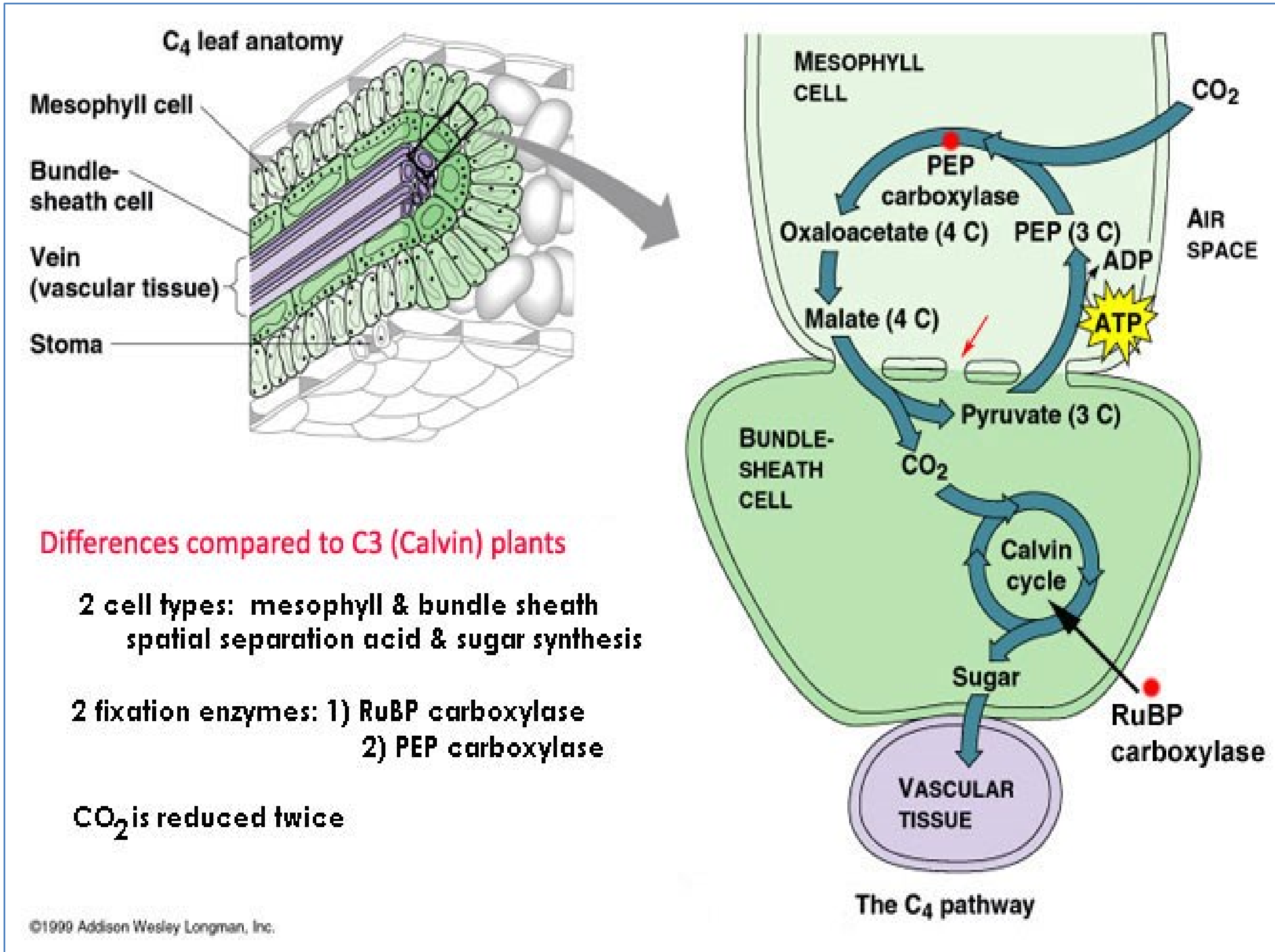
- Here the four-carbon malate is decarboxylated to produce **CO_2**, a three-carbon compound called **pyruvate (pyruvic acid)** and **NADPH**.
- The CO_2 combines with **ribulose bisphosphate** and goes through the Calvin cycle.
- The **pyruvate** re-enters the **mesophyll cells**, reacts with **ATP**, and is converted back to **phosphoenolpyruvate**, the starting compound of the C4 cycle.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

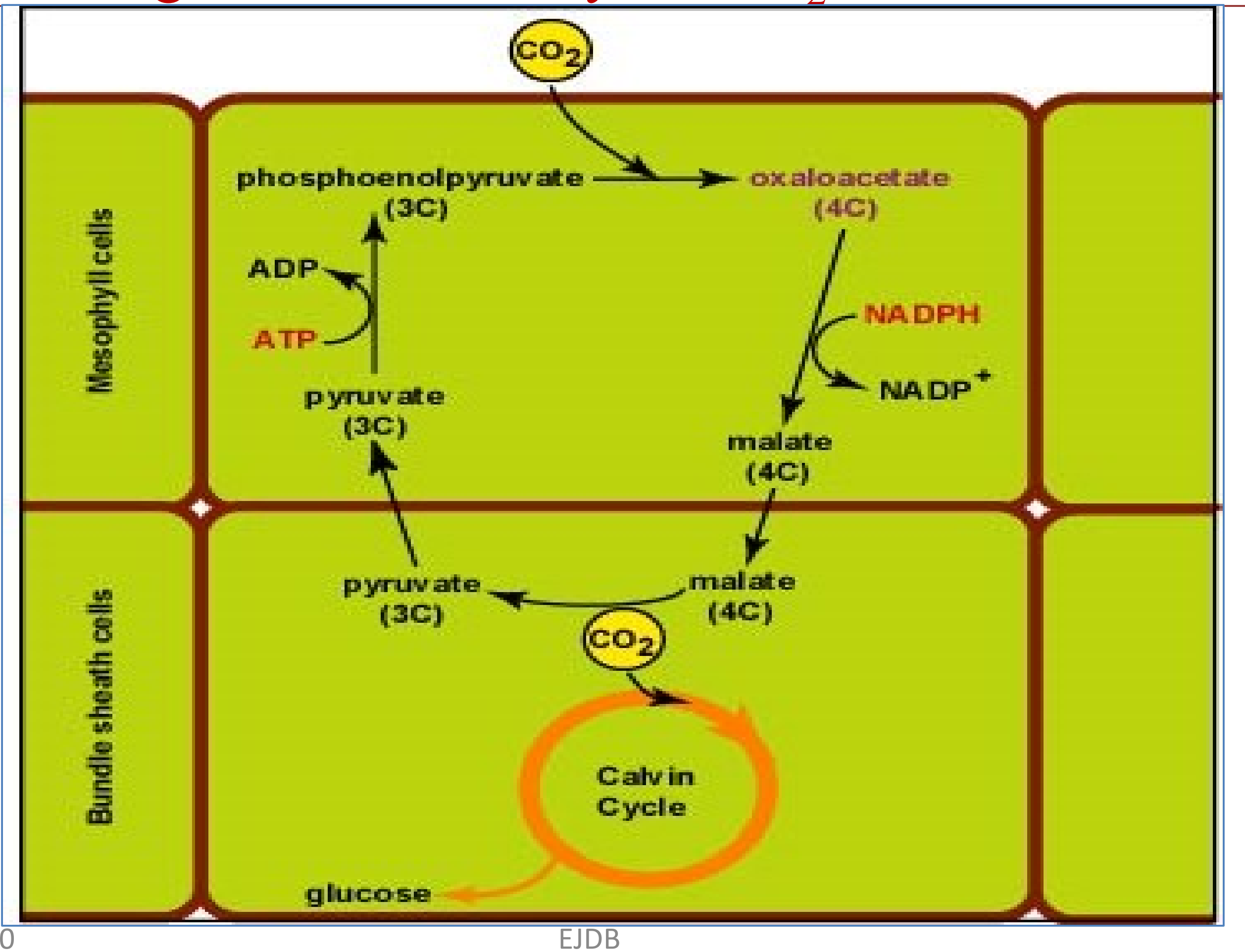


1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – 4-Carbon Pathway

The Hatch-Slack Pathway

C4 pathway is designed to efficiently fix CO_2 at low concentrations.



1.4 The Mechanism of the Process - The light reactions

Light-independent reactions

Differences between C_3 and C_4 Plants

C_3	C_4
CO_2 acceptor is 5C RUBP	CO_2 acceptor is 3C PEP
CO_2 fixing enzyme is RUBP carboxylase	CO_2 fixing enzyme is PEP carboxylase
First product of photosynthesis is PGA (3C)	First product of photosynthesis is oxaloacetic acid (4C)
CO_2 fixation occurs once only	CO_2 fixation twice - Kranz anatomy

1.0 Photosynthesis *contd*.

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – CAM Photosynthesis

Crassulacean Acid Metabolism

- Many succulent plants of more than 20 families including those of the family Crassulaceae (e.g. cacti, orchids, pineapples) carry out Crassulacean Acid Metabolism (CAM Photosynthesis).
- CAM was first observed in the Crassulaceae family, hence it name.
- CAM metabolic strategy adapts plants to extremely hot and dry environments.
- Unlike other plants, they open their stomata to fix CO_2 only at night.
- Like C4 plants, they use PEP carboxylase to fix CO_2 into C4 acids, first forming oxaloacetic acid (oxaloacetate).
- The two differ in that CAM plants do not have the characteristic Kranz leaf anatomy.

1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

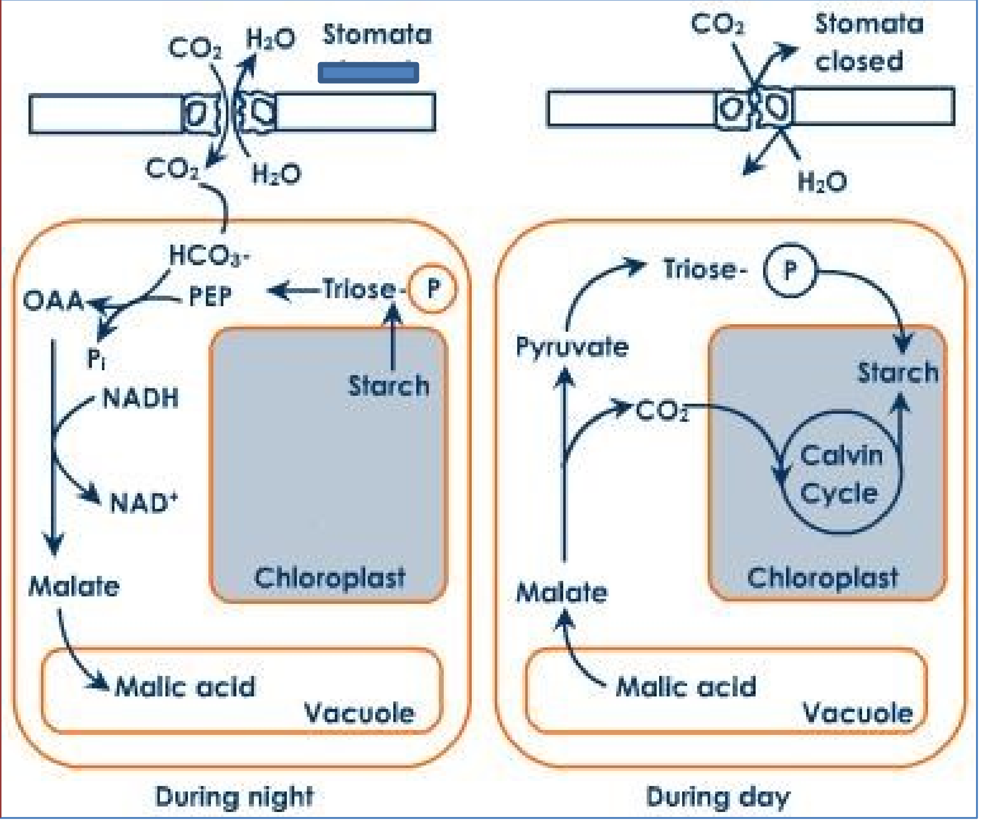
Light-independent reactions – CAM Photosynthesis

Crassulacean Acid Metabolism

- The most important functional difference is the separation of the initial CO_2 incorporation from Calvin Cycle activity.

- In CAM plants separation is temporal rather than spatial. The two mechanisms operate at different times in CAM plants rather than in different locations as they do in C4 plants.

- During the day the stomata are closed (thus preventing water loss) and the CO_2 is released to the Calvin Cycle so that photosynthesis may take place.



1.0 Photosynthesis *contd.*

1.4 The Mechanism of the Process - The light reactions

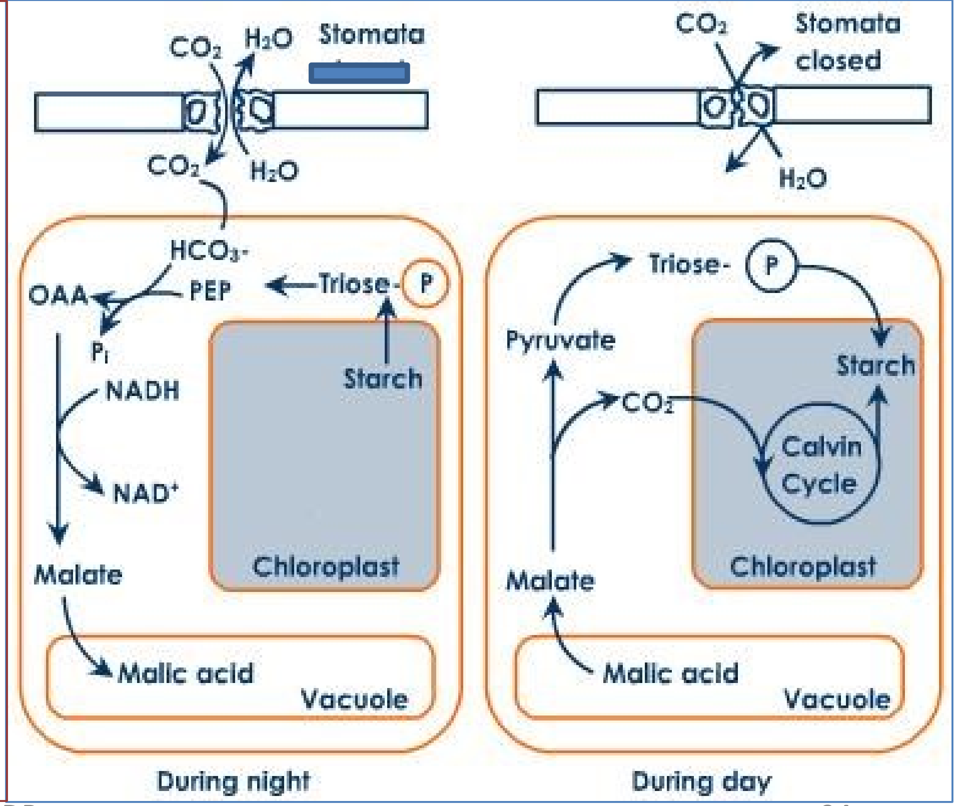
Light-independent reactions – CAM Photosynthesis

Crassulacean Acid Metabolism

- CO_2 is fixed in the mesophyll cells by a PEP reaction similar to that of C4 plants.

- The oxaloacetate is converted to malate which is stored in cell vacuoles. **It is not immediately passed on to the Calvin Cycle**.

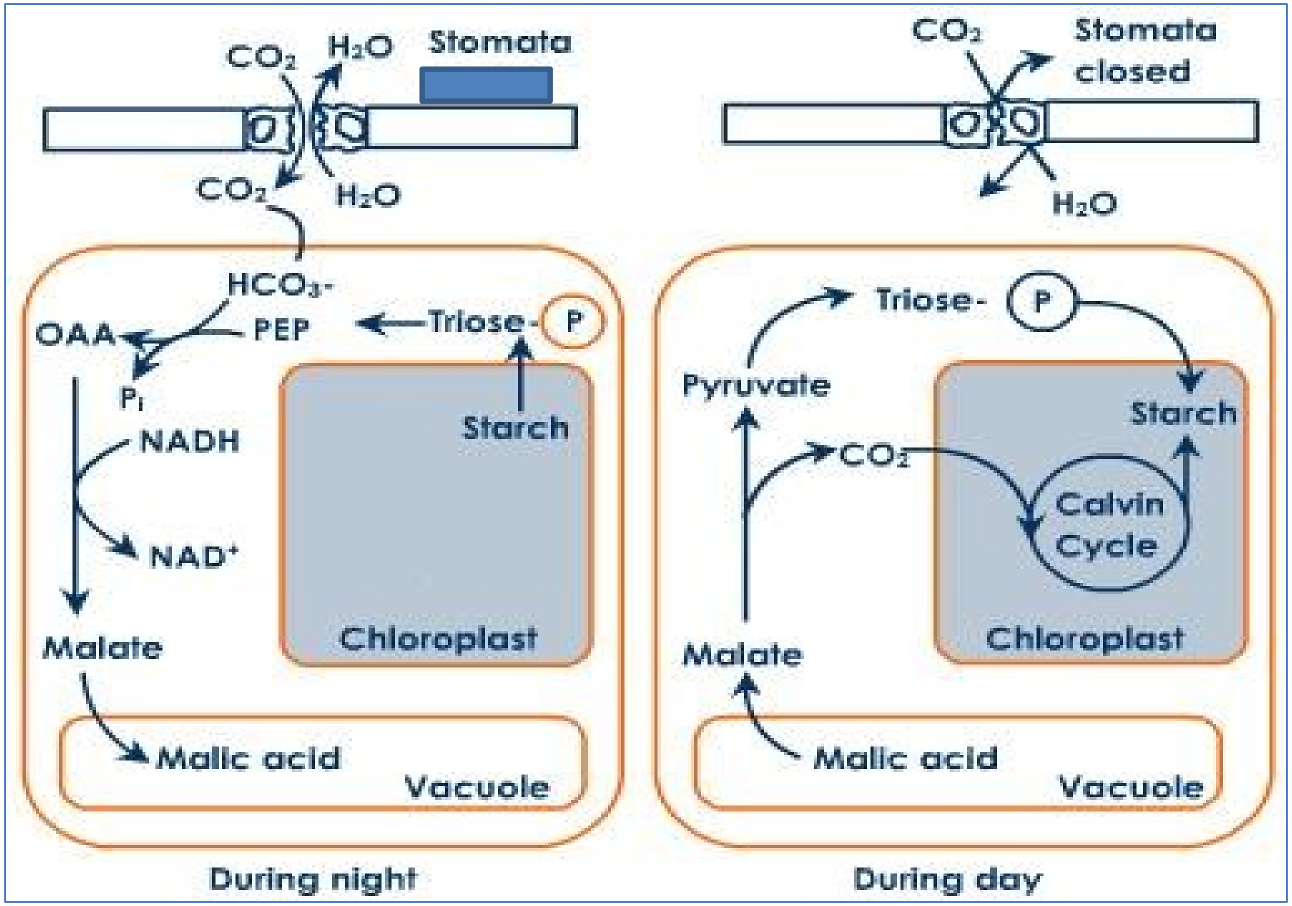
- During the day when the stomata are closed, CO_2 is removed from the stored malate and enters the Calvin cycle, which require ATP and NADPH from light reactions.



1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – CAM Photosynthesis

- CO_2 is fixed in the mesophyll cells by a PEP reaction similar to that of C4 plants.



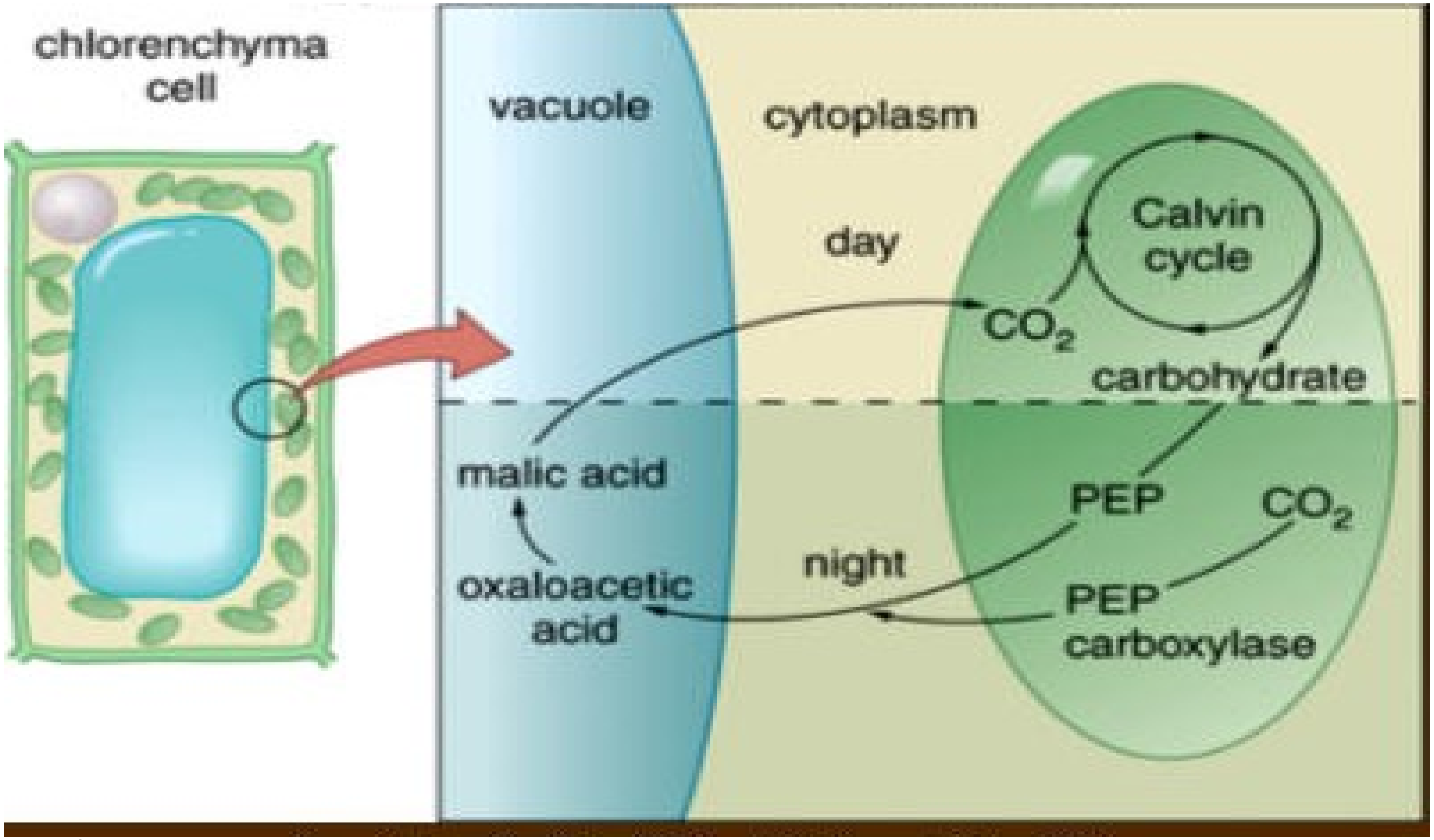
1.0 Photosynthesis *contd*.

1.4 The Mechanism of the Process - The light reactions

Light-independent reactions – CAM Photosynthesis

Crassulacean Acid Metabolism

- CO_2 is fixed in the mesophyll cells by a PEP reaction similar to that of C4 plants.



1.0 Photosynthesis *contd.*

1.5 Factors Affecting Photosynthesis

Limiting factors

- Photosynthesis is a **multi-stage process** therefore the **principle of limiting factors can apply**.
- According to Blackman **when a process is affected by more than one factor its rate is limited by the factor which is nearest its minimum value**.
- It is the limiting factor which directly affects a process if its magnitude is changed.

Limiting factors which affect photosynthesis are:

- **Light intensity**: is necessary to generate ATP and NADPH during the light dependent stages (photochemical).
- **Carbon dioxide concentration**: CO_2 is fixed by reaction with ribulose bisphosphate in the initial reaction of the Calvin cycle.
- **Temperature**: the enzymes catalysing the reactions of Calvin cycle and some of the light dependent stages are affected by temperature (thermochemical).
- **Water availability** and **chlorophyll concentration** are not normally limiting factors.

1.0 Photosynthesis *contd.*

1.5 Factors Affecting Photosynthesis

The main factors affecting photosynthesis are **light intensity**, **carbon dioxide concentration** and **temperature**, known as limiting factors.

- ❖As light intensity increases, the rate of the light-dependent reaction, and therefore photosynthesis generally, increases proportionately.
- ❖As light intensity is increased however, the rate of photosynthesis is eventually limited by some other factor.
- ❖Chlorophyll *a* is used in both photosystems. The wavelength of light is also important. PSI absorbs energy most efficiently at 700 nm and PSII at 680 nm. Light with a high proportion of energy concentrated in these wavelengths will produce a high rate of photosynthesis.

1.5 Factors Affecting Photosynthesis

- An increase in the **carbon dioxide concentration** increases the rate at which carbon is incorporated into carbohydrate in the light-independent reaction and so the rate of photosynthesis generally increases until limited by another factor.

- Photosynthesis is dependent on **temperature**. It is a reaction catalysed by enzymes. As the enzymes approach their optimum temperatures the overall rate increases. Above the optimum temperature the rate begins to decrease until it stops.

1.6 Self Assessment - Discussion/Study Questions

- Describe the role of the raw materials used for photosynthesis.
- Identify the structures composing the chloroplast and indicate the function of each structure in photosynthesis.
- How is light harnessed during the light reactions of photosynthesis an what pigments are involved.
- How is carbon fixed during the Calvin Cycle.
- Distinguish between C4 and CAM metabolism.
- What do you understand by the term limiting factors? How do they affect the rate of photosynthesis?

2.0 RESPIRATION

2.1 Introduction

Respiration is a group of processes that **utilizes the energy** that is stored through the **photosynthetic processes**.

- The steps in respiration are small **enzyme-mediated steps** that release tiny amounts of immediately available energy.
- The energy released is usually stored in ATP molecules which allow for even more efficient use of an organism's energy.
- Respiration occurs in the **mitochondria and cytoplasm of cells**.

There are several forms of respiration:

- ✓aerobic—which requires oxygen,
- ✓anaerobic—which occurs in the absence of oxygen, and
- ✓fermentation—which also occurs in the absence of oxygen.

2.0 Respiration *contd.*

2.1 Introduction

- **Aerobic respiration is the most common form of respiration and cannot be completed without oxygen gas**.

The overall process is the **complete oxidation of glucose** resulting in CO_2 and H_2O and the formation of ATP.

- $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 36\ ATP$

This equation of cellular respiration is **merely a summary** of a complex step-by-step process that has three major stages or pathways:

✓**Glycolysis**

✓The **Krebs Cycle** and the

✓**Electron Transport System**

2.0 Respiration *contd.*

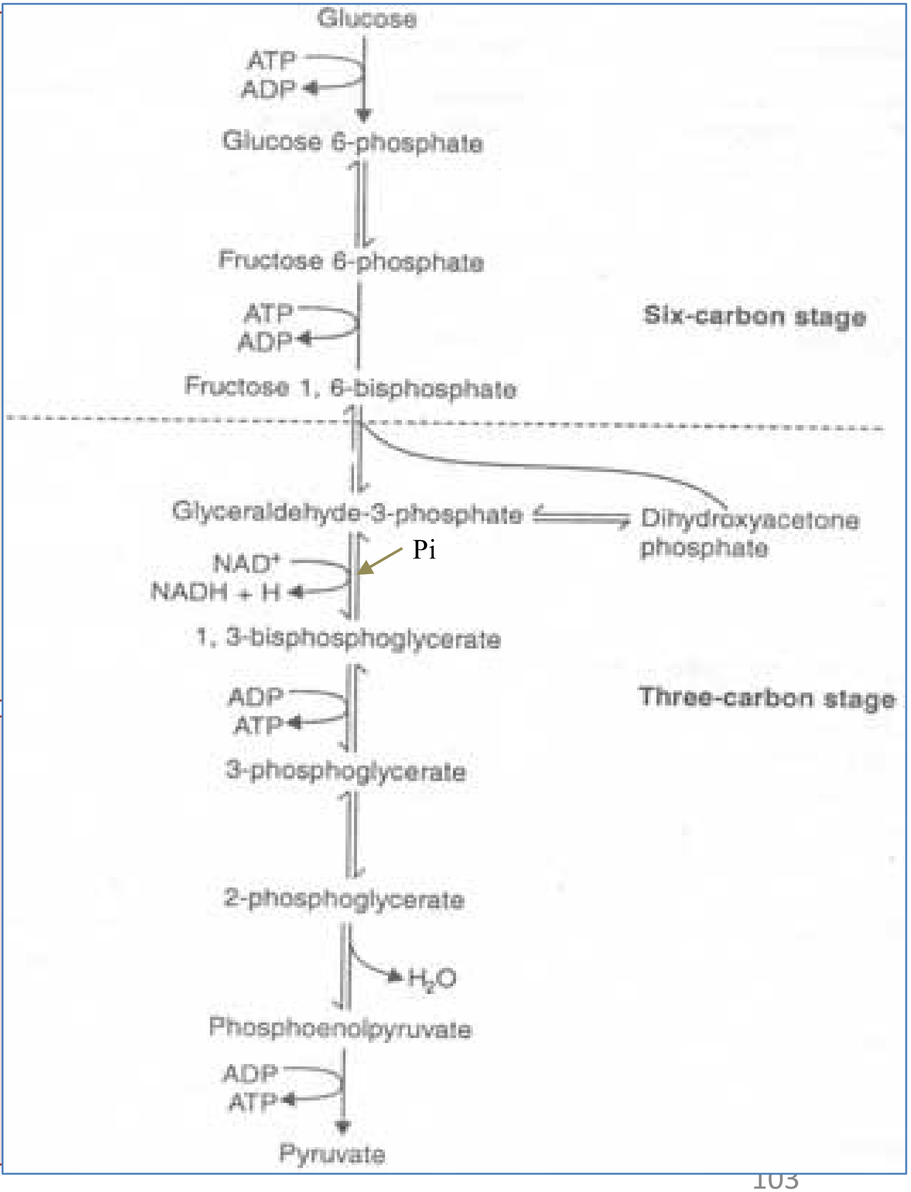
2.2 Glycolysis

Glycolysis: is a series of reactions that takes place in the cytoplasm and result in the breakdown of glucose into two molecules of a three carbon compound.

It is also referred to as **glycolytic pathway** or **Embden-Meyerhof pathway.**

- Glycolysis can be divided into two stages: six carbon stage and three-carbon stage.

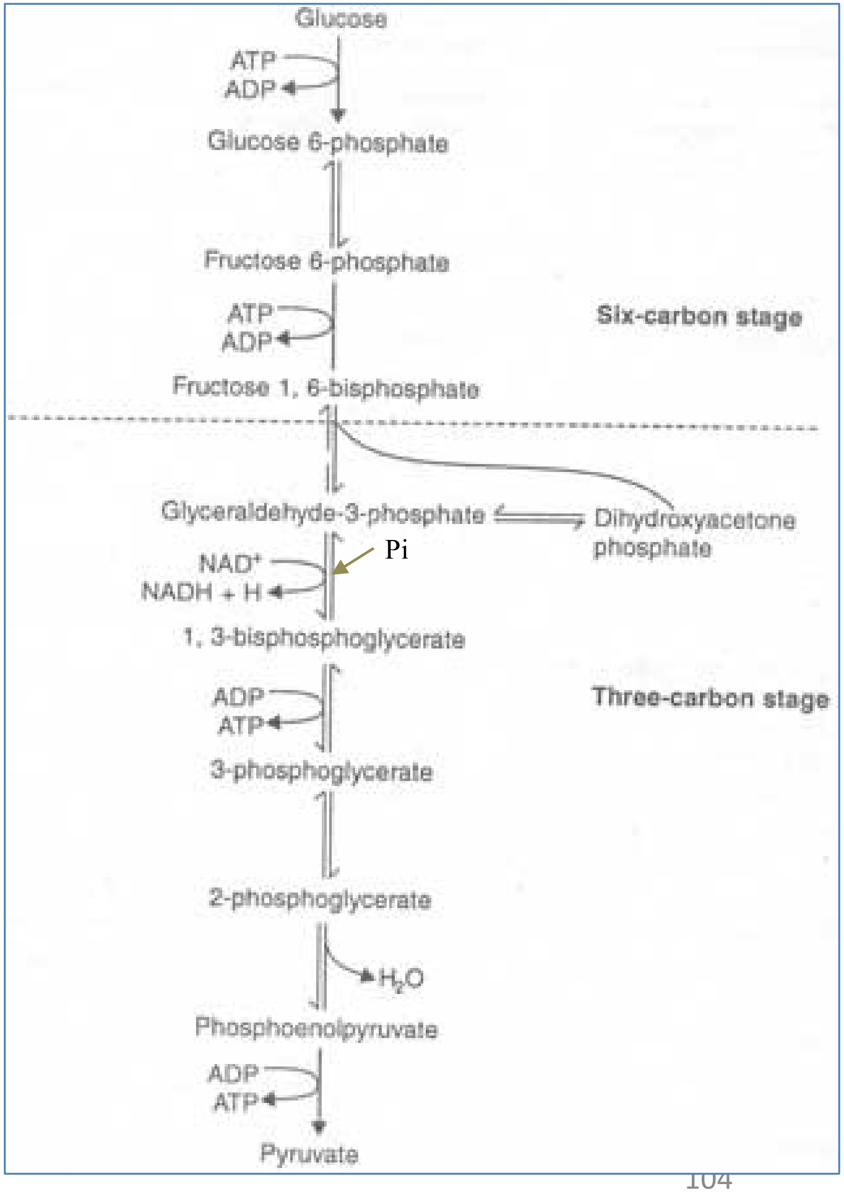
- Along the process NAD is reduced and ATPs are produced.



2.0 Respiration *contd.*

2.2 Glycolysis

- In the six-carbon stage, glucose is phosphorylated twice and finally converted to **fructose 1, 6 bisphos-phate**.
- During this stage, energy is not yielded rather two ATP molecules are used up for each glucose.
- The fructose 1, 6-bisphosphate enters into the 3-carbon stage after being catalyzed by an enzyme.
- It is split into two three-carbon molecule. namely, **glyceraldehyde 3-phosphate** and **dihydroxy-acetone phosphate**.

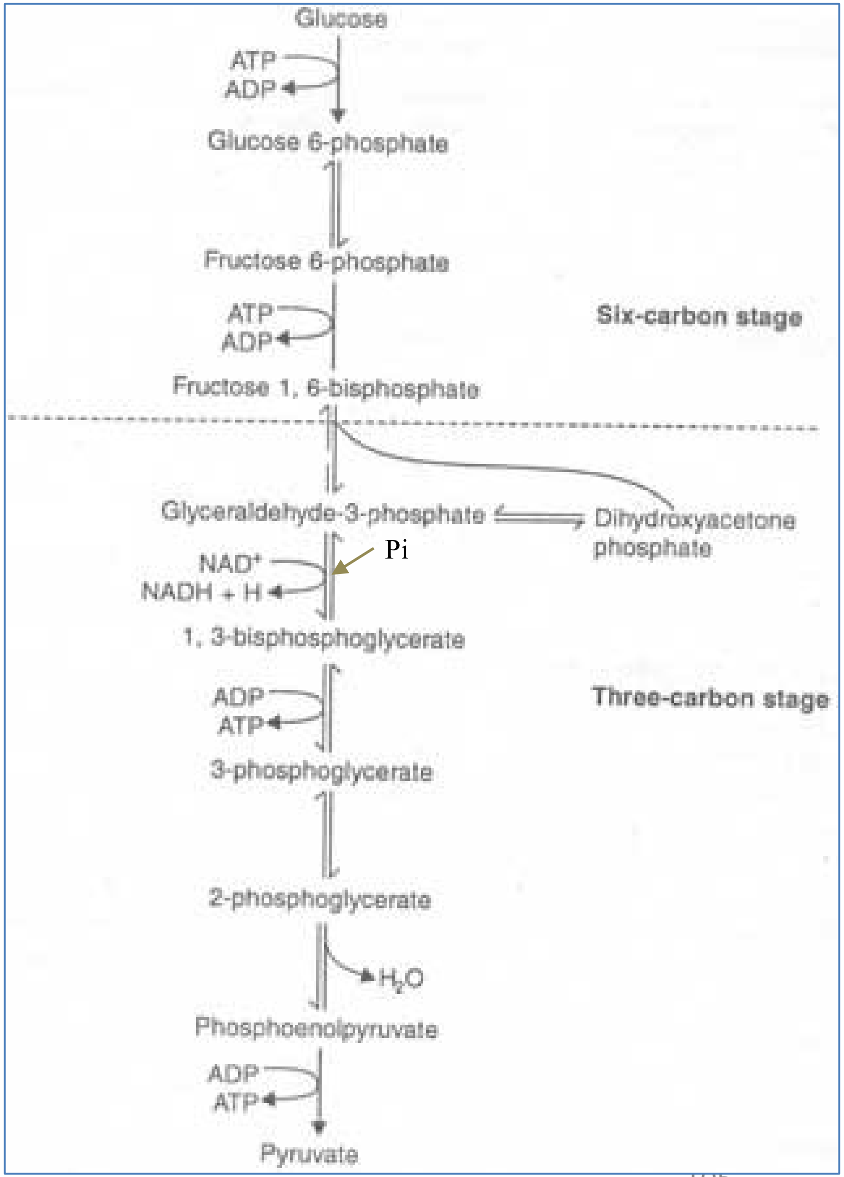


2.2 Glycolysis

- These two molecules are interconvertible, as dihydroxy-acetone phosphate is converted into a second molecule of glyceraldehyde 3-phosphate.

- Both glyceraldehyde 3-phosphate molecules continue on in the pathway so that each of the remaining steps **actually occurs twice**.

- Glyceraldehyde 3-phosphate is oxidized with NAD^+ (nicotinamide adenine dinucleotide) as electron-acceptor and phosphorylated by inorganic phosphate (not by ATP) to produce **1, 3-bisphosphoglycerate**.

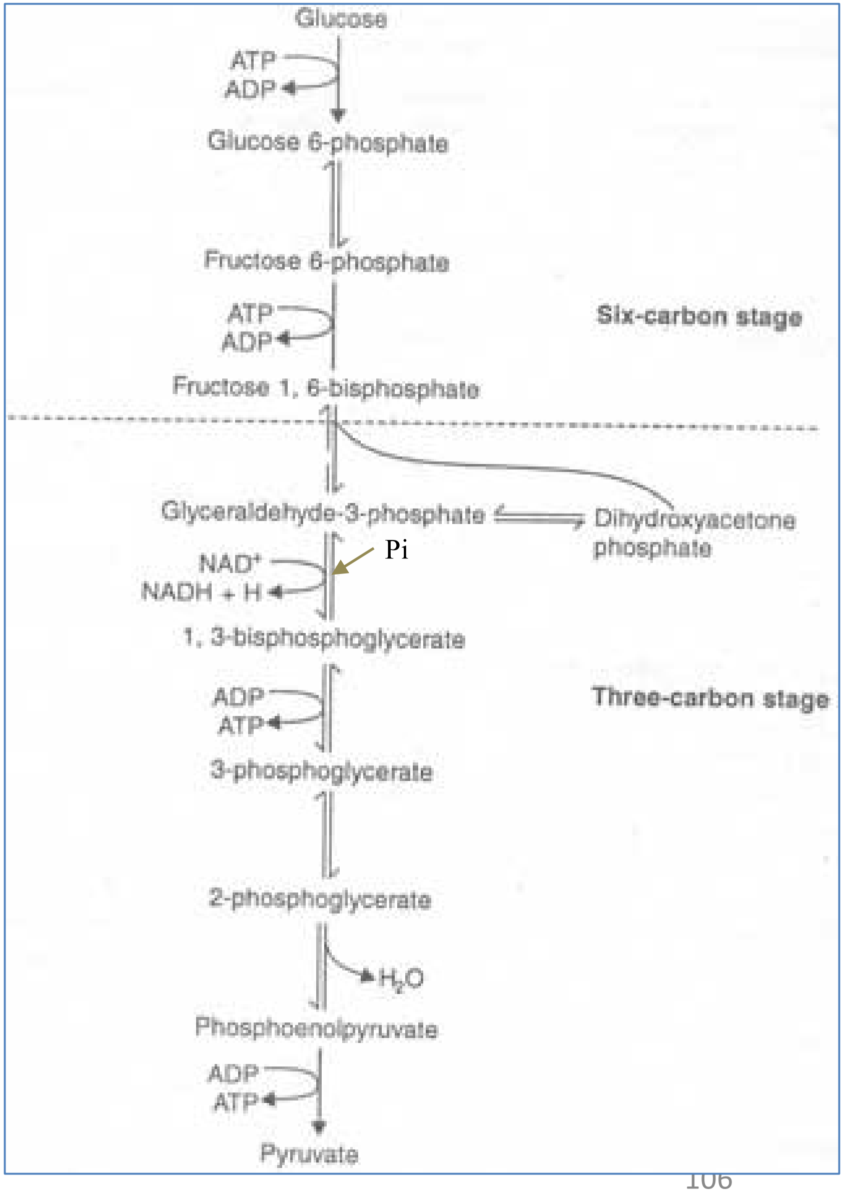


2.2 Glycolysis

- 1, 3 bisphosphoglycerate gives up phosphate and is converted into **3-phosphoglycerate** and ATP is produced.

- 3-phosphoglycerate is then isomerised into **2-phosphogly-cerate** which, in turn, is dehydrated to produce **phospho-enolpyruvate**.

- Phosphoenol-pyruvate is a high energy molecule and is converted into **pyruvate** by donating its phosphate to ADP forming a second ATP.



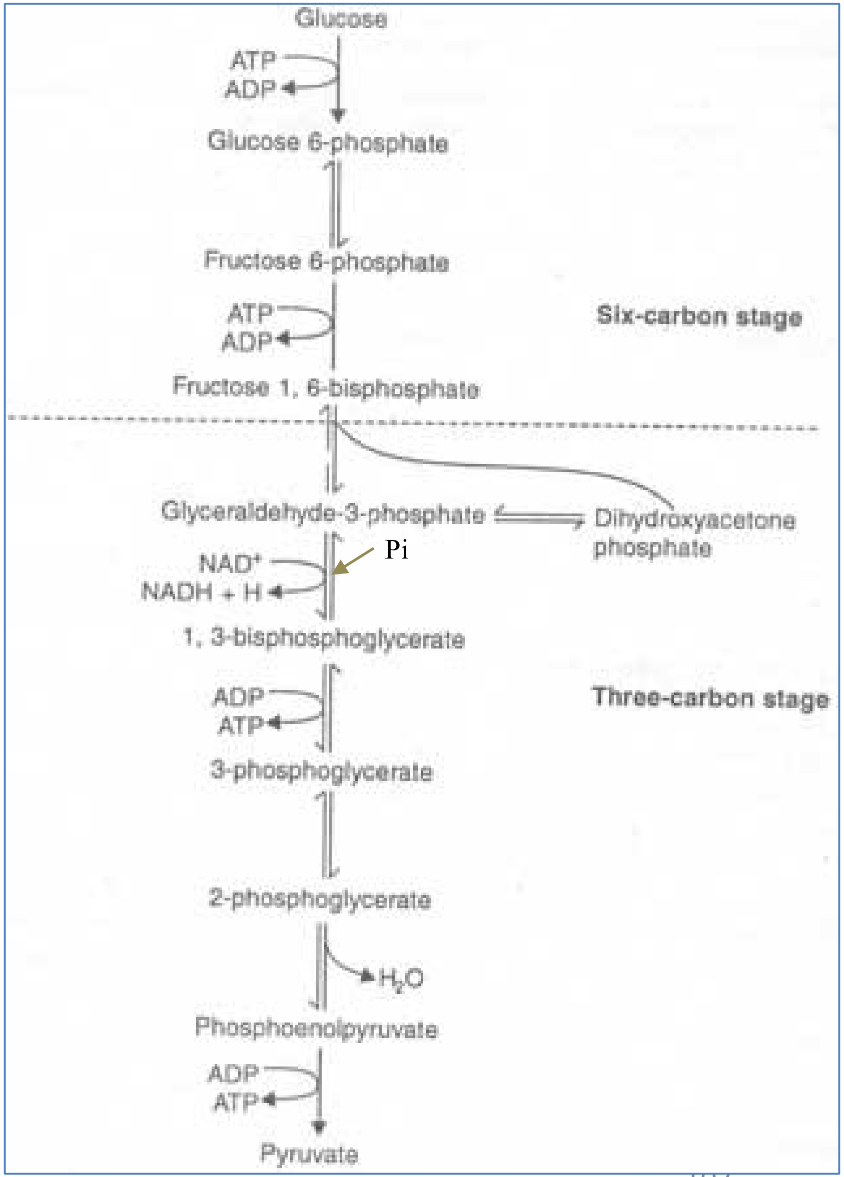
2.2 Glycolysis

- Pyruvate is the end-product of glycolysis.

- During the whole process, two ATP molecules are used up during the six-carbon stage while four ATP molecules are produced during the three-carbon stage.

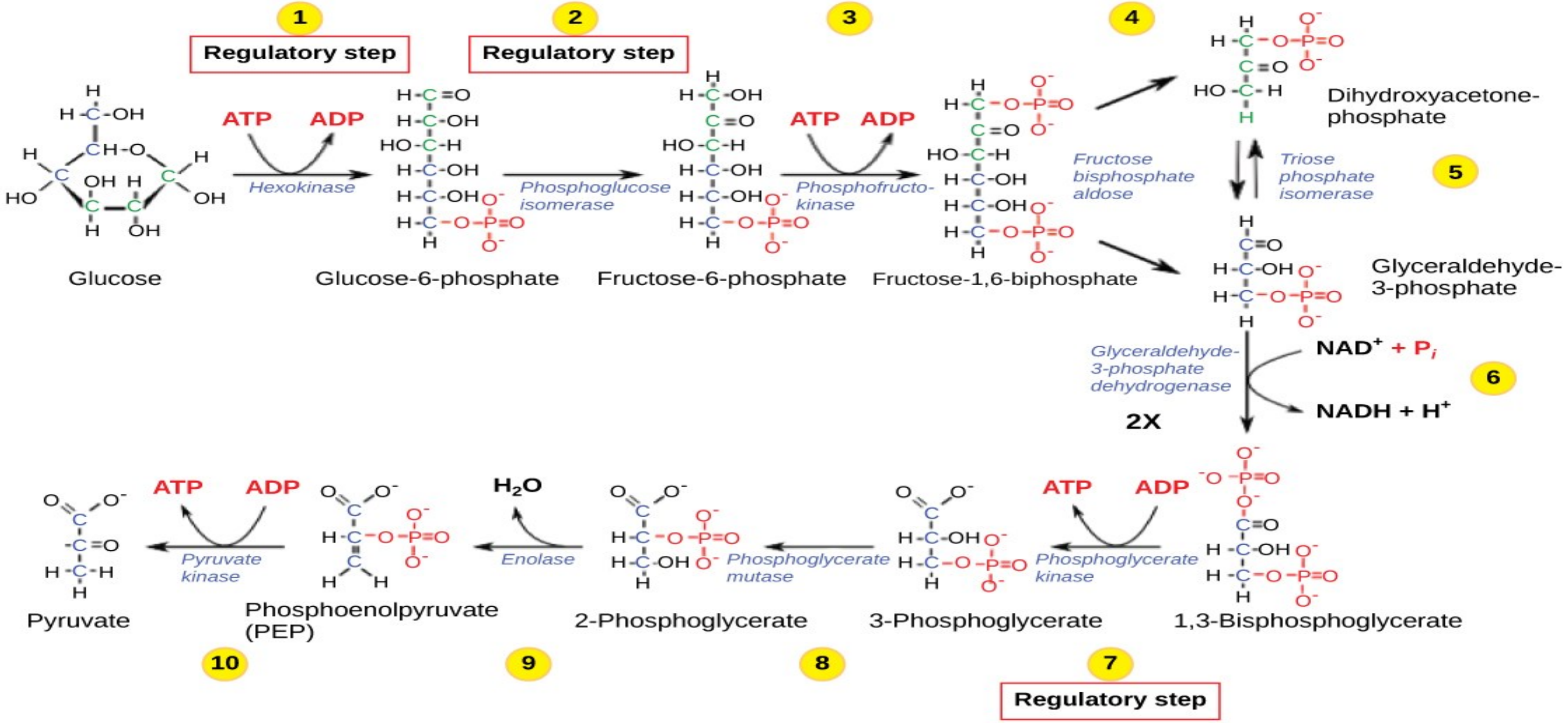
- Thus there is a net gain of two ATP.

- Simultaneously two NADH molecules are also produced in 3-carbon stage.



2.0 Respiration *contd.*

2.2 Steps in the Glycolytic Pathway



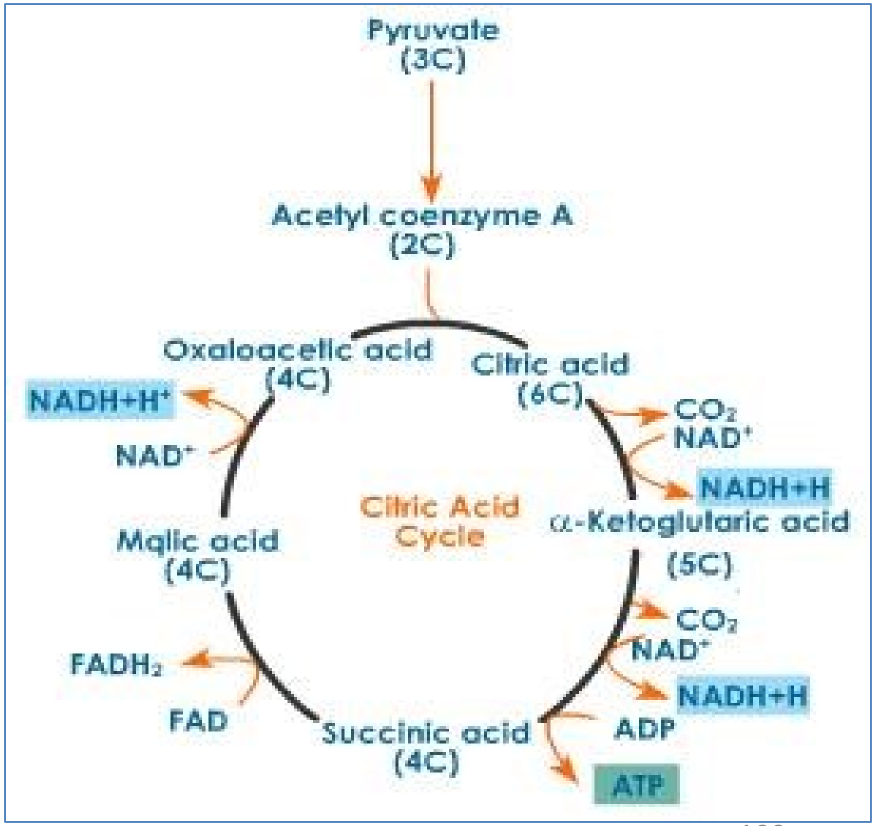
- Glycolysis is the process of breaking down glucose, in the cytoplasm.
- Glycolysis can take place with or without oxygen.
- Glycolysis produces 2 molecules of pyruvate, 2 molecules of ATP, 2 molecules of NADH, and 2 molecules of water.
- There are 10 enzymes involved in breaking down sugar.

2.0 Respiration *contd.*

2.3 The Krebs Cycle

- The Krebs Cycle, named after its discoverer Hans Kreb, takes place in the mitochondria.
- It is also known as the **Citric Acid Cycle** or **Tricarboxylic Acid Cycle**.

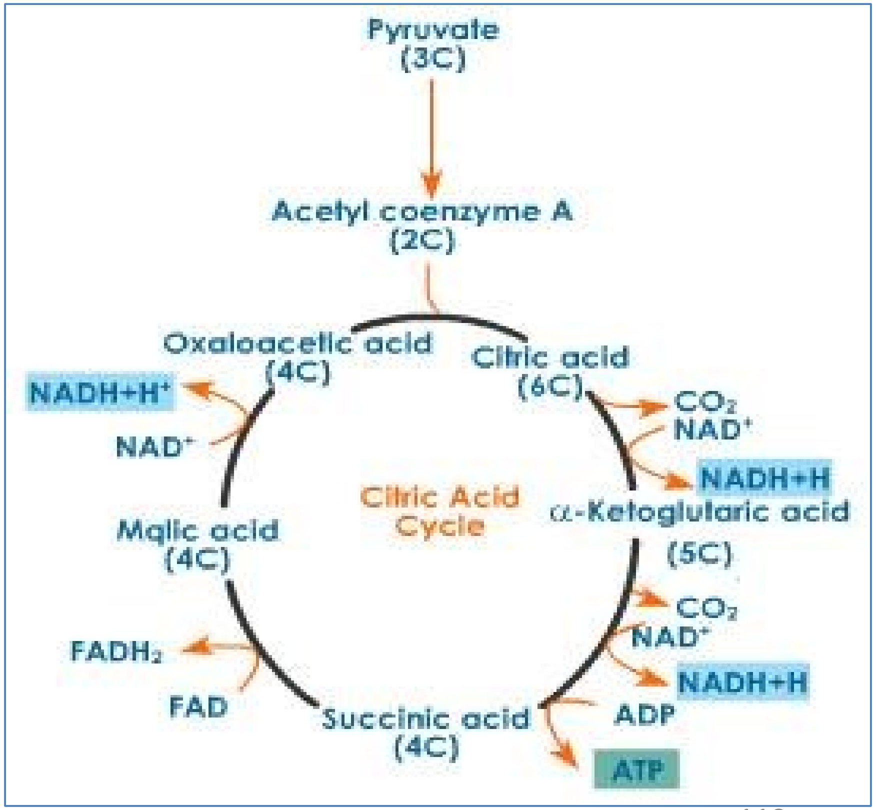
- The molecule of pyruvate from glycolysis is restructured, before it enters the Krebs cycle.
- The molecule is oxidised and decarboxylated. NAD^+ is reduced and CO_2 is lost.
- The resulting 2-carbon compound combines with coenzyme-A to form a complex known as **acetyl CoA**.



2.3 The Krebs Cycle

- Acetyl-CoA enters the Krebs Cycle by combining with a 4-carbon organic acid known as **oxaloacetic acid** (oxaloacetate).
- A six-carbon compound is form known as **citric acid** (citrate).
- The citrate is then converted to **isocitrate**.

- The 6-carbon isocitrate is oxidized by NAD^+ to produce reduced NADH and 5-carbon **alpha-ketoglutarate** (One carbon is lost as CO_2).
- The 5-carbon alpha-ketoglutarate is oxidized by NAD^+ to produce reduced NADH and 4-carbon **succinic acid** and ATP (One carbon is lost as CO_2).

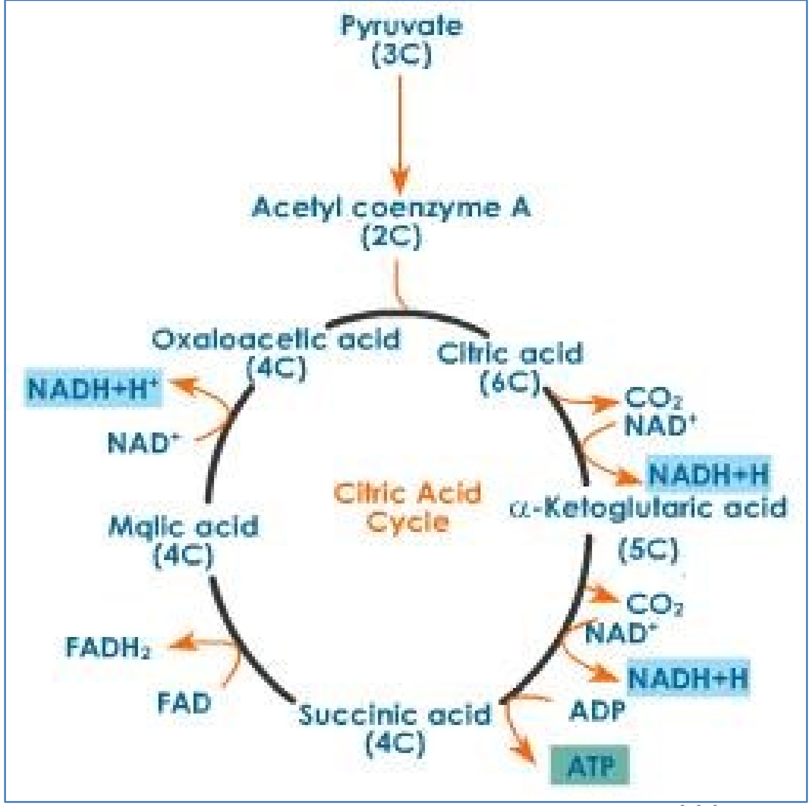


2.0 Respiration *contd.*

2.3 The Krebs Cycle

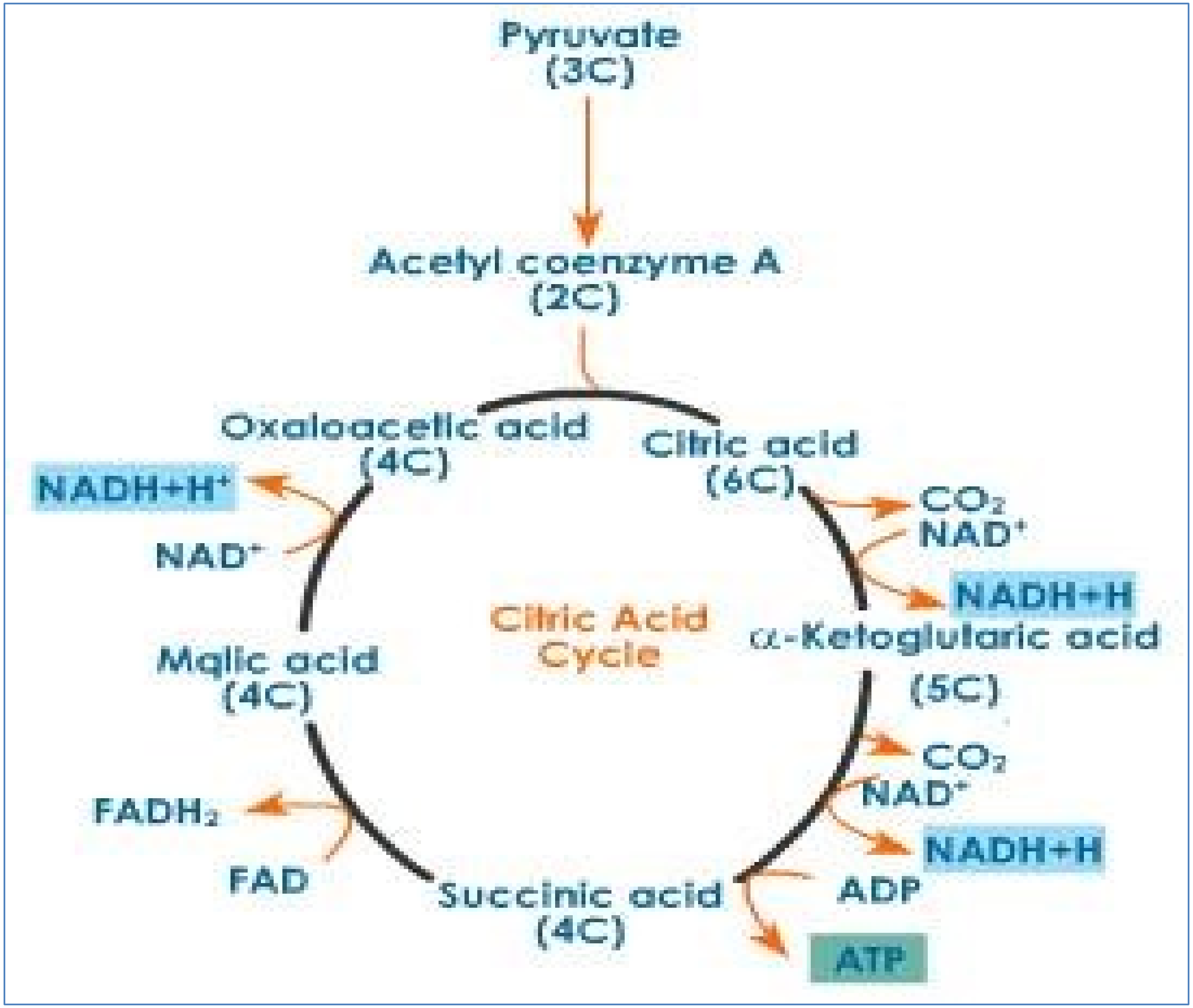
- Oxidation of succinate by FAD (flavin adenine dinucleotide) produces reduced $FADH_2$ and **fumarate**.
- Fumarate is converted into **malate**. Oxidation of malate by NAD+ produces reduced NADH and **oxaloacetic acid**.

- For the two molecules of pyruvate that are converted to two acetyl CoA, **8 molecules of NADH**, **2 molecules of $FADH_2$**, **2 molecules of ATP** are formed, and **6 molecules of CO_2** are released.
- The NADH and $FADH_2$ molecules then **carry electrons** to the electron transport system for further production of ATPs by oxidative phosphorylation.



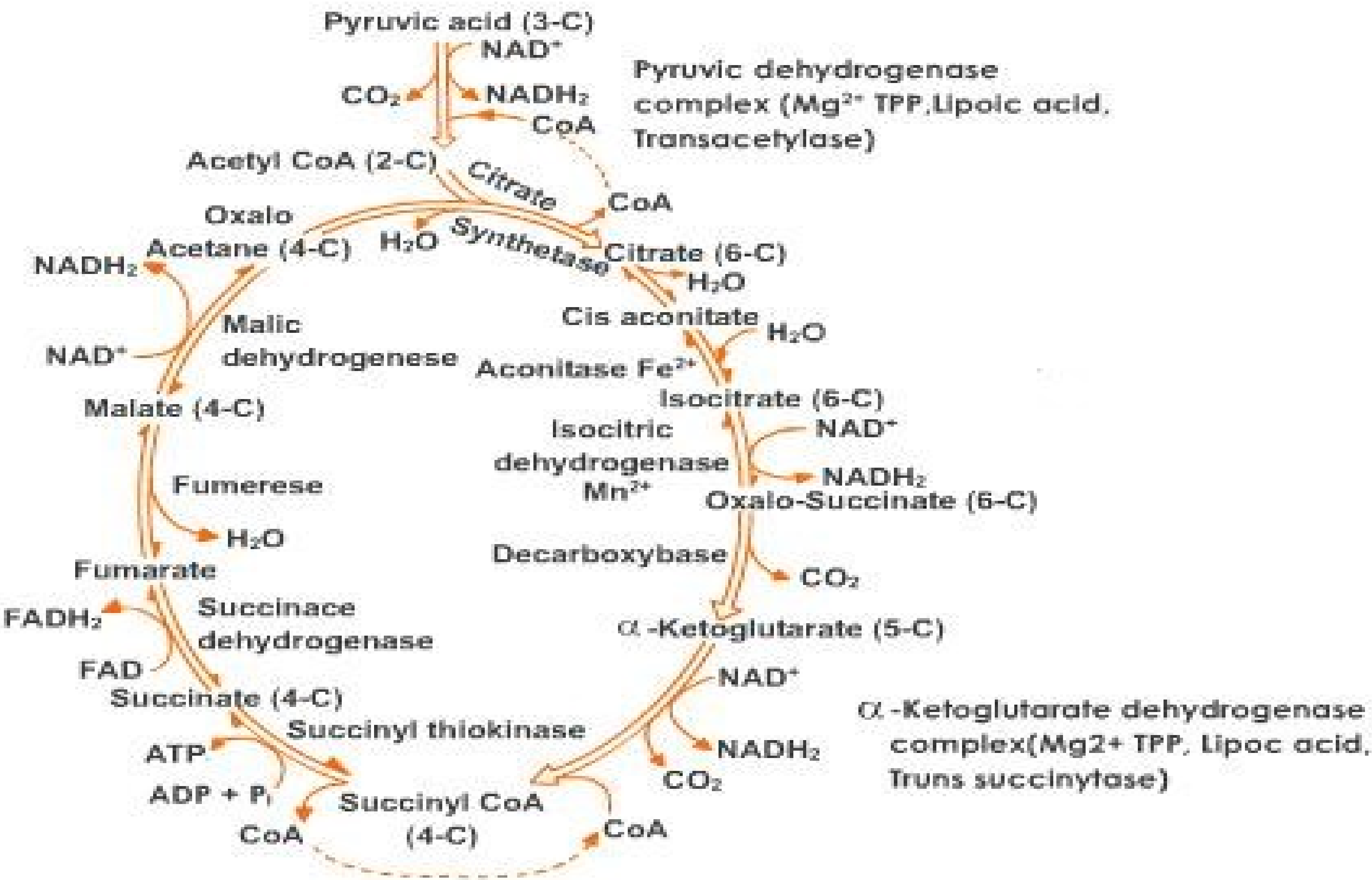
2.0 Respiration *contd.*

2.3 The Krebs Cycle



2.0 Respiration *contd.*

2.3 The Krebs Cycle



2.0 Respiration *contd.*

2.4 Electron Transport System

- The **third and final stage of respiration** occurs on the inner membranes of the mitochondria.
- It involves a series of **enzymes and coenzymes** including several iron-containing cytochromes that are embedded in this layer and **function as electron carriers**.

- During this stage **electrons and hydrogen ions** are passed from NADH and $FADH_2$, formed in glycolysis and the Krebs Cycle down a series of redox reactions and are finally accepted by **oxygen-forming water** in the process.
- The ATP synthesized by this method is referred to as **oxidative phosphorylation**.
- When electron flow begins, from each molecule of NADH, **3 molecules of ATP are produce**. Thus **24 ATP** are produce from **8 NADH**.

2.0 Respiration *contd.*

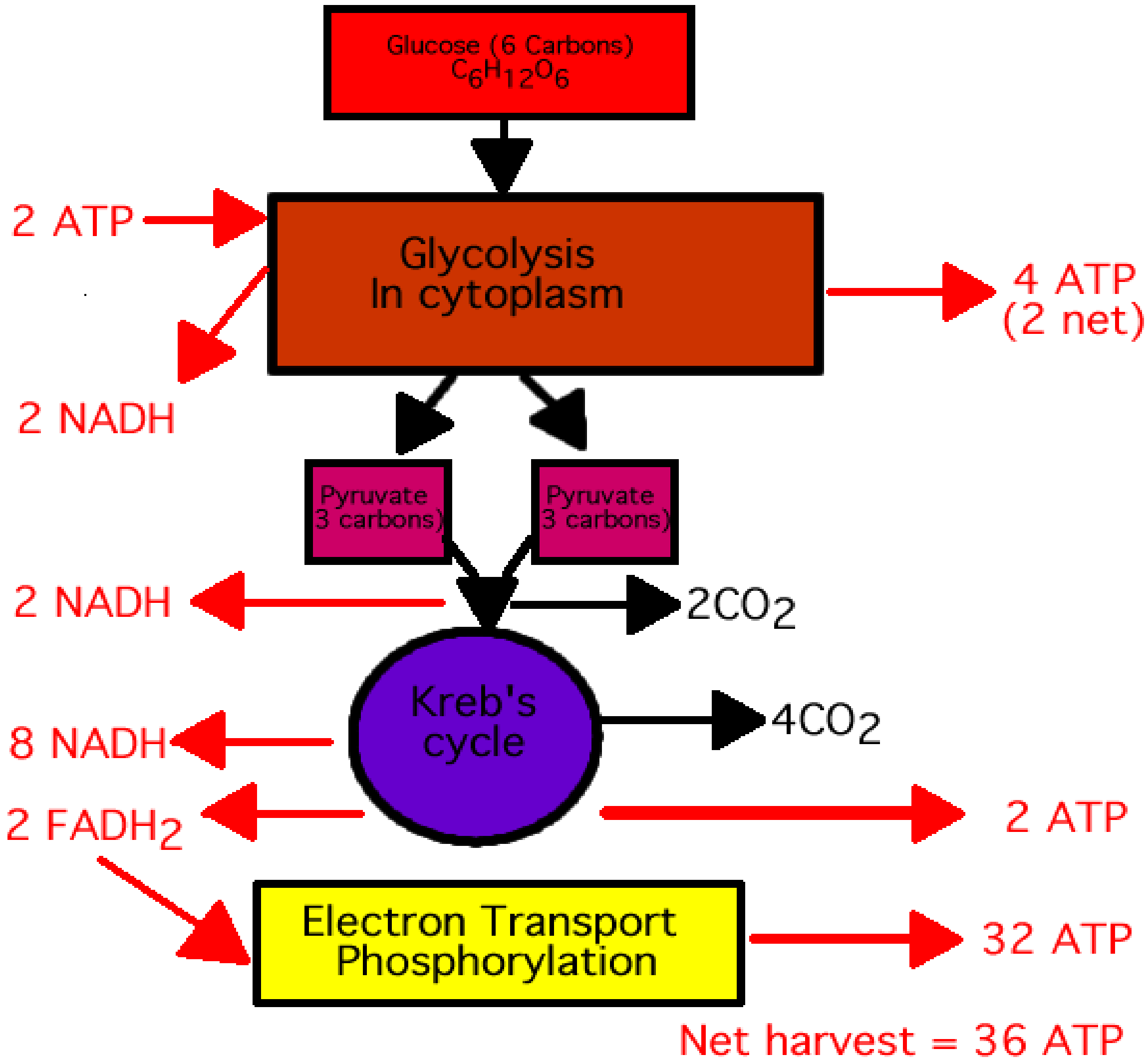
2.4 Electron Transport System

- Two molecules of ATP are also synthesised during the flow of electrons **from each $FADH_2$** produced in the Krebs Cycle, given **4 ATP** and two for **each NADH from glycolysis**, given **4 ATP**.

- Thus during the **Electron Transport System a total of 32 ATP are generated**.

- This number is added to the net yield of **2 ATP** from glycolysis and the **2 ATP produced in the Krebs Cycle** for a **grand total of 36 ATP** for **each molecule of glucose** that completes cellular respiration.

2.4 Net Harvest of ATP



2.0 Respiration *contd.*

2.4 Comparison of Photosynthesis and Respiration

PHOTOSYNTHESIS	RESPIRATION
1. Stores energy in sugar molecules	1. Releases energy from sugar molecules
2. Uses carbon dioxide and water	2. Releases carbon dioxide and water
3. Increases weight	3. Decreases weight
4. Occurs only in light	4. Occurs in either light or darkness
5. Occurs only in cells containing chlorophyll	5. Occurs in all living cells
6. Produces oxygen in green organisms	6. Utilizes oxygen (aerobic respiration)
7. Produces ATP with light energy	7. Produces ATP with energy released from sugar

2.0 Respiration *contd.*

2.5 Self Assessment – Discussion/Study Questions

- Compare aerobic respiration and fermentation in terms of:-
  a. efficiency of obtaining energy from glucose.
  b. end products.

- Describe the mitochondria and respiratory events that occur there.

- Why is glycolysis important to living organisms and where does it occur?

- How many atoms are oxygen are consumed when one molecule of pyruvic acid is oxidised in the TCA cycle and how many molecules of ATP are generate in the ETS.

- **Describe the process of oxidative phosphorylation**.

3.0 Nitrogen Metabolism

3.1 Nitrogen importance in plants

- Nitrogen has many important roles in the **structure and metabolism** of plants.
- With the exception of carbon, hydrogen, and oxygen nitrogen is the most widely distributed element in a living organism.
- It is found in such essential compounds as amino acids, proteins, purines and pyrimidines (constituents of important compounds like nucleic acids DNA and RNA), in various coenzymes and in ATP.
- It is also important in phytochrome and tetrapyrrole (haemoglobin and chlorophyll).
- They are also found in vitamins and plant hormones.

3.0 Nitrogen Metabolism

3.2 Forms of Nitrogen available plants

Nitrogen is required in specialized chemical states by various organisms e.g. most plants cannot utilise atmospheric nitrogen.

Atmospheric nitrogen:

- The soil contains small amounts of nitrogen (N_2).
- Most of the earth's nitrogen is in the atmosphere and it accounts for 78% of molecules presents in the atmosphere.
- However, it is difficult for living organisms to obtain atmospheric N_2 directly for their use.
- Nitrogen in this form is unavailable for use by most plants.
- Very few plants species can use N_2 of the air directly.
- Higher plants lack this ability to use it directly except in symbiotic association with certain microbes.
- The conversion of atmospheric N_2 into organic compounds by living organisms is called **nitrogen fixation**.

3.2 Forms of Nitrogen available plants

Ammonia (NH_3)

- The atmosphere contains only traces (NH_3).
- Certain nitrogen deficient plants absorb NH_3 from the atmosphere.
- The rain carries some nitrogen as NH_3 into the soil and the amount of this NH_3 precipitated is closely related to the amount of rainfall.

3.0 Nitrogen Metabolism

3.2 Forms of Nitrogen available plants

Nitrogen compounds in the soil:

- **Amino acids**:
  - some soils contain small amounts of various amino acids which are probably formed by the action of microbes on decaying organic matter and from excretion by living roots.
- **Urea**:
  - It is usually rapidly absorbed and metabolised. Some plants can use it as the sole source of N_2.
  - Urea has been successfully used as a fertilizer.
- **Pyrimidines, purines and soluble proteins**:
  - These are complex organic compounds and they are known to be absorbed and utilised, but their importance in plant nutrition is minor because dissolved amounts of these compounds in soils is insignificant.

3.2 Forms of Nitrogen available plants

➢ Nitrate (NO_3) and Ammonium (NH_4) ions:

- Most plants readily absorb and utilise the inorganic ions (**nitrate and ammonium**) as sources of their nitrogen requirements and these two are the most effective nitrogen source for most plants.
- **Nitrates** are usually the preferred source but few plants grow better on ammonium source e.g. potato, pineapple, yam and cereals.
- As cereals mature they tend to absorb nitrates more readily.
- Some investigators have reported that sugar beet utilises more ammonium salts than nitrate at pH 7 but the reverse occurs at pH 5.
- In general plants use ammonium better under neutral and slightly alkaline conditions than at lower pH values while nitrates are taken up better in slightly acidic medium.

3.0 Nitrogen Metabolism

3.2 Forms of Nitrogen available plants

Nitrogen form	Symbol	Use in soils and plants
Dinitrogen (Atmospheric Nitrogen)	N_2	Dinitrogen is the most common form. It makes up 78 percent of the atmosphere but cannot be used by plants. It is taken into the soil by bacteria, some algae, lightning, and other means.
Nitrate	NO_3	Nitrate is the form of nitrogen most used by plants for growth and development. Nitrate is the form that can most easily be lost to groundwater.
Ammonium Nitrogen	NH_4	Ammonium taken in by plants is used directly in proteins. This form is not lost as easily from the soil.
Organic Nitrogen	$C\text{-}NH_2$ (where C is a complex organic group)	Organic nitrogen exists in many different forms. It is changed into ammonium, then into nitrates, by microorganisms. Both of these inorganic forms can be used by the plant.

3.3 Nitrate Reduction

- Plants obtain most of their nitrogen by absorbing the nitrate or ammonium ions present in the soil solution.
- Although nitrate ions are normally the chief source of nitrogen available to plants they cannot be used directly, hence they must be reduced to ammonia before it is incorporated into amino acids and other nitrogenous compounds.
- The reduction of nitrate to ammonia in plants takes place in three stages by the following pathway:

$$\underset{\text{(nitrate)}}{NO_3^-} \xrightarrow[\text{reductase}]{\text{nitrate}} \underset{\text{(nitrite)}}{NO_2^-} \xrightarrow[\text{reductase}]{\text{nitrite}} \underset{\text{(hydroxylamine)}}{NH_2OH} \xrightarrow[\text{reductase}]{\text{hydroxylamine}} \underset{\text{(ammonia)}}{NH_3}$$

3.0 Nitrogen Metabolism

3.3 Nitrate Reduction

NO_3^- (nitrate) $\xrightarrow[\text{reductase}]{\text{nitrate}}$ NO_2^- (nitrite) $\xrightarrow[\text{reductase}]{\text{nitrite}}$ NH_2OH (hydroxylamine) $\xrightarrow[\text{reductase}]{\text{hydroxylamine}}$ NH_3 (ammonia)

- The main evidence for the existence of this pathway is that the **reductase enzymes necessary for all three stages** have been shown to be present in flowering plants in the chloroplast.
- The enzyme **nitrate reductase** catalyse the conversion of nitrates to nitrites. This enzyme contains FAD as a tightly bond coenzyme.
- The reduction of nitrite to hydroxylamine is catalysed by **nitrite reductase** whilst the conversion of hydroxylamine to ammonia is by **hydroxylamine reductase**.

3.4 Relationship of nitrate reduction

Relationship of nitrate reduction to respiration and photosynthesis:

- The overall equation for the reduction of nitrate to ammonia is an **energy dependent process**, that is the process requires energy.
- Carbohydrates produced in photosynthesis through their breakdown in respiration provides the energy needed for nitrate reduction.
- Respiration and photosynthesis provides the **NADH** and **NADPH** as well as the reduced **Ferredoxin** needed for nitrate reduction.
- Reduction of nitrates is competitive with CO_2 reduction in the dark reactions of photosynthesis. Under conditions of high nitrate reduction and assimilation especially in the dark, carbohydrates levels in the plants are significantly lowered. **This is because both require electrons arising ultimately from photosynthetic light reactions**.

3.0 Nitrogen Metabolism

3.5 Conversion of ammonia into organic compounds

In flowering plants the **incorporation of the nitrogen in ammonia into amino acids molecules takes place in only one way**, by the initial formation of glutamic acid.

- This is accomplished by the **reductive amination** of **α-ketoglutaric acid** (one of the acids produced in the Tricarboxylic acid cycle (TCA).
  α-ketoglutaric acid + NH_3 + 2(H) = glutamic acid + H_2O
- As in nitrate reduction, the hydrogen donor (which is NADH or NADPH) can be provided either by respiration or photosynthesis.

$$\mathbf{NH_4^+ + \alpha\text{-ketoglutaric acid} + NADPH \xrightarrow[\text{dehydrogenase}]{\text{glutamate}} glutamate + H_2O + NADP}$$

3.5 Conversion of ammonia into organic compounds

- Once glutamic acid has been formed it can function as the **precursor or for the synthesis of other amino acids** by the process of **transamination** (i.e. the transfer of an amino group, **-**NH_2 from one molecule to another without the formation of ammonia).

- This process is catalysed by the **transaminase** (or, as they are sometimes called, **aminotransferase**) enzymes which accept an amino group from an amino acid and transfer it to an **α-keto acid** which is thereby converted into the corresponding amino acid.

3.5 Conversion of ammonia into organic compounds

- For example, transfer of the amino group from **glutamic acid to oxaloacetic acid** results in the formation of **α-ketoglutaric acid** (the α-keto acid corresponding to glutamic acid) and aspartic acid (the amino acid corresponding to oxaloacetic acid).

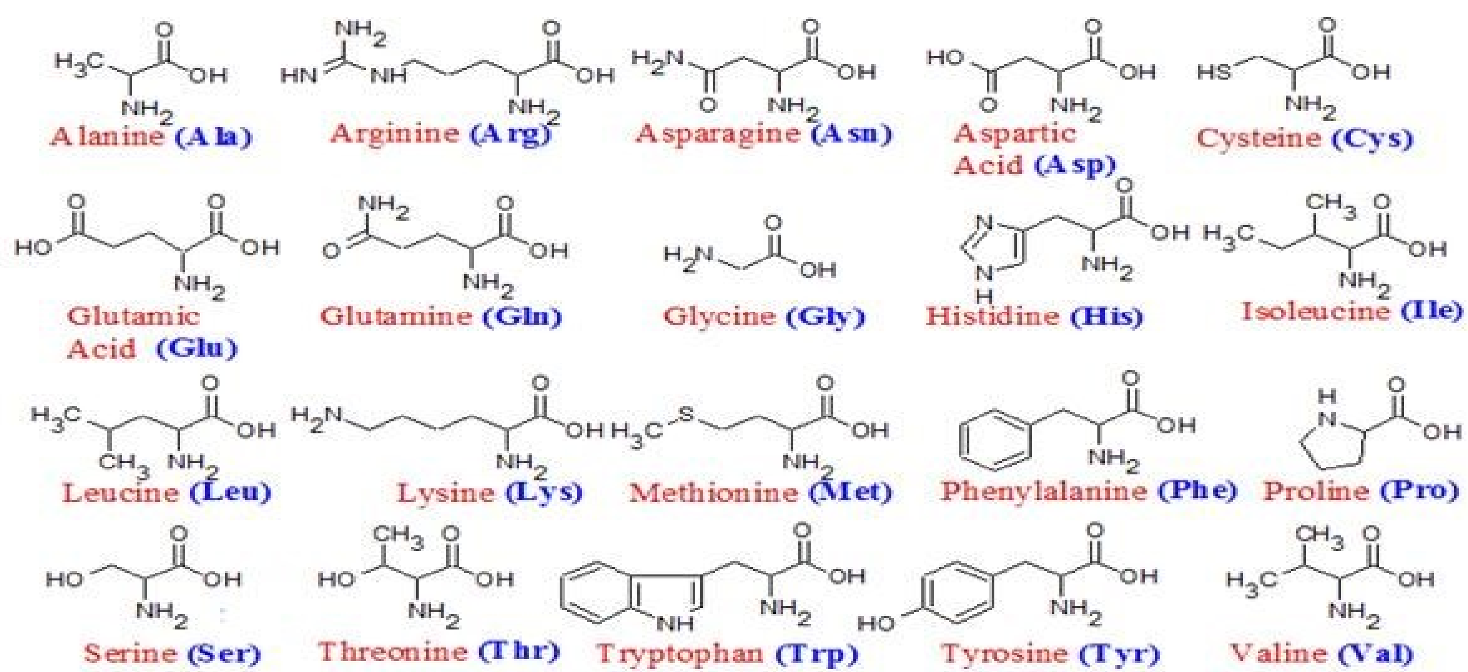
glutamic acid +	**oxaloacetic acid** $\rightleftharpoons$	**α-ketoglutaric acid** +	**aspartic acid**
(amino acid)	(α-keto acid)	(α-keto acid)	(amino acid)

- Since a wide variety of α-keto acids occurs in plant tissues, it seems likely that many of the naturally occurring amino acids are formed by transamination of glutamic acid, or an amino acid derived from it, with the appropriate α-keto acid.

3.0 Nitrogen Metabolism

3.5 Conversion of ammonia into organic compounds

- Glutamic acid is the main amino acid from which 19 other amino acids are formed through transamination.
- Each amino acid is made up of one carboxyl group (-COOH) and one or more amino groups ($-NH_2$).



- Transamination involves the transfer of amino group from one amino acid to the α-ketogroup of α-keto acid. The enzyme responsible for transamination is **transaminase**.

3.0 Nitrogen Metabolism

3.5 Conversion of ammonia into organic compounds

- The transaminations ultimately depends on the reductive amination of α-ketoglutaric acid because this is the only α-keto acid capable of reacting with ammonia directly.

NH_3 + 2(H) α-ketoglutaric acid $RCHNH_2COOH$ (amino acid) $R^1COCOOH$ (α-keto acid)

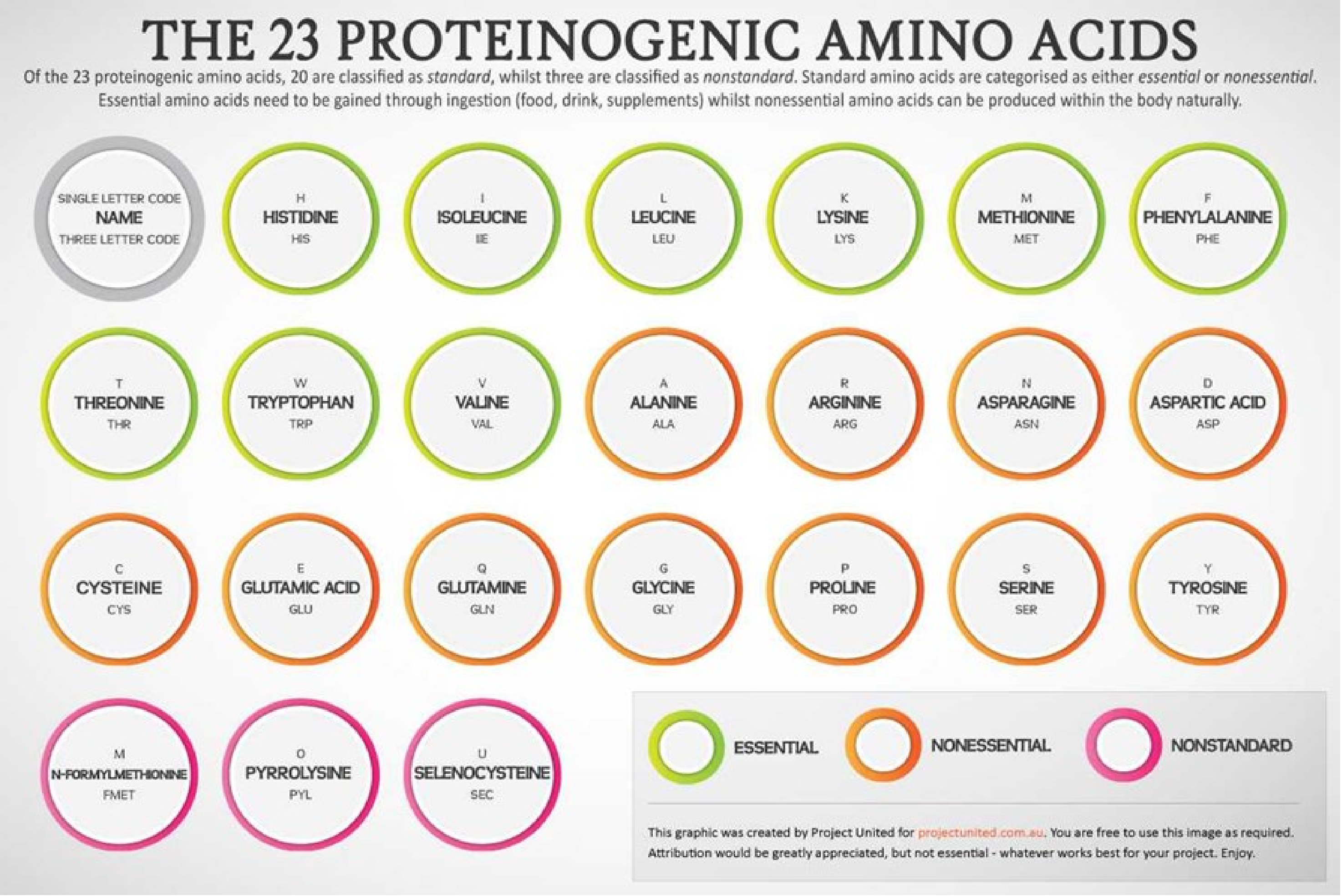
reductive amination **trans-amination** **trans-amination**

H_2O glutamic acid $R^1COCOOH$ (α-keto acid) $RCHNH_2COOH$ (amino acid)

3.5 Amino acids found in plants

Characteristics of the side chains	Amino Acid
Aliphatic	Alanine
	Glycine
	Isoleucine
	Leucine
	Proline
	Valine
Aromatic	Phenylalanine
	Tryptophan
	Tyrosine
Acidic	Aspartic Acid
	Glutamic Acid
Basic	Arginine
	Histidine
	Lysine
Hydroxylic	Serine
	Threonine
Sulfur Containing	Cysteine
	Methionine
Amidic (amide group)	Asparagine
	Glutamine

3.5 Amino acids classified



3.6 Assignment – Discussion/Study Questions

- Give a detail description of the nitrogen cycle.
- Describe the mechanism of biological nitrogen fixation.
- What are amino acids? How are they synthesized in plants?

4.0 MINERAL NUTRITION

4.0 Introduction

4.1 Criteria for Essentiality (essential elements)

4.2 Classification of Essential Elements

4.3 Role of Mineral Nutrients in Plant Metabolism

4.4 Symptoms of Mineral Deficiency

4.5 Symptoms of Mineral Toxicity

4.0 Mineral Nutrition

- ***Mineral***: An inorganic element
  Acquired mostly in the form of inorganic ions from the soil.

- ***Nutrient***: A substance needed to survive or necessary for the synthesis of organic compounds.

Plants use inorganic minerals for nutrition, whether grown in the field or in a container.

The process of absorption, translocation and assimilation of nutrients by the plants is known as **mineral nutrition**.

4.0 Mineral Nutrition

- For its fertility, plants rely on the inherent capacity of soil to supply nutrients in **adequate amounts** and in **suitable proportions**.
- Plants require minerals for its metabolism, growth and replacement of tissue.
- The use of **soilless mixes** and increased research in nutrient cultures and **hydroponics** as well as advances in plant tissue analysis, have led to a broader understanding of plant nutrition.
- Plant nutrition requires a complex balance of elements **essential** and **beneficial** minerals for optimum plant growth.

4.0 MINERAL NUTRITION

4.1 Essentiality of Mineral Nutrients

Three main criteria are essential for a mineral element to be considered essential. These criteria are:

1. A plant must be **unable to complete** its life cycle in the absence of the mineral element.
2. The function of the element must **not be replaceable** by another mineral element.
3. The element must be **directly involved** in plant metabolism.

- These criteria are important guidelines for plant nutrition but exclude **beneficial minera**l elements.

- **Beneficial elements** are those that can **compensate for toxic effects of other elements** or may replace mineral nutrients in some other less specific function such as the maintenance of osmotic pressure.

4.0 MINERAL NUTRITION

4.2 Classification of Essential Elements

The essential elements can be classified based on the **amount required**, their **mobility** in the plant and soil, their **chemical nature and their functions** inside the plant.

Amount of Nutrients: Depending on the quantity of nutrients present in plants, they can be classified into three:

- **Basic Nutrients:**

  The basic nutrients, carbon, hydrogen and oxygen, constitute 96% of total dry matter of plants. Among them, carbon and oxygen constitute 45% each.

4.2 Classification of Essential Elements

Macronutrients:

- The nutrients required in **large quantities** are known as **macronutrients**.

- They are **Nitrogen** (N), **Phosphorus** (P), **Potassium** (K), **Calcium** (Ca), **Magnesium** (Mg), and **Sulphur** (S).

- Among these, **N**, **P**, and **K** are called primary nutrients and **Ca**, **Mg** and **S** are known as secondary nutrients.

- The later are known as secondary nutrients as they are inadvertently applied to the soils when **N**, **P**, and **K** fertilizers, which contain these nutrients, are used.

4.0 MINERAL NUTRITION

4.2 Classification of Essential Elements

Micronutrients:

- The elements which are required in **small quantities** are known as **micronutrients or trace elements**.

- Essential trace elements include **Boron** (B), **Chlorine** (Cl), **Copper** (Cu), **Iron** (Fe), **Manganese** (Mn), **Sodium** (Na), **Zinc** (Zn), **Molybdenum** (Mo), and **Nickel** (Ni).

- These elements are very efficient and minute quantities produce optimum effects.

- On the other hand, even a **slight deficiency or excess** is **harmful to the plants**.

4.0 MINERAL NUTRITION

4.2 Classification of Essential Elements

Functions in plants:

Based on the functions, nutrients are grouped into four groups:

- Elements that provide basic structure to the plant – **C**, **H** and **O**.
- Elements useful in energy storage, transfer and bonding – **N**, **S**, and **P**.
- Elements necessary for charge balance – **K**, **Ca**, and **Mg**. They act as regulators and carriers.
- Elements involved in enzyme activation and electron transport – **Fe**, **Mn**, **Zn**, **Cu**, **B**, **Mo**, and **Cl**. These elements are catalysers and activators.

4.0 MINERAL NUTRITION

4.2 Classification of Essential Elements

Mobility of nutrients in the soil:

- Mobility of nutrients in the soil has considerable influence on availability of nutrients to plants and method of manure application.
- For plants to take up these nutrients, two processes are important: **movement of nutrient ions to the absorbing root surface**, and **roots reaching the area where nutrients are available**.

- In the case of immobile nutrients, the roots have to reach the area of nutrient availability and forage volume is limited to root surface area.
- For highly mobile nutrients, the entire volume of the root zone is forage area.
- Based on the mobility in the soil, the nutrient ions can be grouped as **mobile**, **less mobile** and **immobile**.

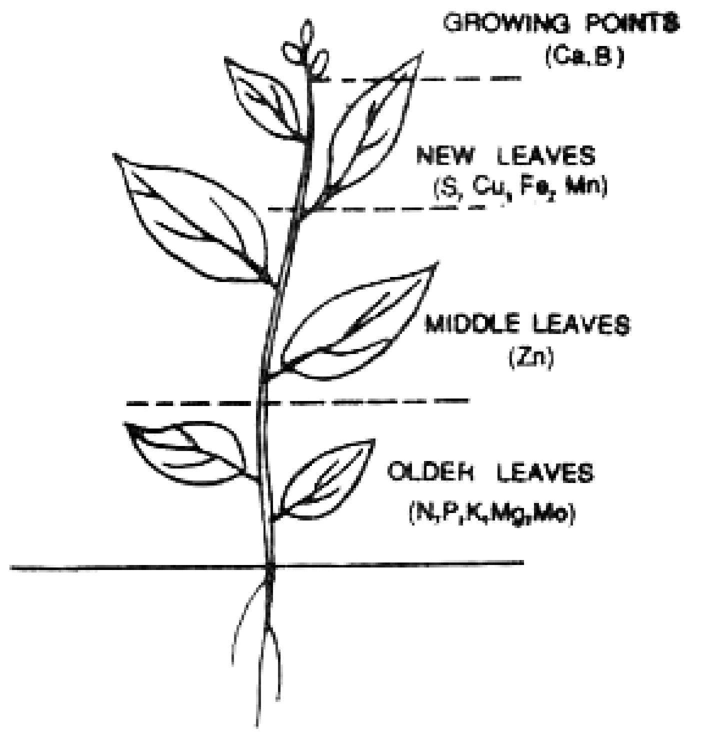
4.2 Classification of Essential Elements

Mobility of nutrients in plants:

- **Knowledge of the mobility of nutrients in the plant helps in finding what nutrient is deficient.**

- A mobile nutrient in the plant moves to the growing points in case of deficiency.
- Deficiency symptoms, therefore, in most cases first appear on the lower leaves.

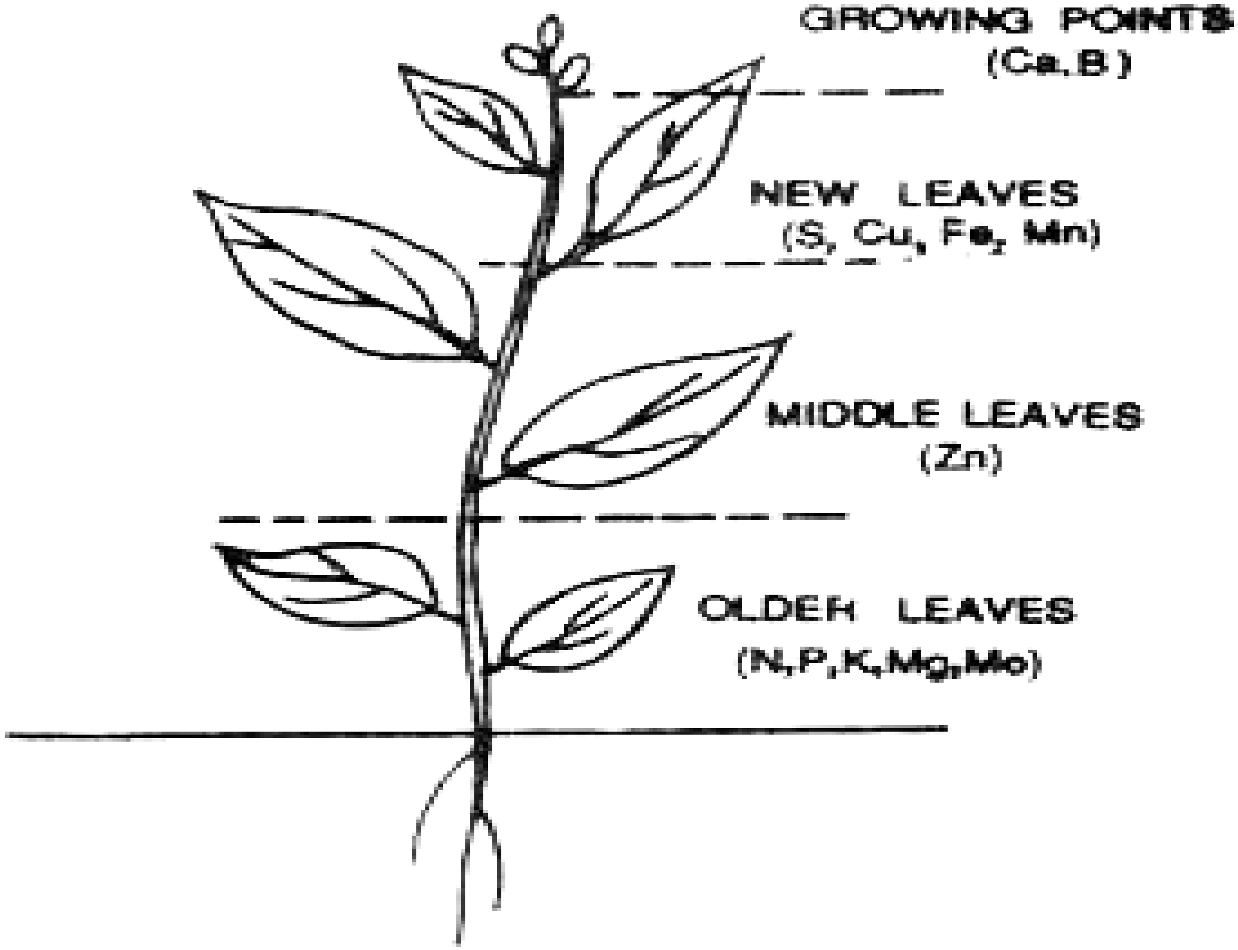
- **N**, **P**, and **K** are highly mobile.
- **Zn** is moderately mobile.
- **S**, **Fe**, **Mn**, **Cu**, **Mo** and **Cl** are less mobile.
- **Ca** and **B** are immobile.



Region of occurrence of deficiency symptoms

4.0 MINERAL NUTRITION

4.2 Classification of Essential Elements



Region of occurrence of deficiency symptoms

4.3 Role of Mineral Nutrients in Plant Metabolism

Macronutrients

Nitrogen (N)

- Is a major component of proteins, hormones, chlorophyll, vitamins and enzymes essential for plant life.
- Nitrogen metabolism is a major factor in stem and leaf growth (vegetative growth).

Phosphorus (P)

- Is necessary for seed germination, photosynthesis, protein formation and almost all aspects of growth and metabolism in plants.
- It is essential for flower and fruit formation.

4.3 Role of Mineral Nutrients in Plant Metabolism

Macronutrients

Potassium (K)

- Is necessary for formation of sugars, starches, carbohydrates, protein synthesis and cell division in roots and other parts of the plant.
- It helps to adjust water balance, improves stem rigidity and cold hardiness, enhances flavour and colour on fruit and vegetable crops, increases the oil content of fruits and is important for leafy crops.

Sulphur (S)

- Is a structural component of amino acids, proteins, vitamins and enzymes and is essential to produce chlorophyll.
- It imparts flavour to many vegetables.

4.3 Role of Mineral Nutrients in Plant Metabolism

Macronutrients

Magnesium (Mg)

- Is a critical structural component of the chlorophyll molecule and is necessary for functioning of plant enzymes to produce carbohydrates, sugars and fats.
- It is used for fruit and nut formation and essential for germination of seed.

Calcium (Ca)

- Activates enzymes, is a structural component of cell walls, influences water movement in cells and is necessary for cell growth and division.

4.3 Role of Mineral Nutrients in Plant Metabolism

Micronutrients

Iron (Fe)

- Is necessary for many enzyme functions and as a catalyst for the synthesis of chlorophyll. It is essential for the young growing parts of plants.

Manganese (Mn)

- Is involved in enzyme activity for photosynthesis, respiration, and nitrogen metabolism.

Boron (B)

- Is necessary for cell wall formation, membrane integrity, calcium uptake and may aid in the translocation of sugars.
- Boron affects at least 16 functions in plants. These functions include flowering, pollen germination, fruiting, cell division, water relationships and the movement of hormones.
- Boron must be available throughout the life of the plant. It is not translocated and is easily leached from soils.

4.3 Role of Mineral Nutrients in Plant Metabolism

Micronutrients

Zinc (Zn)

- Is a component of enzymes or a functional cofactor of a large number of enzymes including auxins (plant growth hormones).
- It is essential to carbohydrate metabolism, protein synthesis and internodal elongation (stem growth).

Copper (Cu)

- Is concentrated in roots of plants and plays a part in nitrogen metabolism.
- It is a component of several enzymes and may be part of the enzyme systems that use carbohydrates and proteins.

4.3 Role of Mineral Nutrients in Plant Metabolism

Micronutrients

Molybdenum (Mo)

- Is a structural component of the enzyme that reduces nitrates to ammonia.
- Without it, the synthesis of proteins is blocked and plant growth ceases.
- Root nodule (nitrogen fixing) bacteria also require it.
- Seeds may not form completely, and nitrogen deficiency may occur if plants are lacking molybdenum.

Chlorine (Cl)

- Is involved in osmosis (movement of water or solutes in cells), the ionic balance necessary for plants to take up mineral elements and in photosynthesis.

4.3 Role of Mineral Nutrients in Plant Metabolism

Micronutrients

Nickel (Ni)

- It is required for the enzyme urease to break down urea to liberate the nitrogen into a usable form for plants.
- Nickel is required for iron absorption.
- Seeds need nickel in order to germinate.
- Plants grown without additional nickel will gradually reach a deficient level at about the time they mature and begin reproductive growth.
- If nickel is deficient plants may fail to produce viable seeds.

Sodium (Na)

- Is involved in osmotic (water movement) and ionic balance in plants.

4.3 Role of Mineral Nutrients in Plant Metabolism

Micronutrients

Cobalt (Co)

- Is required for nitrogen fixation in legumes and in root nodules of non-legumes.

Silicon (Si)

- Is found as a component of cell walls.
- Plants with supplies of soluble silicon produce stronger, tougher cell walls making them a mechanical barrier to piercing and sucking insects.
- It significantly enhances plant heat and drought tolerance.

4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency

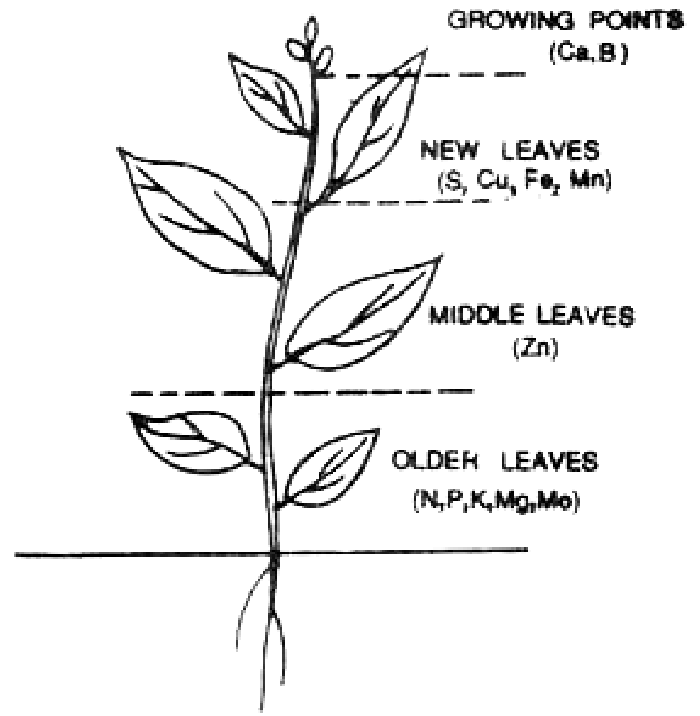
- Not all plant problems are **caused by insects or diseases**.
- Sometimes an unhealthy plant is suffering from a **nutrient deficiency** or even **too much of any one nutrient**.
- Plant nutrient deficiencies often manifest as **foliage discoloration** or **distortion**.
- Unfortunately many problems have **similar symptoms** and sometimes it is a **combination of problems**.

- When nutrient is not present in **sufficient quantity**, plant growth is affected.
- Plants may not show **visual symptoms** up to a certain level of nutrient content, but growth is affected and this situation is known as "**hidden hunger**".
- When the nutrient level continues to fall, plants will show characteristic symptoms of deficiency. These symptoms though vary with crop, have a general pattern.

4.4 Symptoms of Mineral Deficiency - Identification

Deficiency symptoms can be distinguished based on the **region of occurrence**, **presence or absence of dead spots**, and **chlorosis of entire leaf or interveinal chlorosis**. The deficiency symptoms appear clearly in crops with larger leaves.

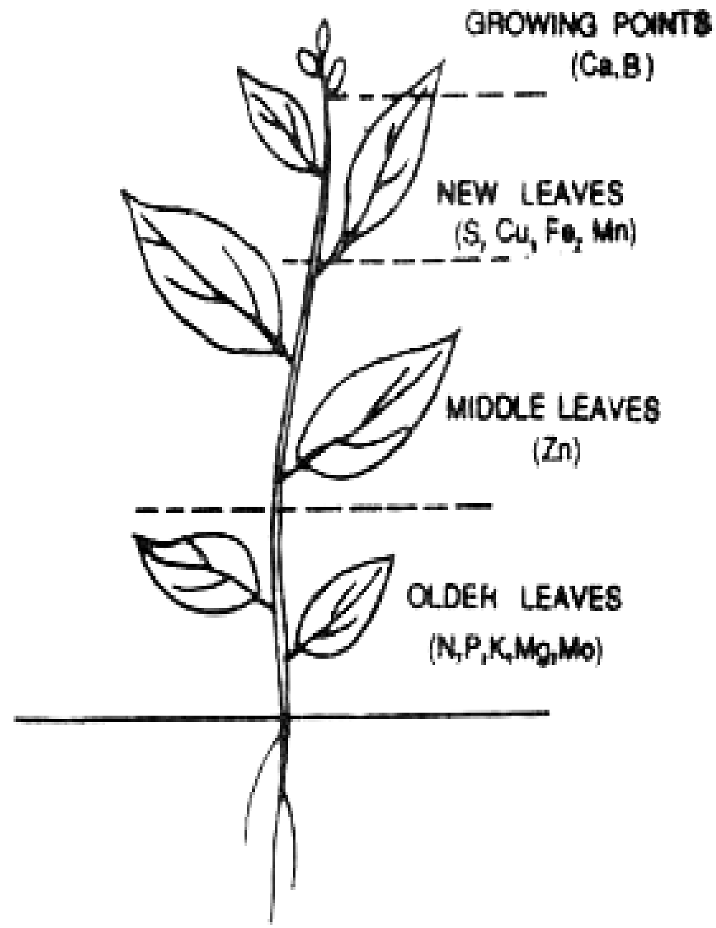
- The region of appearance of deficiency symptoms depends on mobility of nutrient in plants.
- The nutrient deficiency symptoms of **N**, **P**, **K**, **Mg**, and **Mo** appear in lower leaves because of their mobility inside the plants.
- These nutrients move from lower leaves to growing leaves thus causing deficiency symptoms in lower leaves.



Region of occurrence of deficiency symptoms

4.4 Symptoms of Mineral Deficiency

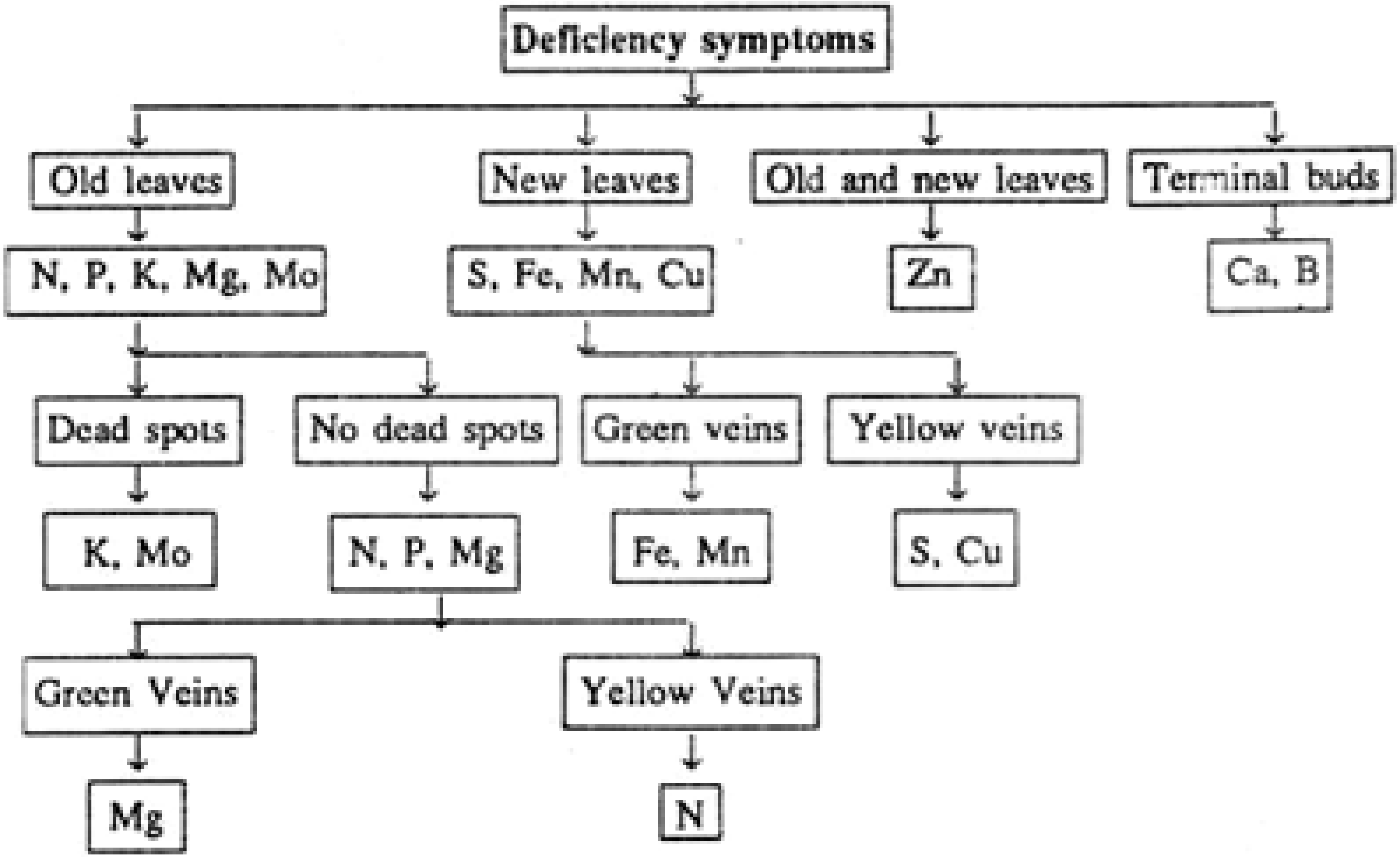
- Zinc is moderately mobile in plants and deficiency symptoms, therefore, appear in **middle leaves**.
- The deficiency symptoms of less mobile elements (S, Fe, Mn and Cu) appear on **new leaves**.
- Since Ca and B are immobile in plants, deficiency symptoms appear on **terminal buds**.
- Chlorine deficiency is less common in crop.



Region of occurrence of deficiency symptoms

4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency



Identification of deficiency symptoms

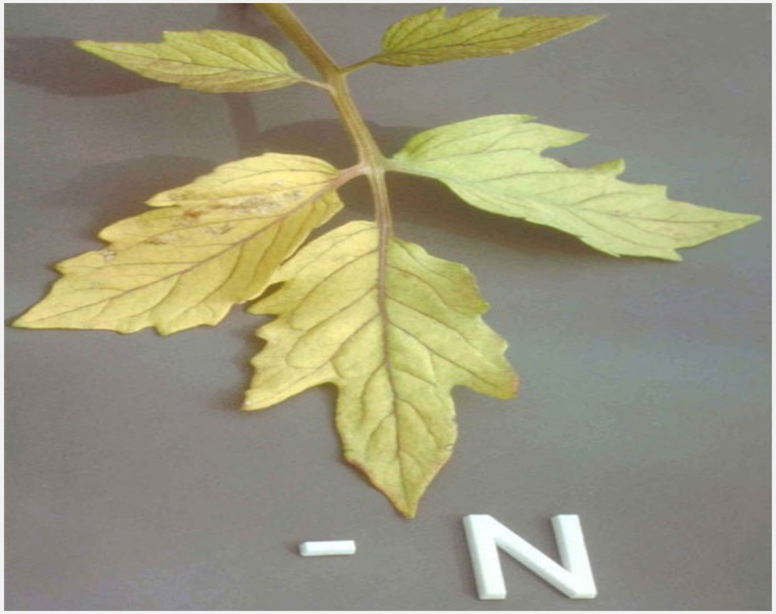
4.4 Symptoms of Mineral Deficiency - Macronutrients

Calcium (Ca)

- New leaves are distorted or hook shaped.
- The growing tip may die.
- Contributes to blossom end rot in tomatoes, tip burn of cabbage.

Nitrogen (N)

- Older leaves, generally at the bottom of the plant, will yellow.
- Remaining foliage is often light green.
- Stems may also yellow and may become spindly. Stunted growth.



4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency - Macronutrients

Magnesium (Mg)

- Slow growth and leaves turn pale yellow, sometimes just on the outer edges.
- Mottled chlorosis with veins green and leaf tissues yellow or white. Necrotic spots may develop.

Phosphorus (P)

- Small leaves that may take on a reddish-purple tint.
- Leaf tips can look burnt and older leaves become almost black.
- Reduced fruit or seed production.

4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency - Macronutrients

Potassium (K)

- Older leaves may look scorched around the edges and/or wilted.
- Interveinal chlorosis (yellowing between the leaf veins) develops.
- Stunted growth, little/no flowering.

Sulphur (S)

- New growth turns pale yellow, with red or purple pigmentation, older growth stays green.
- Stunted growth, marked decrease in leaf size. Fruit formation suppressed.

4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency - Micronutrients

Boron (B)

- Dwarf plant, poor stem and root growth.
- Leaves become twisted and necrotic.
- Stalk finally die from terminal bud end.

Copper (Cu)

- Stunted growth, leaves can become limp, curl, or drop (permanently wilted) without spotting.
- Seed stalks also become limp and bend over (unable to stand erect).

4.4 Symptoms of Mineral Deficiency - Micronutrients

Manganese (Mn)

- Chlorosis of young leaves with spots of dead tissues scattered over leaf.
- Leaves take on a gray sheen, develop dark freckled and necrotic spots along veins with increased deficiency.
- Leaves, shoots and fruit diminished in size. Failure to bloom.

Molybdenum (Mo)

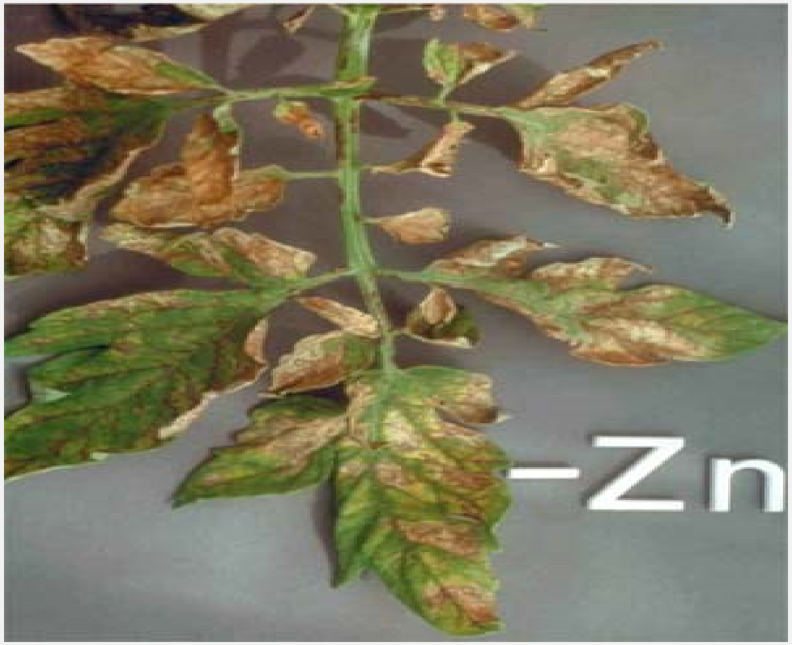
- Older leaves mottled yellow, remaining foliage turns light green.
- Leaves can become narrow and distorted.

4.0 MINERAL NUTRITION

4.4 Symptoms of Mineral Deficiency - Micronutrients

Zinc (Zn)

- Necrotic spots large and spreading to veins.
- Leaves become leathery, margins twisted.
- Terminal (end) leaves may form a rosette.



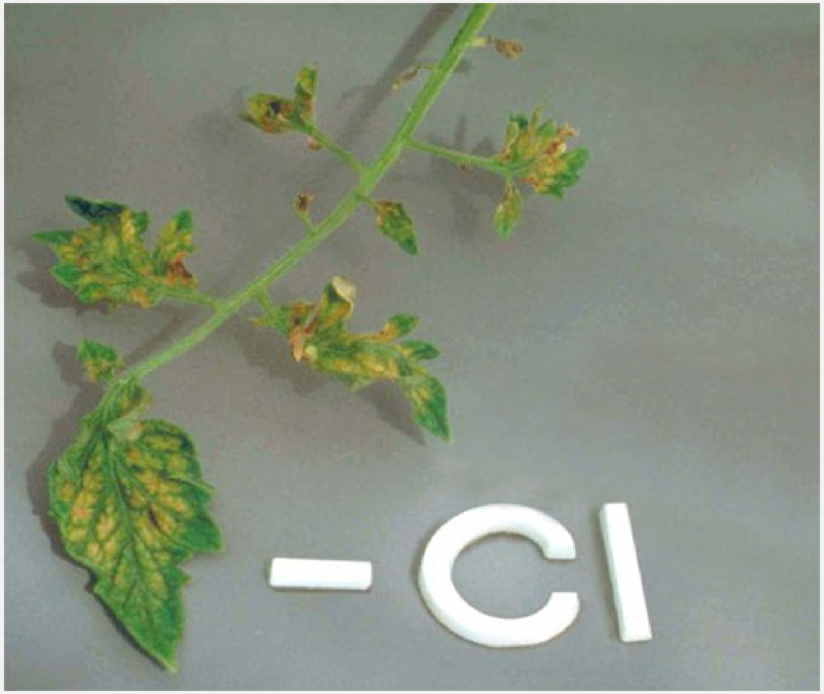
Iron (Fe)

- Leaves show strong chlorosis at the base with some green netting.
- Interveinal chlorosis of the youngest leaves, bleached leaf.

4.4 Symptoms of Mineral Deficiency - Micronutrients

Chloride (Cl)

- Leaves have abnormal shapes, with distinct interveinal chlorosis and wilting of the young leaves.



4.0 MINERAL NUTRITION

4.5 Symptoms of Mineral Toxicity

When a nutrient is present in the soil in excess of plant's requirement, the nutrient is absorbed in higher amounts which causes imbalance of nutrients or disorder in physiological processes. Unlike deficiency symptoms, toxicity symptoms are less common.

Nitrogen:

- Excess nitrogen causes delay in maturity and increases succulency. **The adverse effects of excess nitrogen are lodging and abortion of flowers**. Crops becomes susceptible to pest and diseases.

Phosphorus:

- Excess phosphorus causes **deficiency of iron and zinc**. In some plants like maize, leaves develop purple colouration and plant growth is stunted.

4.5 Symptoms of Mineral Toxicity

Iron:

- Tiny brown spots appear on lower leaves of rice starting from tips and spreading towards bases. Leaves usually remain green. In extreme case, **the entire leaf turns purplish brown in colour**.

Manganese:

- The plant is stunted and tillering is often limited. **Brown spots develop on the veins of the leaf blade and leaf sheath, especially on lower leaves**. Manganese toxicity occurs in lowland rice.

Boron:

- **Chlorosis occurs at the tips of the older leaves, especially along the margins**. Large, dark brown, elliptical spots appear subsequently. The leaves ultimately turn brown and dry up.

4.0 MINERAL NUTRITION

4.5 Symptoms of Mineral Toxicity

4.6 Self Assessment – Discussion/Study Questions

- Identify and diagnose common plant nutrient deficiency and toxicity symptoms.
- What are the potential limitations of visual diagnosis.
- Distinguish between mobile and immobile nutrient deficiencies.