Chapter VII Photosynthesis - Photosynthesis and Importance

I. Overview

1. Carbon is a basis for life of plants

   ① Carbon accounts for 45% of organic matters;

   ② Carbon constitutes the main skeleton of all organic compounds. .

2. By nutritive form of carbon, plants may be classified into

   Heterotrophyte: The plants,which can only use ready-made organic matters as nutrients;

   Autophyte: The plants, which use inorganic carbon compounds as nutrients and synthsize them into organic matters.

3. Carbon assimilation: A process in which autophyte absorbs CO_2 and convert it into organic matters, and includes

- Bacterial photosynthesis
- Photosynthesis of green plants (most extensive, largest quantity and closest)
- Chemosynthesis (nitrifying bacteria, thiobacteria and iron bacteria)

II. Definition of Photosynthesis

A process in which green plants absorb optical energy, assimilate CO_2 and H_2O, generate organics and release O_2

III. Importance of Photosynthesis

1. Turn inorganic matters into organic matters (2×10^{11} t C/a, 40% from phytoplankton and 60% from terrestrial plants)
2. Accumulate solar energy (3×10^{21} J/a)
3. Environmental protection (5.35×10^{11} t O_2/a)

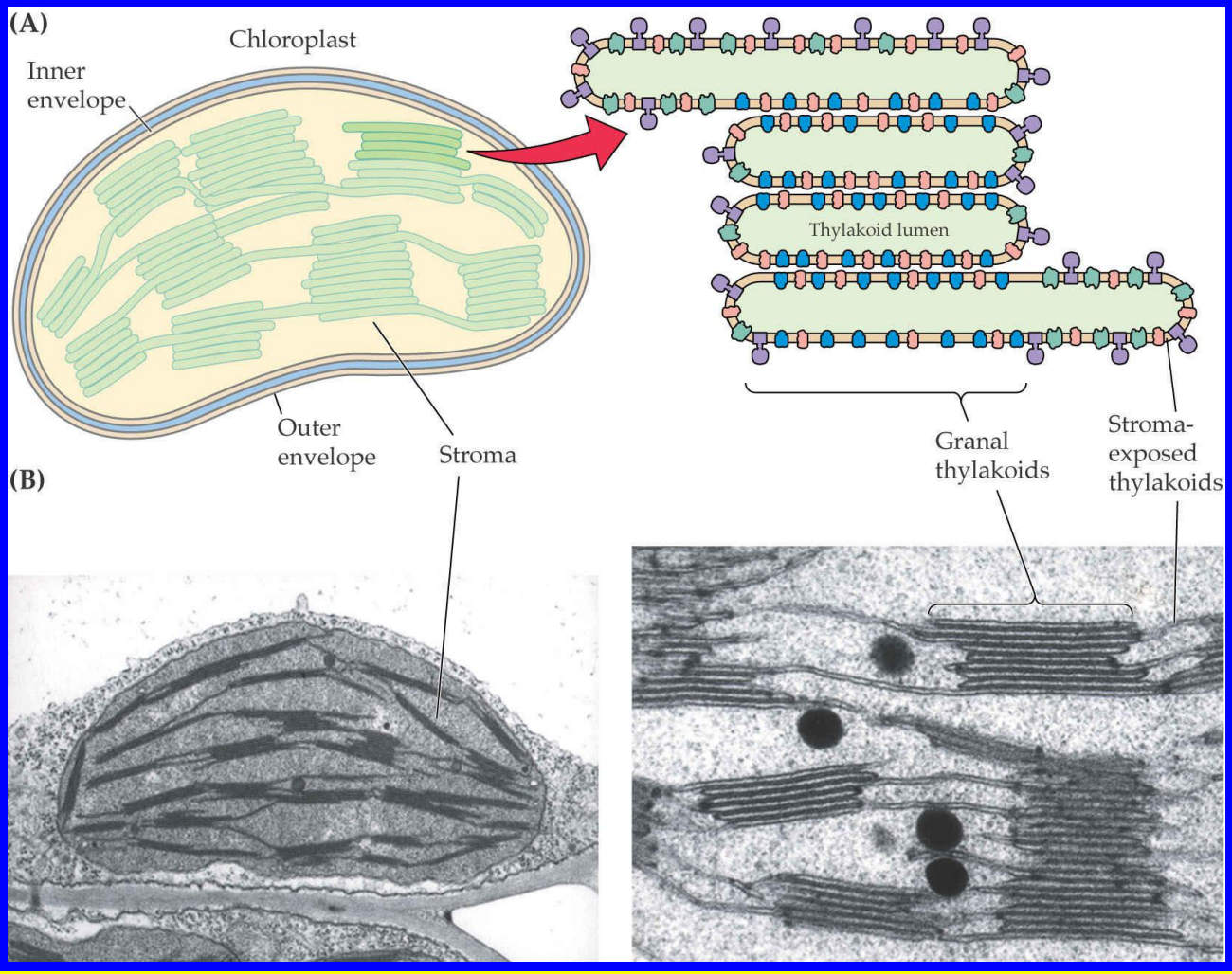
Chapter VII Photosynthesis - Chloroplast and Chloroplast Pigment

I. Structure and Composition of Chloroplast

(I) Structure

- Chloroplast membrane
  - Outer membrane
  - Inner membrane: Selective barrier
- Stroma: Mainly enzymes and other metabolic active substances. Fixe CO_2, form and store starch and contain lipid droplets.
- Granum
  - Granal thylakoid: Thylakoid of stacking part
  - Stroma thylakoid: Thylakoid between two stromata

(A) Schematic diagram of plant chloroplast, showing compart-mentation of the organelle.



(B) Transmission electron micrographs of plant chloroplast reveal its ultrastructure.

(II) Composition

- H_2O: 75%
- Protein: 30%-45% of dry matter
- Pigment: 8% of dry matter
- Lipid: 20-40% of dry matter
- Stored matter: 10%-20% of dry matter
- Ash elements: 10% of dry matter (Fe, Cu, Zn, K, P, Ca, Mg)

II. Chemical Characteristics of Photosynthetic Pigment

(I) Chlorophyll

1. Types and properties

Insoluble in water and soluble in organic solvents, it is ester of chlorophyllin, dicarboxylic acid + methanol and phytol, including

Chlorophyll *a*: Bluish green, $C_{55}H_{72}O_5N_4Mg$

Chlorophyll *b*: Yellowish green, $C_{55}H_{70}O_6N_4Mg$

2. Molecular structure and function of chlorophyll

① 4 pyrrol rings + 4 methylene groups⟶porphyrin rings, Mg is at the center;

② 1 minor loop of carbonyl group and carboxyl (homocyclic ring V)+methanol;

③ Propionic acid + phytol on porphyrin ring IV;

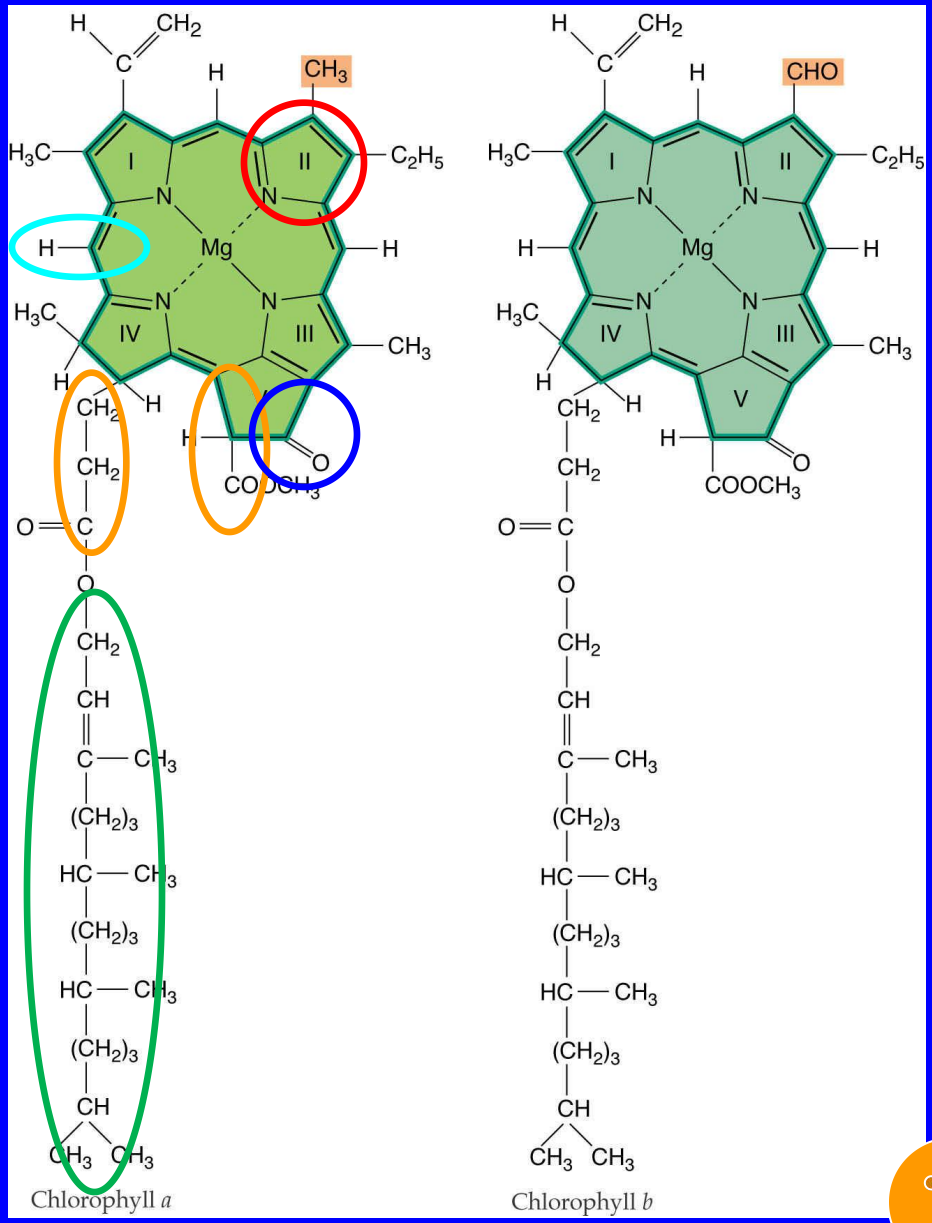
④ There is a polar head and a non-polar tail;

⑤ Conjugated system

⑥ Chlorophyll *b* and most of chlorophyll *a* play a role in harvesting optical energy;

⑦ Not participate in hydrogen transport or redox and participate in photoreaction in form of electron transport and conjugated transport.

Structure of chlorophylls. Chlorophyll molecules have a porphyrin-like ring structure that contains a central Mg atom coordinated to the four modified pyrrole rings. Chlorophylls also contain a long hydrocarbon tail that makes the molecules hydrophobic.



(II) Carotenoid

1. Types and properties

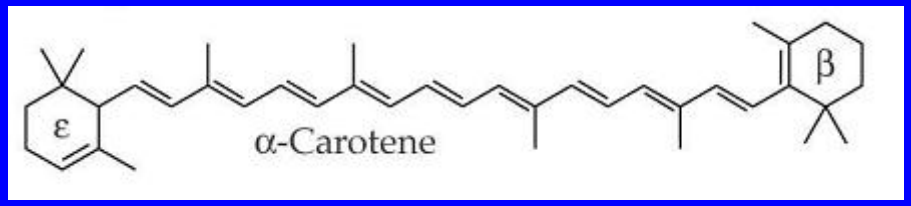
Insoluble in water and soluble in organic solvents, including

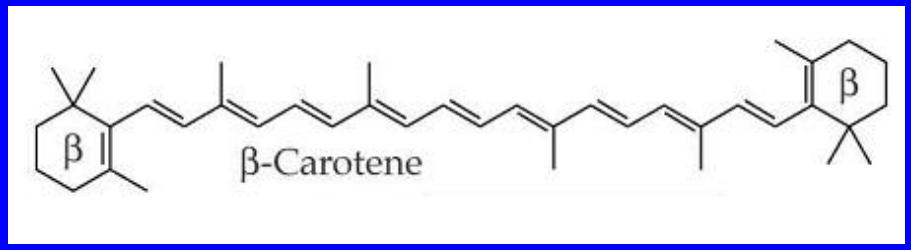
Carotene: Orange-yellow, unsaturated hydrocarbons, $C_{40}H_{56}$, having three isomers α-, β-, γ-.

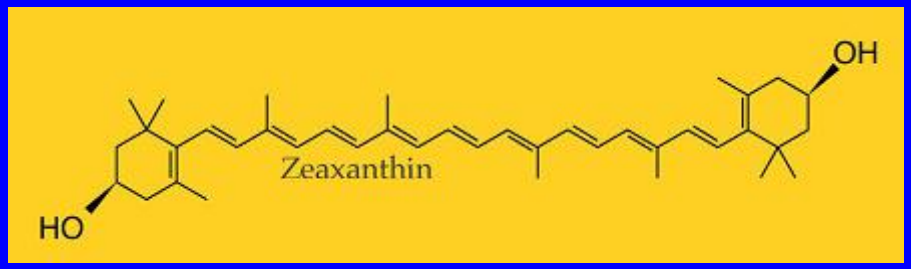
Lutein: Yellow, alcohols derived from carotene, $C_{40}H_{56}O_2$.

2. Effects

Collection of optical energy; protection.





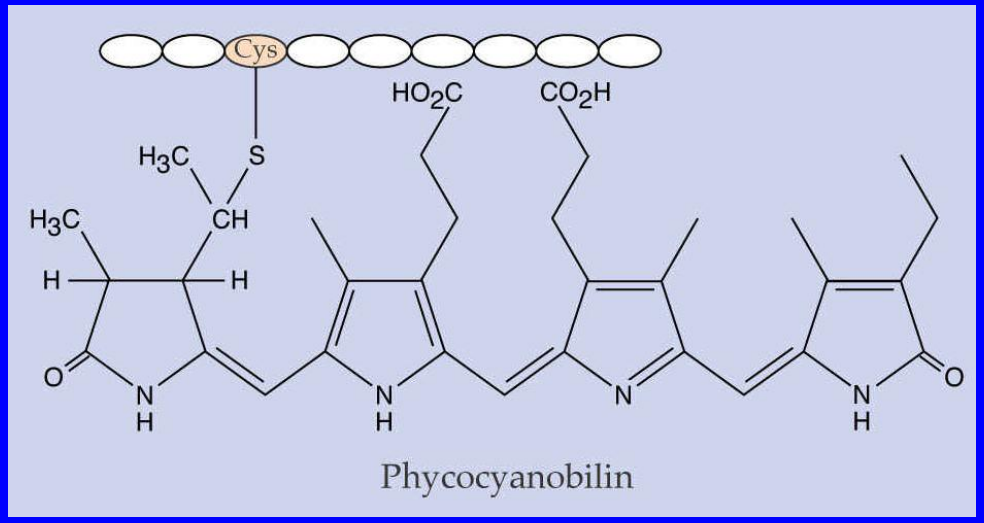


(III) Phycobilin

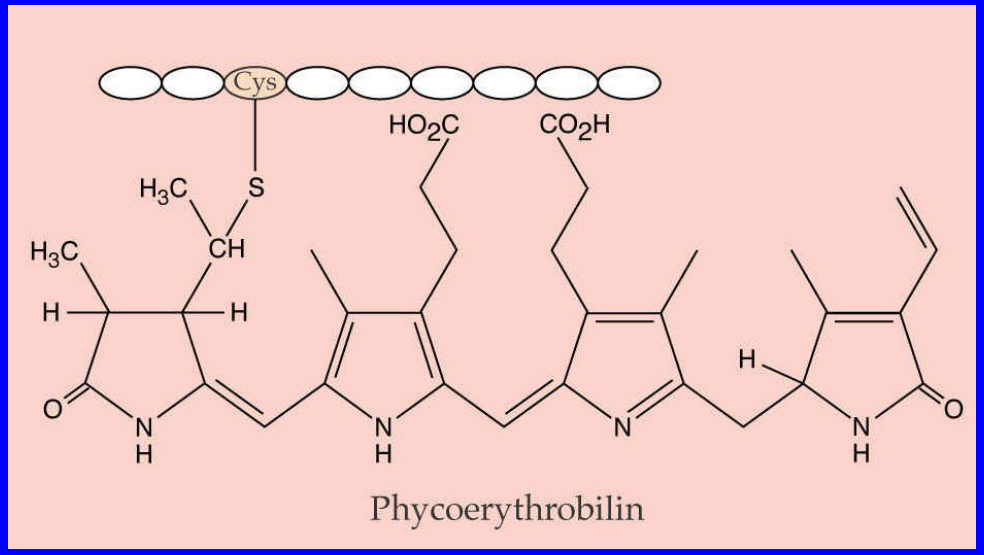
Structurally, it is a linear conjugate system consisting of four pyrrol rings, and often bound with protein into phycobiliproteins, including

- Phycocyanin: Blue
- Phycoerythrin: Red

Absorb and transfer optical energy



Phycocyanobilin



Phycoerythrobilin

III. Optical Characteristics of Photosynthetic Pigment

(I) Radiant energy

Light waves are both electromagnetic waves and moving particle flows. The energy carried by photons is inversely proportional to wavelength, i.e.:

$$E = Lh\nu = Lhc/\lambda$$

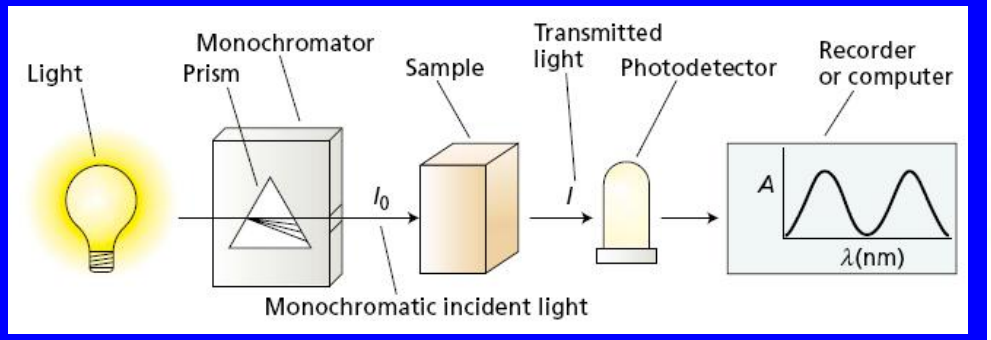
(II) Absorption spectrum

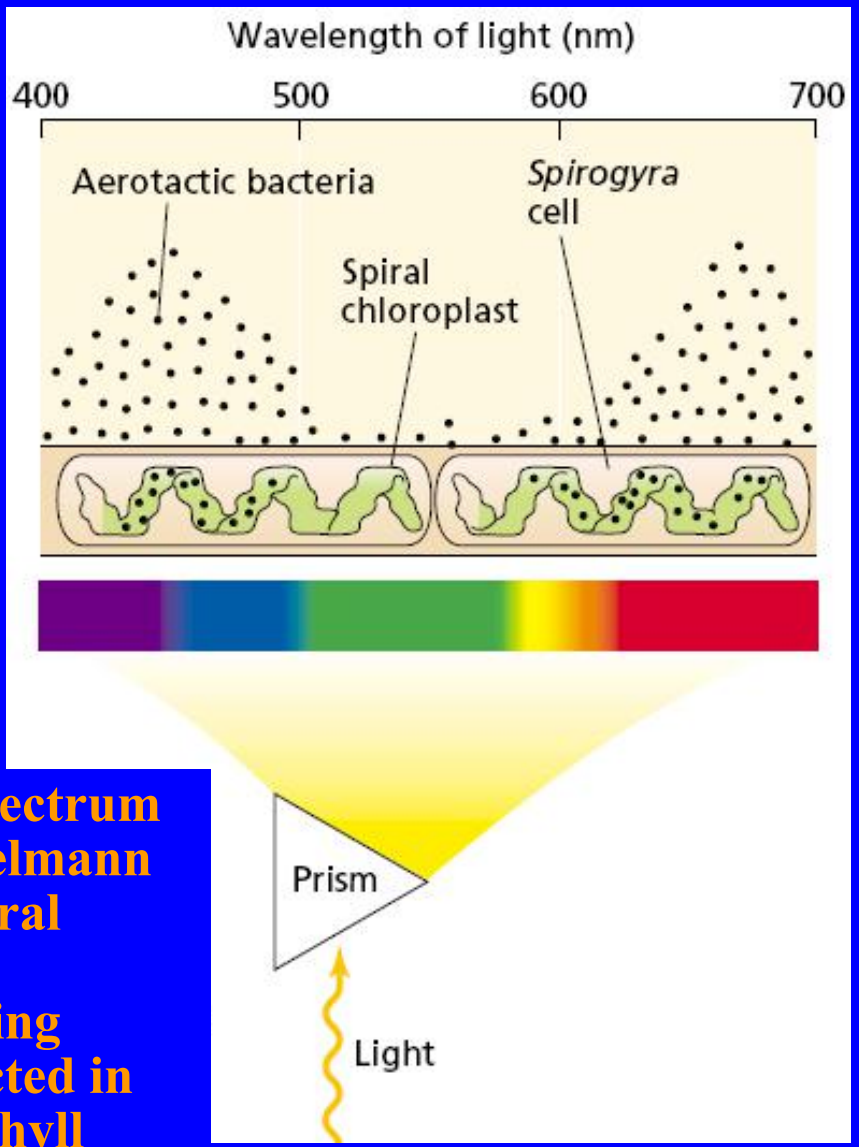
1. Chlorophyll

(1) There are two strongest absorption sections:

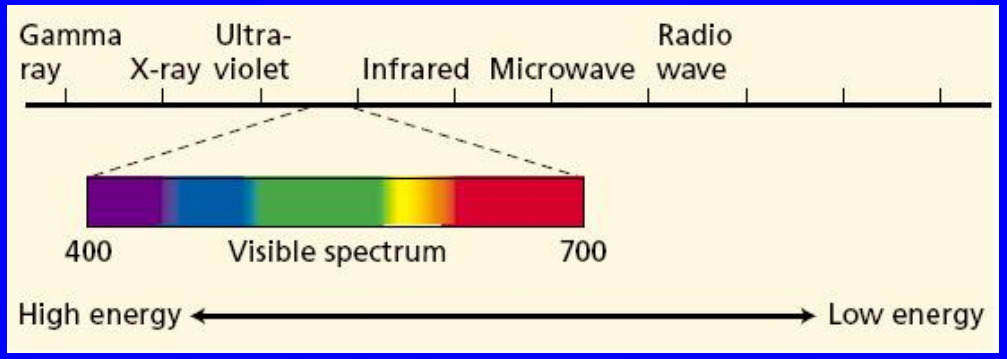
- 640-660 nm red light section
- 430-450 nm bluish purple section

(2) It absorbs the least green light, so a chlorophyll solution is green.

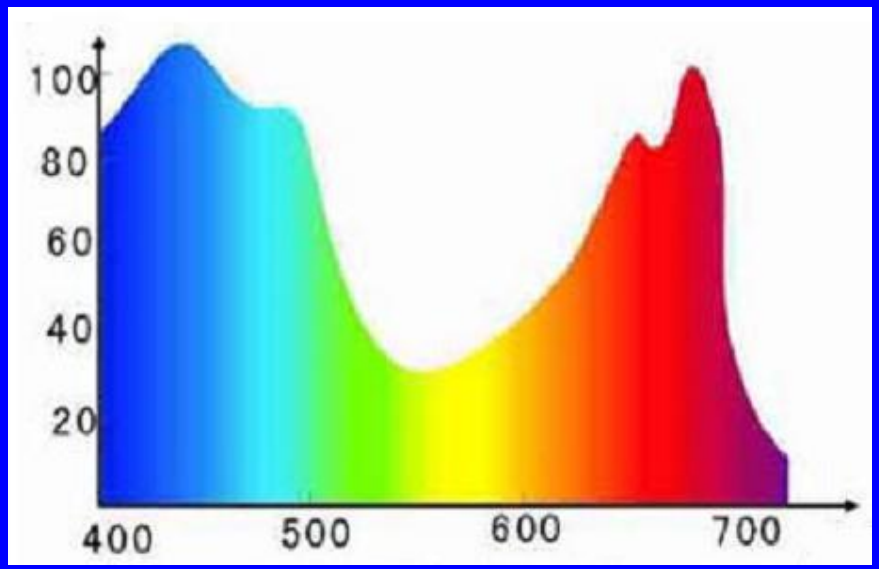




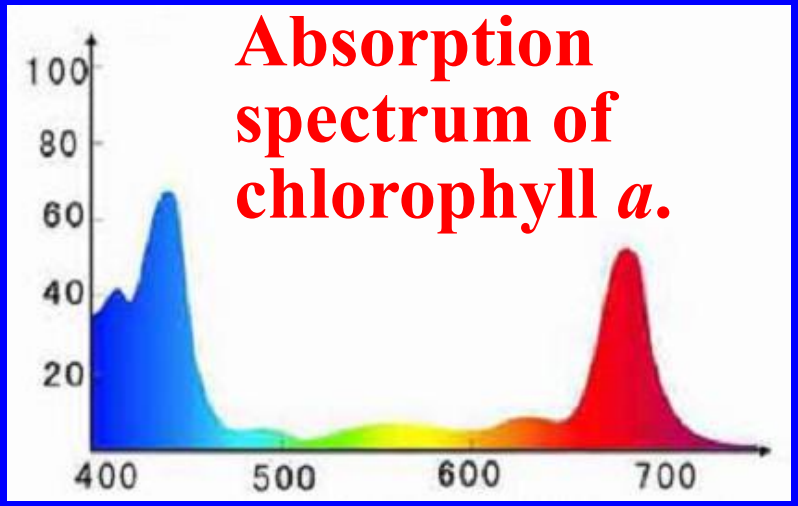
Light Schematic diagram of the action spectrum measurements by T. W. Engelmann. Engelmann projected a spectrum of light onto the spiral chloroplast of the filamentous green alga *Spirogyra* and observed that oxygen-seeking bacteria introduced into the system collected in the region of the spectrum where chlorophyll pigments absorb.



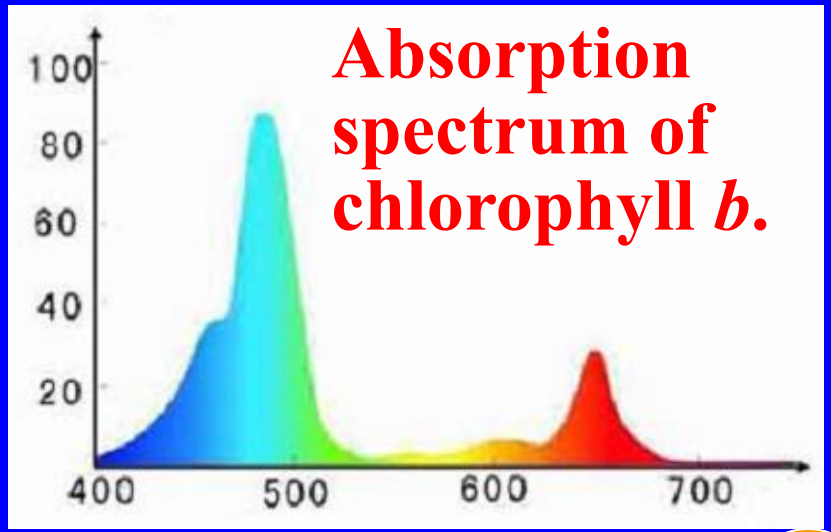
Visible solar spectrum.



Absorption spectrum of chlorophylls.



Absorption spectrum of chlorophyll *a*.



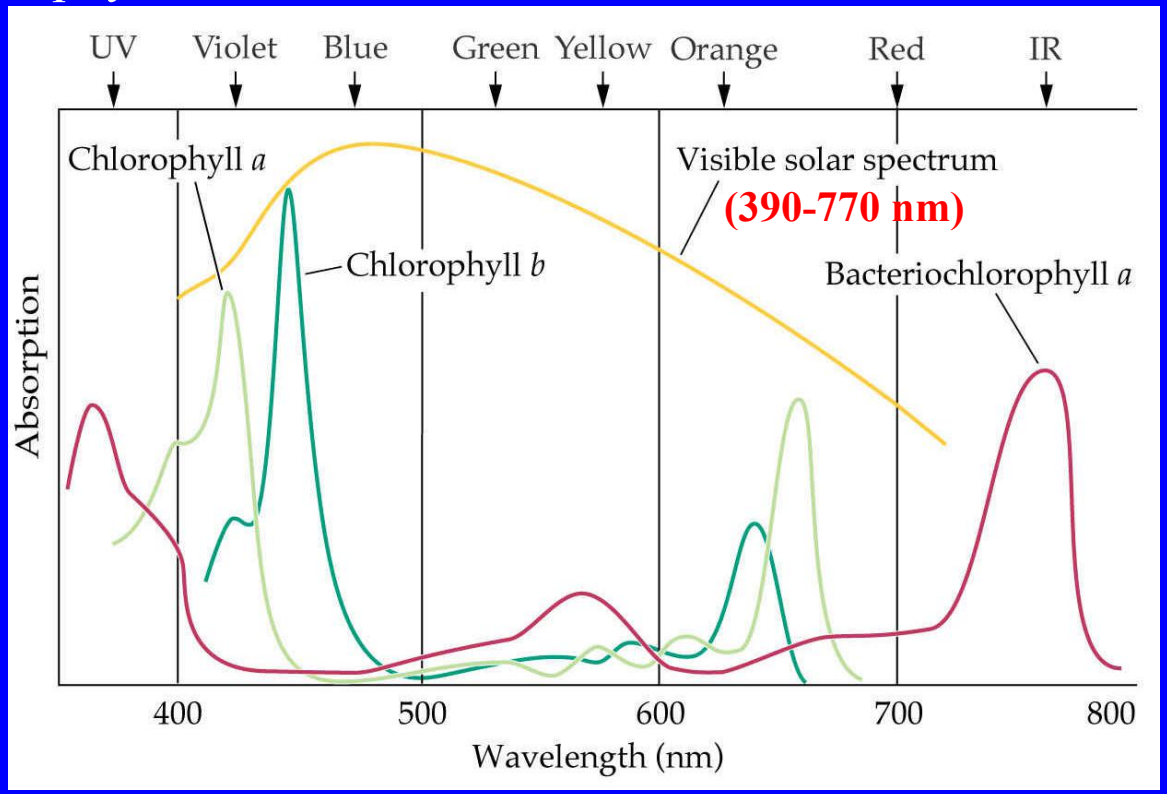
Absorption spectrum of chlorophyll *b*.

(3) Difference between chlorophyll *a* and chlorophyll *b*:

① In the red light section, the absorption of chlorophyll *a* is wide, and that of chlorophyll *b* is narrow;

② In the bluish purple section, the absorption of chlorophyll *a* is narrow and that of chlorophyll *b* is wide;

③ Chlorophyll *a* is biased to long wavelength in the red light section and to short wavelength in the bluish purple section.



2. Carotenoid

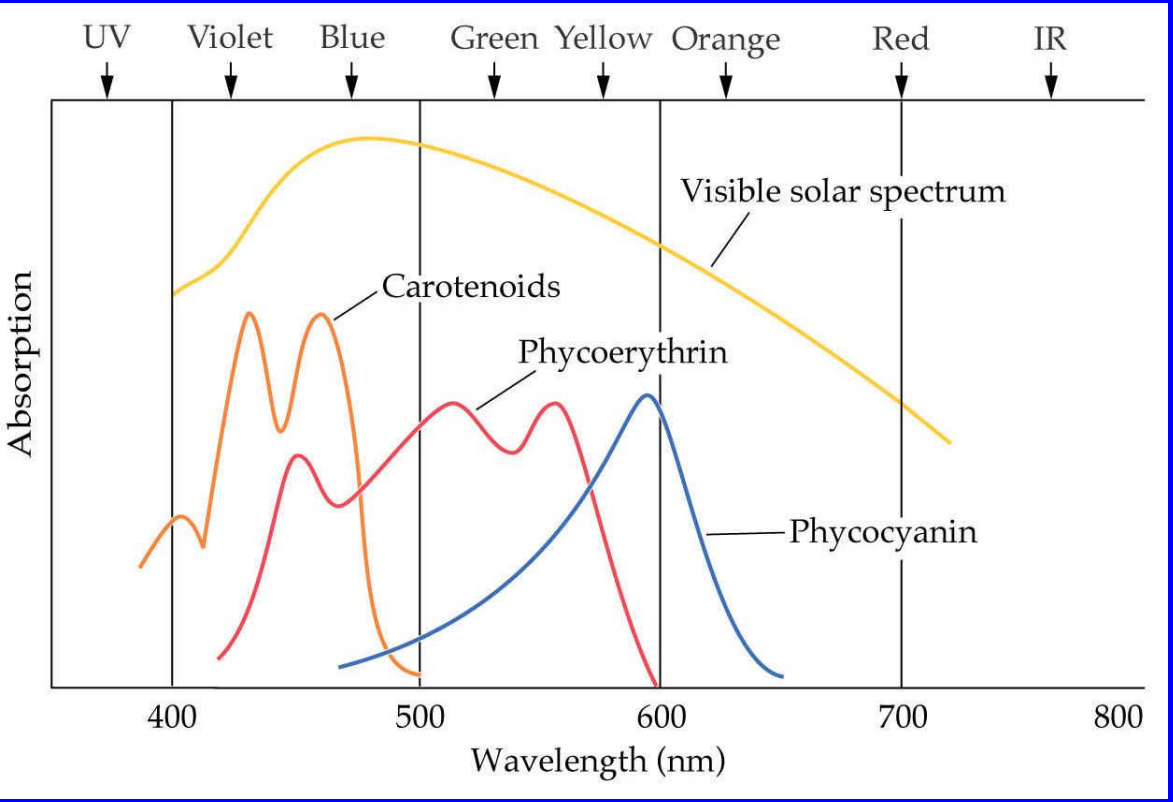
The maximum absorption band is in the bluish purple section and does not absorb red light and other light with a long wavelength.

3. Phycobilin

Mainly absorb green and orange lights. Specifically,

Phycocyanin: Orange red light;

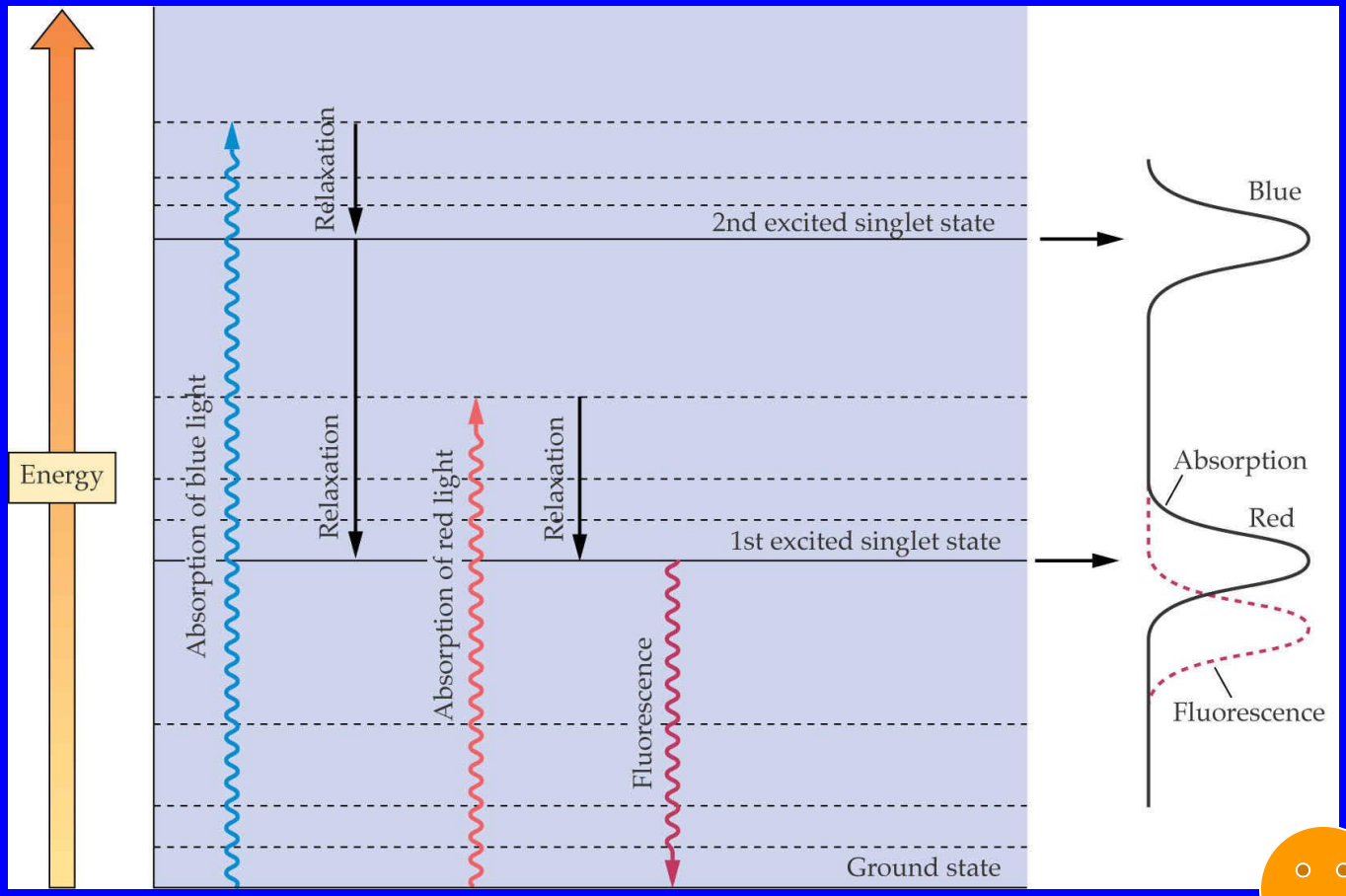
Phycoerythrin: Green light and yellow light.



(III) Fluorescence and phosphorescence

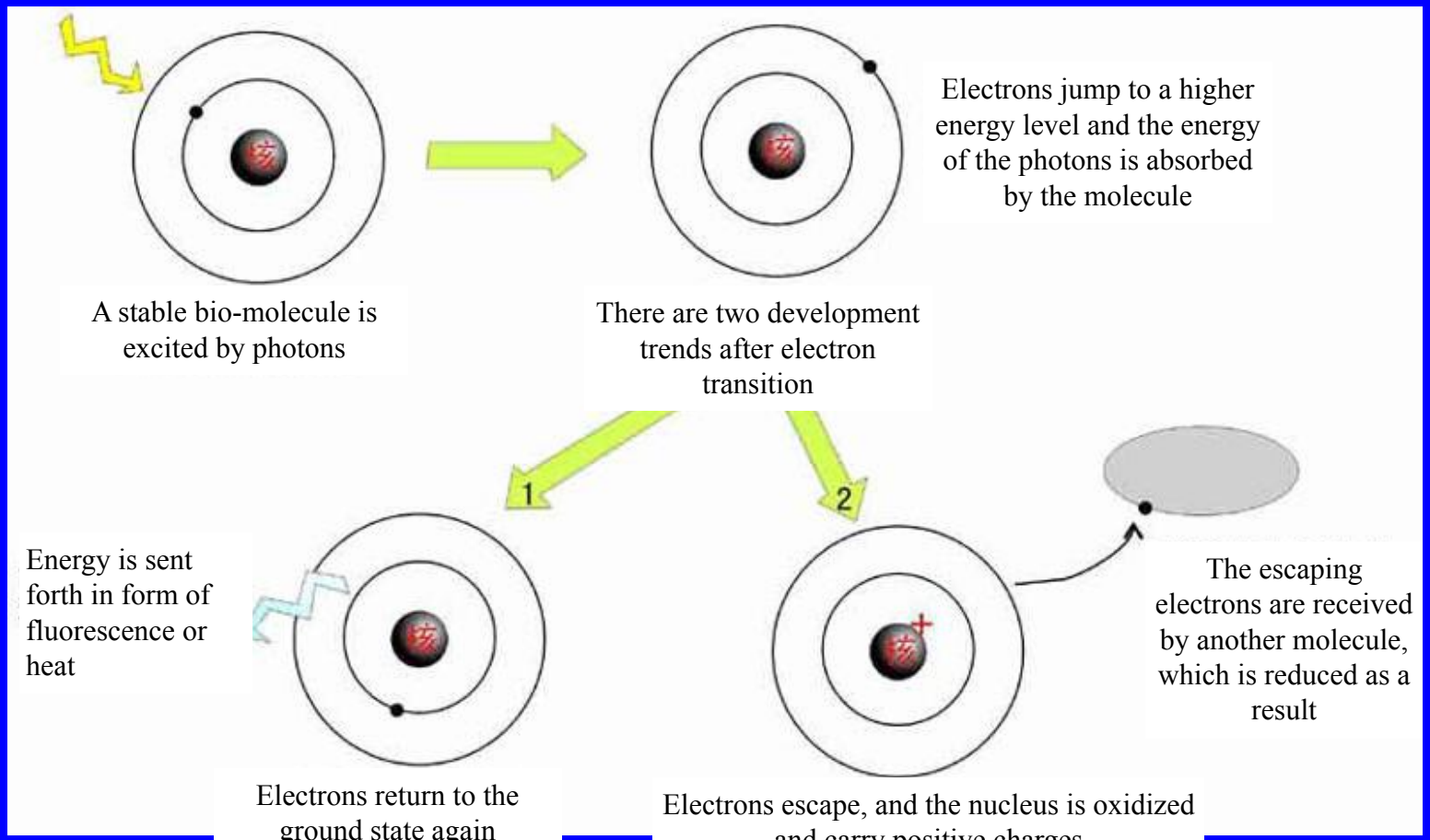
1. Fluorescence: Refer to the light emitted during return from the first singlet state to the ground state. The life is very short, 10^{-8}-10^{-9} s.

2. Phosphorescence: Refer to the light emitted during return from the first triplet state to the ground state. The life is long, 10^{-2} s.



Chapter VII Photosynthesis - Chloroplast and Chloroplast Pigment

Photons illuminate some biological molecules ➔ Electrons jump to a higher energy level ➔ Excited state:

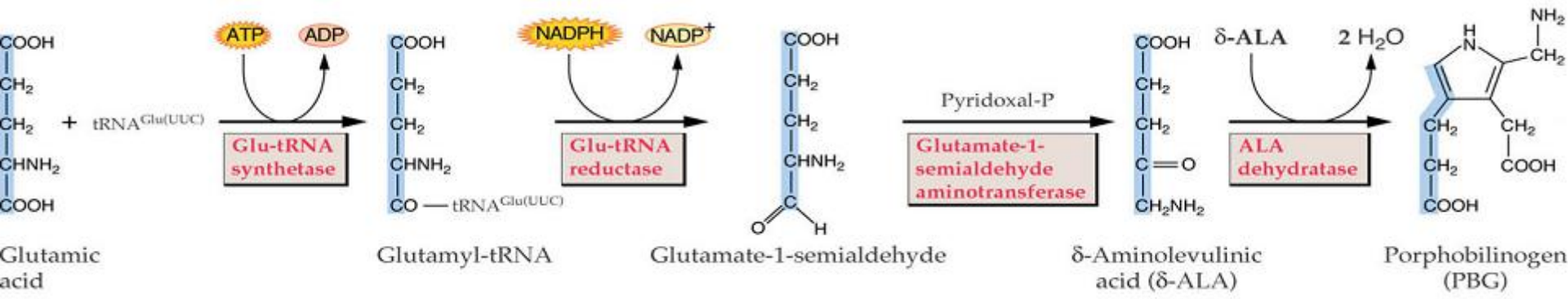


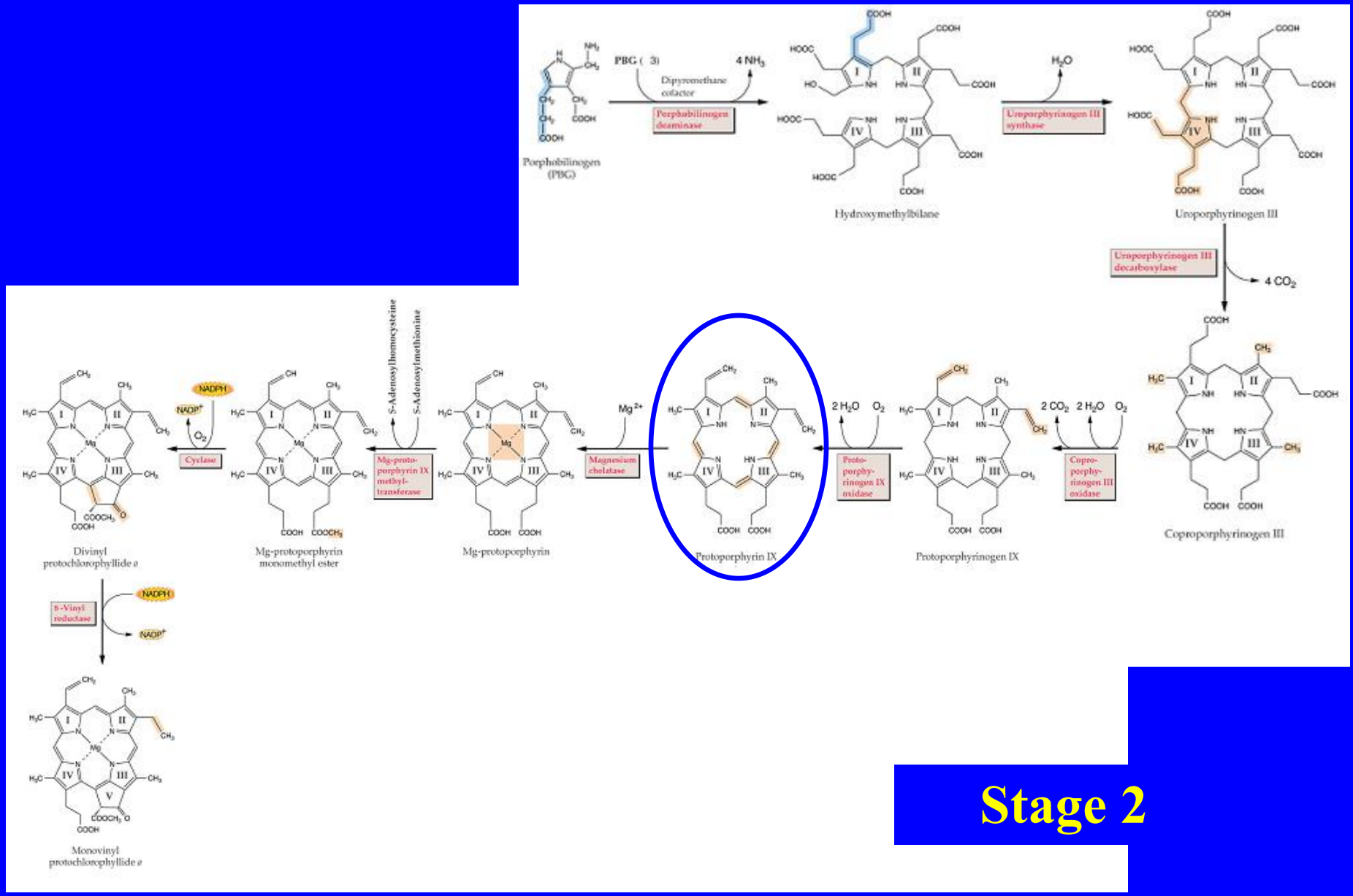
Chlorophyll molecule is a pigment molecule that can be excited by visible light. The electron gain and loss reaction driven by photons is the most fundamental reaction in the process of photosynthesis.

IV. Formation of Chlorophyll

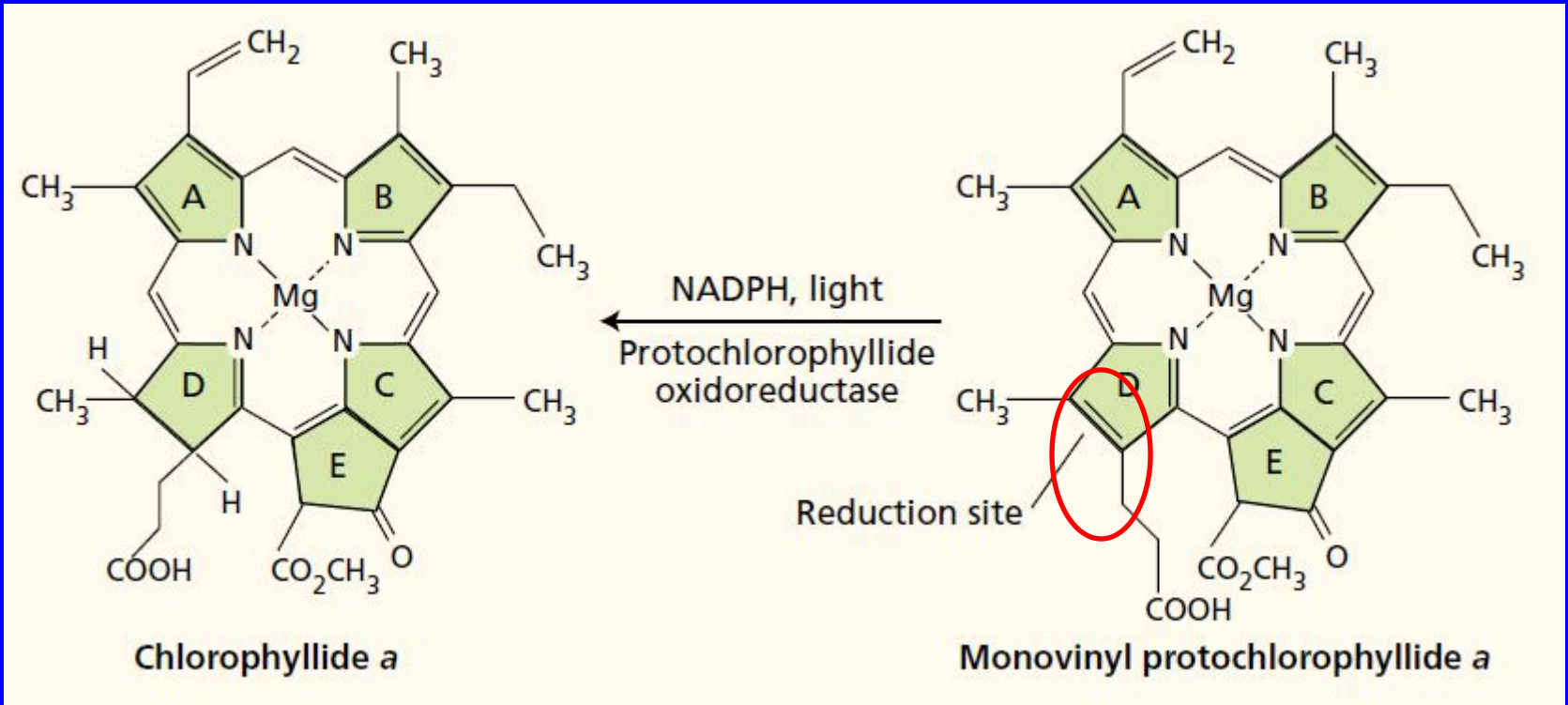
(I) Biosynthesis of chlorophyll

Stage 1



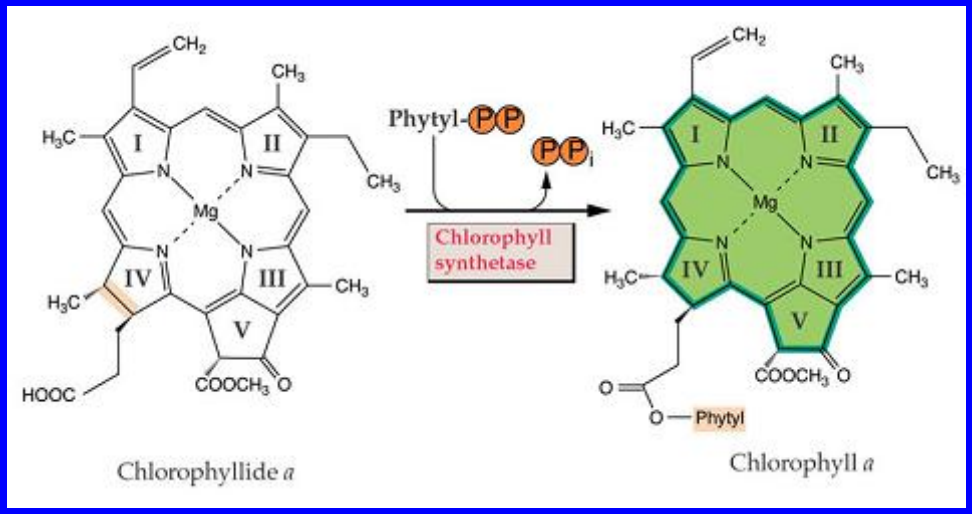

Porphobilinogen (PBG)
PBG (3)
4 NH3
Dipyrromethane cofactor
Porphobilinogen deaminase
Hydroxymethylbilane
H2O
Uroporphyrinogen III synthase
Uroporphyrinogen III
Uroporphyrinogen III decarboxylase
4 CO2
Coproporphyrinogen III
2 CO2 2 H2O O2
Copro-porphy-rinogen III oxidase
Protoporphyrinogen IX
2 H2O O2
Proto-porphy-rinogen IX oxidase
Protoporphyrin IX
Mg2+
Magnesium chelatase
Mg-protoporphyrin
S-Adenosylhomocysteine
S-Adenosylmethionine
Mg-proto-porphyrin IX methyl-transferase
Mg-protoporphyrin monomethyl ester
NADPH
NADP+
O2
Cyclase
Divinyl protochlorophyllide a
8-Vinyl reductase
NADPH
NADP+
Monovinyl protochlorophyllide a

Stage 2

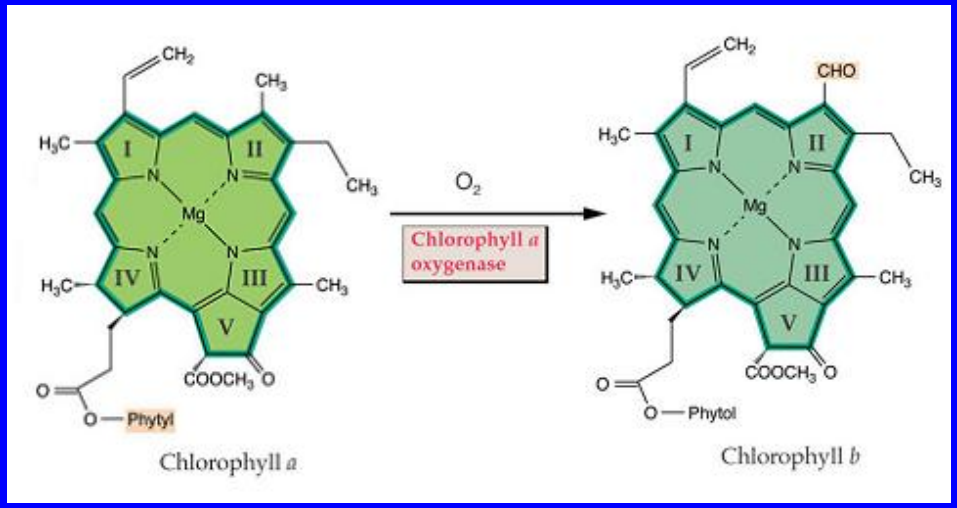

NADPH, light
Protochlorophyllide oxidoreductase
Reduction site
Chlorophyllide a
Monovinyl protochlorophyllide a

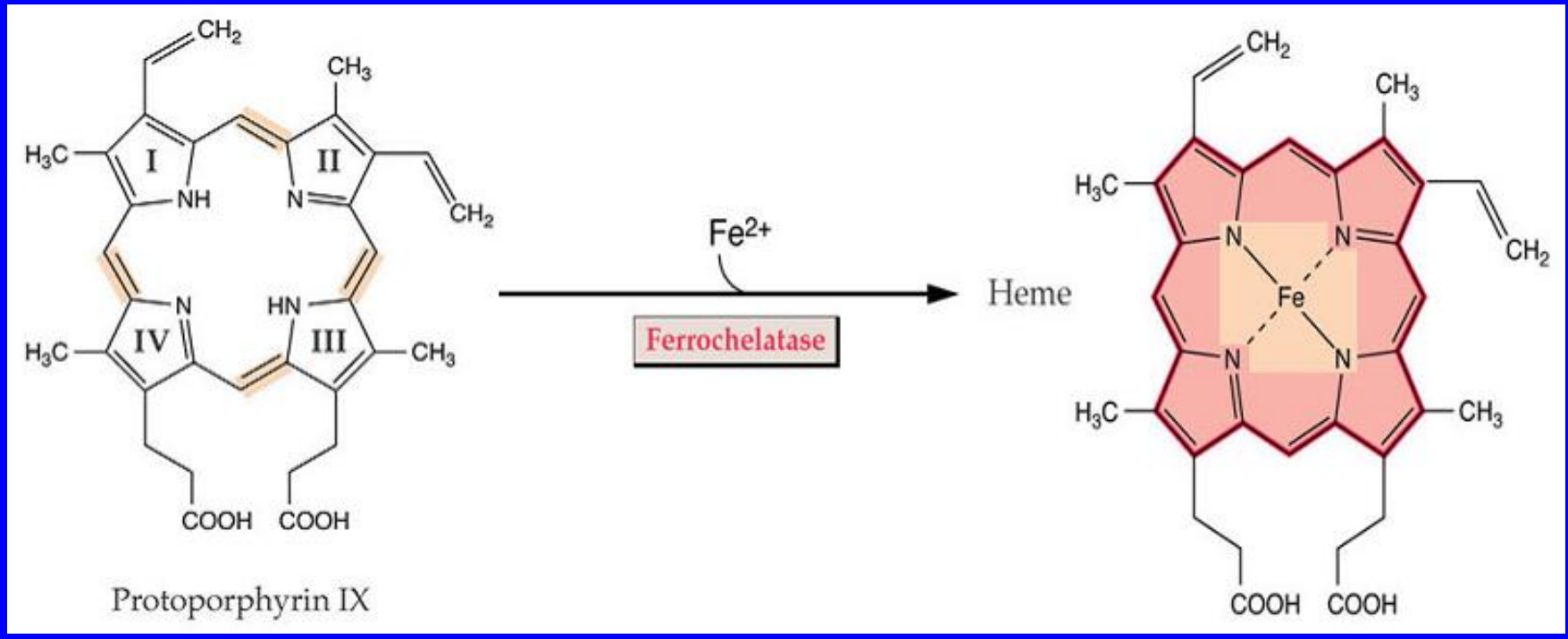
Stage 3

Stage 4



Synthesis of chlorophyll *b*





Formation of ferroheme

(II) Leaf color of plants

① The color of plant leaves is the overall manifestation of all pigments of the leaves;

② The quantity of pigments is relevant with plant type, leaf freshness, growth period and season;

③ Generally speaking, chlorophyll : carotenoid =3: 1, chlorophyll *a*: chlorophyll *b*=3: 1, lutein : carotene=2: 1.

(III) Ambient conditions influencing chlorophyll synthesis

1. Light

   ① Except wavelength of above 680 nm, other visible lights all can promote the formation of chlorophyll;

   ② Yellowing: Refer to the phenomenon that lack of any condition hampers the formation of chlorophyll and results in yellowing of leaves.

2. Temperature: Influence the activities of enzymes; the most suitable temperature is around 30 °C, minimum 2-4 °C, maximum 40 °C.

3. Mineral elements:

   Lack of elements N, Mg, Fe, Mn, Cu and Zn cannot form chlorophyll and causes “chlorosis”.