COMPLEMENTARY CHEMISTRY COURSES
SEMESTER - III
19U3CPCHE03.2
BIO-INORGANIC AND HETEROCYCLIC CHEMISTRY

(*For students who have opted Life Sciences as main*)

Bioinorganic Chemistry

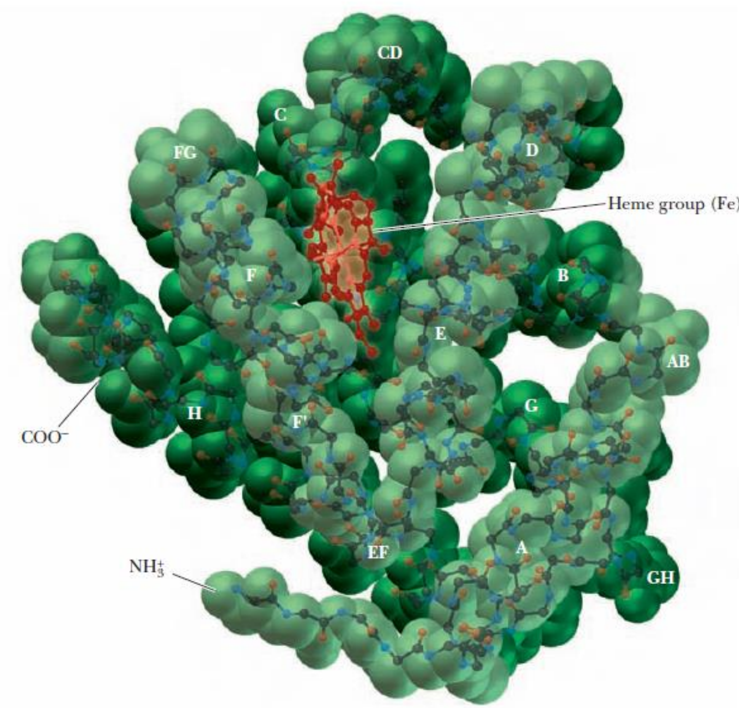
Dr. T.V. SOUMYA
Dept. of Chemistry
Sacred Heart College

Contents

- Oxygen Carriers: Hemoglobin and myoglobin Structure and function.
- Oxygen transport mechanism, cooperativity of hemoglobin, Perutz mechanism, Bohr effect.
- Hemocyanin, Hemerythrin (Structure and function only).
- Photosynthesis: Photosynthetic pigments, Chlorophyll, Structure
- Different types of chlorophyll.
- Photosystem-I, photosystem-II, Z- Scheme, photophosphorylation

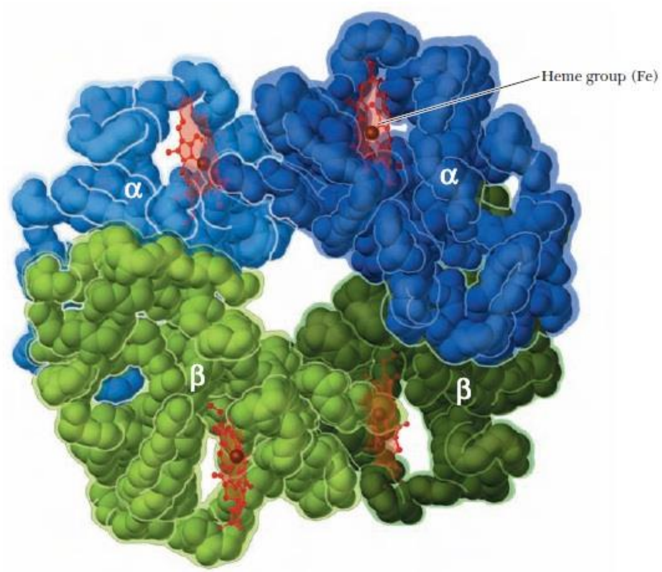
Myoglobin

- Was the first protein the complete tertiary structure was determined by X-tray crystallography
- Has 8 α-helical region and **no β-pleated**
- Hydrogen binding stabilize the α-helical region
- Consist of **a single polypeptide** chain of 153 a.acid residue and includes prosthetic group- one heme group
- Store oxygen as reserve against oxygen deprivation



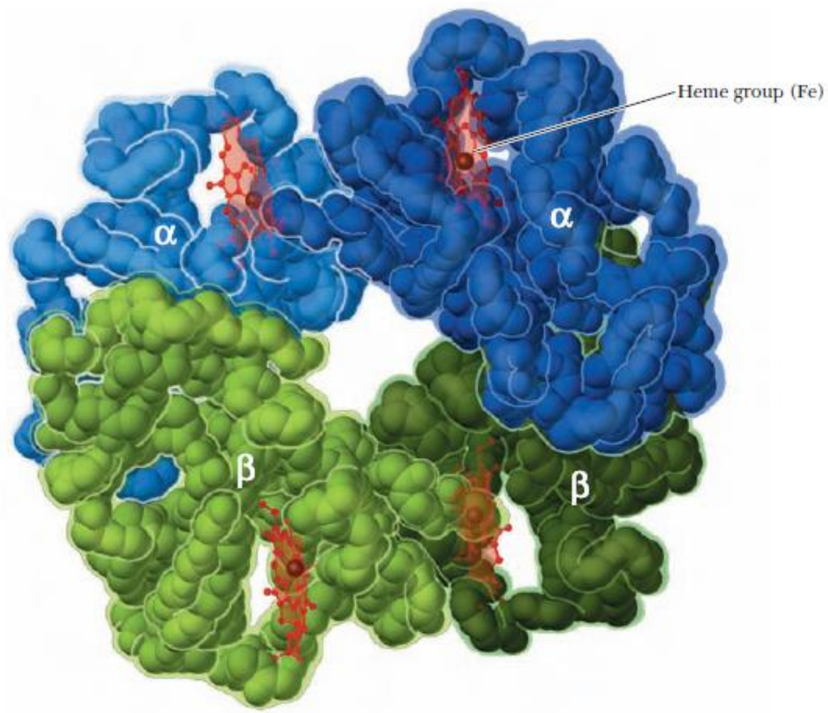
Hemoglobin

- Example of quaternary structure of protein
- Consist 4 polypeptide chain -4 subunit- tetramer
- Each subunit consist one heme group (the same found in myoglobin)
- The chain interact with each other through noncovalent interaction – electrostatic interaction, hydrogen bonds, and hydrophobic interaction
- any changes in structure of protein- will cause drastic changes to its property
- this condition is called allostery



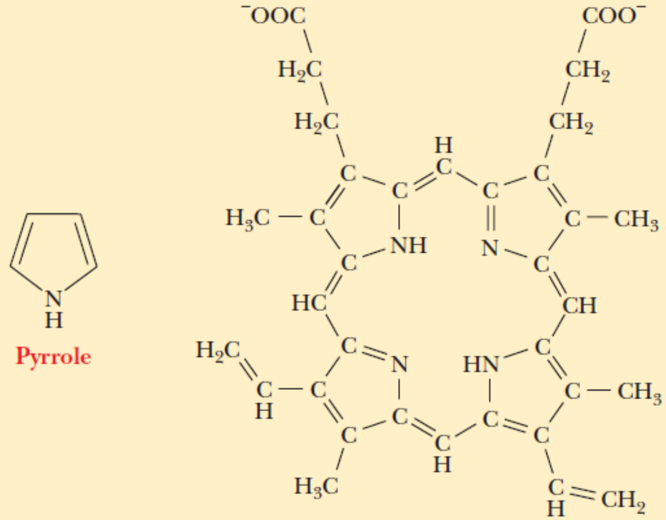
Hemoglobin

- An allosteric protein
- Tetramer, 4 polypeptide chains (α2β2) - 2α-chains and 2β-chains – nothing to do with αhelix and βsheet- its just a greek name
- Bind O2 in lungs and transport it to cells
- Transport C02 and H+ from tissue to lungs
- The same heme group in mb and hb
- Cyanide and carbon monoxide kill because they disrupt the physiologic function of hemoglobin
- 2,3- biphosphoglycerate (BPG) promotes the efficient release of 02



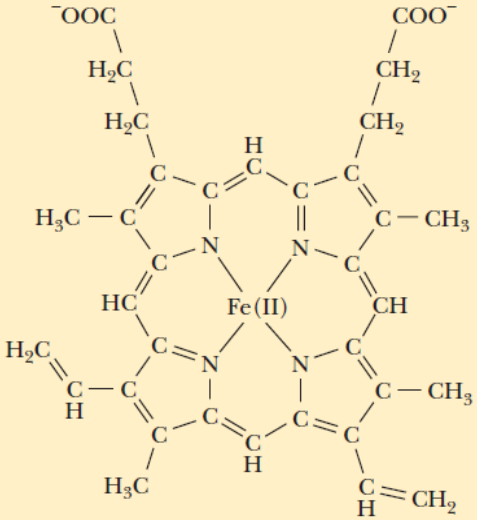
Heme Group

- Mb and Hb contain heme – a prosthetic group
- Consist of heterocyclic organic ring (porphyrin) and iron atom (Fe2+)
- Responsible to bind to 02
- Fe has 6 coordination sites
- Four are occupied by the N atoms
- Oxidation of Fe 2t to Fe3+ destroy their biologic activity



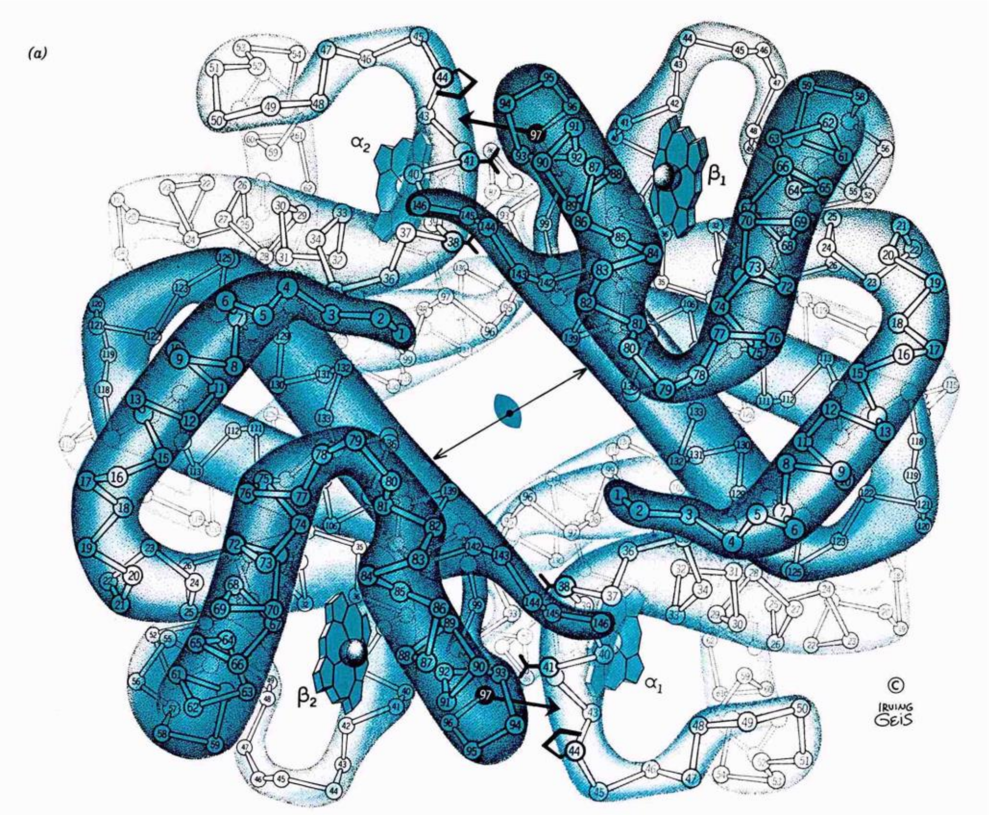
Pyrrole

Protoporphyrin IX

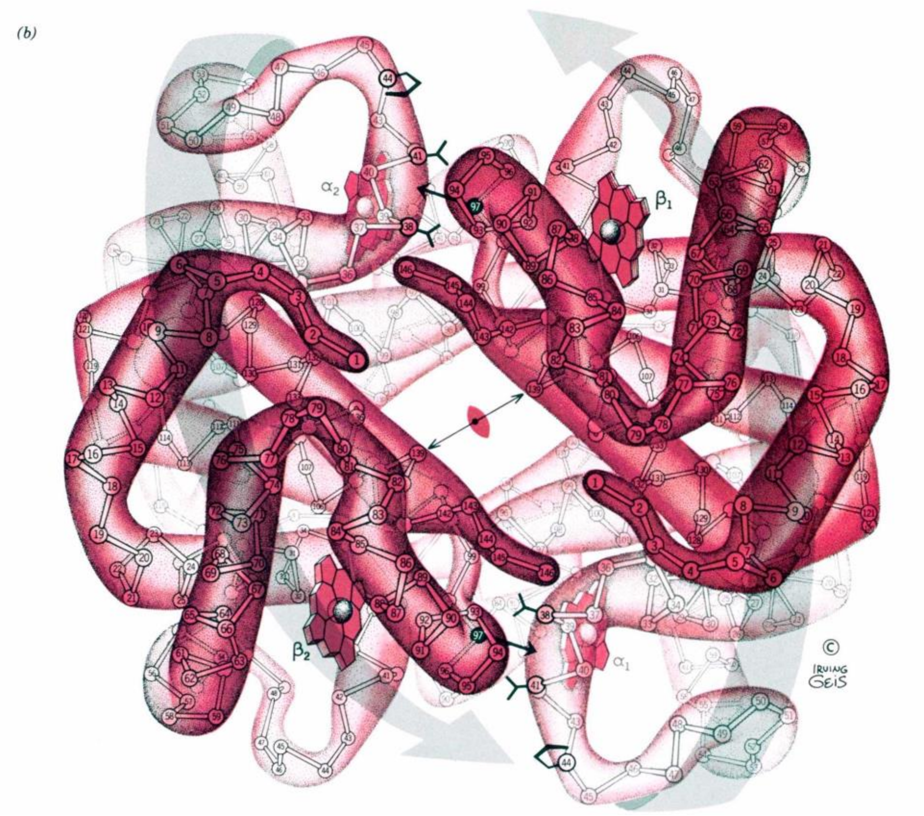


Heme
(Fe-protoporphyrin IX)

Quaternary structure of deoxy- and oxyhemoglobin



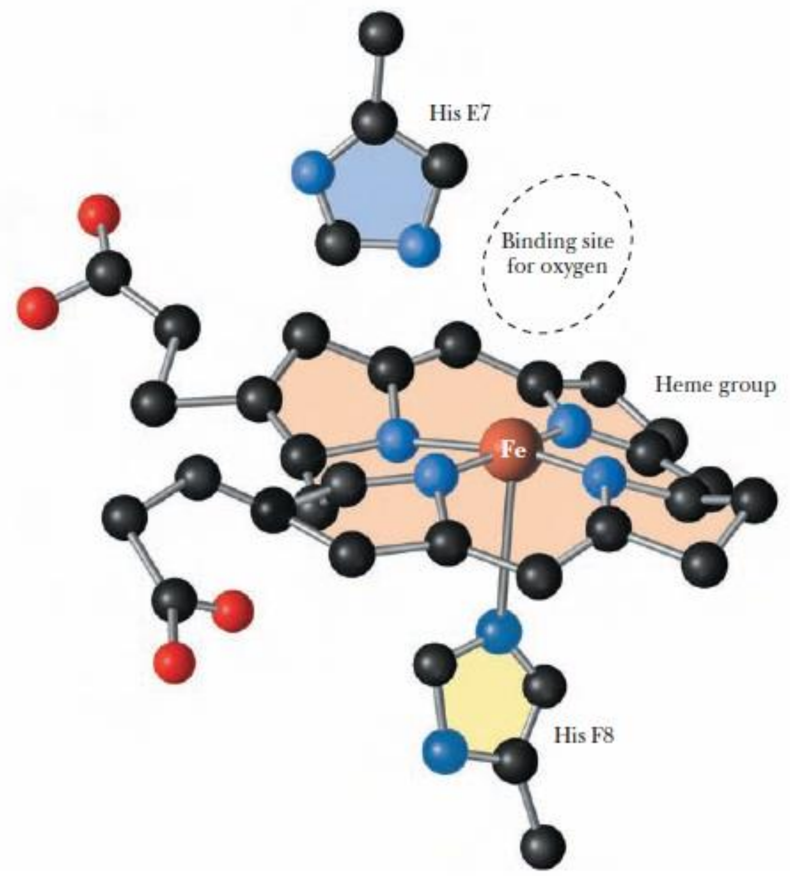
T-state



R-state

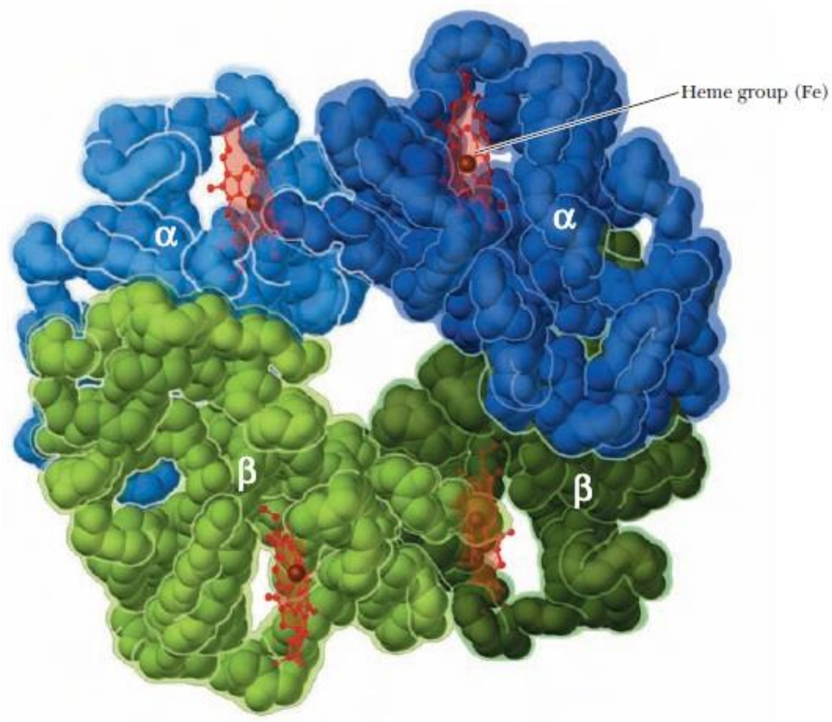
Structure of heme group in Mb and Hb

- **The perfect orientation for CO binding is when all 3 atoms (Fe, C and O) perpendicular to the to the plane of heme**
- **Mb and Hb create hindered environment- do not allow O2 to bind at the required orientation- less affinity**
- **The fifth coordination is occupied by Histidine residue F8**
- **The O2 is bound at the 6th coordination site of iron**



Oxygen saturation in Mb and Hb

- One molecule of Mb- can bind one molecule 02
- HB (4 molecule)- can bind 4 02
- O2 bind to HB thru positive cooperativity – when one O2 is bound, it become easier for the next to bind
- Dissociation of one O2 from oxygenated Hb will make the dissociation of 02 from other subunits easier

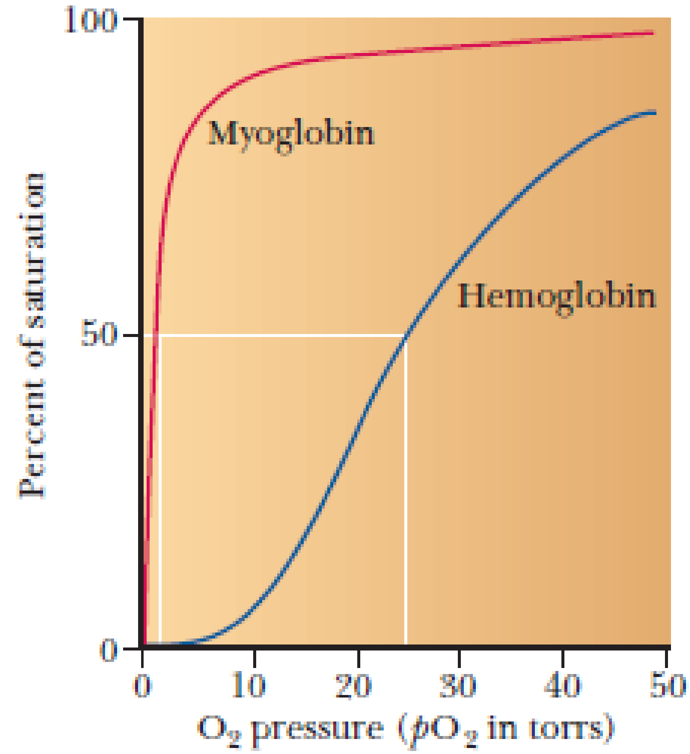


Different form of HB

- Hb is bound to 02- oxyhemoglobin – relaxed (R state)
- Without 02 – deoxyhb – tense (T) state
- If Fe2+ is oxidized to Fe3+ – unable to bind 02- methemoglobin
- C0 and NO have higher affinity for heme FE2+ than 02- toxicity

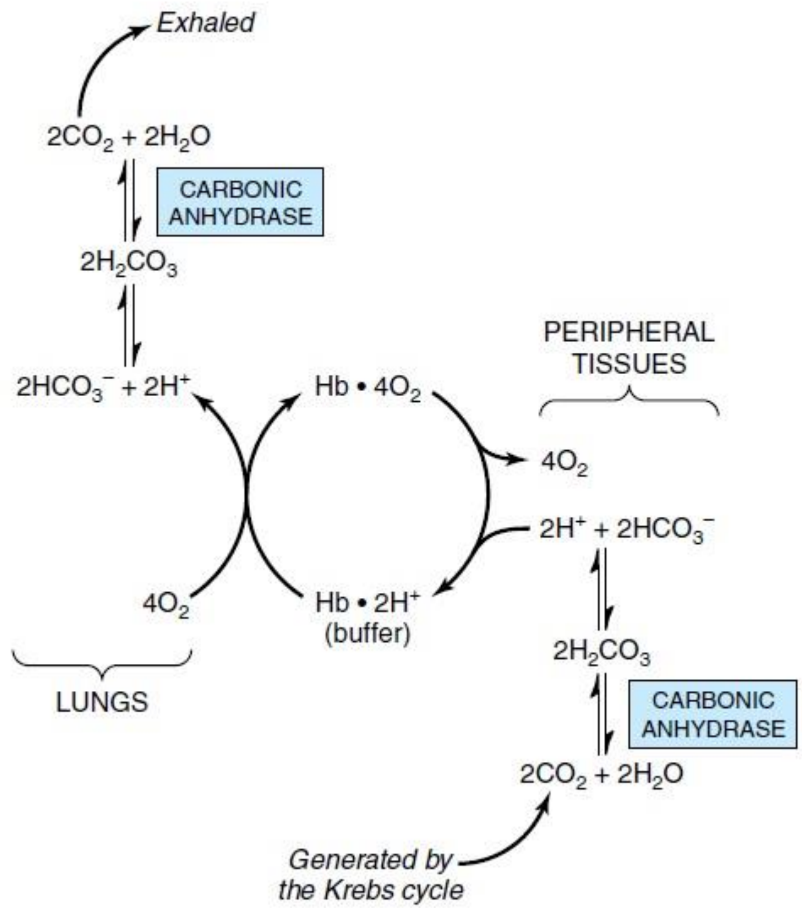
Oxygen-saturation curve

- Myoglobin is showing hyperbolic cu – easily saturated by increment of O pressure
- Hb-sigmoidal curve – under the san pressure where Mb already near to saturation, Hb is still 'struggling' to catch 02.
- But, once one 02 bind to the molecu more will bind to it-cooperativity- increase in saturation
- Same condition for dissociation of C
- Hb will release 02 easily in tissues compare to MB-thus make it a good 02 transporter



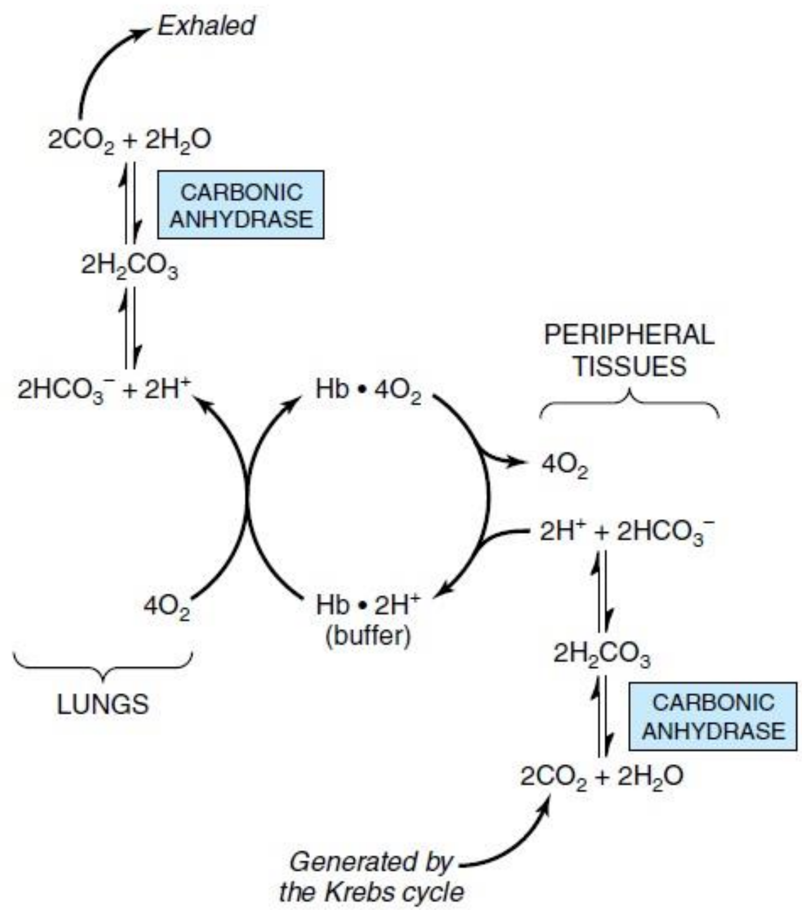
Bohr Effect

- Hb also transport CO2 and H+ from tissues to lungs
- When H+ and C02 bind to Hb affect the affinity of Hb for oxygen – by altering the 3D structure
- The effect of H+ - Bohr Effect
- Not occur in Mb



Bohr effect

- ↑[H+] – protonation of N terminal in Hb
- Create a salt bridge
- Low affinity of Hb to O2
- Metabolically active tissues need more 02- they generate more C02 and H+ which causes hemoglobin to release its 02
- C02 produced in metabolism are in the form of H2CO3→ HCO3- and H+
- HC03- is transported to lungs and combined with H+→ C02 – exhaled
- This process allow fine tuning Ph and level of C02 and 02



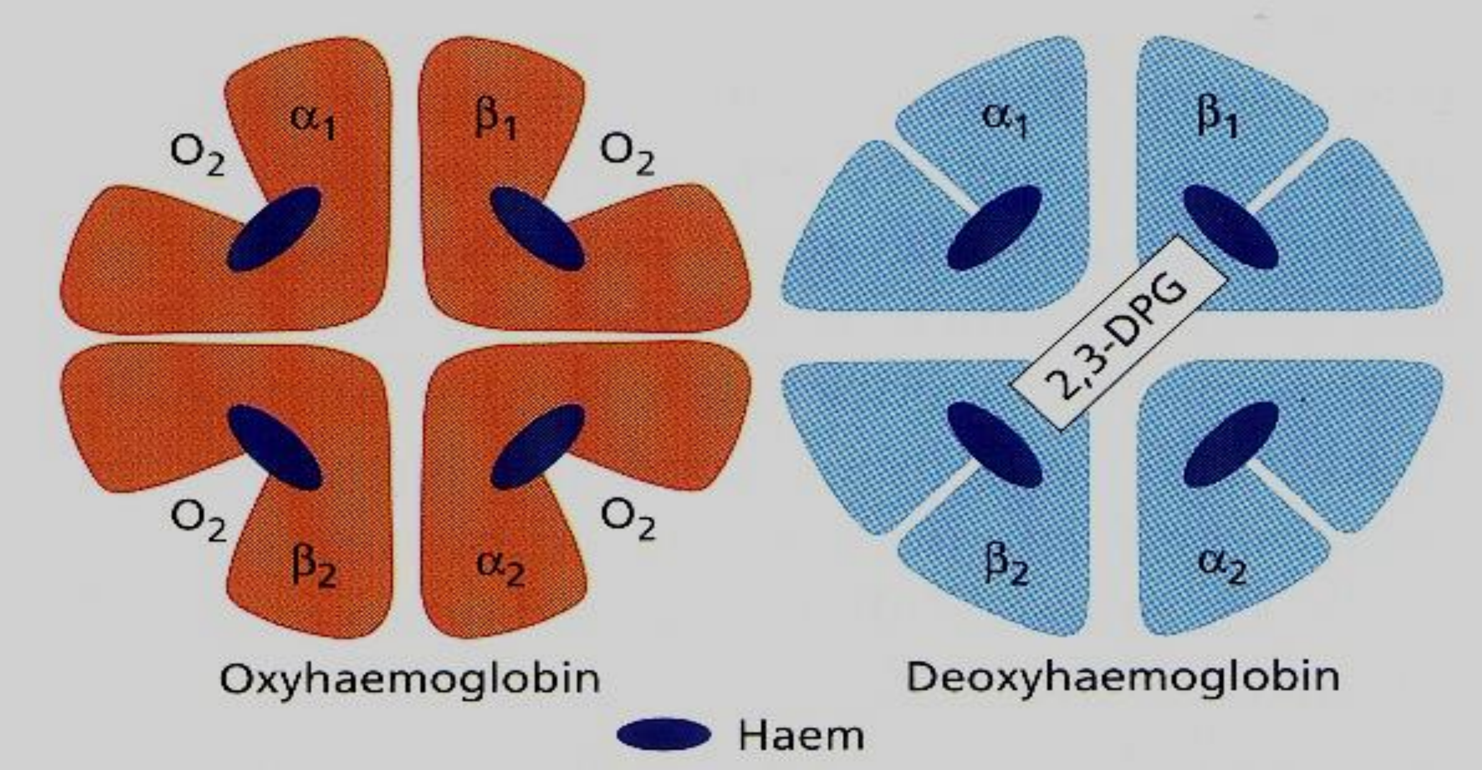
Functions of Haemoglobin

Oxygen delivery to the tissues

Reaction of Hb & oxygen

- ✓Oxygenation not oxidation
- ✓One Hb can bind to four O2 molecules
- ✓Less than .01 sec required for oxygenation
- ✓b chain move closer when oxygenated
- ✓When oxygenated 2,3-DPG is pushed out
- ✓b chains are pulled apart when O2 is unloaded, permitting entry of 2,3-DPG resulting in lower affinity of O2

Oxy & deoxyhaemoglobin



Normal Hemoglobin Function

- When fully saturated, each **gram** of hemoglobin binds **1.34 ml** of oxygen.

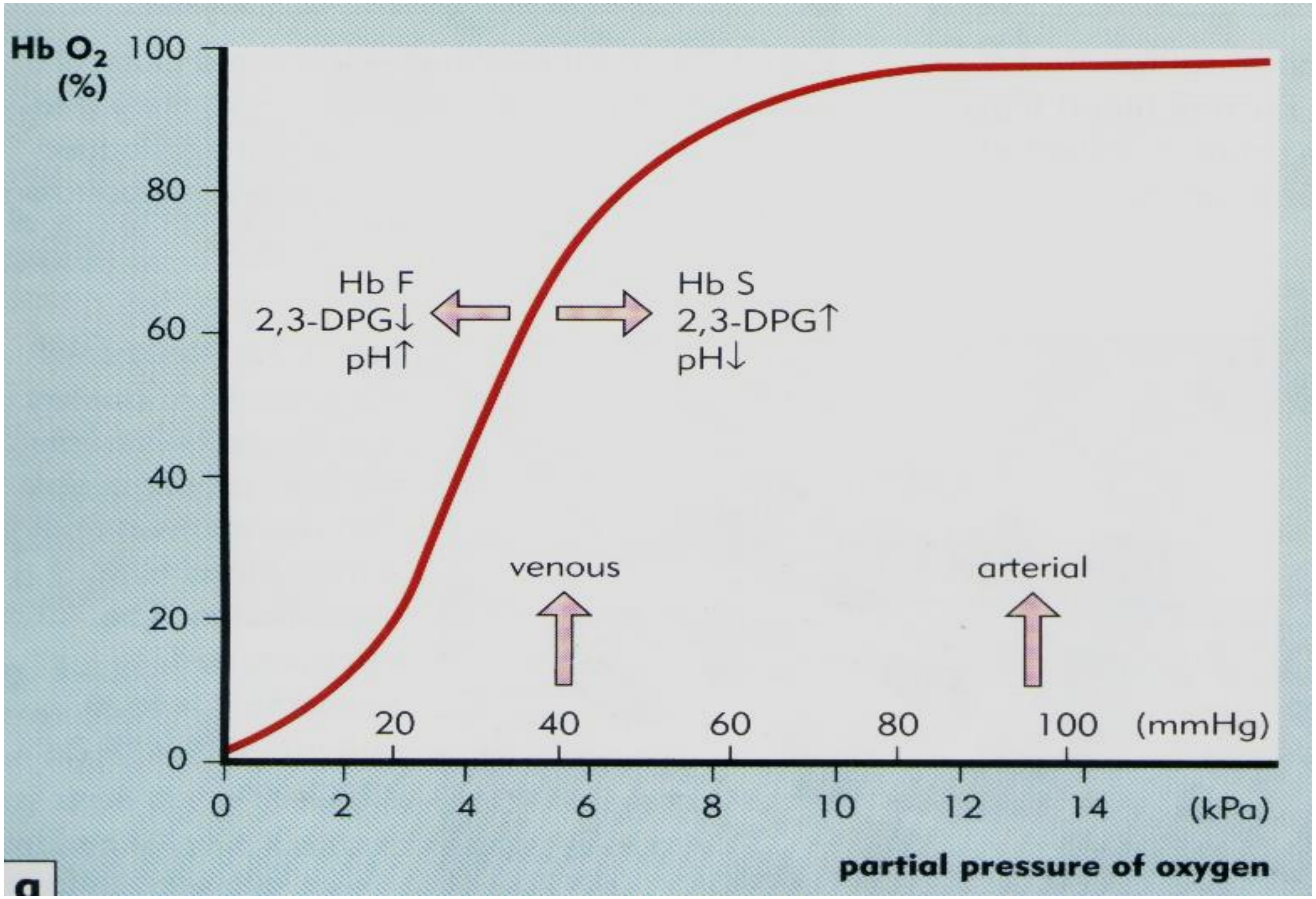
- The degree of saturation is related to the oxygen tension (pO2), which normally ranges from 100 mm Hg in arterial blood to about 35 mm Hg in veins.
-
- The relation between oxygen tension and hemoglobin oxygen saturation is described by the **oxygen-dissociation curve of hemoglobin**.

- The characteristics of this curve are related in part to properties of hemoglobin itself and in part to the environment within the erythrocyte

Hb-oxygen dissociation curve

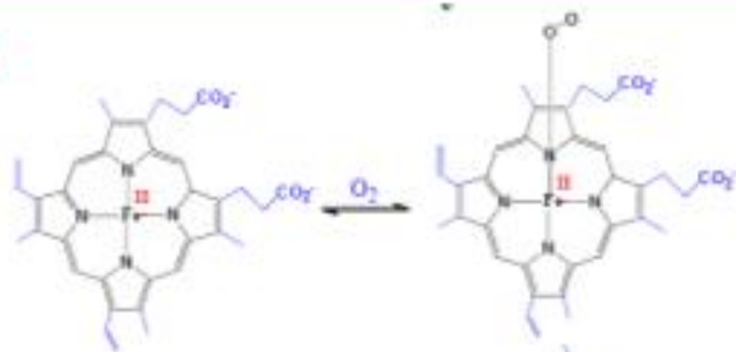
- The normal position of curve depends on
  - Concentration of 2,3-DPG
  - H^+ ion concentration (pH)
  - CO_2 in red blood cells
  - Structure of Hb

Hb-oxygen dissociation curve



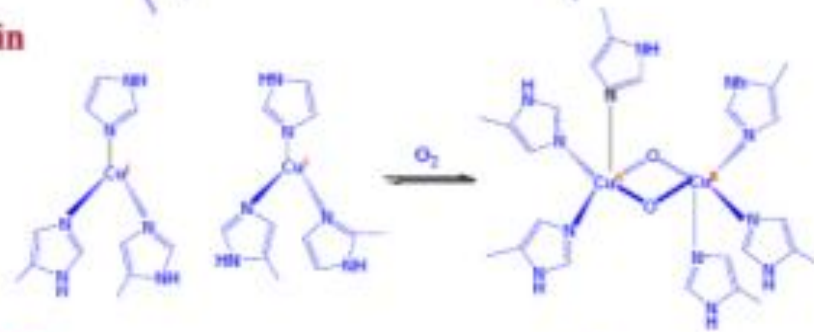
Inorganic Prosthetic group of three well known oxygen carriers

Hemoglobin



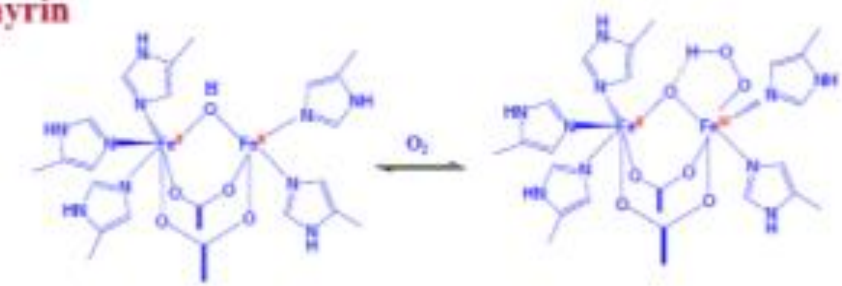
Present in Vertebrates

Hemocyanin

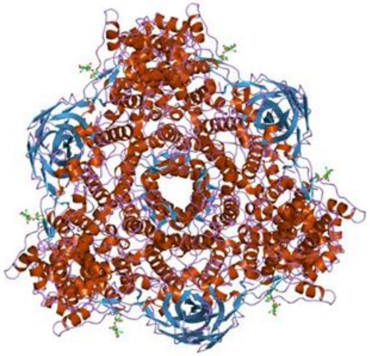


Present in molluscs

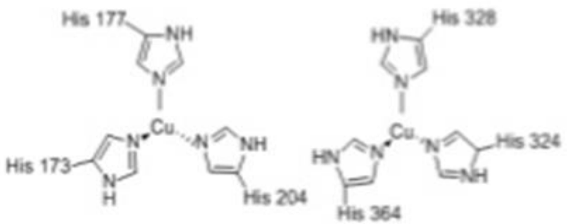
Hemerythyrin



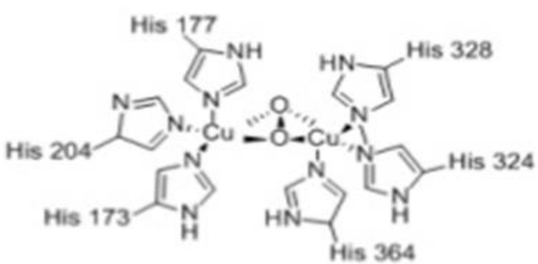
Present in some sea worms



Hemocyanin structure .



Deoxyhemocyanin



Oxyhemocyanin

- The oxygen binding centre is composed of a pair of copper atoms. Each Cu atom is bounded by 3 histidine ligands.An empty cavity exist between the Cu atoms.
- The Cu is in +1 oxidation state in the deoxy form & it is diamagnetic in nature & so it is colourless.
- The Cu is in +2 oxidation state in the oxy form & it is paramagnetic in nature & so it is blue in color.
- The polypeptide chain must have a molecular weight between 50000-75000
- The O_2 is bridged between the two copper centers. It means oxyhemocyanine binds with oxygen because of which the Cu gets oxidized from +1 to +2

If the hemocyanine contains n number of Cu centers then it will contain n/2 of O_2 molecules. It is also called as oxo species

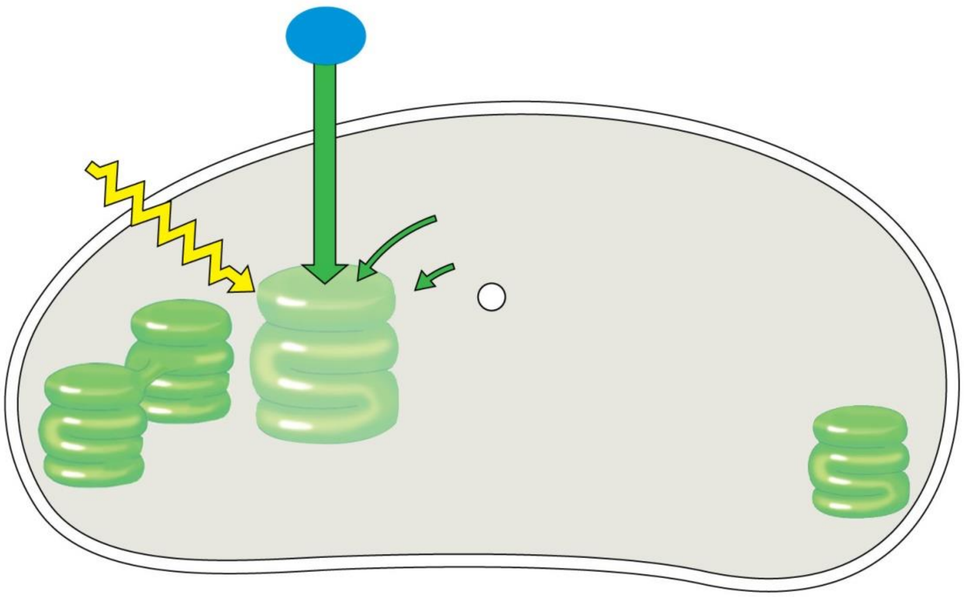
Photosynthesis

Atmospheric Co_2 Is "Fixed" By Plants And Cyanobacteria

- A Light-driven Process
- The Carbon Becomes Available As C '
  Hydrate (Ch_2o)
- The Overall Reaction Is:

$$CO_2 + H_2O \rightarrow (CH_2O) + O_2$$

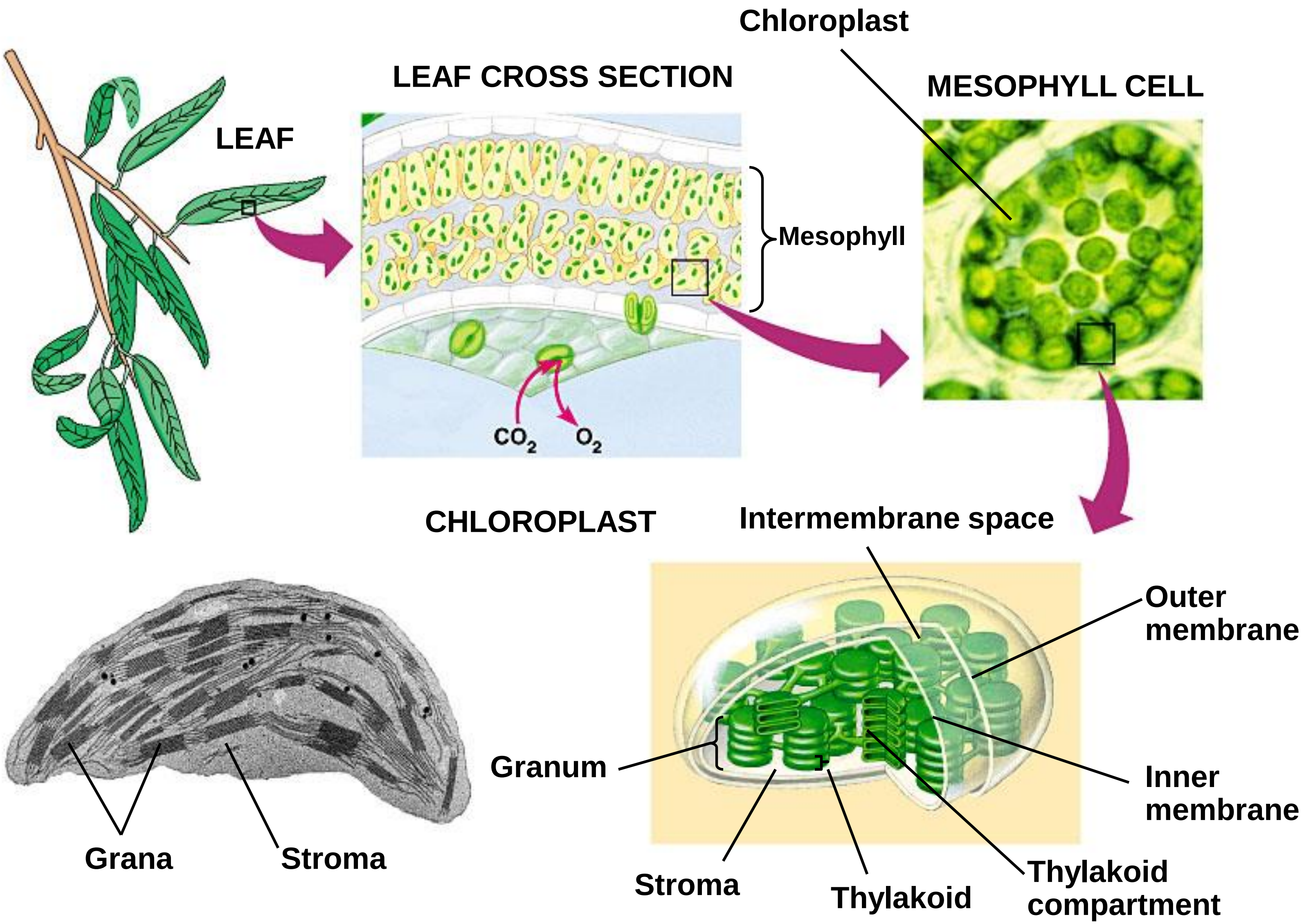
- CO_2 Is Reduced
- H_2O Is Oxidized



Photosynthesis occurs in chloroplasts

- In most plants, photosynthesis occurs primarily in the leaves, in the chloroplasts
- A chloroplast contains:
  - stroma, a fluid
  - grana, stacks of thylakoids
- The thylakoids contain chlorophyll
  - Chlorophyll is the green pigment that captures light for photosynthesis

- The location and structure of chloroplasts



Chloroplast Pigments

- Chloroplasts contain several pigments
  - Chlorophyll a
  - Chlorophyll b
  - Carotenoids
  - Xanthophyll

Figure 7.7

Chlorophyll Is The Major Photoreceptor In Photosynthesis

- A Cyclic Tetrapyrrole, Like Heme, But:
  - HAS A CENTRAL Mg^{2+} ION
  - A Cyclopentanone Ring (Ring V) Is Fused To Pyrrole Ring Iii
  - Partial Reduction Of Ring Iv
    - In Eukaryotes And Cyanobacteria
      - **CHLOROPHYLL A**
      - **CHLOROPHYLL B**
  - OR IN RINGS II AND IV
    - In Photosynthetic Bacteria
      - **BACTERIOCHLOROPHYLL A**
      - **BACTERIOCHLOROPHYLL B**

There Are Two Phases In Photosynthesis

- THE "LIGHT REACTION"
  - H_2O IS SPLIT
    - **2 H_2O → O_2 + 4 [H•]**
  - NADPH AND ATP ARE GENERATED
- THE "DARK REACTION"
  - NADPH AND ATP FROM THE LIGHT REACTION DRIVES CH_2O PRODUCTION FROM CO_2 AND [H•] :
    - **4 [H•] + CO_2 → (CH_2O) + H_2 O**
  - IT'S REALLY A LIGHT-INDEPENDENT REACTION
  - YOU HAVE ALREADY STUDIED IT
    - **THE "CALVIN CYCLE"**

Molecular Events During Light Absorption

- PHOTONS (LIGHT "PARTICLES")
  - ENERGY = $h\nu$
- PHOTORECEPTORS
  - HIGHLY CONJUGATED MOLECULES
    - STRONGLY ABSORB VISIBLE LIGHT
- ABSORPTION OF A PHOTON USUALLY PROMOTES A GROUND-STATE ELECTRON TO A MOLECULAR ORBITAL OF HIGHER ENERGY
  - LAW OF CONSERVATION OF ENERGY
- EACH ELECTRONIC ENERGY LEVEL HAS
  - VIBRATIONAL AND ROTATIONAL SUB-STATES

Steps of Photosynthesis

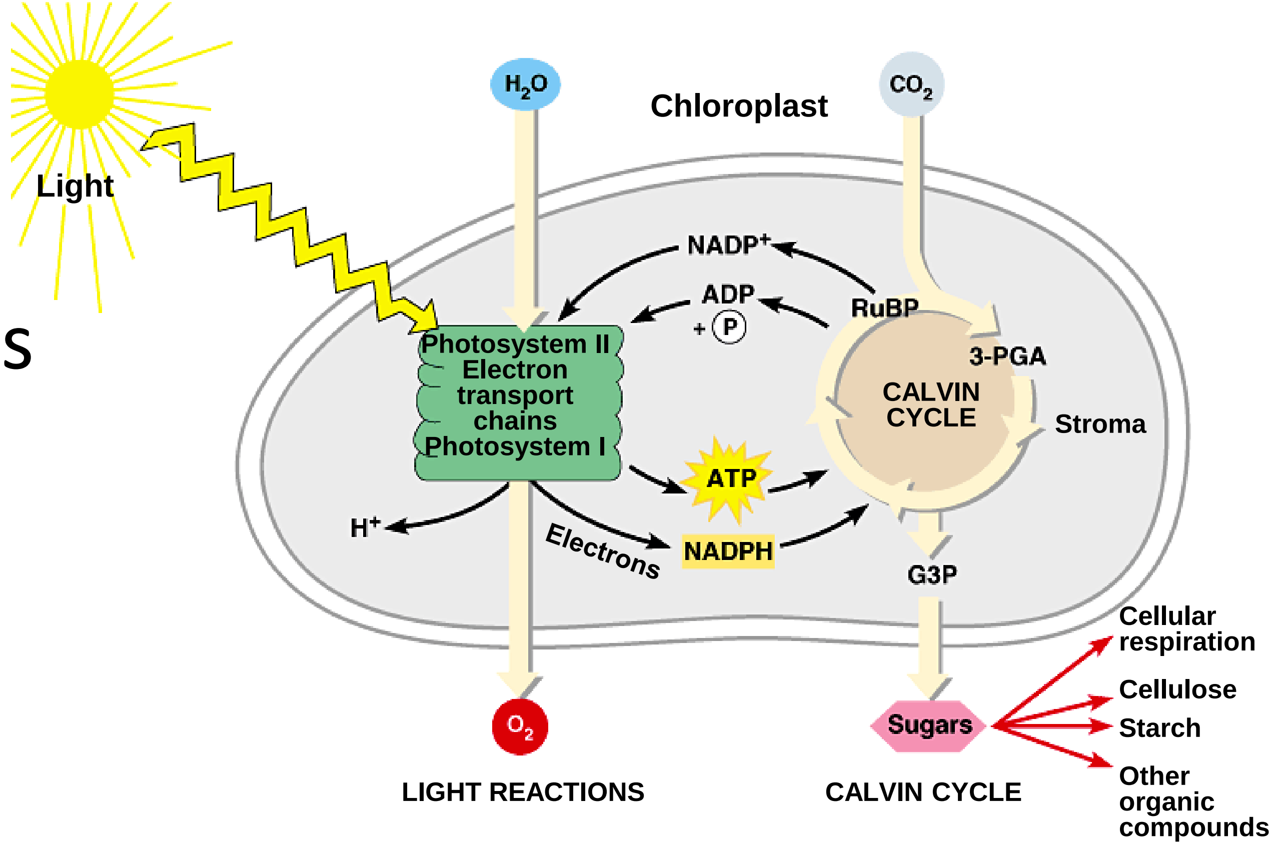
- Light hits reaction centers of chlorophyll, found in chloroplasts
- Chlorophyll vibrates and causes water to break apart.
- Oxygen is released into air
- Hydrogen remains in chloroplast attached to NADPH
- “THE LIGHT REACTION”

Steps of Photosynthesis

- The DARK Reactions= Calvin Cycle
- CO2 from atmosphere is joined to H from water molecules (NADPH) to form glucose
- Glucose can be converted into other molecules with yummy flavors!

Review: Photosynthesis uses light energy to make food molecules

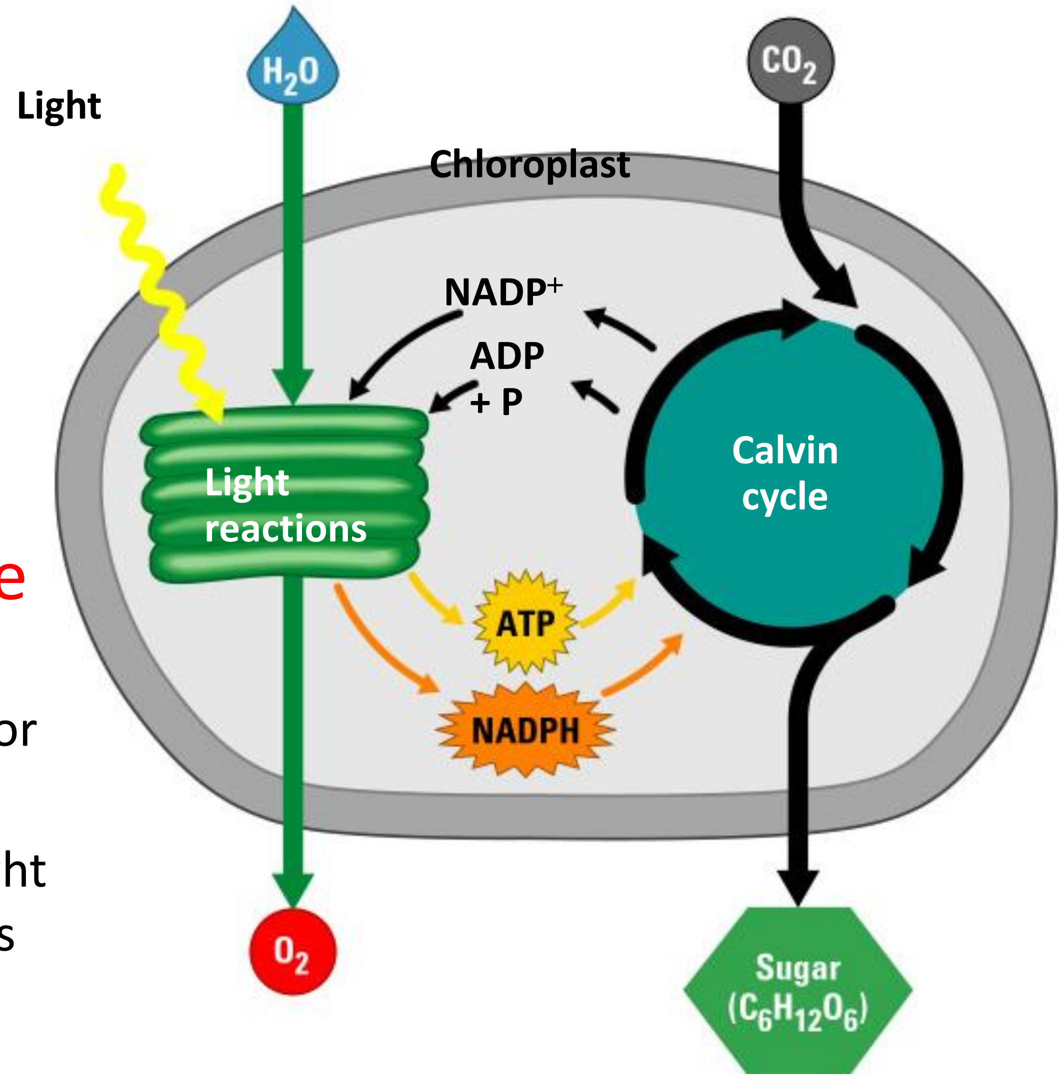
- A summary of the chemical processes of photosynthesis



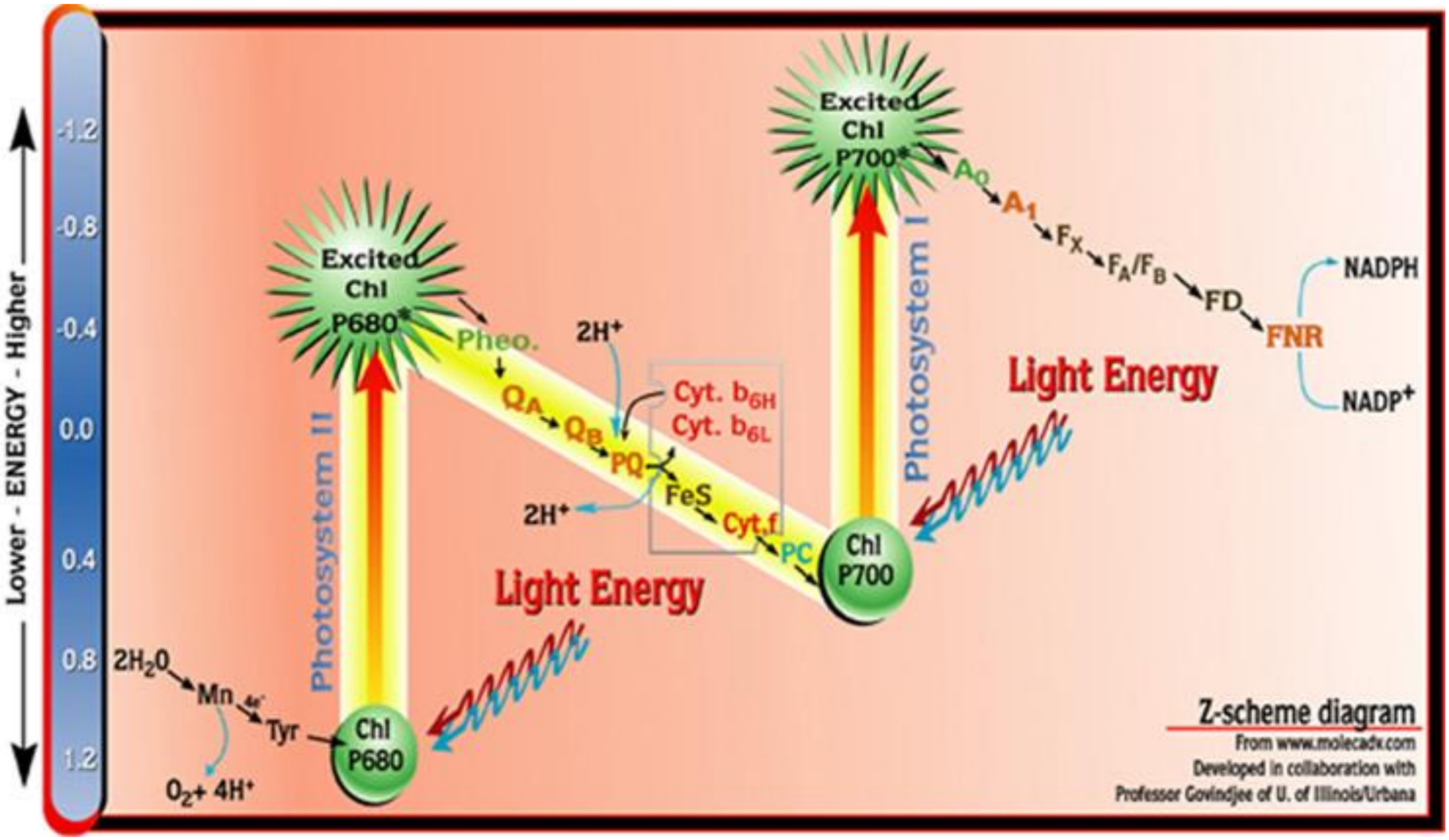
AN OVERVIEW OF PHOTOSYNTHESIS

- The light reactions convert solar energy to chemical energy
  - Produce ATP & NADPH

- The Calvin cycle makes sugar from carbon dioxide
  - ATP generated by the light reactions provides the energy for sugar synthesis
  - The NADPH produced by the light reactions provides the electrons for the reduction of carbon dioxide to glucose



Z Scheme



Lower - ENERGY - Higher
-1.2
-0.8
-0.4
0.0
0.4
0.8
1.2
Excited Chl P700*
Excited Chl P680*
Pheo.
Q_A
Q_B
PQ
$2H^+$
$2H^+$
Cyt. b_{6H}
Cyt. b_{6L}
FeS
Cyt.f
PC
Chl P700
Chl P680
A_0
A_1
F_X
F_A/F_B
FD
FNR
NADPH
$NADP^+$
Photosystem II
Photosystem I
Light Energy
Light Energy
$2H_2O$
Mn
Tyr
O_2+ $4H^+$
Z-scheme diagram
From www.molecadx.com
Developed in collaboration with
Professor Govindjee of U. of Illinois/Urbana

Thank you