BIOINORGANIC CHEMISTRY

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Elements of the living organism:

1. **Elements in large scale: 11 elements**
   H, C, N, O, Na, Mg, P, S, Cl, K, Ca

2. **Elements in small scale: 7 elements**
   Mn, Fe, Co, Cu, Zn, I, Mo

3. **Elements of a few species: 7 elements**
   B, F, Si, V, Cr, Se, Sn

Metals essential for life:

- The role for most is uncertain
- Na, K, Mg, Ca- in large Quantities – bulk metal ions
- Fe,Cu,Zn trace metal ions
- V, Cr, Mn, Co, Ni, Zn, Sn,Pb,Li,Mo, W-ultra trace metals

Important functions metal ions in biological systems

- **1. Regulatory Action** — **Sodium potassium channels and pump**
- **Na, K** — ***Nerve signals and impulses, action potential muscle contraction***
- **2. Structural Role** — **Calcium in bones, teeth**
- **Ca, Mg** — ***provide strength and rigidity***
- **3. *Electron transfer agents*** — **Cytochromes: redox intermediates**
- **Fe^{2+}/Fe^{3+}** — ***membrane-bound proteins that contain heme groups and carry out electron transport in Oxidative phosphorylation***
- **4. *Metalloenzymes* (metal as cofactors)** — **Carbonic anhydrase, Carboxypeptidase (Zn)**
- ***superoxide dismutase (Cu), Cytochrome P-450 (Fe)***
- **5. *Oxygen carriers and storage*** — **Hemoglobin, Myoglobin, Haemerythrins,Hemocyanin**
- **Fe, Cu** — ***18 times more energy from glucose in presence of O_2***
- **6. Metallo coenzymes** — **Vitamin B 12 -**
- **Co** — ***biomethylation***

Iron biochemistry

- Most widespread transition metal in living systems

Various processes which contain iron are

1. Oxygen carrier in the blood –haemoglobin
2. Oxygen storage in muscles –myoglobin
3. Electron carrier –cytochromes
4. Electron transfer –Ferridoxin
5. Storage and scavenging of iron – ferritin,transferrin,haemosiderin
6. As nitrogenase
7. Aldehyde oxidase,catalase, peroxidase and succinic dehydrogenase

Haemoglobin and Myoglobin

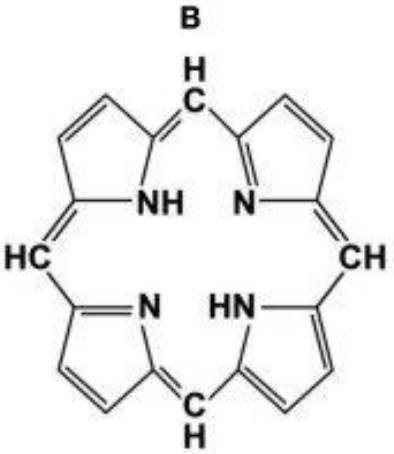
- Oxygen transfer and storage agents in the blood and muscle tissue.
  - Hemoglobin transports oxygen (O_2) from the lungs/gills to tissues and muscles.
  - Myoglobin stores oxygen (O_2) in the muscles and tissues.

  Oxygen commonly transfers from the hemoglobin to the myoglobin for later use.

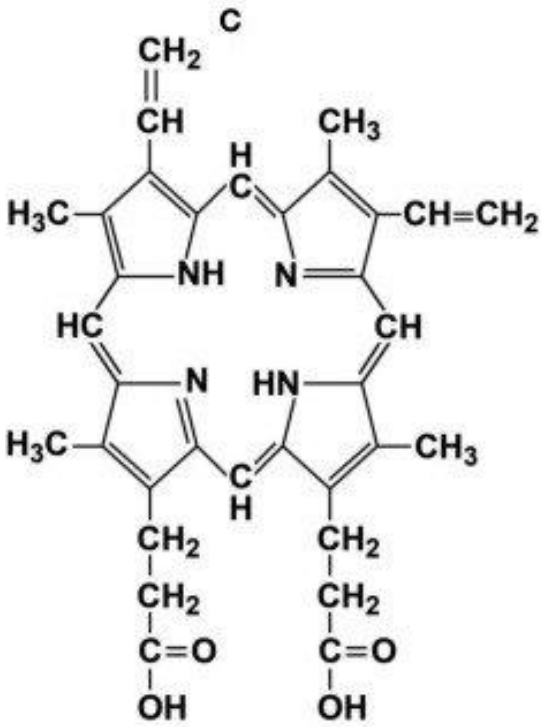
  Both are made up of globin protein subunits (α and β).
  - Each protein partially encloses a heme group.
- Hb and Mb are related.
- Hb -64500 Mol.Wt- 4 subunits each contain haem unit
- Mb -17000 Mol.Wt- 1 unit
- Aminoacid sequence are different for Hb and Mb

Iron chelates of porphyrin (macrocyclic ligand)

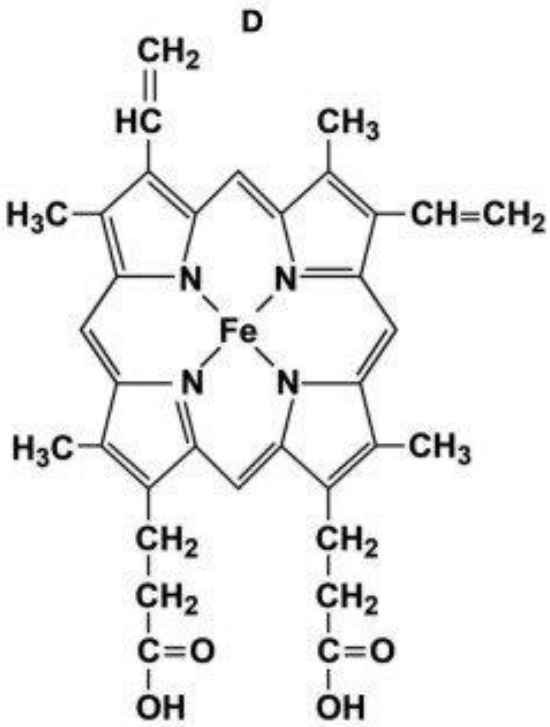
- Porphyrin –derivatives of porphin in which four pyrrole units are linked by four methine (-CH=)



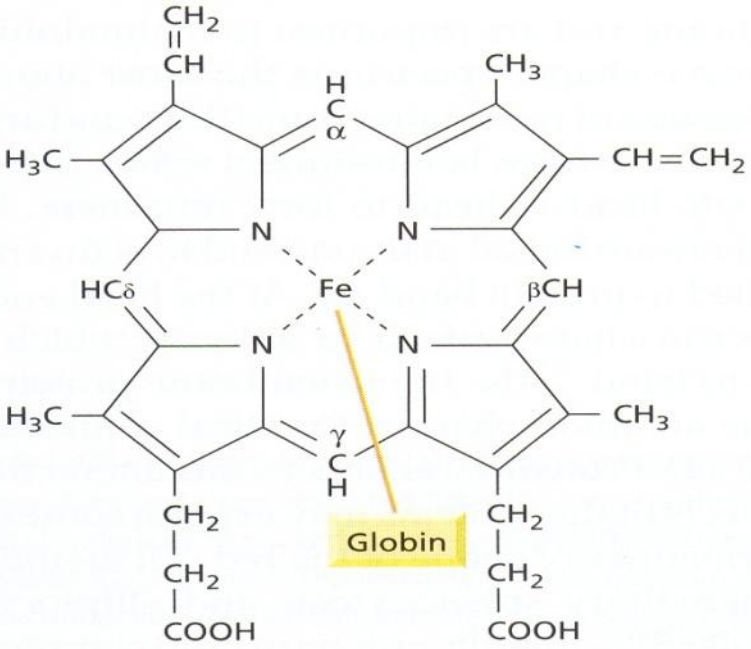
Porphin

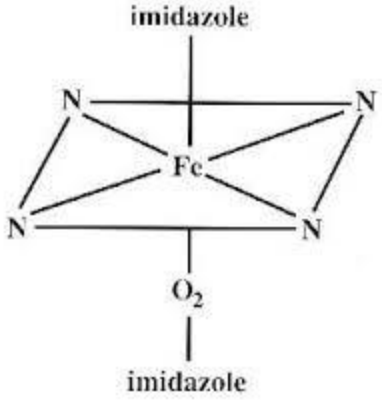


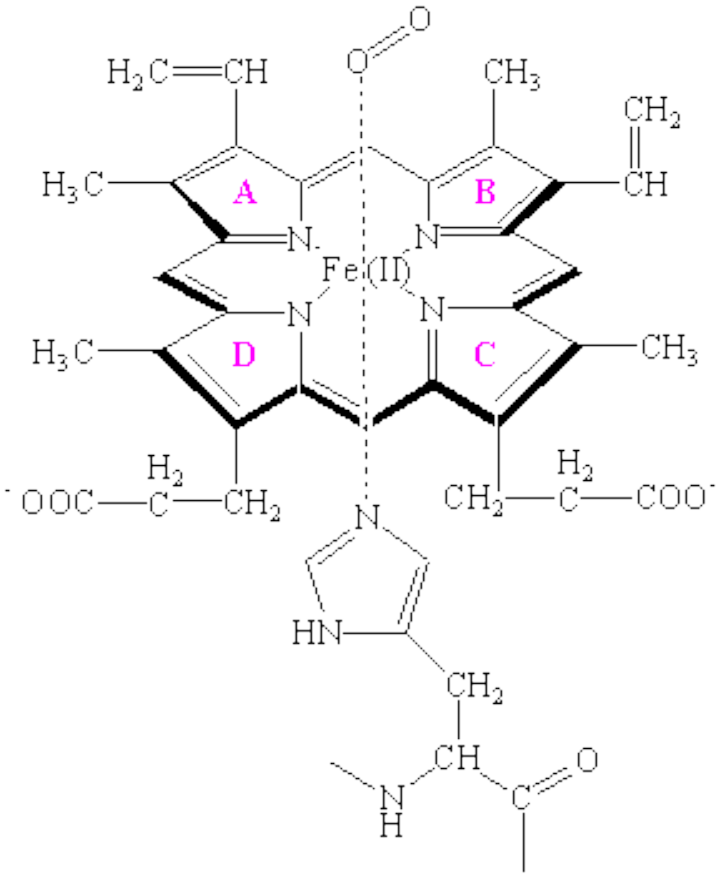
Porphyrin

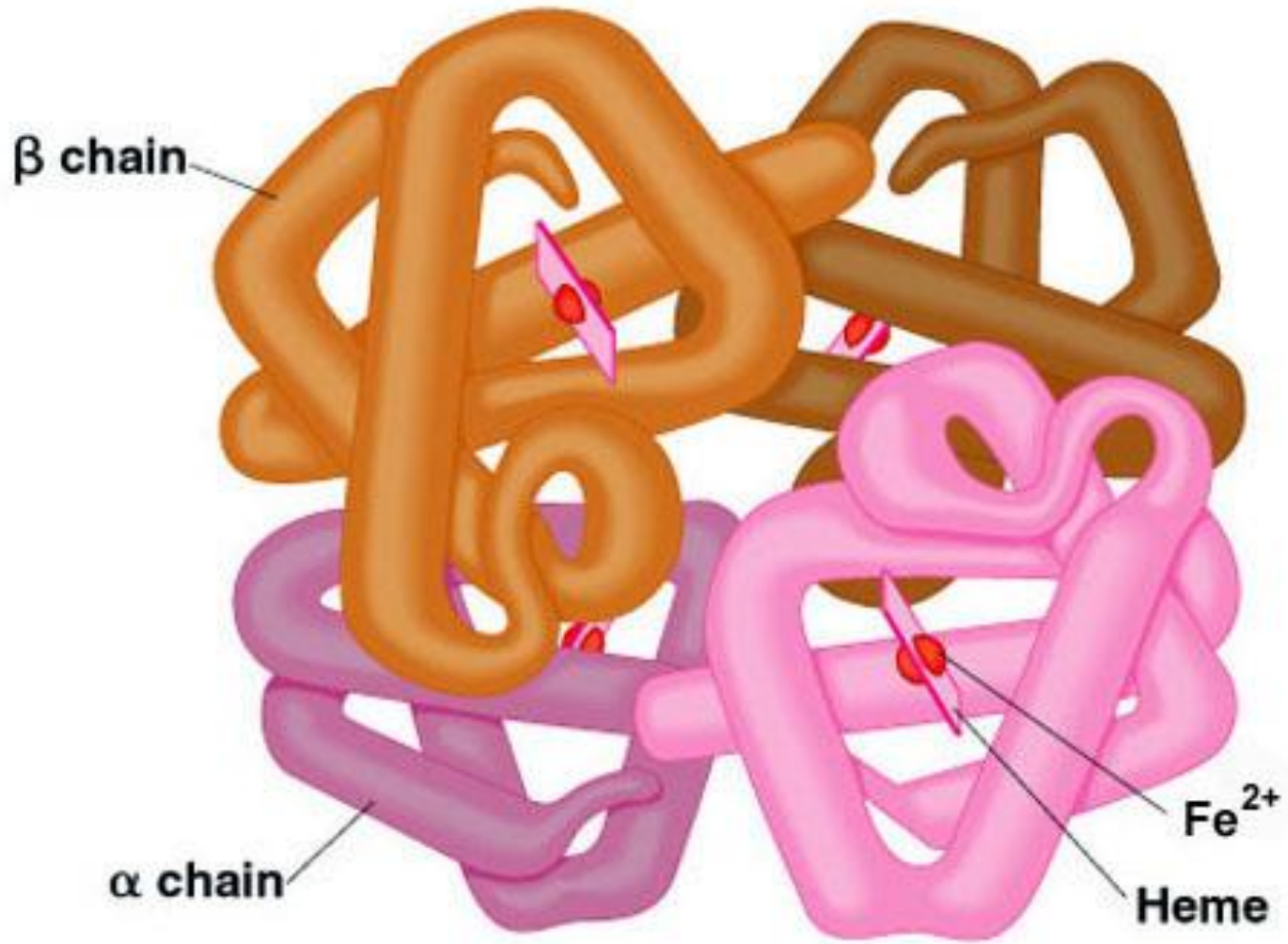


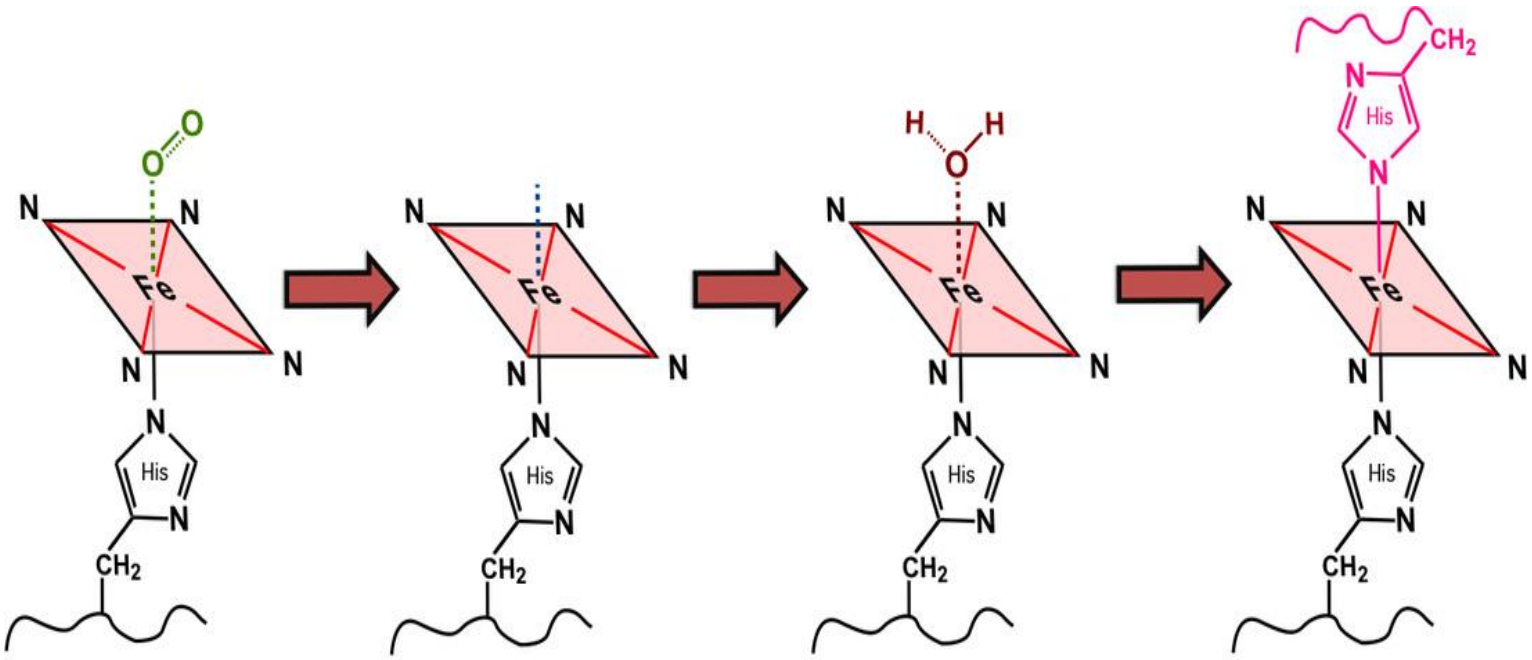
Heme-Iron porphyrin comple


CH2
CH
CH3
H
C
α
H3C
CH=CH2
N
N
HCδ
Fe
βCH
N
N
H3C
CH3
γ
C
H
CH2
CH2
COOH
Globin
CH2
CH2
COOH


imidazole
N
N
Fe
N
N
O2
imidazole


O
O
H2C=CH
CH3
CH2
H3C
A
B
CH
N
N
Fe(II)
N
N
H3C
D
C
CH3
H2
H2
OOC—C—CH2
CH2—C—COO
N
HN
CH2
CH
O
N
H
C

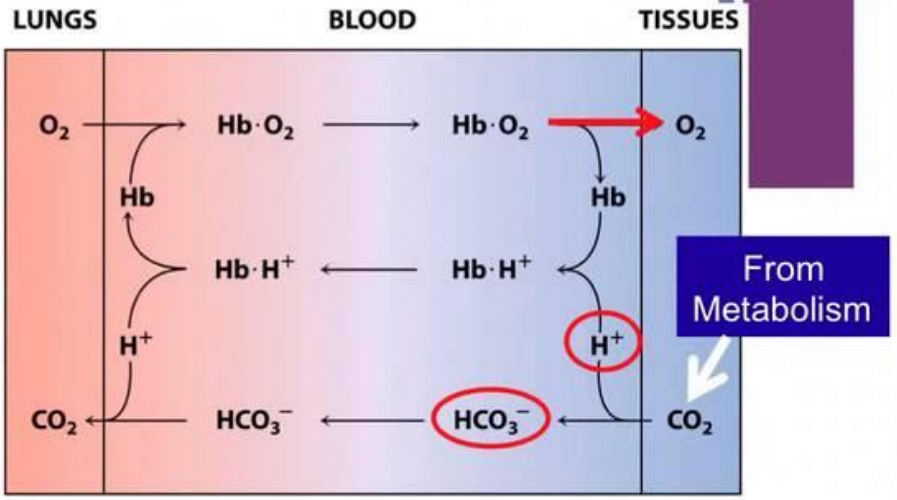

β chain
α chain
Fe2+
Heme


O
O
N
N
Fe
N
N
His
N
CH2
Oxyhemoglobin
(O2)
Deoxyhemoglobin
(empty)
H
H
O
Methemoglobin
(H2O or OH-)
CH2
His
Hemichromes
(E7 His residue)

Mechanism of oxygen binding in Hb

- Pyrolprotophyrin made up of four pyrrole rings with methyl, vinyl, or propionate side chains.
- Iron atom binds to 4 N in center of ring, Fe^{+2} can form 2 additional bonds on either side of heme plane. One bond is to (HisF8=proximal His), the other (sixth) coordinate is where oxygen close (but not bond) to (His E7=distal His).
- Deoxy Mb= 6^{th} position is empty
- Oxy Mb= 6^{th} position is O_2
- Ferri myoglobin = 6^{th} position is water

Regulating O_2 Binding to Hb

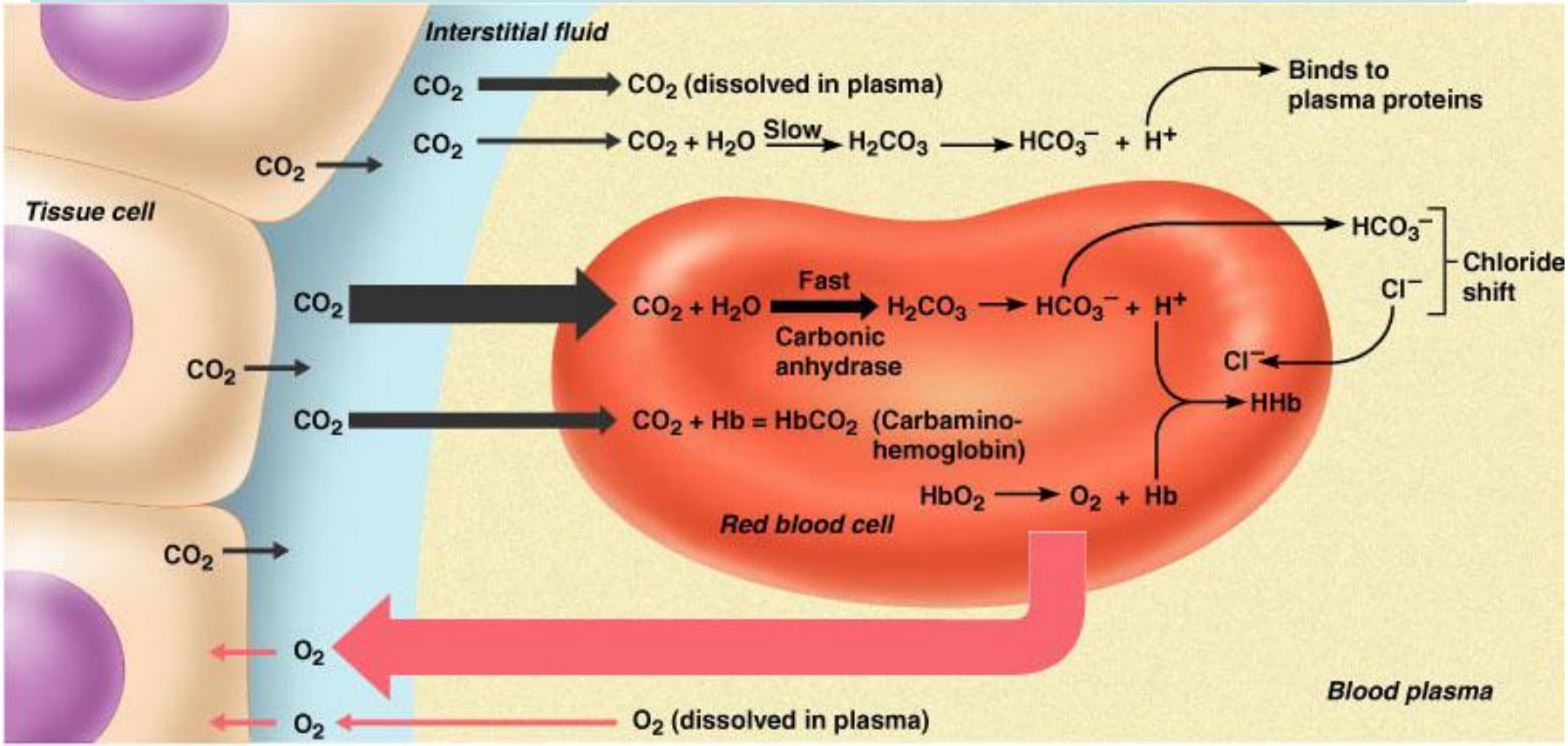


- Bohr effect
  - What happens in **tissues**?
    - They use O_2 in respiration and produce CO_2
    - CO_2 diffuses into red blood cells (RBCs have Hb)
    - Carbonic anhydrase converts to bicarbonate and produces H^+

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

    - Low pH induces Hb to release O_2
    - Net effect: release O_2 in tissues, RBCs takes up CO_2 (Hb binds some)

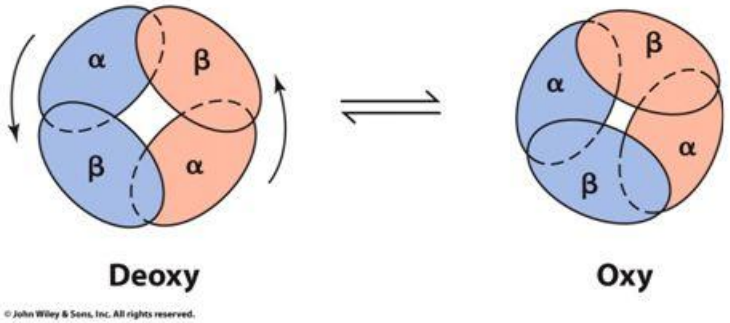
OXYGEN TRANSPORT

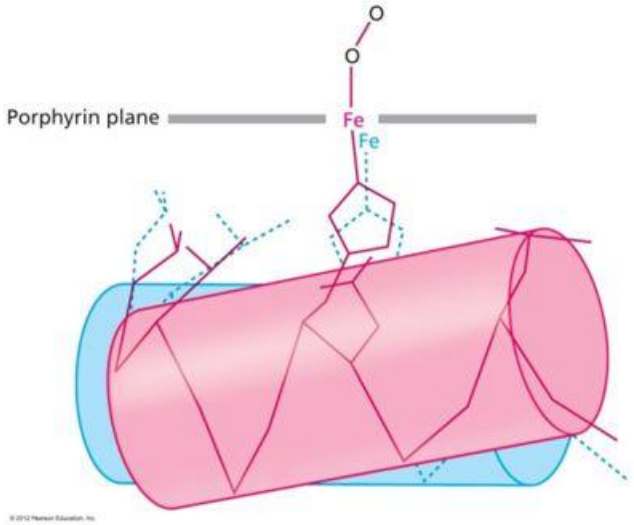


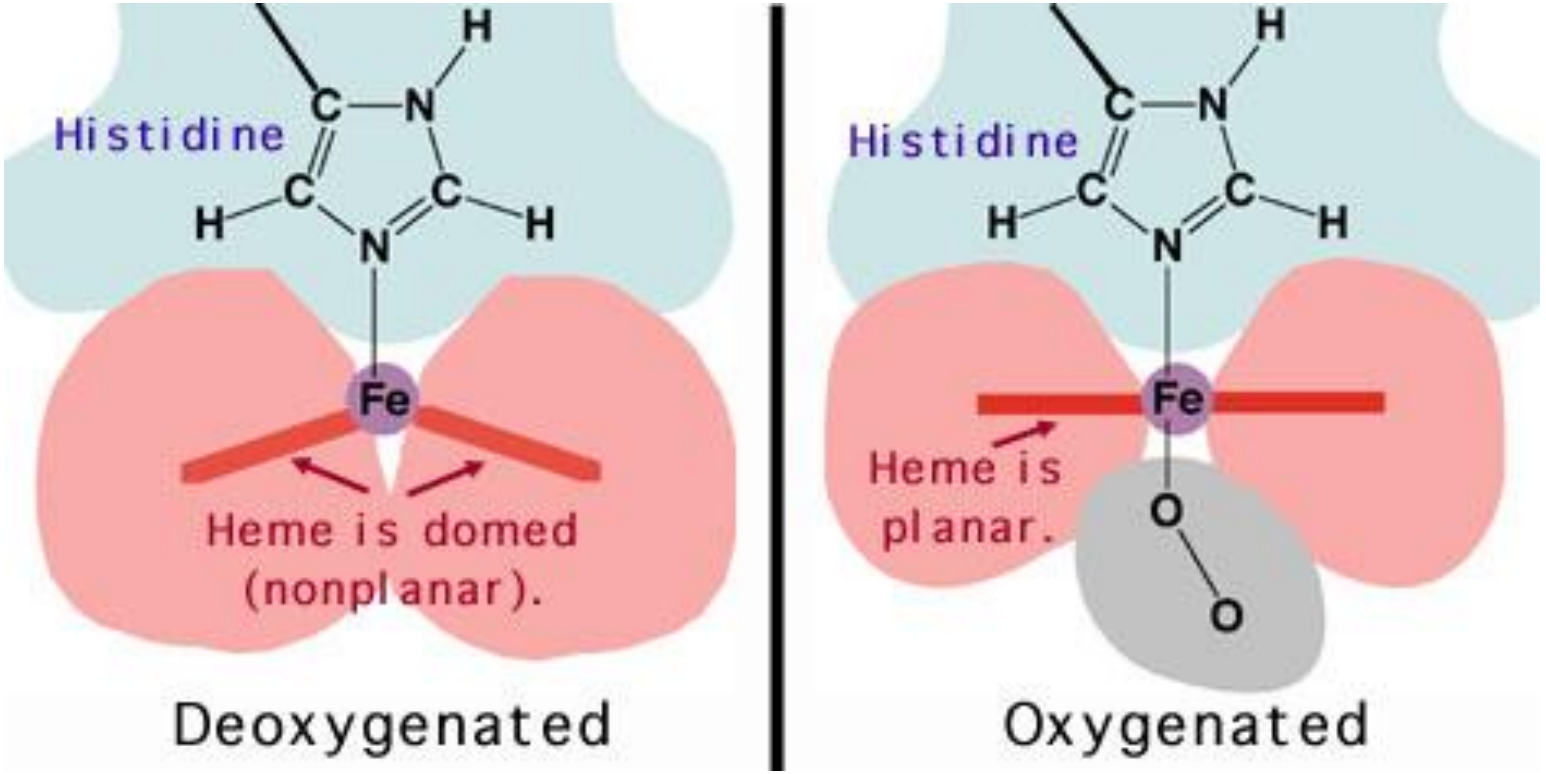
(a) Oxygen release and carbon dioxide pickup at the tissues

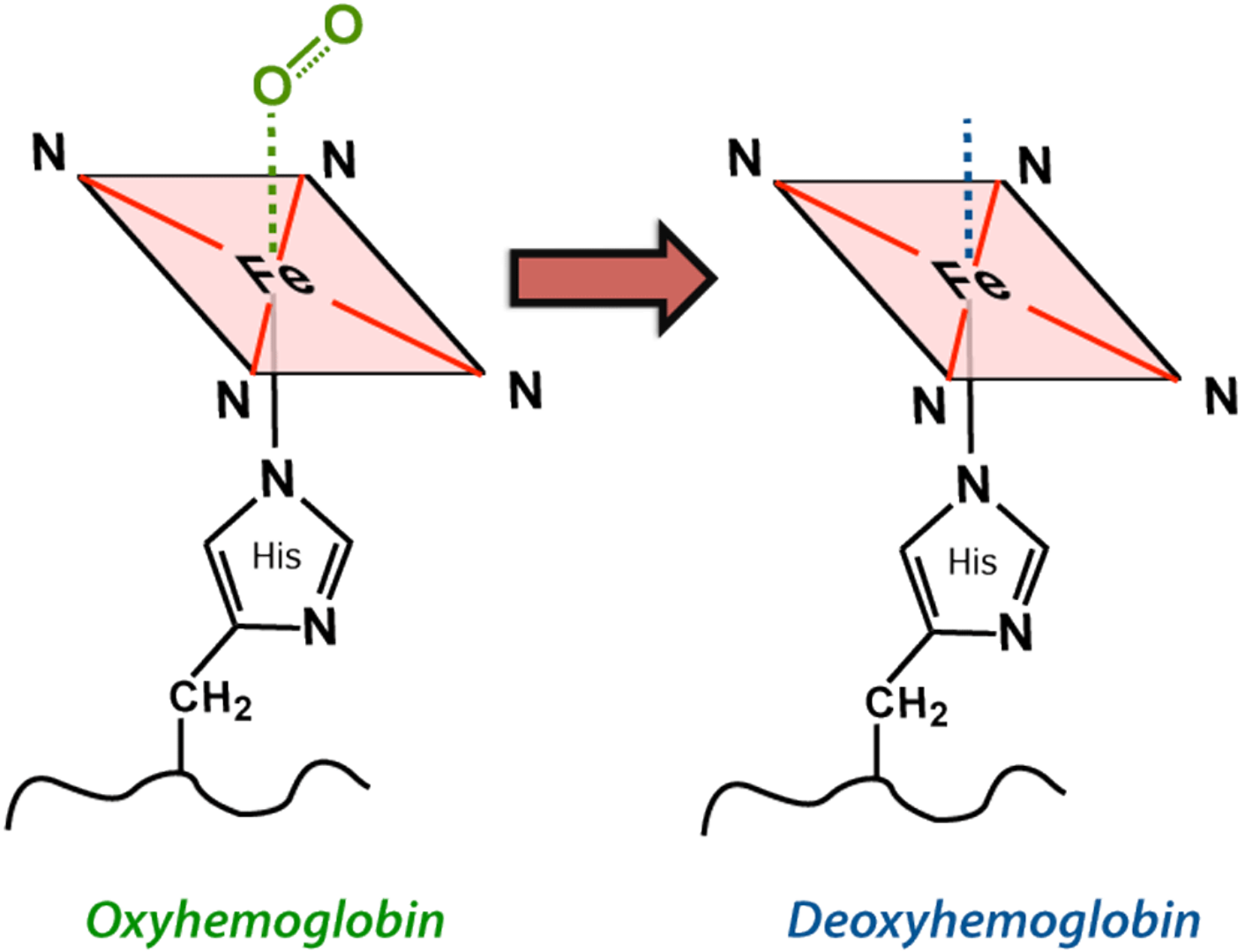
Cooperativity

- Binding of Oxygen changes shape of unit
- Shape of subunit affects shapes of other subunits
  - Oxygen-bound unit causes other subunits to become **relaxed**
  - The rich become richer
  - Cooperative binding



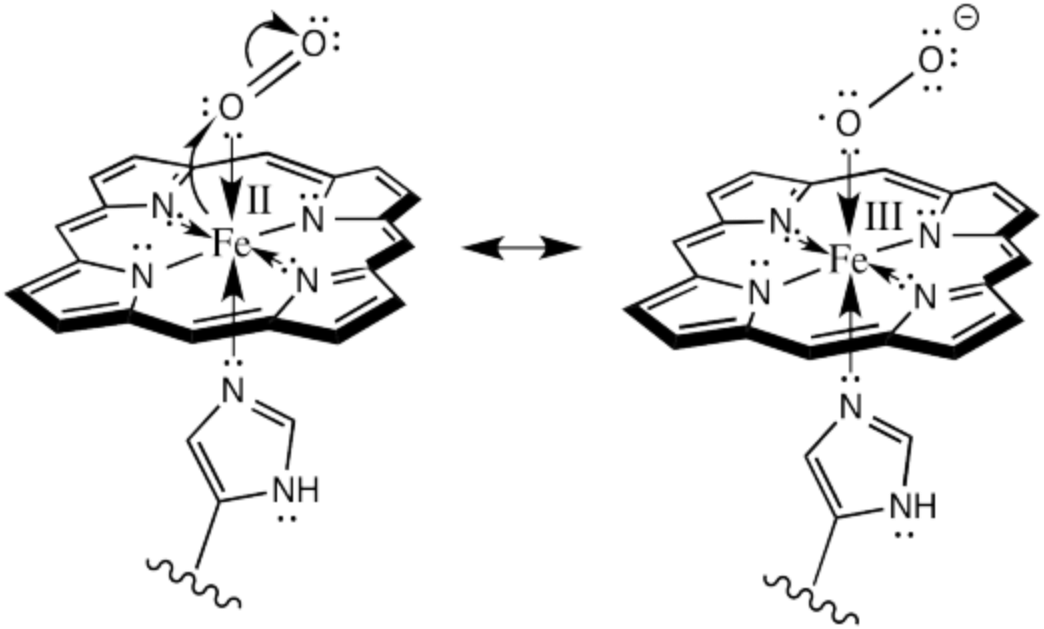



Histidine
H
C
N
C
C
H
H
N
Fe
Heme is domed
(nonplanar).
Deoxygenated
Histidine
H
C
N
C
C
H
H
N
Fe
Heme is
planar.
O
O
Oxygenated



Oxyhemoglobin

Deoxyhemoglobin


O
O
N
II
N
Fe
N
N
N
NH
O
O
N
III
N
Fe
N
N
N
NH

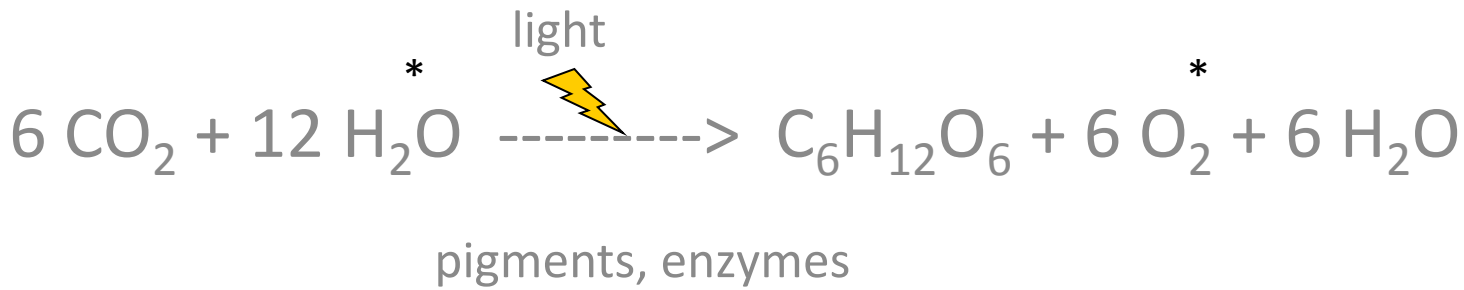
DERIVATIVES OF Hb

- 1. Hb + O_2 → HbO_2 (Oxyhaemoglobin) Iron in ferrous state)
- 2. Hb + Cyanide → Methaemoglobin Iron in ferric state.
- 3. Hb + CO_2 → Carbamino hemoglobin
- 4. Hb + CO → Carboxy hemoglobin
- 5. Hb + H_2S → Sulphemoglobin.
- 6. Hb + Glucose → Glycosylated (attached to terminal Valine)

I. Introduction to photosynthesis

Definition: **PHOTOSYNTHESIS** is the process whereby plants, algae, some bacteria, use the energy of the **sun** to synthesize organic compounds (**sugars**) from inorganic compounds (**CO_2 and water**).

GENERAL FORMULA FOR PHOTOSYNTHESIS



- Oxygen on earth allowed for the evolution of aerobic respiration and higher life-forms.

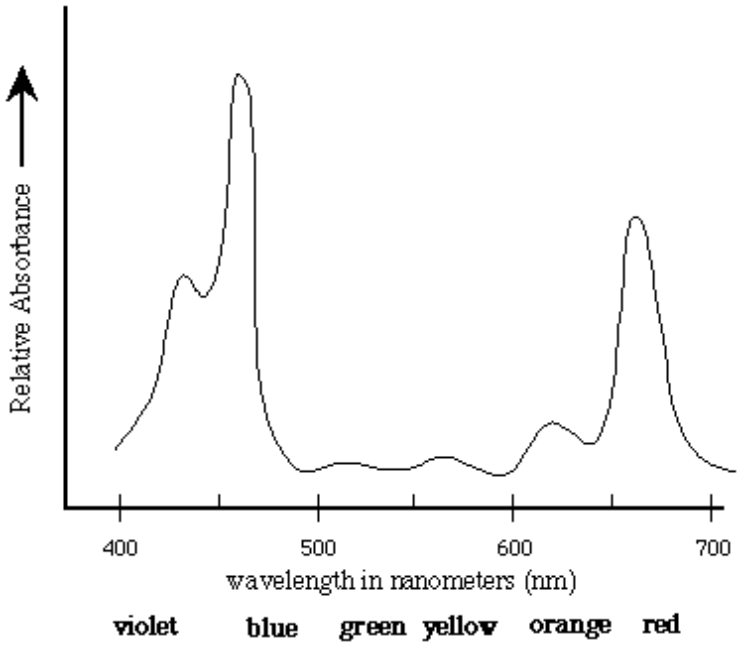
- Respiration: extracting energy from compounds (sugars)

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

Light is absorbed by **pigments**

- The primary pigment for photosynthesis is *chlorophyll a*
- It absorbs blue and red light, not green (green light is reflected back!)

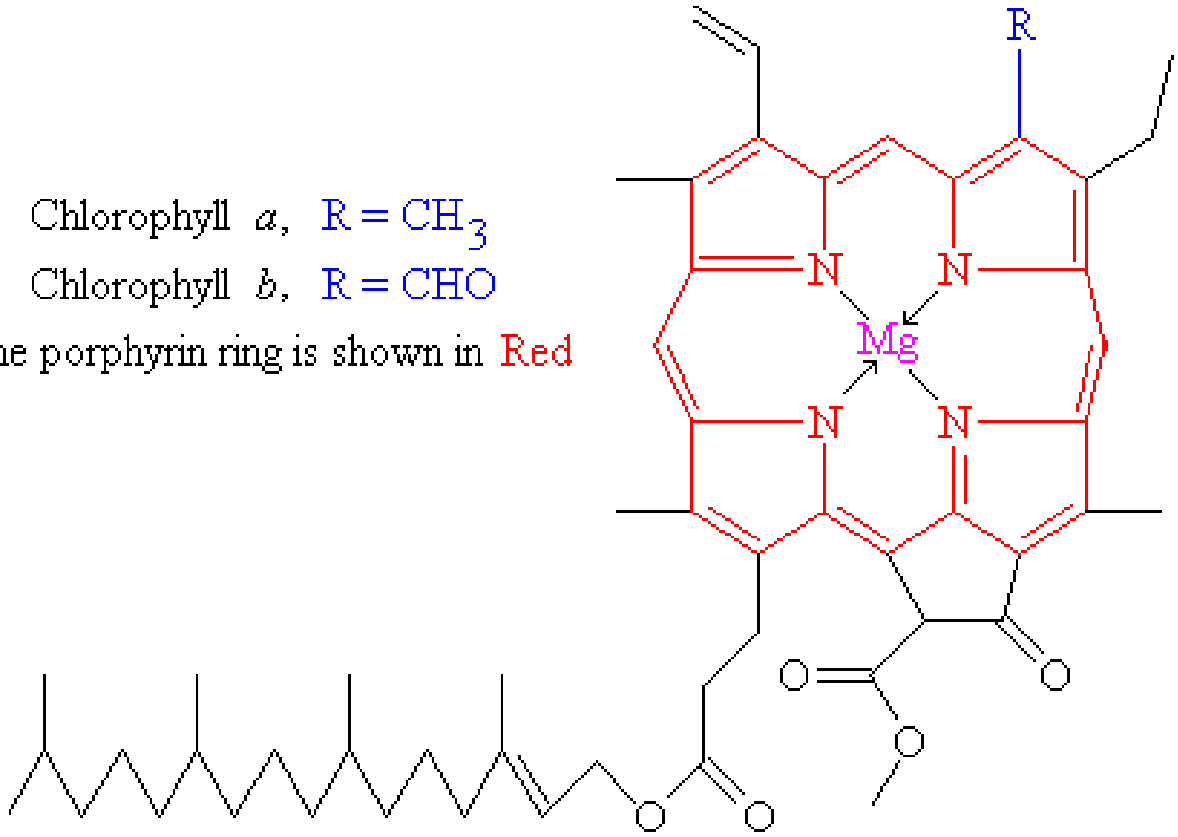
Absorption spectrum of *chlorophyll a*



Chlorophyll *a*, R = CH_3

Chlorophyll *b*, R = CHO

The porphyrin ring is shown in Red



Accessory pigments like *chlorophyll b* and carotenoids (beta-carotene, lycopene):

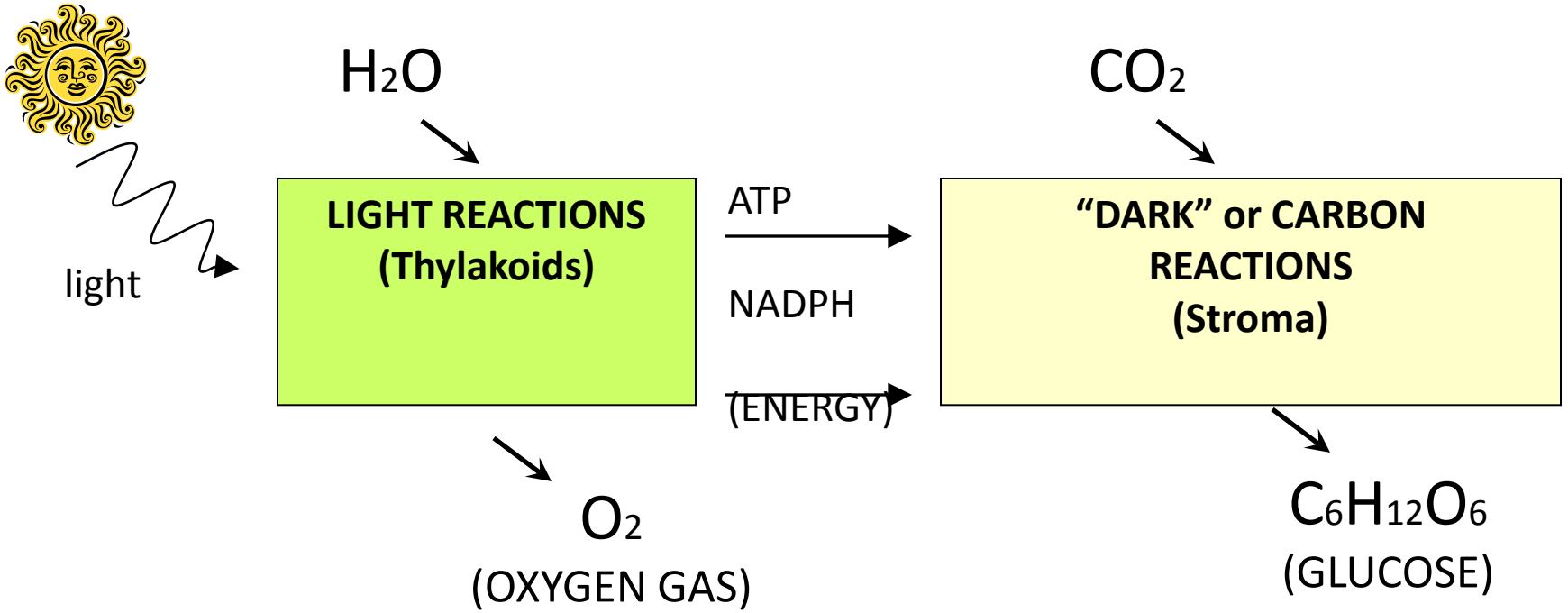
- absorb light at different wavelengths, (extending the absorption range)
- help transfer some energy to *chlorophyll a*
- protect cell from harmful byproducts

Chlorophyll a is the primary photosynthetic pigment that drives photosynthesis.

Accessory pigments absorb at different wavelengths, extending the range of light useful for photosynthesis.

Overview of photosynthesis:

Note: The Light and "Dark"or Carbon reactions happen at different sites in the chloroplast



IV. The Light Reactions

1. Light dependent
2. Occur in the **thylakoid membrane** of chloroplast
3. **Water** is split into **oxygen gas** (O_2) and **H^+**
4. Use **light energy** (photons) to generate two **chemical energy** compounds: ATP & NADPH

Chemical energy compounds made in the light reactions

$$ADP + Pi + Energy \leftrightarrow ATP$$

adenosine diphosphate

inorganic phosphate

adenosine triphosphate

$$NADP^+ + 2e^- + H^+ \leftrightarrow NADPH$$

Nicotinamide adenin dinucleotide phosphate

Summary of the Light reactions

$$2\ H_2O + 2\ NADP^+ + 3\ ADP + 3\ P_i$$

$$O_2 + 2\ NADPH + 3\ ATP + 4\ e^- + 2\ H^+$$

(gas)

<u>Light reactions</u>: Chemical energy compounds are made from light energy, water is split into O_2 and protons

V. The"Dark" or Carbon Reactions

1. Light independent (can occur in light or dark; some enzymes require activation by light)
2. Occur in the **stroma** of chloroplasts
3. Use the **chemical energy** produced in Light Reactions (ATP; NADPH) to reduce CO_2 to carbohydrate (sugar).
4. CO_2 is converted to sugar by entering the Calvin Cycle

Summary of Carbon Reactions

$$6\ CO_2 + 18\ ATP + 12\ NADPH + 12\ H_2O$$

$$C_6H_{12}O_6 + 18\ ADP + 18\ P_i + 12\ NADP^+$$

glucose

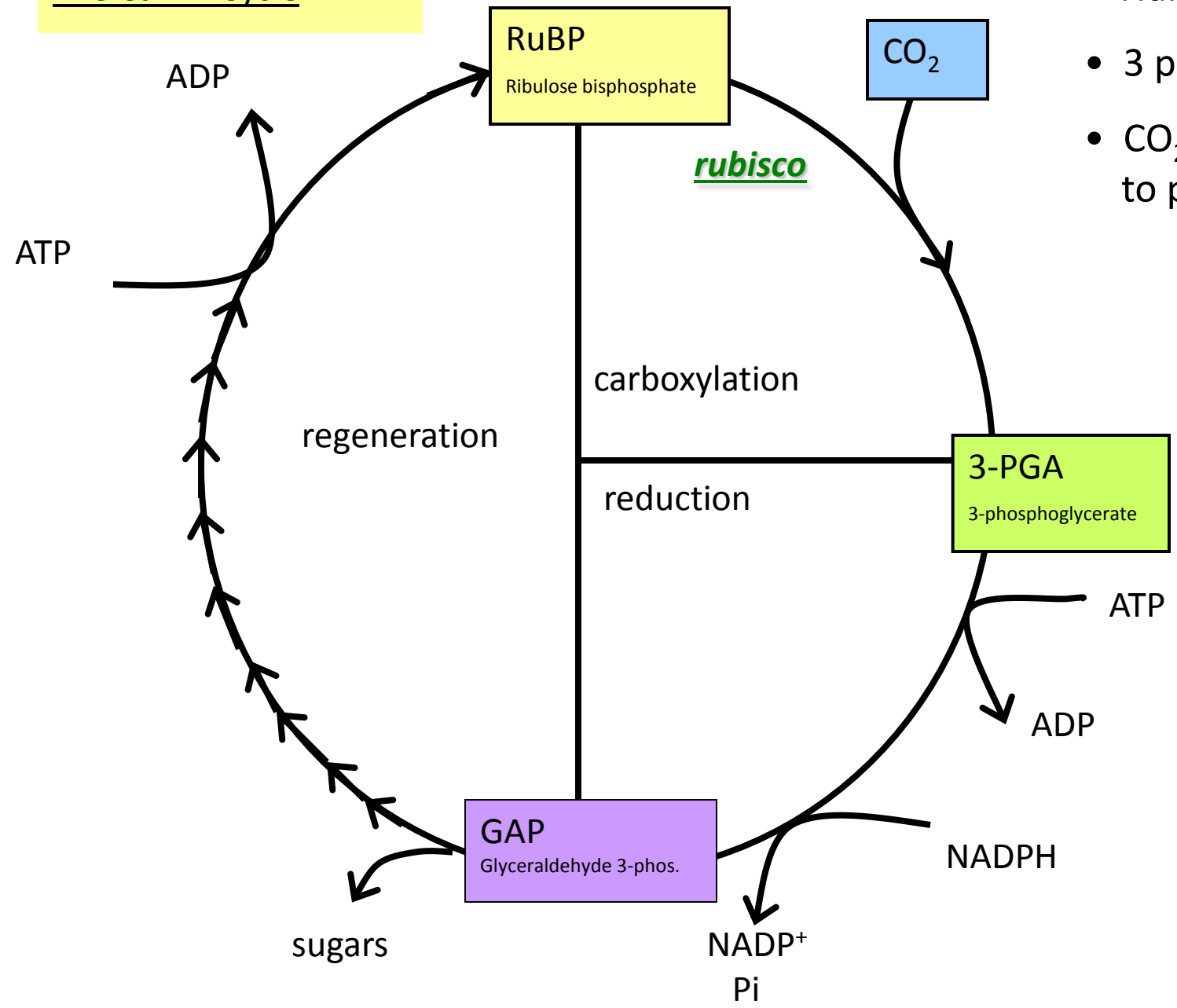
$$+ 6\ H_2O + 6\ O_2$$

Carbon reactions: Use CO_2 and chemical energy (ATP & NADPH) to produce sugars by means of the Calvin Cycle

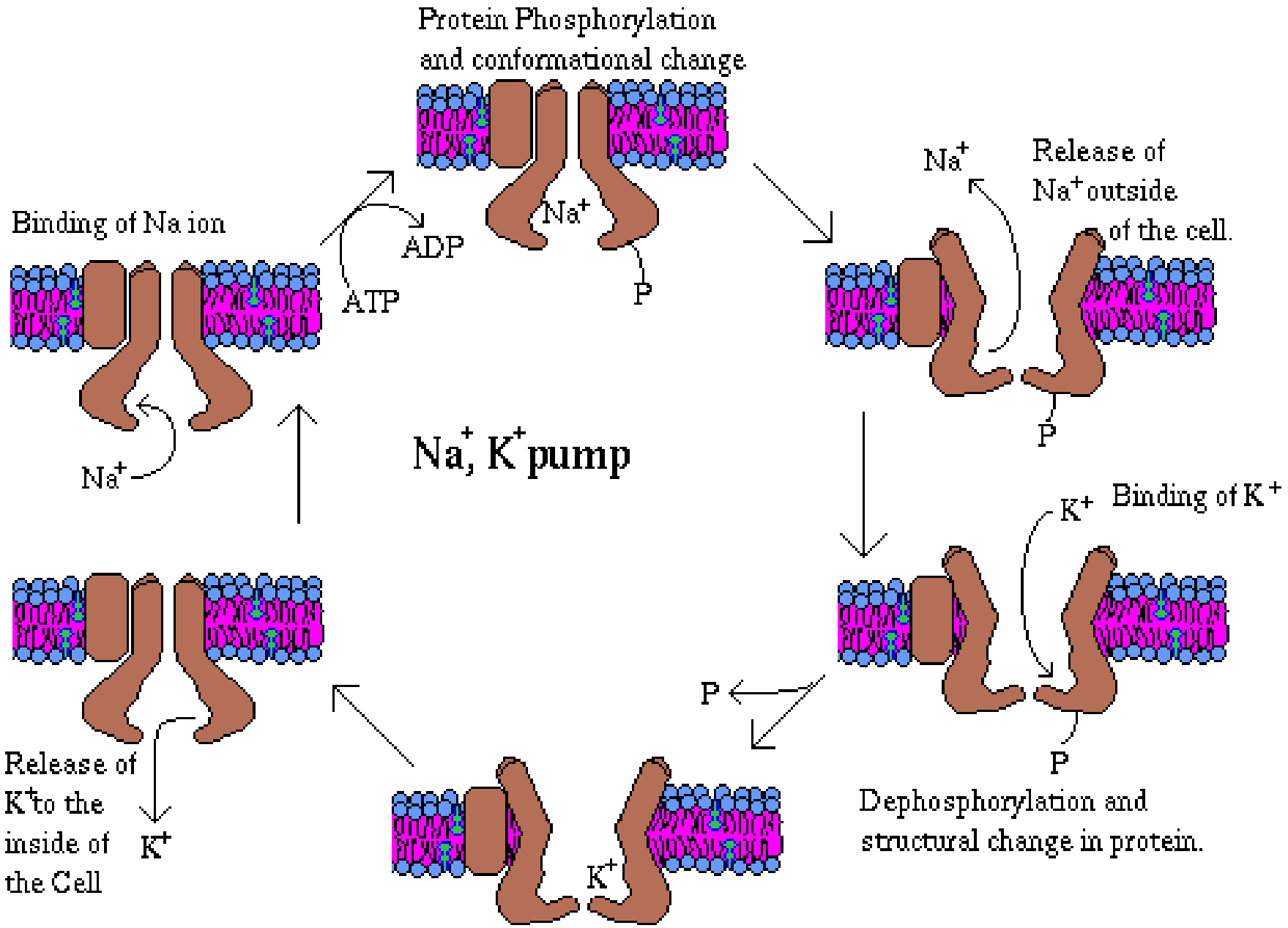
The Calvin Cycle

- CO_2 enters the **Calvin Cycle**
- First product is a 3-carbon molecule: 3-PGA (phosphoglyceric acid). That's why it's also called C-3 cycle.
- Enzyme RUBISCO (ribulose bisphosphate carboxylase/oxygenase) is the main enzyme that catalyzes the first reactions of the Calvin Cycle.
- RUBISCO: Is the most abundant protein on earth!

The Calvin Cycle



- Named for M. Calvin
- 3 phases, 13 steps
- CO_2 goes 6 cycles to produce 1 glucose



- The Top is the Outter membrane.
- The Bottom is the inner membrane (inside of the Cell)

Sodium-Potassium Pump

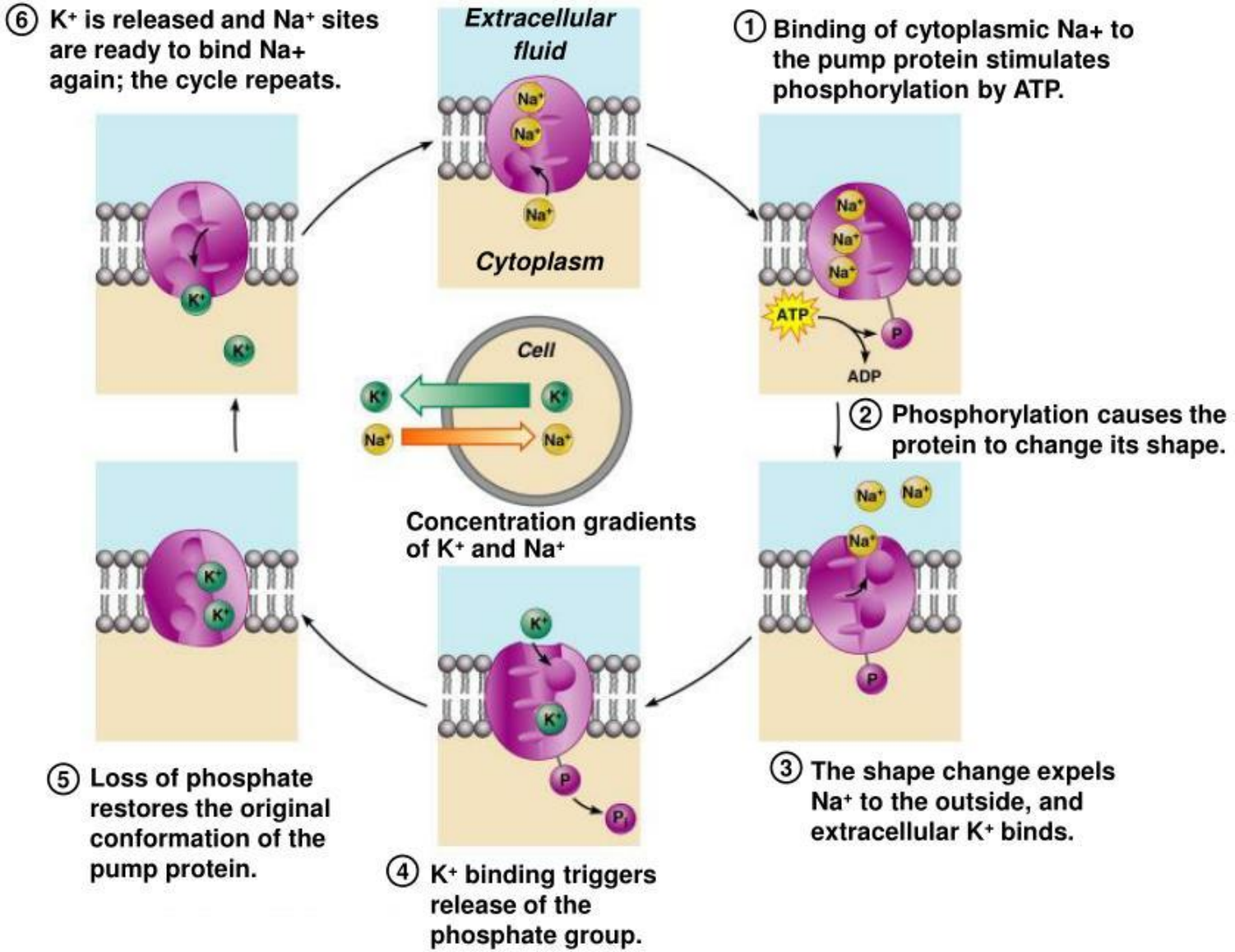


Figure 3.10

Role of Calcium

- More than 99% of total body calcium is stored in the bones and teeth where it functions to support their structure. The remaining 1% is found throughout the body in blood, muscle, and the fluid between cells.
- Calcium is also critical for the normal transmission of nerve impulses. Calcium flows into nerve cells and stimulates the release of molecules called neurotransmitters.
- Calcium also plays the role in muscle contraction, healthy blood pressure, the initiation of blood clotting, and the regulation of various hormones and enzymes.