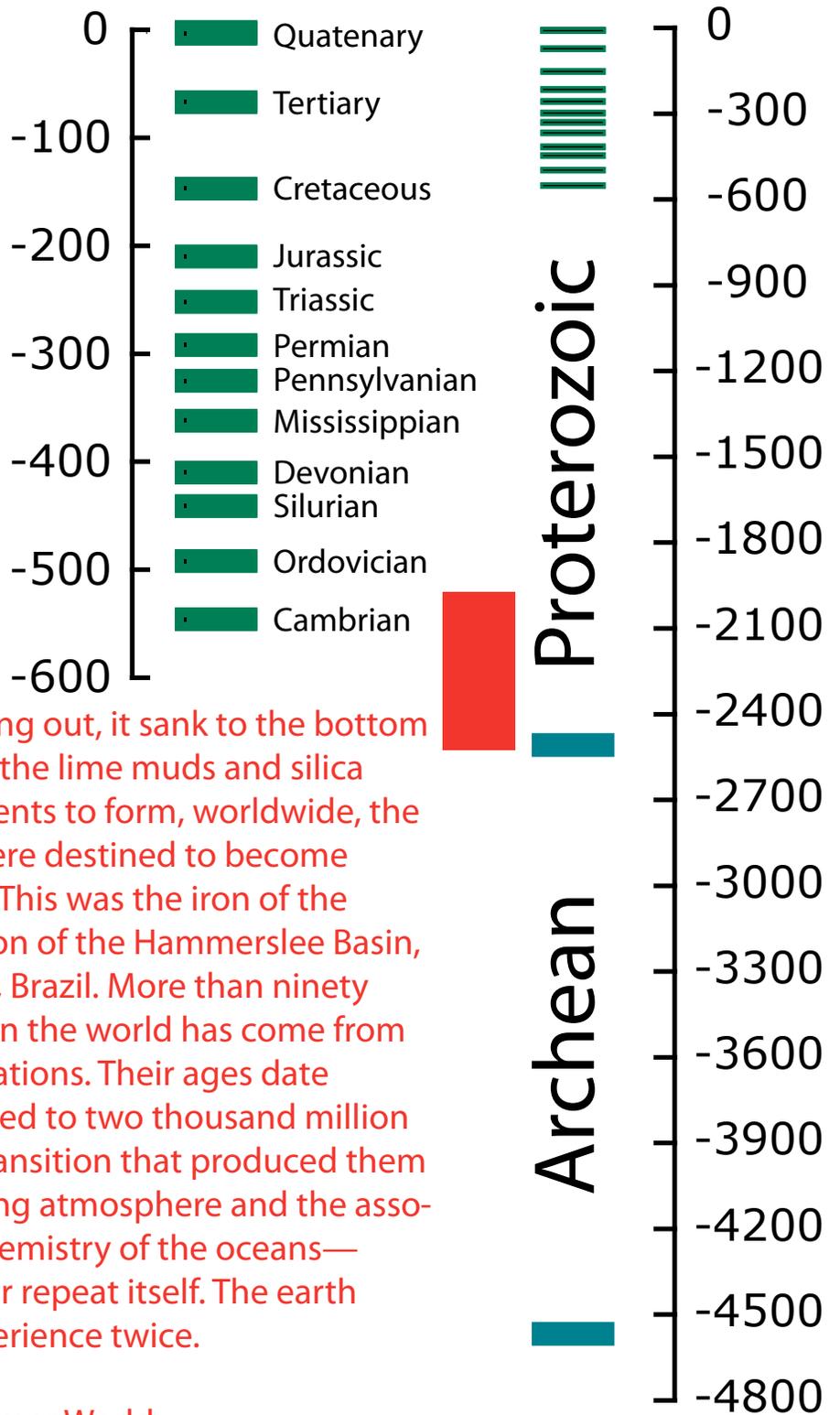


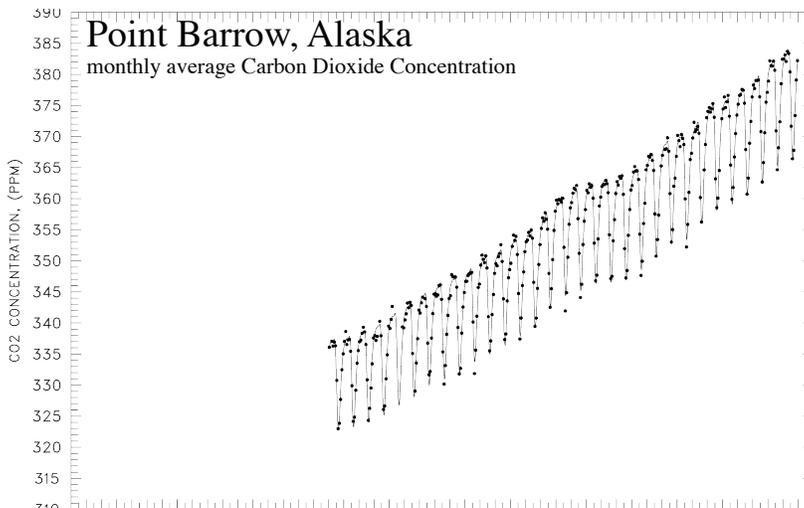
Although life had begun in the form of anaerobic bacteria early in the Archean Eon, photosynthetic bacteria did not appear until the middle Archean and were not abundant until the start of the Proterozoic. The bacteria emitted oxygen. The atmosphere changed. The oceans changed. The oceans had been rich in dissolved ferrous iron, in large part put into the seas by the extruding lavas of two billion years. Now with the added oxygen, the iron became ferric, insoluble and dense. Precipitating out, it sank to the bottom as ferric sludge, where it joined the lime muds and silica muds and other seafloor sediments to form, worldwide, the banded-iron formations that were destined to become rivets, motorcars, and cannons. This was the iron of the Mesabi Range, the Australian iron of the Hamersley Basin, the iron of Michigan, Wisconsin, Brazil. More than ninety percent of the iron ever mined in the world has come from Precambrian banded-iron formations. Their ages date broadly from twenty-five hundred to two thousand million years before the present. The transition that produced them—from a reducing to an oxidizing atmosphere and the associated radical changes in the chemistry of the oceans—would be unique. It would never repeat itself. The earth would not go through that experience twice.

John McPhee. *Annals of the Former World*

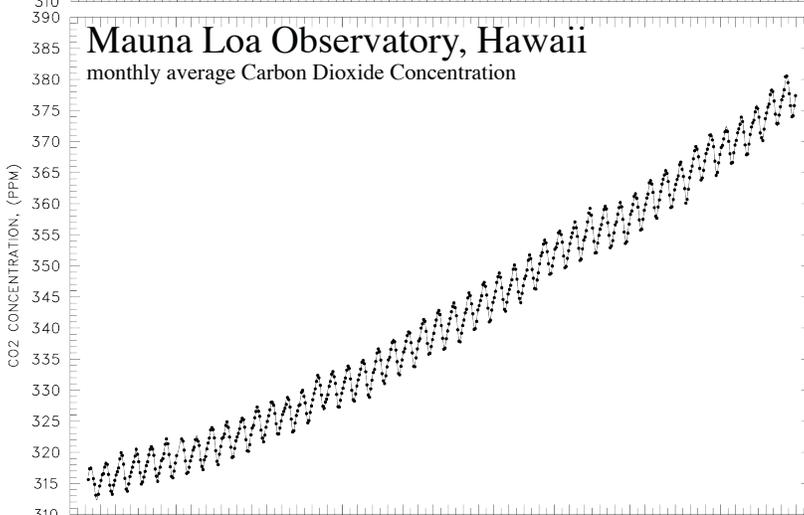
Plant Biology
SC/BIOL 2010



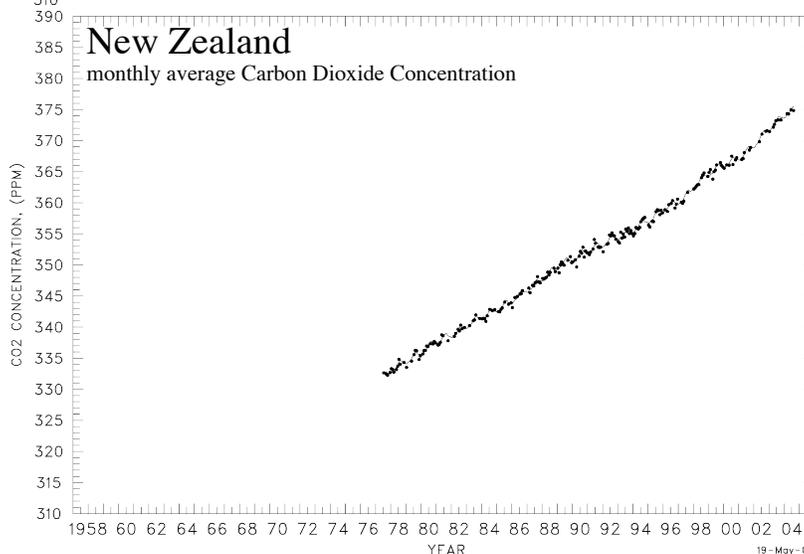
GO
green



Charles David Keeling, a professor at the Scripps Institution of Oceanography in La Jolla, California, measured carbon dioxide concentrations for extended periods of time in a number of locations around the world. The best known data series is from the dormant volcano in Hawaii, Mauna Loa (middle graph). The steady rise in carbon dioxide concentrations has been a key observation in support of ‘global warming’, since elevated atmospheric carbon dioxide acts to ‘trap’ long wave IR radiation, resulting in elevated atmospheric temperatures (the greenhouse effect).



There is a noticeable ‘wobble’ in the data series, an annual periodic fluctuation. The fluctuation is very large at northern latitudes (the Point Barrow, Alaska data, upper panel), smaller in magnitude at mid northern latitudes (Mauna Loa, Hawaii, middle panel), and absent in southern latitudes (New Zealand, lower panel).



Presumably, the annual fluctuations arise from the seasonal variation in photosynthesis and respiration of terrestrial plants (northern latitudes contain most of the earth’s land mass). Normally, these cycles are well balanced, since the magnitude of the fluctuation is little changed, even as carbon dioxide concentrations have increased.

The data are clear evidence for the Power of Photosynthesis in biotic control of the earth’s environment.

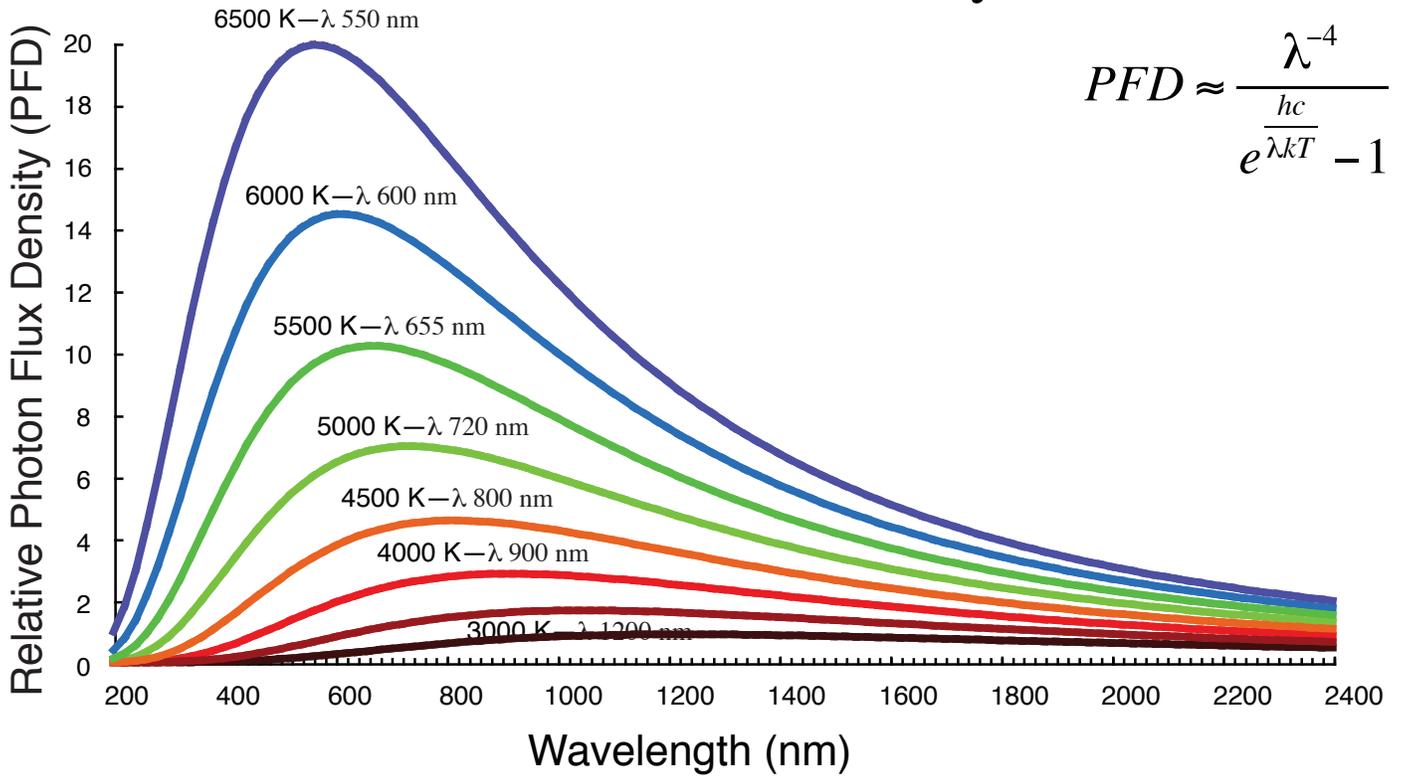
The data are from:

<http://gcmd.gsfc.nasa.gov/KeywordSearch/Metadata.do?Portal=GCMD&KeywordPath=&NumericId=2520&MetadataView=Text&MetadataType=0&lbnode=mdlb2>



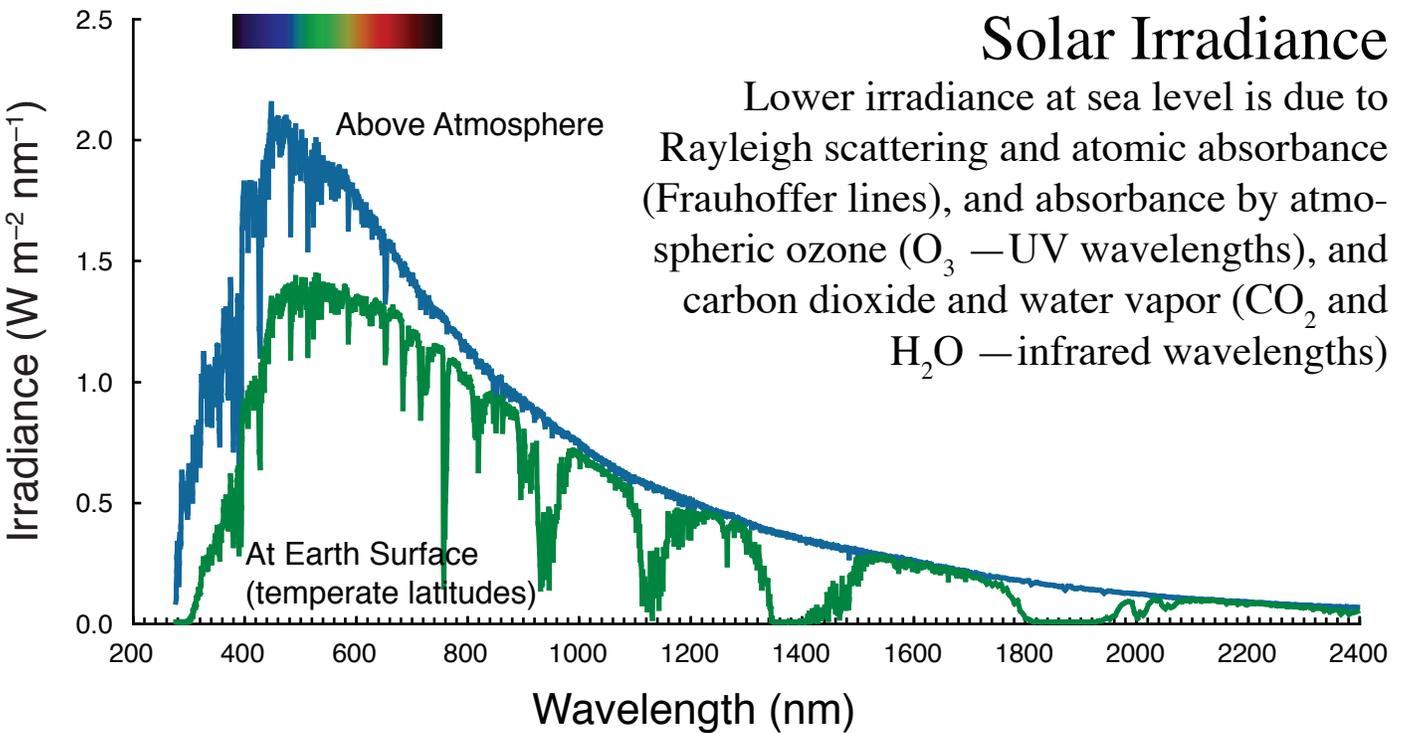
Planck's Black Body Radiation Law

$$PFD \approx \frac{\lambda^{-4}}{e^{\frac{hc}{\lambda kT}} - 1}$$



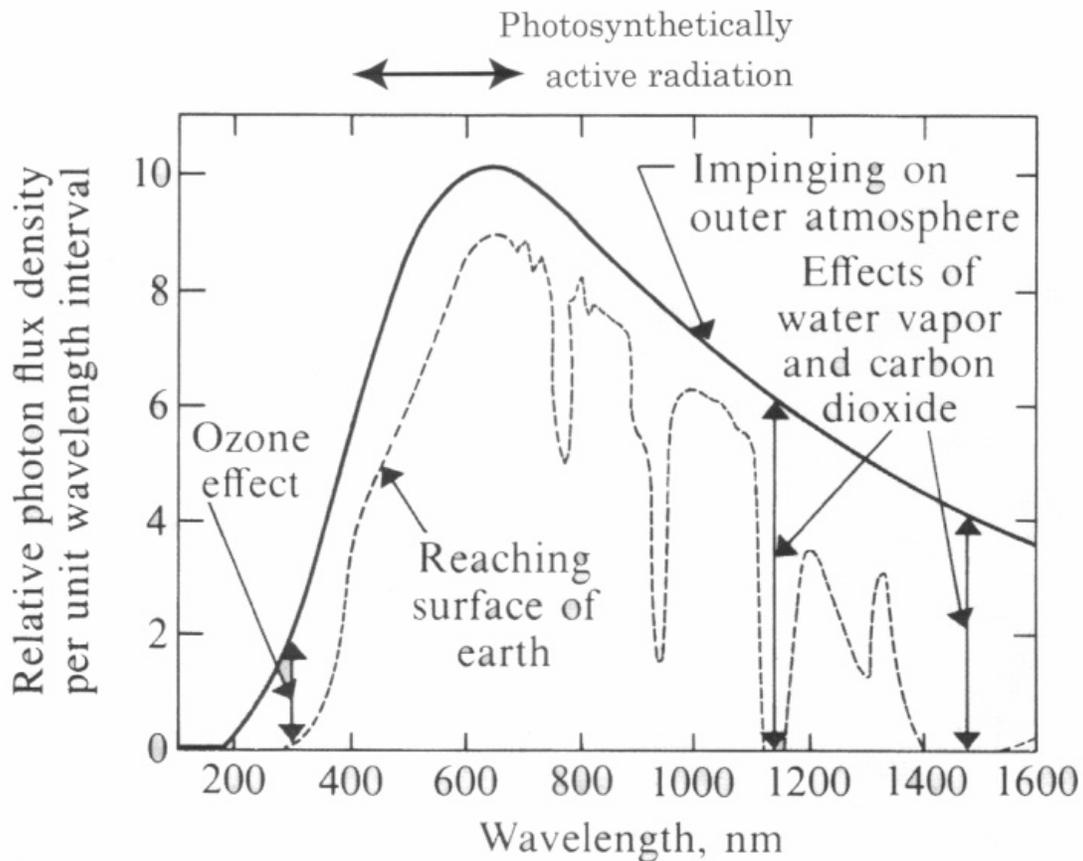
Solar Irradiance

Lower irradiance at sea level is due to Rayleigh scattering and atomic absorbance (Fraunhofer lines), and absorbance by atmospheric ozone (O₃ — UV wavelengths), and carbon dioxide and water vapor (CO₂ and H₂O — infrared wavelengths)



Photosynthesis
 SC/BIOL 4160

Lucida
 Photosynthetica

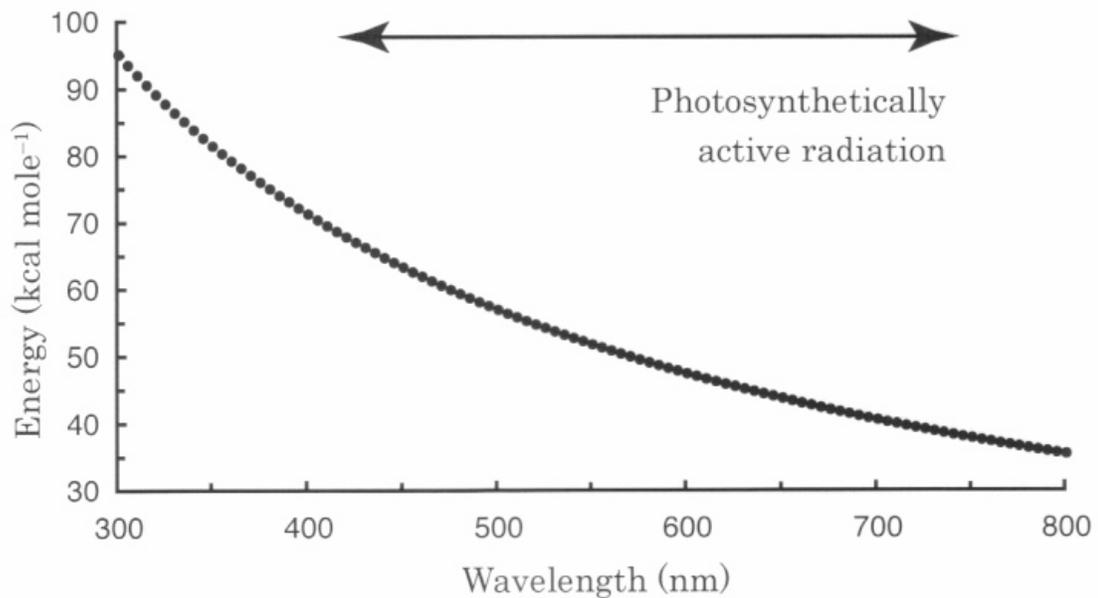


Distribution of photon intensity (flux) on the earth's atmosphere and its surface. The photon flux from the sun is a function of temperature: The maximal wavelength:

$$\lambda_{\max} = \frac{3.6 \cdot 10^6 \text{ (nm K)}}{^{\circ}\text{K}}$$

is about 620 nm for the temperature of the sun (about 5800 °K).

Nobel, PS (1991) *Physicochemical and Environmental Plant Physiology*. Academic Press. pp. 191–204



The energies of light are shown versus wavelength, calculated from the relation discovered by Planck and Einstein:

$$E = h \cdot \frac{\nu}{\lambda}$$

where h is Planck's constant ($1.584 \cdot 10^{-37}$ kcal \cdot sec), ν is the velocity ($3 \cdot 10^{10}$ cm \cdot sec⁻¹ in vacuum) and λ is the wavelength.

Nobel, PS (1991) Physicochemical and Environmental Plant Physiology. Academic Press. pp. 191–204

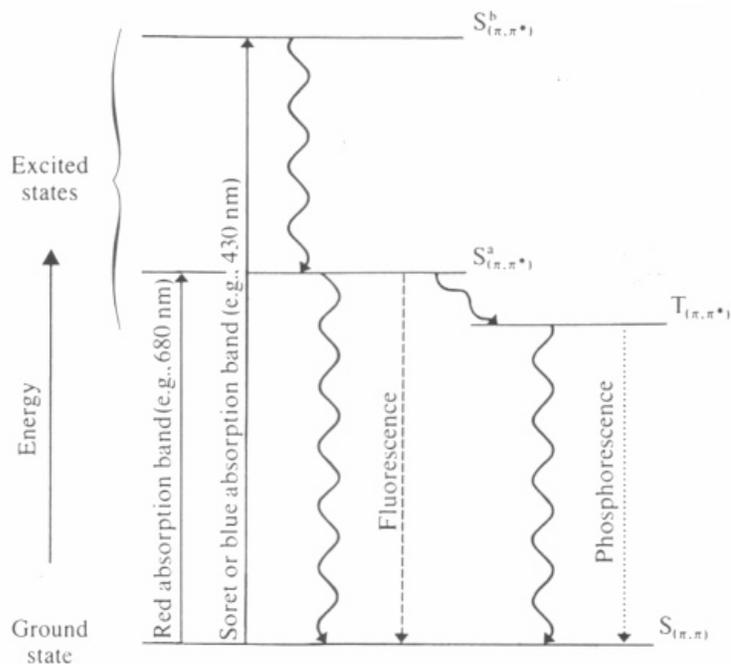


Figure 4.5

Energy level diagram indicating the principal electronic states and some of the transitions of chlorophyll. Straight vertical lines represent the absorption of light; wavy lines indicate radiationless transitions, for which the energy is eventually released as heat; broken lines indicate those de-excitations accompanied by radiation.

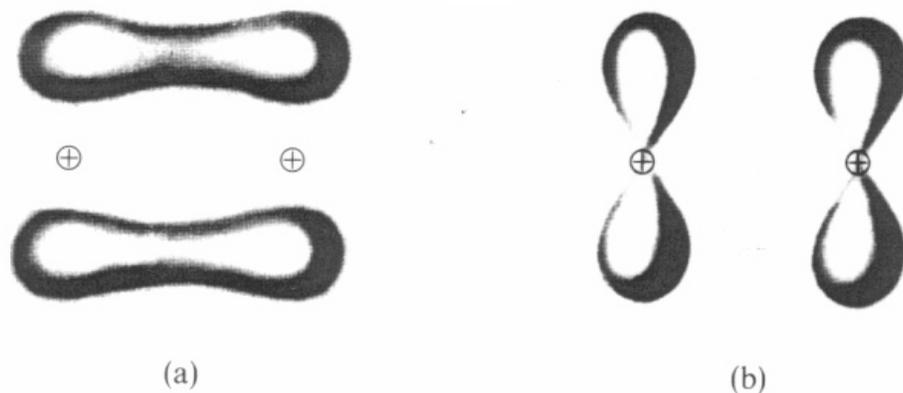


Figure 4.4

Typical π and π^* orbitals, indicating the spatial distribution about the nuclei (\oplus) where the greatest probability of finding the electrons occurs: (a) π orbital (bonding), and (b) π^* orbital (antibonding).

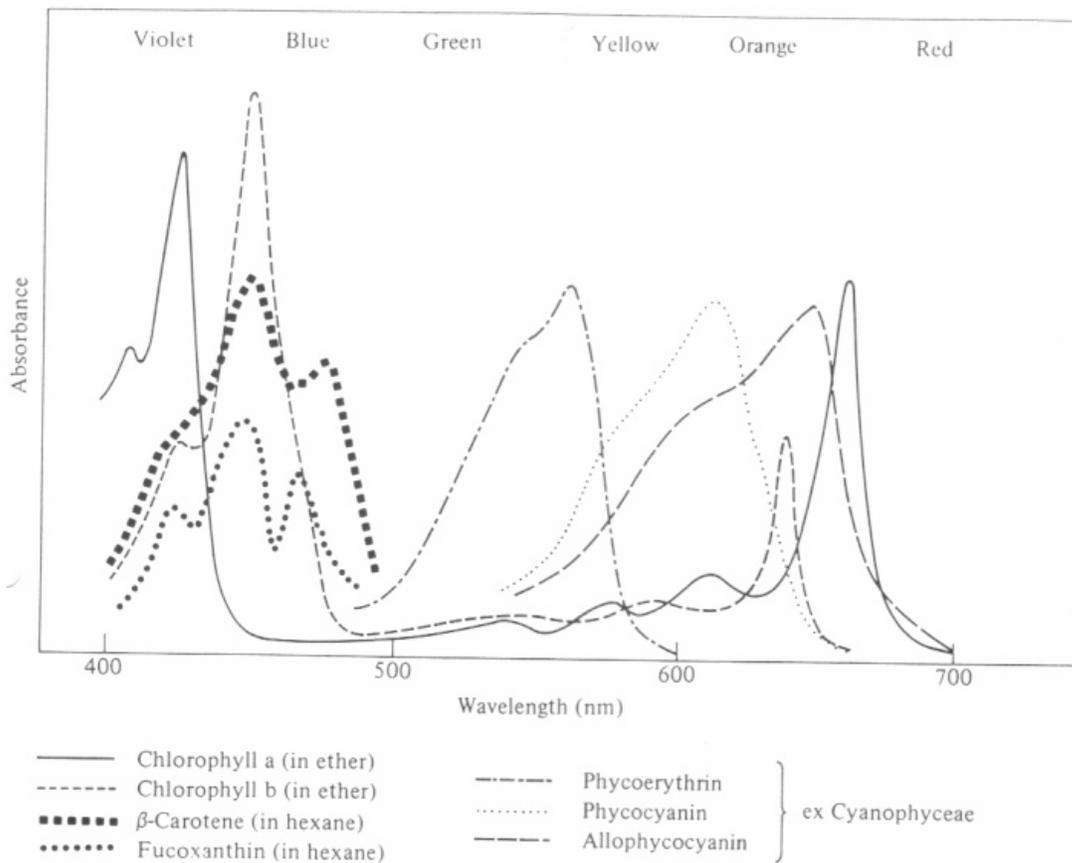
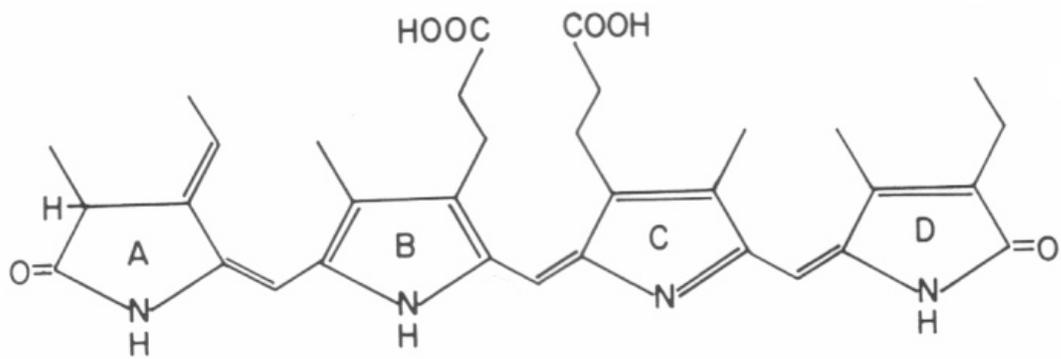
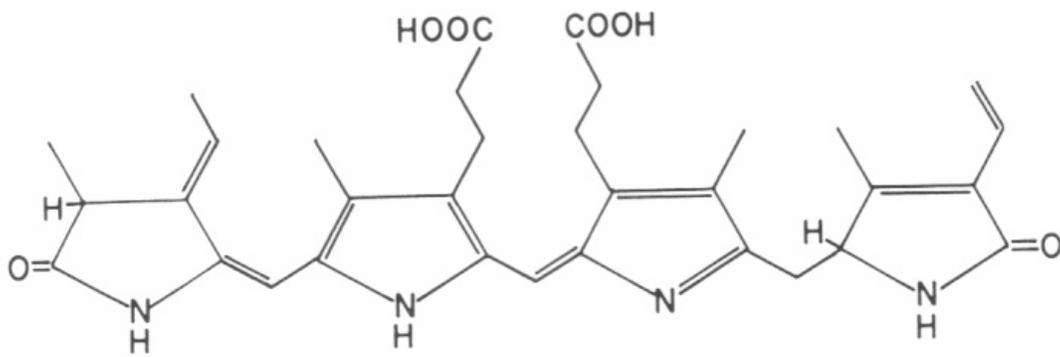


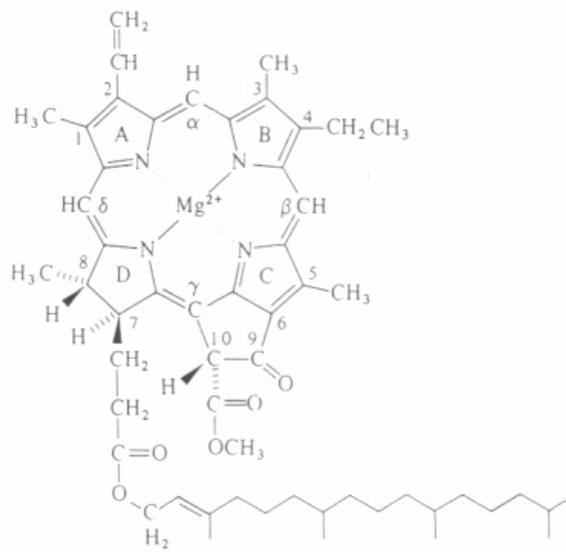
Fig. 5.7. Absorption spectra of selected members of the three groups of photosynthetic pigments, the chlorophylls, the carotenoids and the phycobilins.



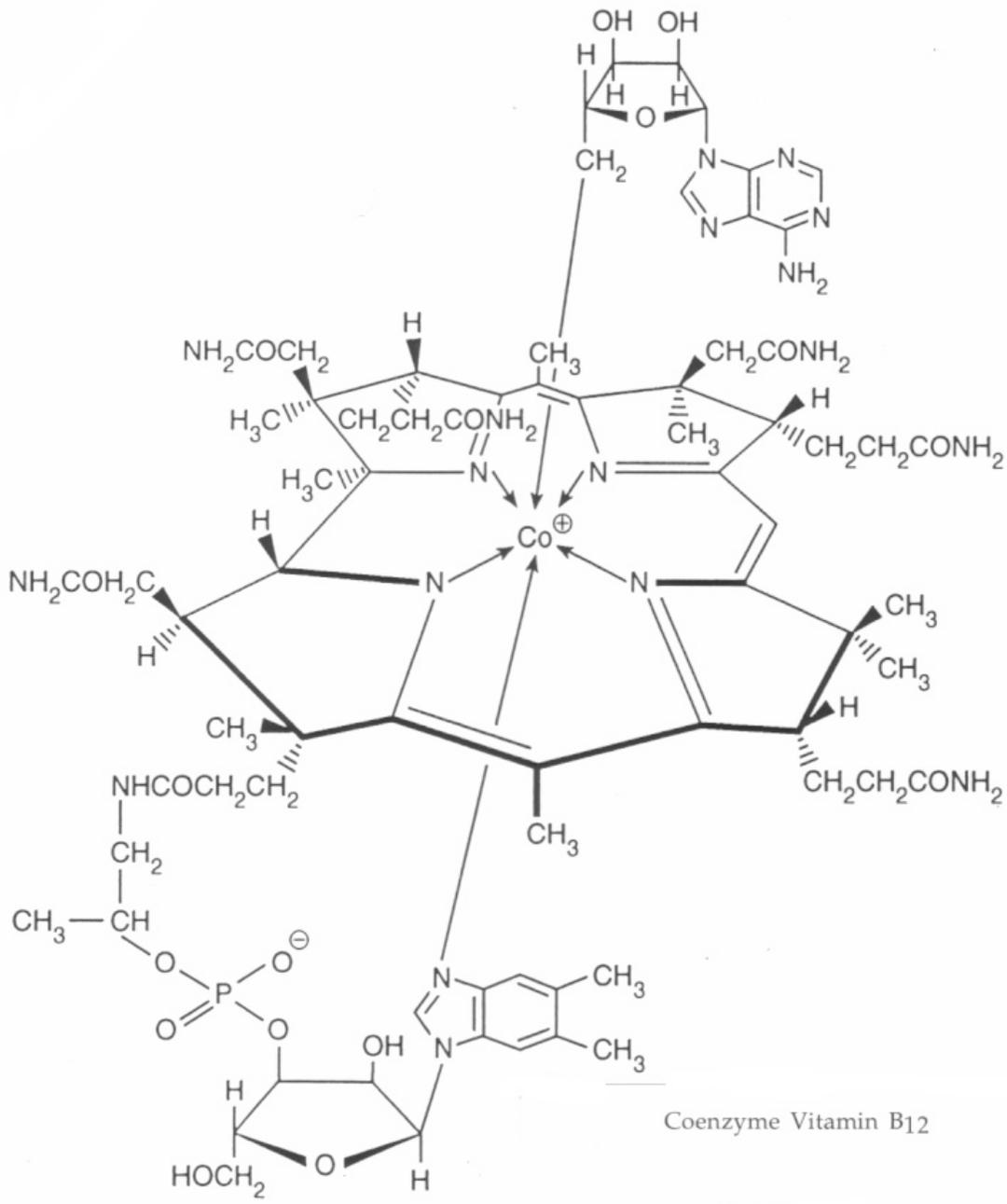
Phycocyanobilin



Phycoerythrobilin

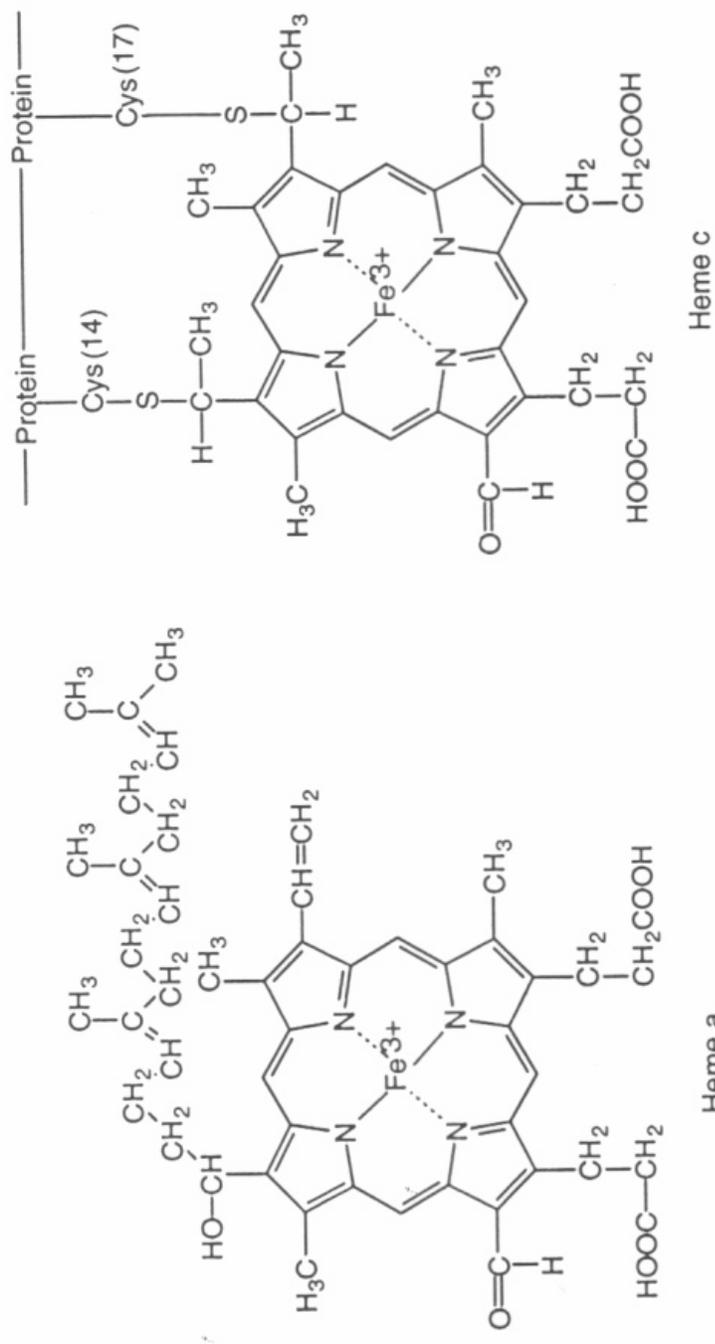


(12.1)



Coenzyme Vitamin B12

from: Lionel R. Milgrom. 1997. *The Colours of Life: An introduction to the chemistry of porphyrins and related compounds*. Oxford University Press.

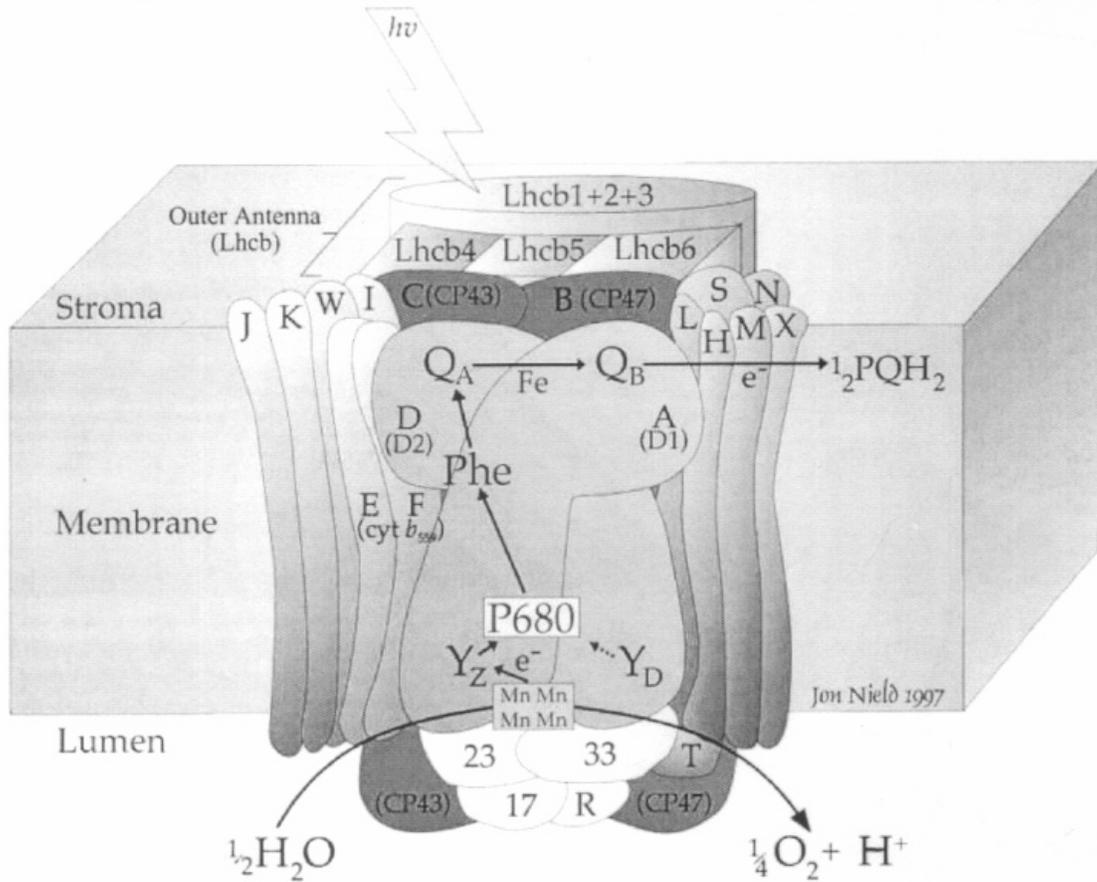


Comparison of heme *a* (cytochrome *a*) and heme *c* (cytochrome *c*).

from: Lionel R. Milgrom, 1997. *The Colours of Life: An introduction to the chemistry of porphyrins and related compounds*. Oxford University Press.

Protein subunits of PSII - Barber et al. (1997) *Physiol. Plant.* 100:817-827

At present there are 25 genes which have been identified as encoding proteins for the PSII core and are referred to as *psb* (photosystem b) genes. In higher plants and algae, most of these genes are located in the chloroplast genome, but some are nuclear encoded. There are undoubtedly more to be discovered. In some cases these components are restricted to a particular class of organism. In addition there are the genes that encode the proteins of the outer antenna systems; *cab* genes in higher plants and green algae give rise to a series of chlorophyll a/chlorophyll b binding proteins (Lhcb1-6) while the *apc* and *cpc* genes encode the protein of the phycobilisomes of cyanobacteria and red algae.



from: <http://www.bio.ic.ac.uk/research/barber/photosystemII/PSII-subunits.html> The Barber Research Group at Imperial College of Science, Technology and Medicine. London UK.

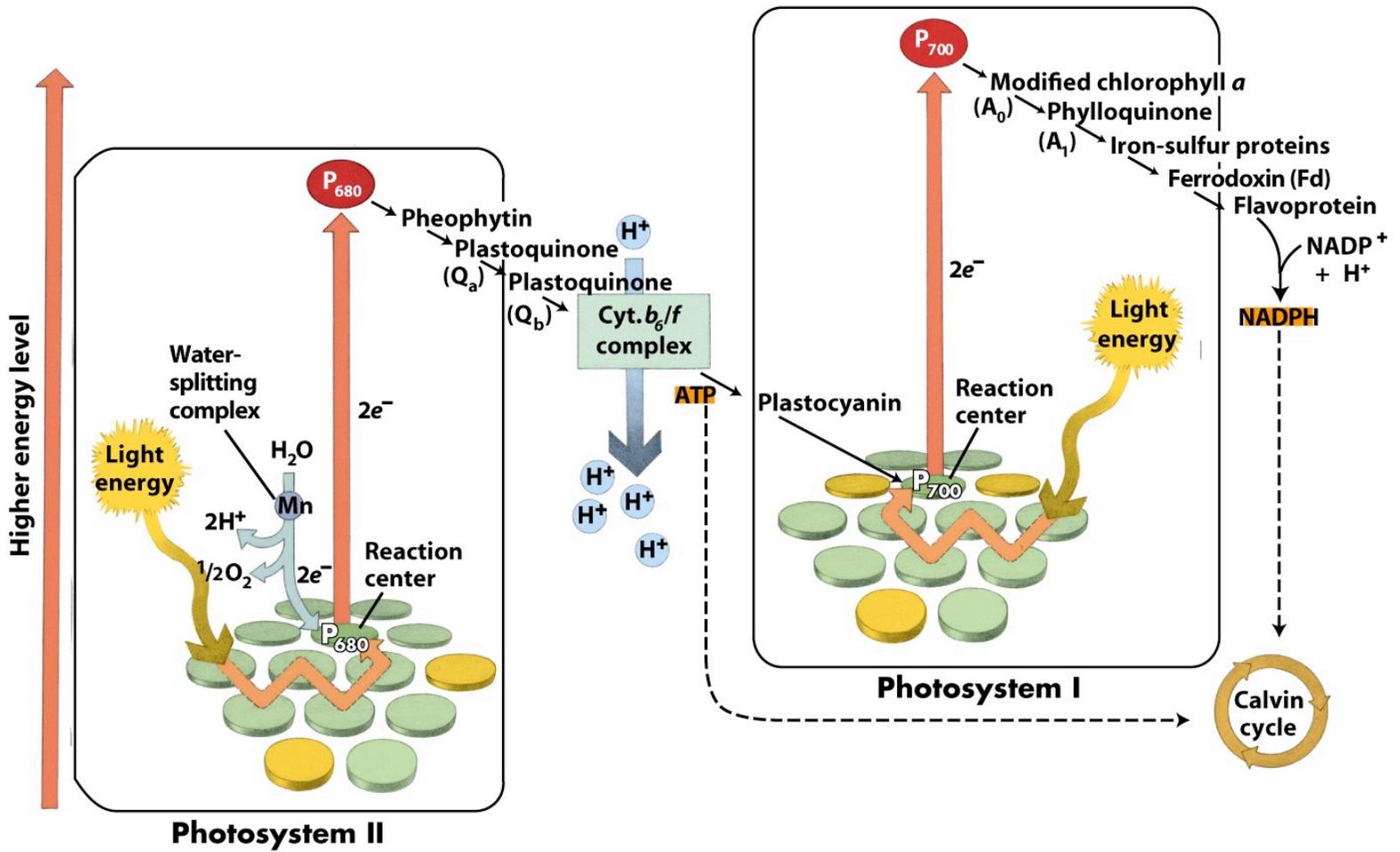
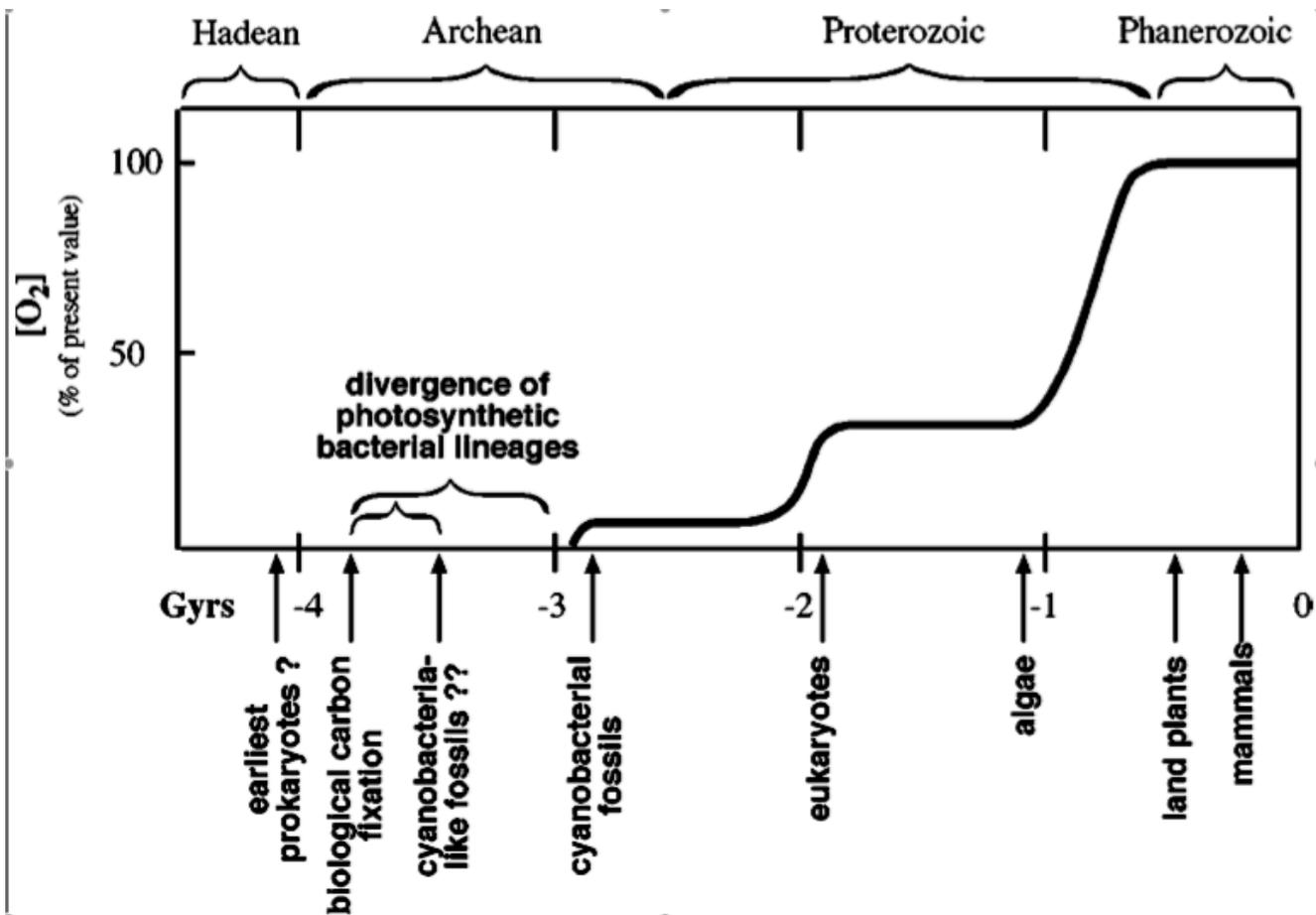


Figure 7-11
 Biology of Plants, Seventh Edition
 © 2005 W.H. Freeman and Company

Figure 1 Schematic representation of the rise of oxygen level on Earth during the early history of life [modified from (27)¹]. Major evolutionary landmarks are indicated by arrows on the lower x-axis, and major geological periods are indicated by brackets on the upper x-axis. Putative stages of early divergence of photosynthetic prokaryotes are indicated by brackets above the lower x-axis: one assumes ~ 3–3.8 Gyrs and the other 3.5–3.8 Gyrs, depending on what date is accepted as the starting point for oxygenic photosynthesis.



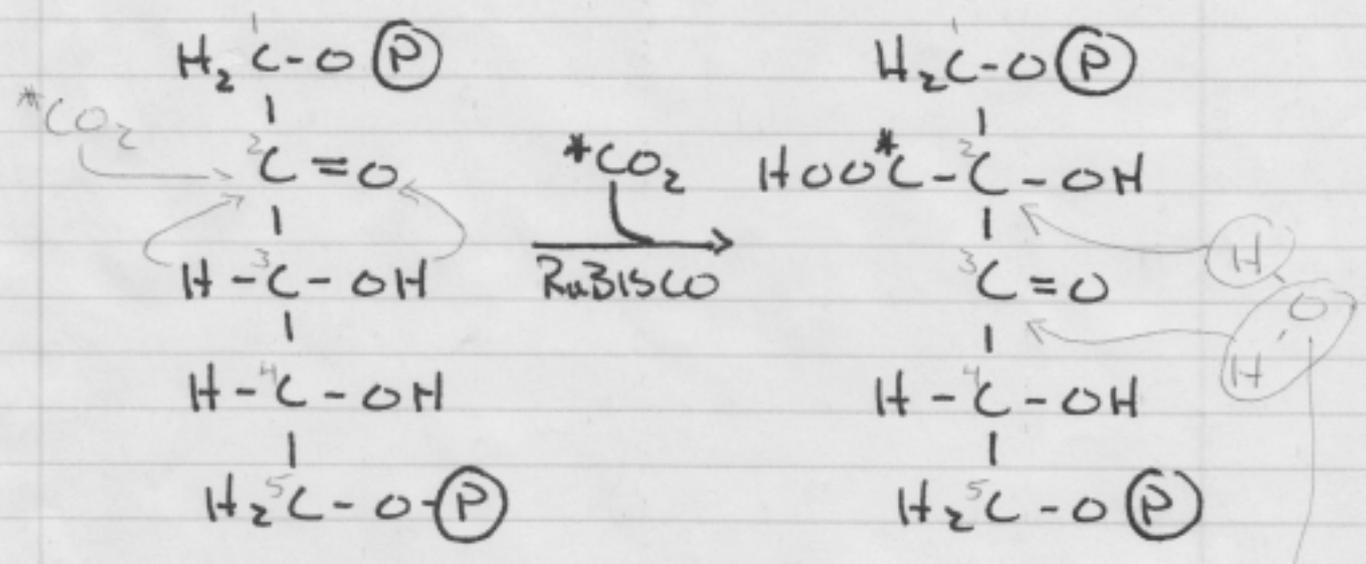
Carl E. Bauer and Jin Xiong (2002) Complex evolution of photosynthesis. *Annual Review of Plant Biology* 53:503–521.

¹ Nitschke W, Muhlenhoff U, Liebl U. 1998. Evolution. In *Photosynthesis: A Comprehensive Treatise*, ed. A. Raghavendra, pp. 286–304. Cambridge, UK: Cambridge Univ. Press

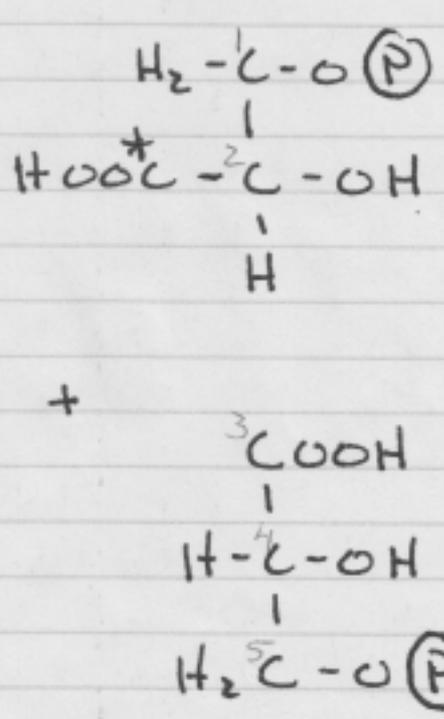
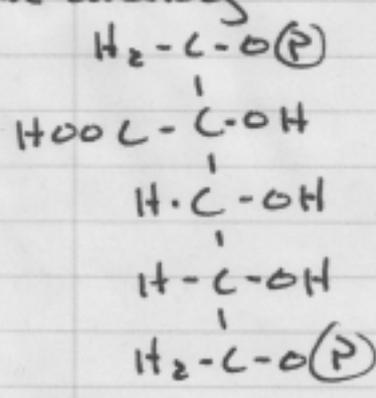
CO₂ FIXATION

(Ribulose 1,5-diphosphate)

6-carbon intermediate*
(2-carboxy-3-keto-D-ribitol 1,5-diphosphate)



*RuBISCO cleaves
2-carboxy-3-keto-D-ribitol
1,5-diphosphate
to 3-PGA (2) and
an analog



3-phospho
glycerate
(3PGA)

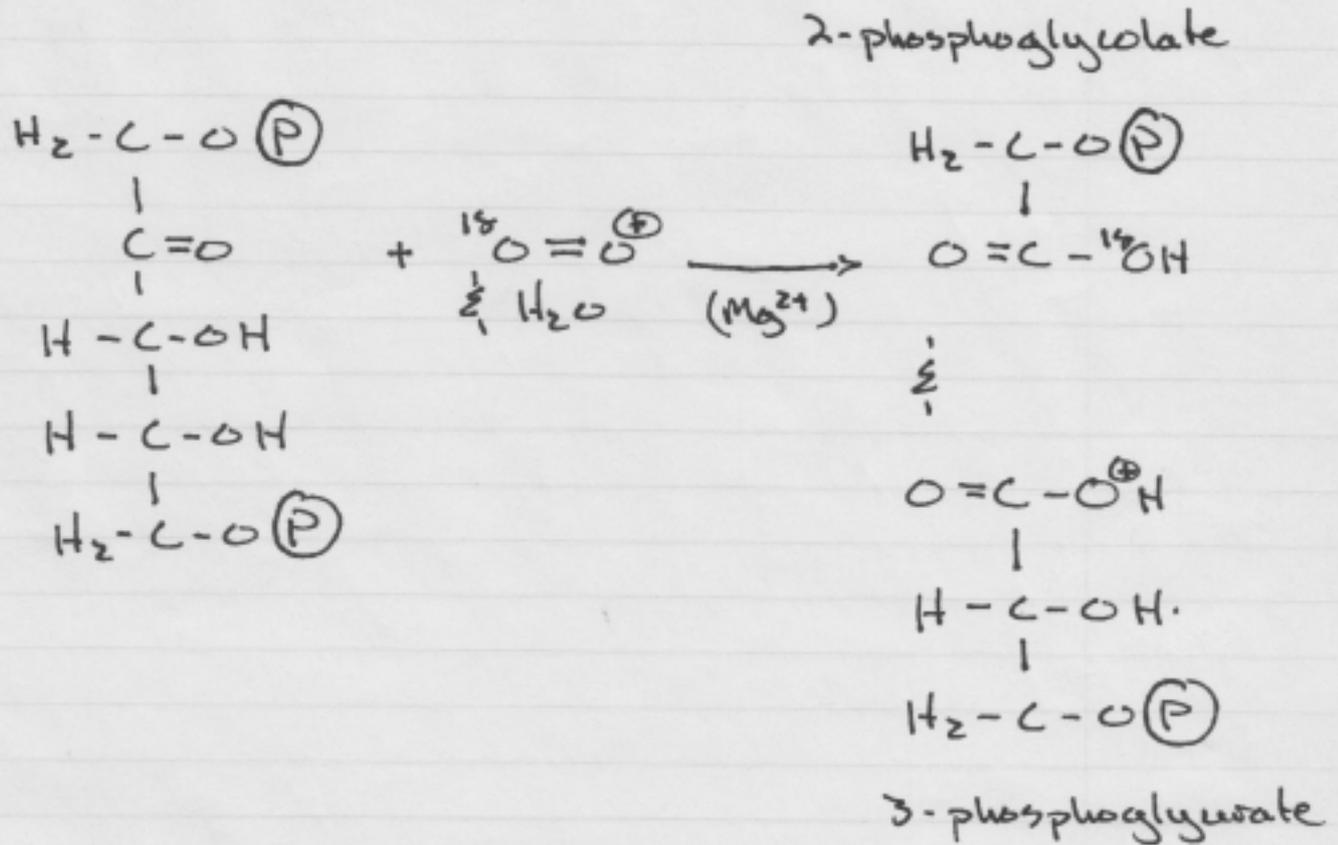
inhibits irreversibly
(forms an intermediate
form during the
enzymatic reaction)

ketoribitol (Hosokawa)
also called ketoarabinitol (Eikenberg & Strop)
ketopentitol (Goodwin & Mascer)
why? I don't know

PHOTORESPIRATION

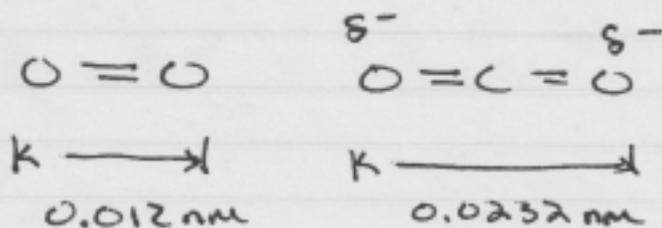
In addition to the carboxylation reaction of RuBisCo, it also has a biochemically significant oxygenase reaction.

The reaction:



while the 3-phosphoglycerate can enter the Calvin Cycle, the 2-phosphoglycolate must be "regenerated" in a series of reactions in the chloroplast, peroxisome and mitochondria.

Oxygen and carbon dioxide are very different



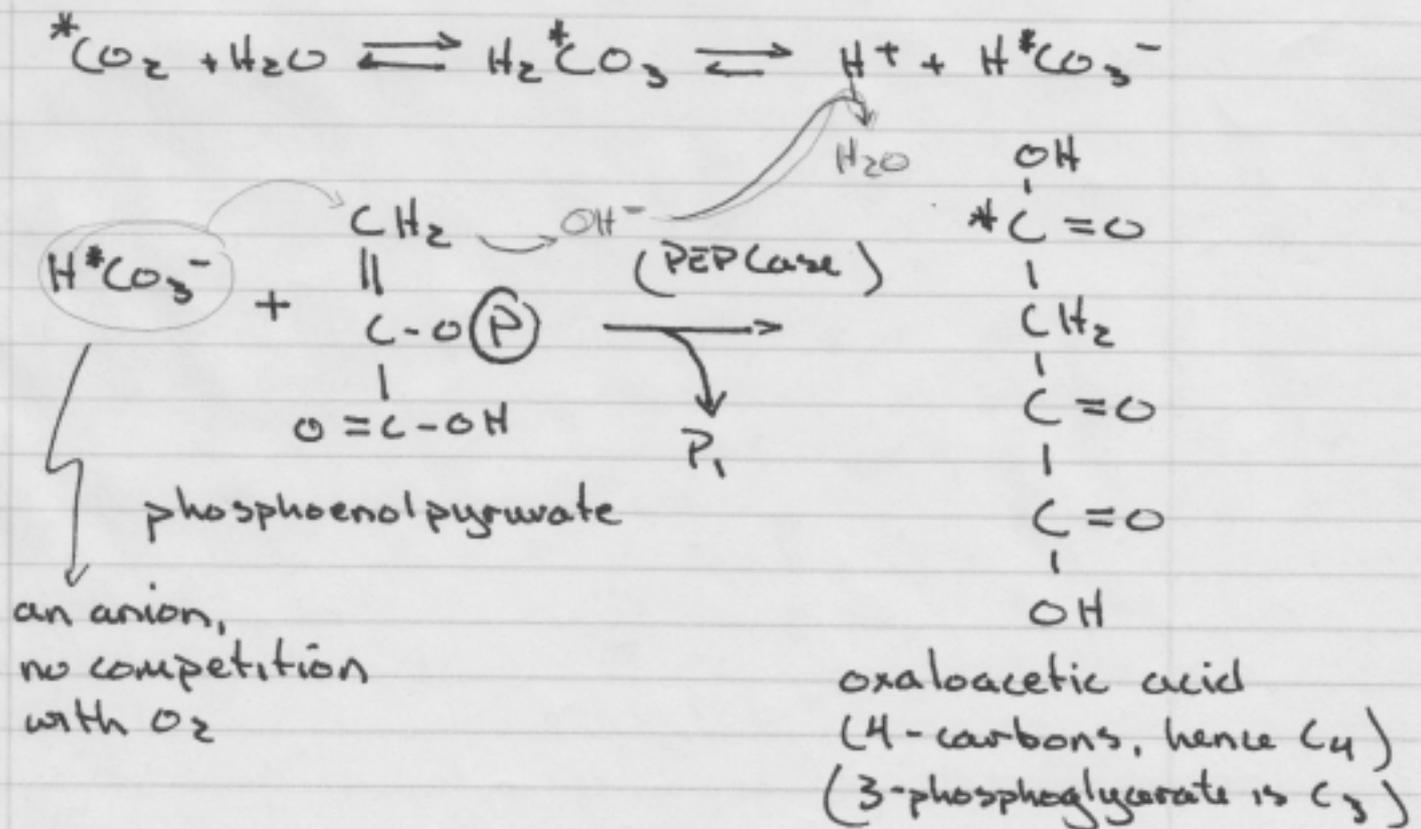
C₄ PATHWAY OF CARBON FIXATION

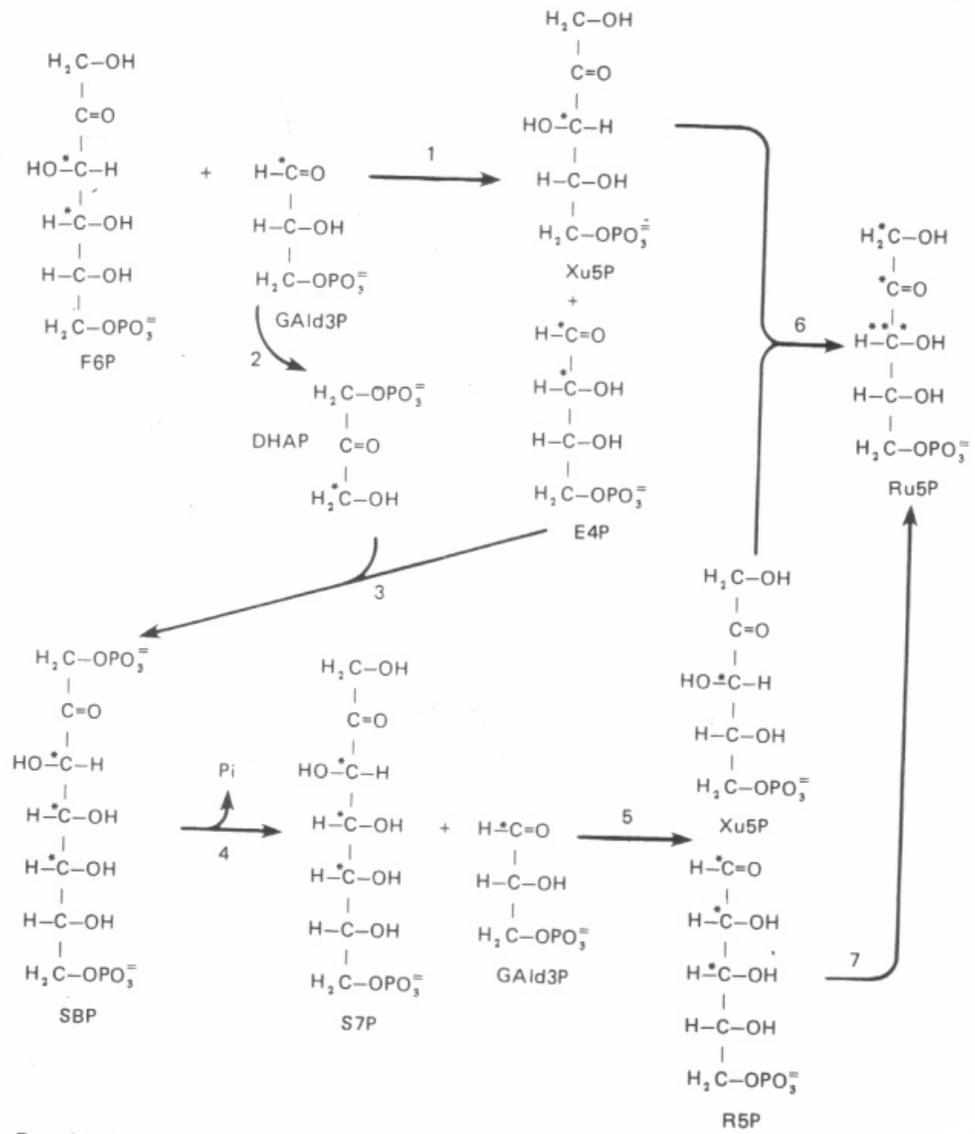
To overcome the intrinsic problem of oxygenase activity of RuBisCO, photosynthetic organisms have evolved

CARBON DIOXIDE CONCENTRATING MECHANISMS.

The "simplest" of these is to actively take up CO₂ into the cell (chloroplast) to increase [CO₂] for RuBisCO. This is done in aquatic organisms, both eukaryotic algae and prokaryotic cyanobacteria.

In terrestrial plants "concentrating mechanisms" involve biochemical fixation of CO₂ via a different enzyme: phosphoenolpyruvate carboxylase (PEPCase).





- Reaction:
1. Fructose 6-phosphate + glyceraldehyde 3-phosphate $\xrightarrow{\text{transketolase}}$ xylulose 5-phosphate + erythrose 4-phosphate
 2. Glyceraldehyde 3-phosphate $\xrightarrow{\text{triose phosphate isomerase}}$ dihydroxyacetone phosphate
 3. Erythrose 4-phosphate + dihydroxyacetone phosphate $\xrightarrow{\text{aldolase}}$ sedoheptulose 1,7-bisphosphate
 4. Sedoheptulose 1,7-bisphosphate $\xrightarrow{\text{sedoheptulose biphosphatase}}$ sedoheptulose 7-phosphate + inorganic phosphate
 5. Sedoheptulose 7-phosphate + glyceraldehyde 3-phosphate $\xrightarrow{\text{transketolase}}$ xylulose 5-phosphate + ribose 5-phosphate
 6. Xylulose 5-phosphate $\xrightarrow{\text{ribulose phosphate-3-epimerase}}$ ribulose 5-phosphate
 7. Ribose 5-phosphate $\xrightarrow{\text{ribose phosphate isomerase}}$ ribulose 5-phosphate

SOURCE:
Hooper, JK (1984)
Chloroplasts