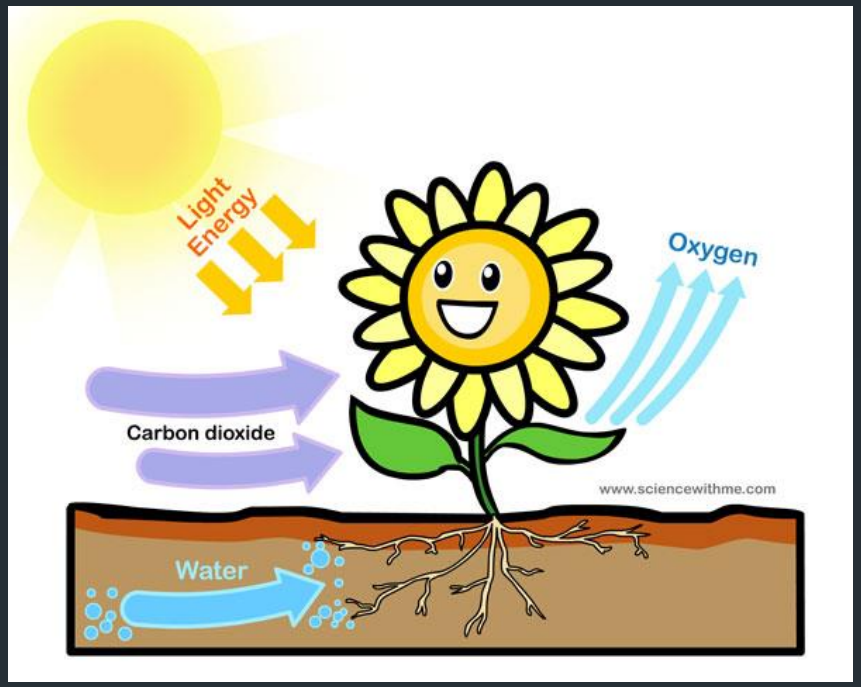
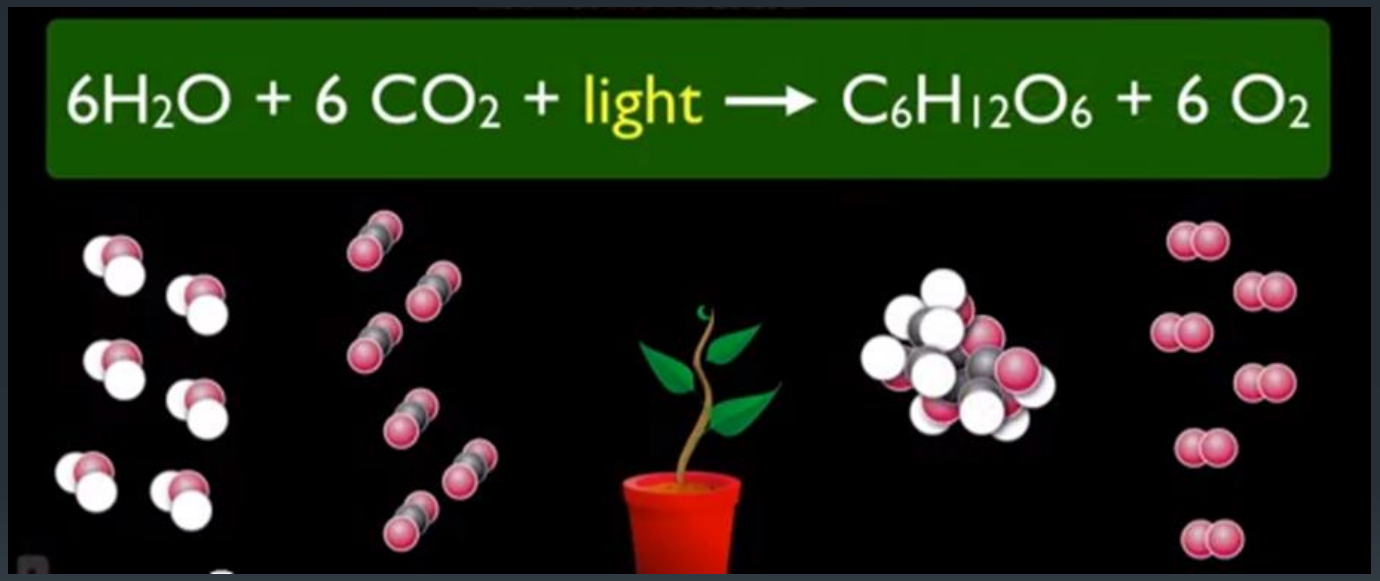


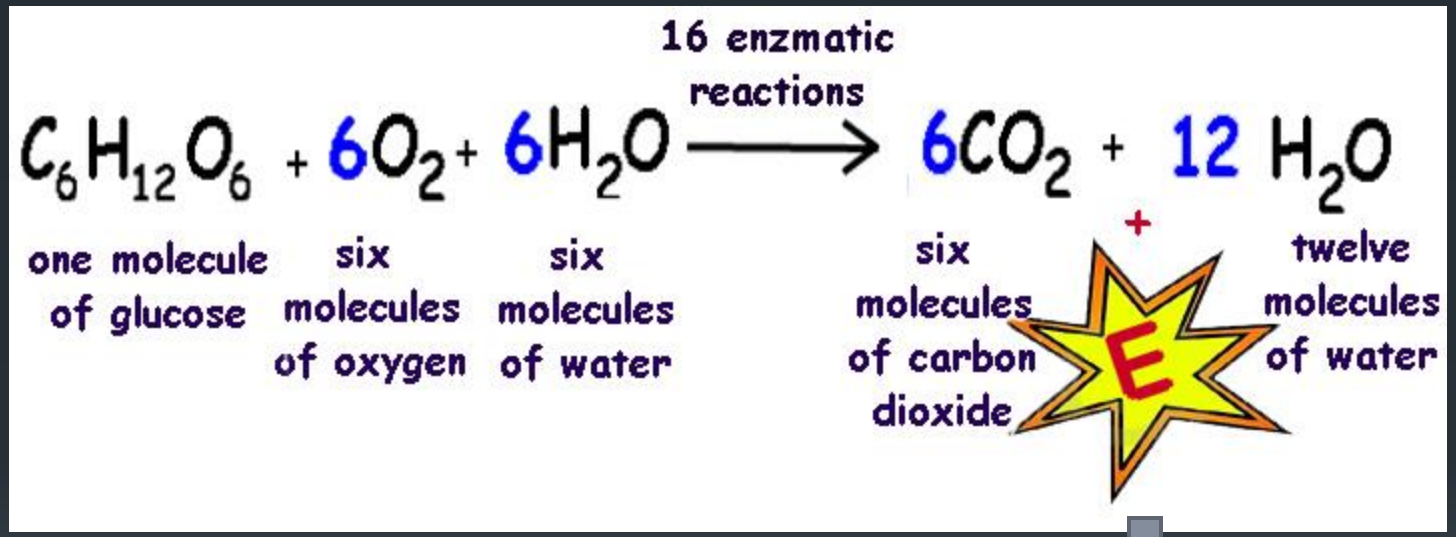
Photosynthesis

Summary Reaction



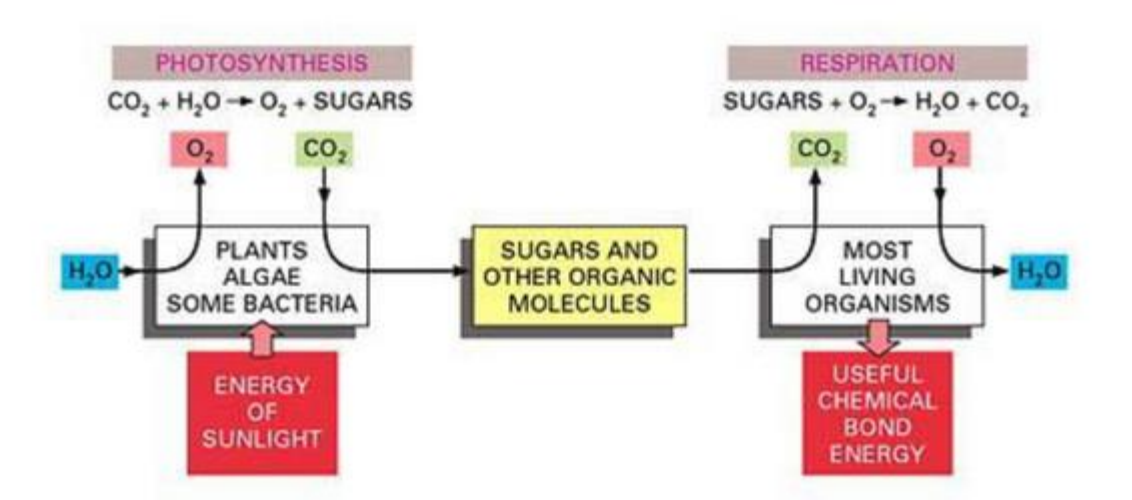
Water Carbon dioxide Glucose Oxygen

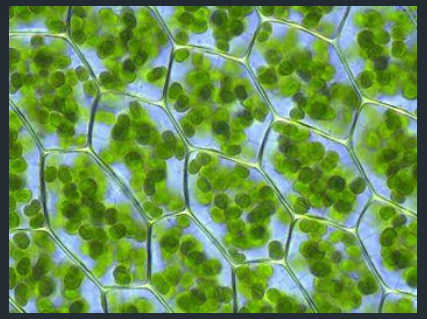
Overview of Cellular Respiration



Energy in Form of ATP

Respiration and Photosynthesis: Complementary processes– to a point

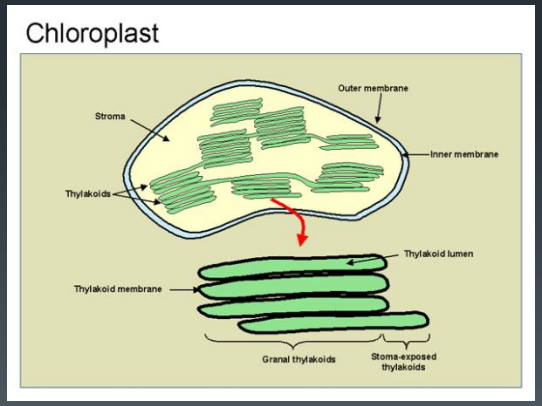




Two sets of reactions in Chloropasts

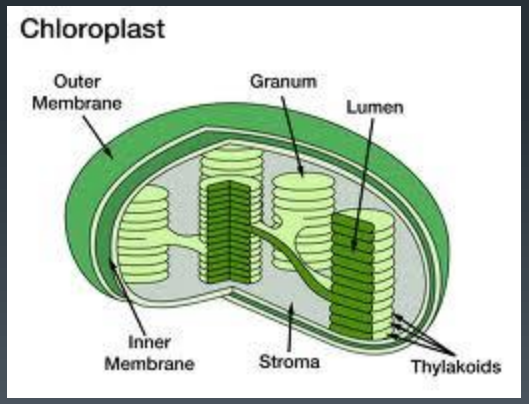
Light Dependent Rxn

- Thylakoids

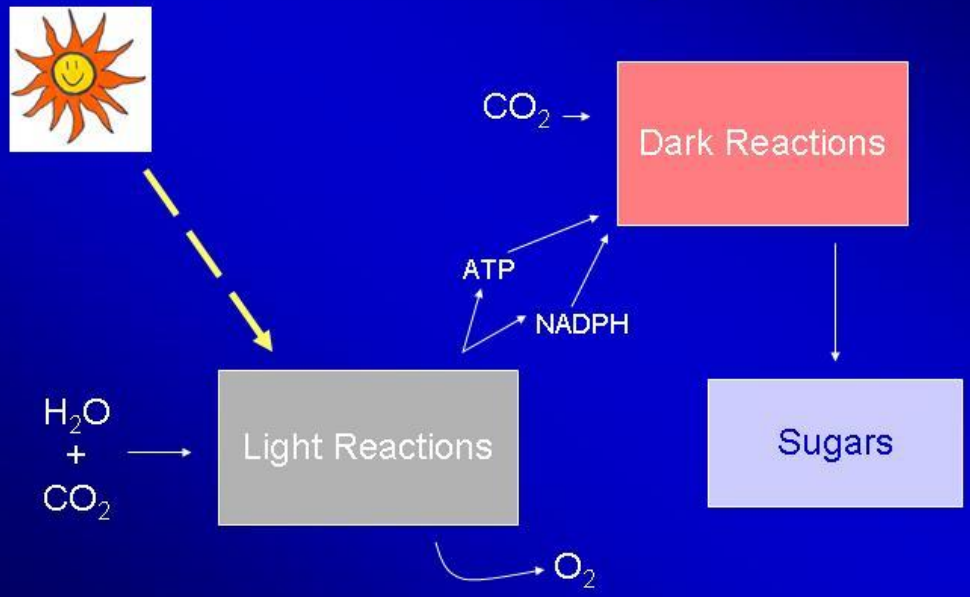


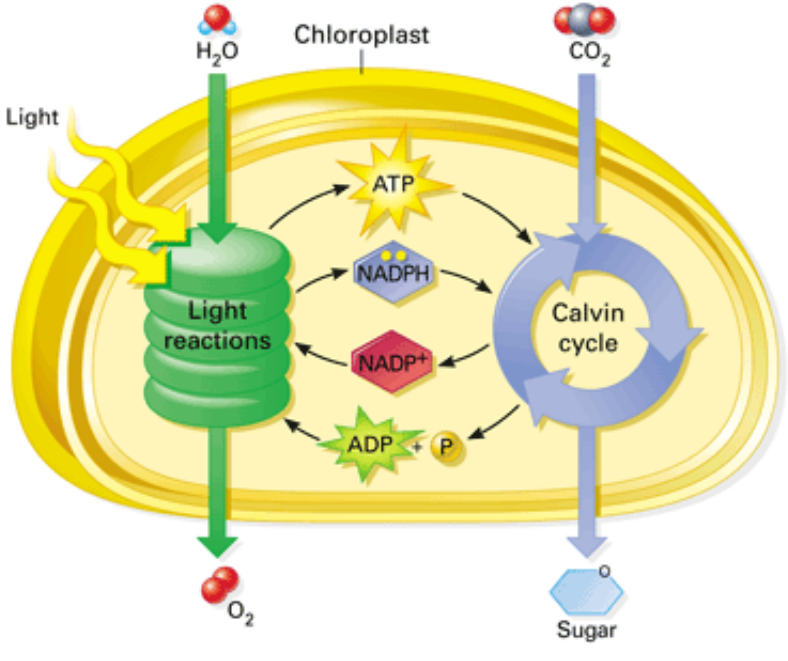
Light Independent Rxn

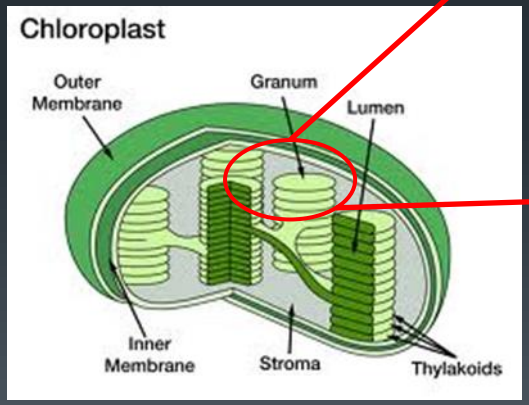
- Stroma

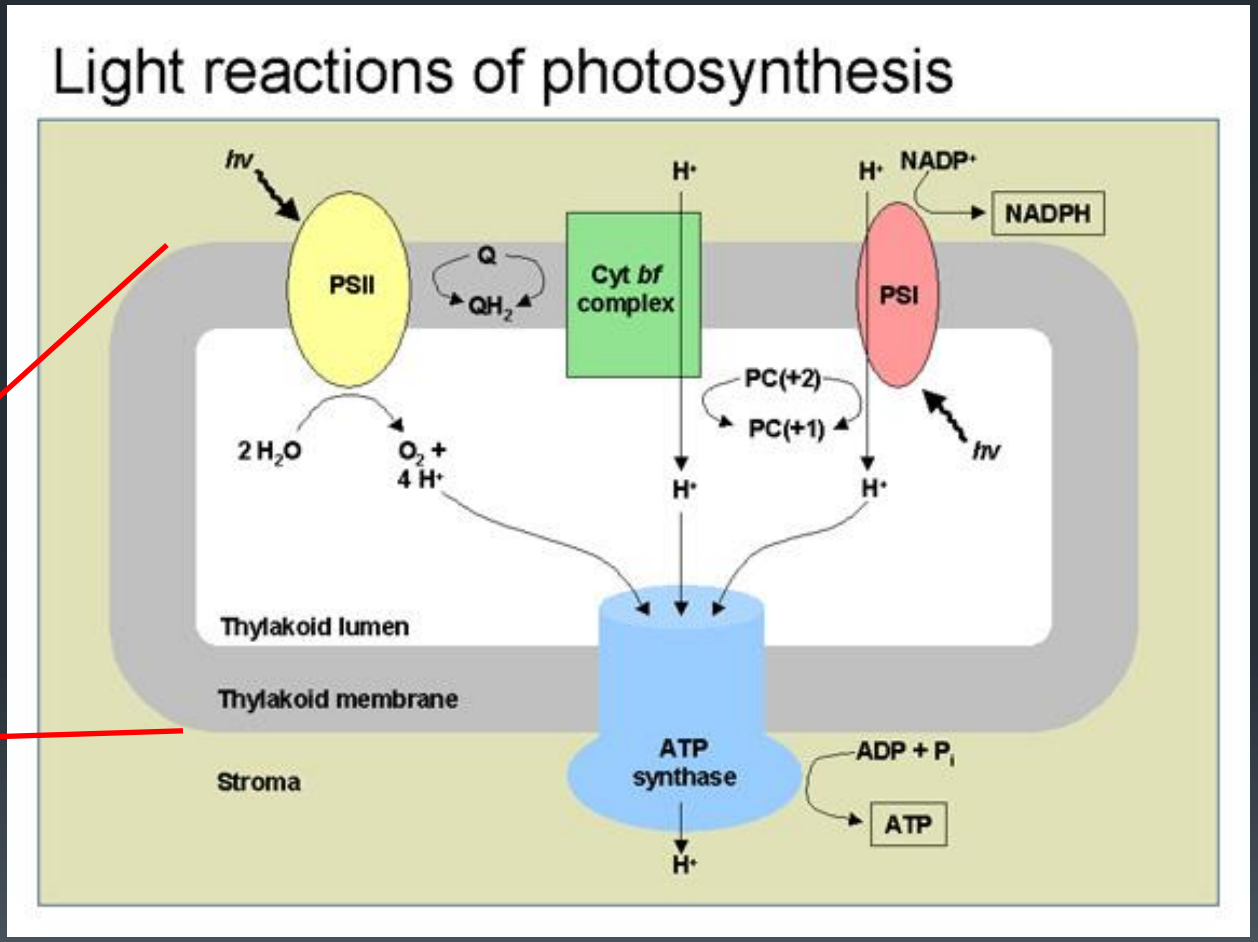


Overview of Photosynthesis



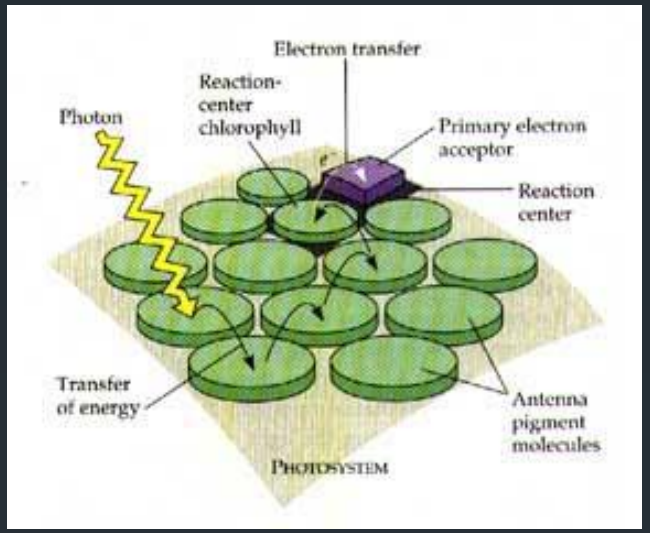



Chloroplast
Outer Membrane
Granum
Lumen
Inner Membrane
Stroma
Thylakoids

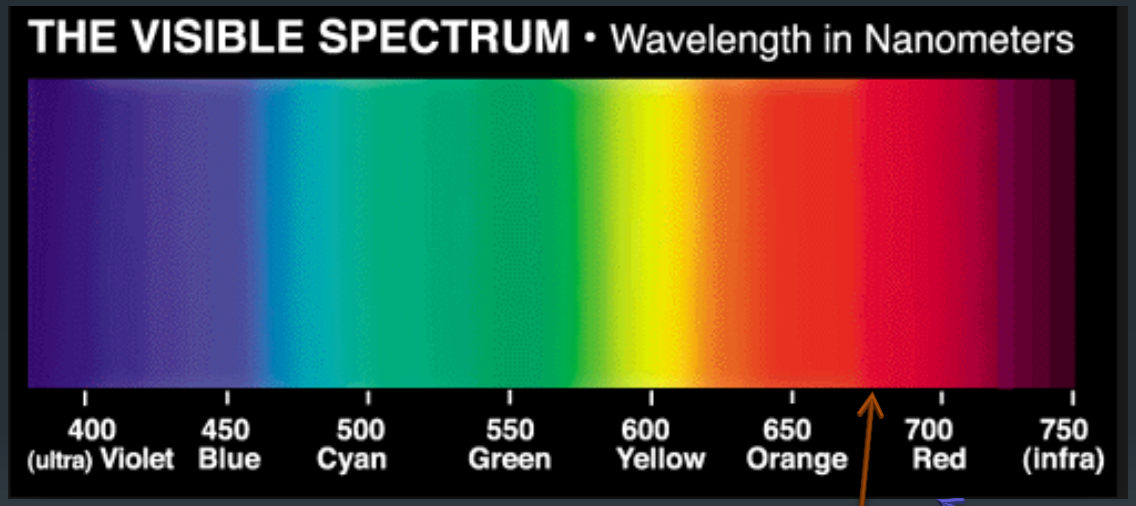

Light reactions of photosynthesis
hν
PSII
Q
QH2
Cyt bf complex
H+
H+
NADP+
NADPH
PSI
PC(+2)
PC(+1)
hν
2 H2O
O2 + 4 H+
H+
H+
Thylakoid lumen
Thylakoid membrane
Stroma
ATP synthase
ADP + Pi
ATP
H+

Photosystems I and II

- Action center of photosystem = modified chlorophyll a
- Reaction-center PS I is known as P700 with absorption peak at 700 nm (far-red portion of spectrum)
- PS II is called P680 has absorption peak of 680 nm (red part of the light spectrum)
- P700 and P680, are identical chlorophyll *a* molecules association with different protein molecules in the thylakoid membrane accounts for the slight differences in light-absorbing properties



Visible Spectrum



Chlorophyll molecules transmit energy from excited electrons in the antenna complex to a reaction center.

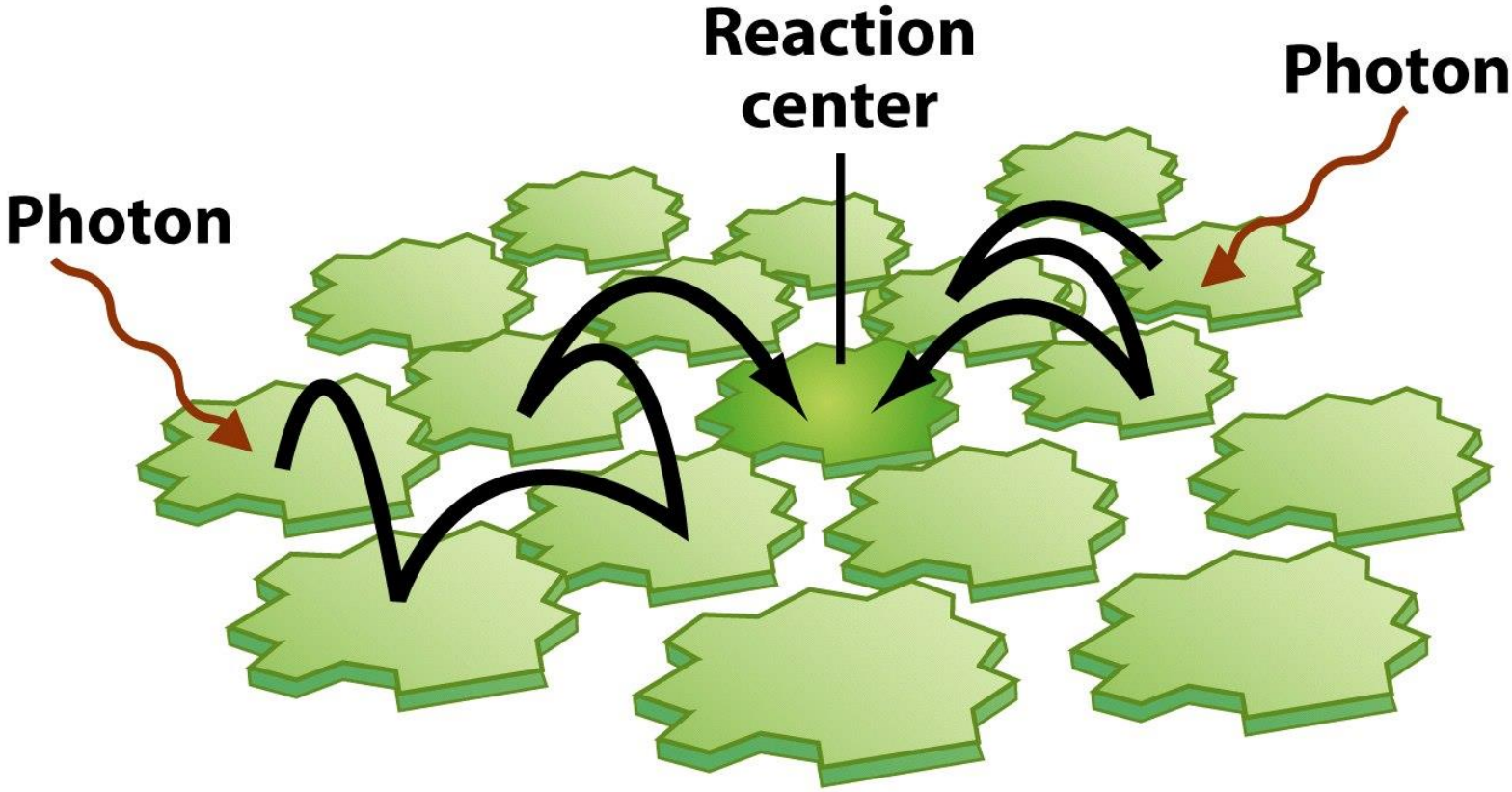
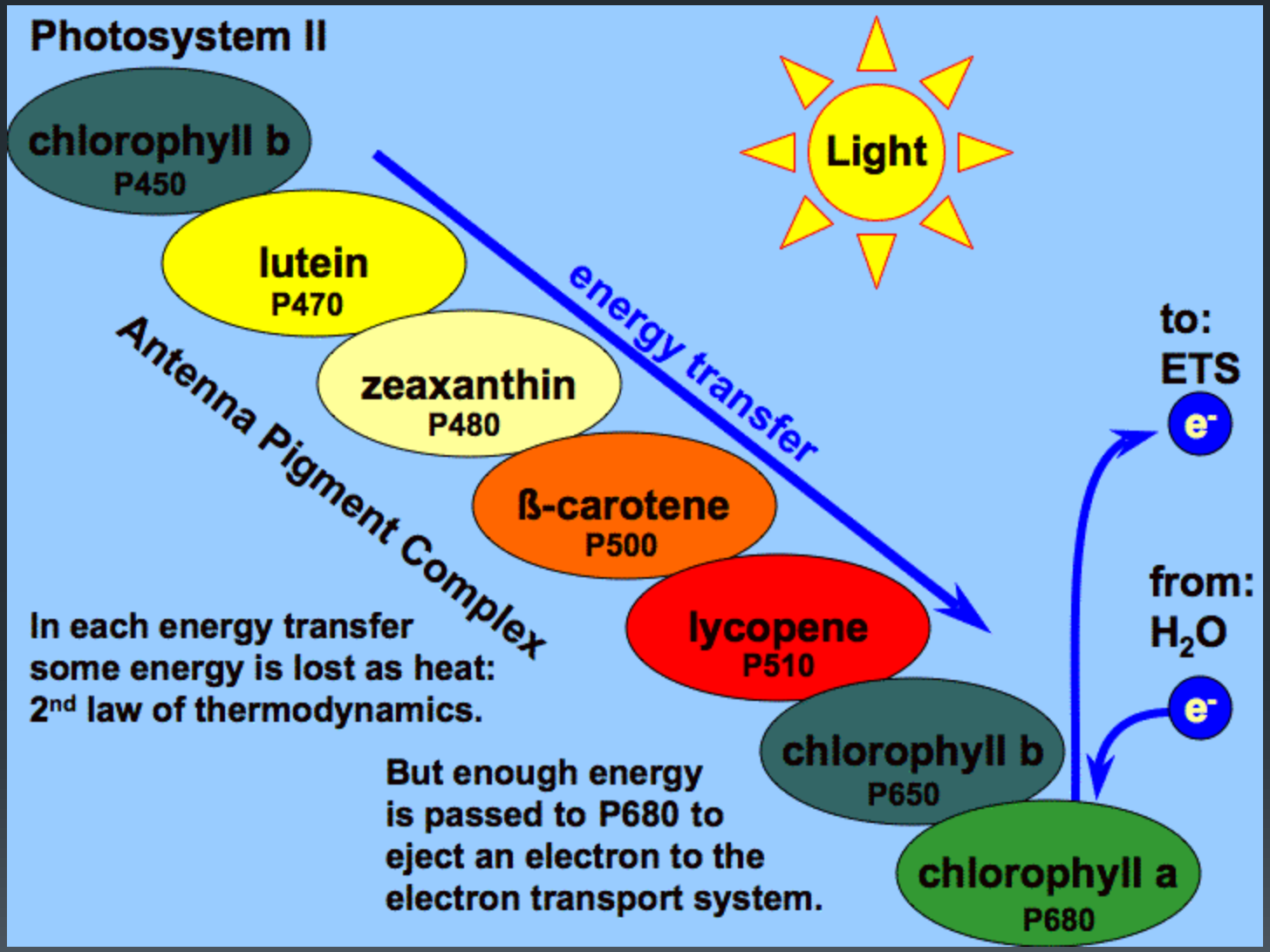
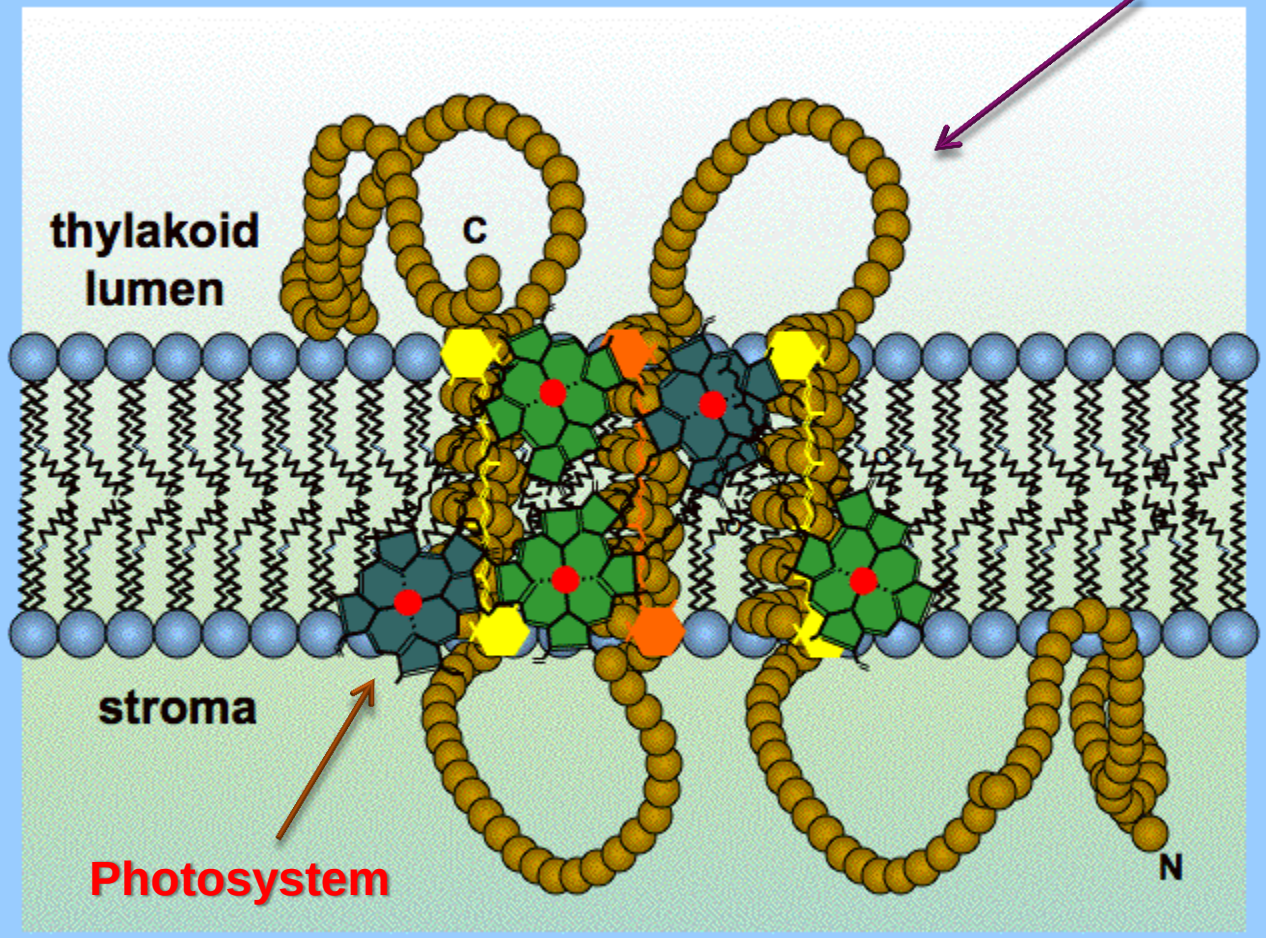


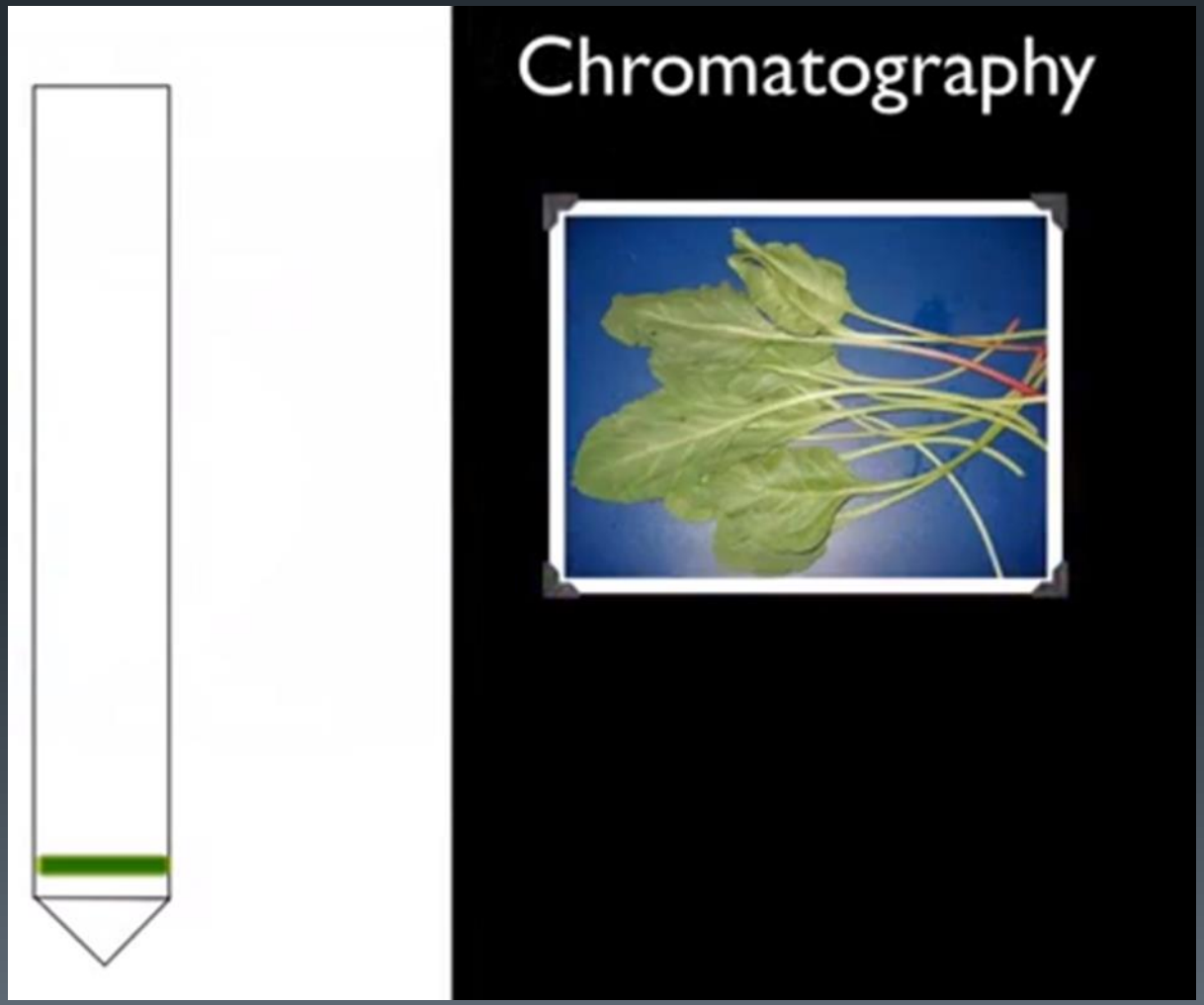
Figure 10-12a Biological Science, 2/e


Photosystem II
chlorophyll b
P450
lutein
P470
zeaxanthin
P480
ß-carotene
P500
lycopene
P510
chlorophyll b
P650
chlorophyll a
P680
Light
energy transfer
Antenna Pigment Complex
to:
ETS
e-
from:
H2O
e-
In each energy transfer some energy is lost as heat: 2nd law of thermodynamics.
But enough energy is passed to P680 to eject an electron to the electron transport system.

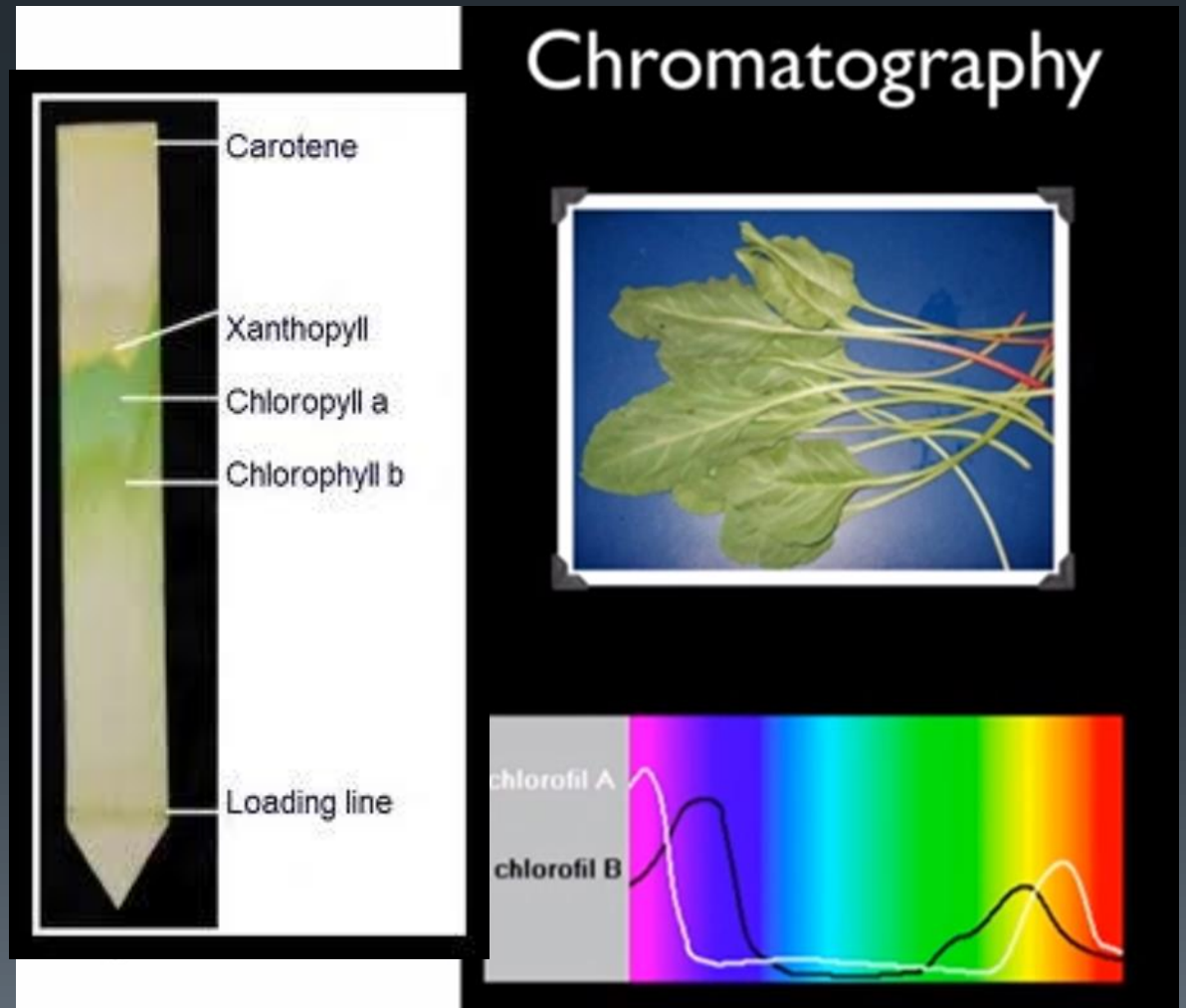
Photosynthetic pigments are associated with membrane proteins

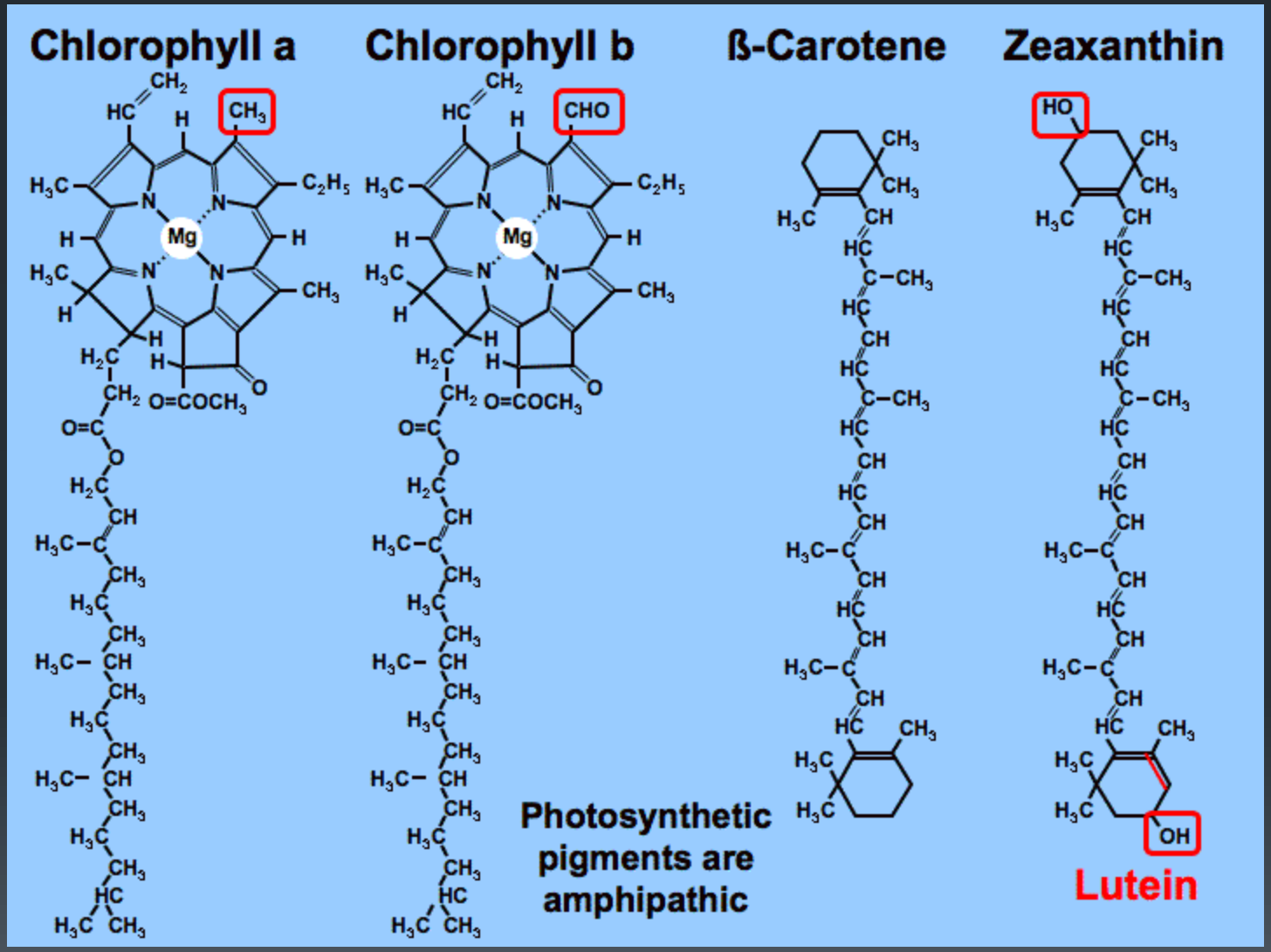


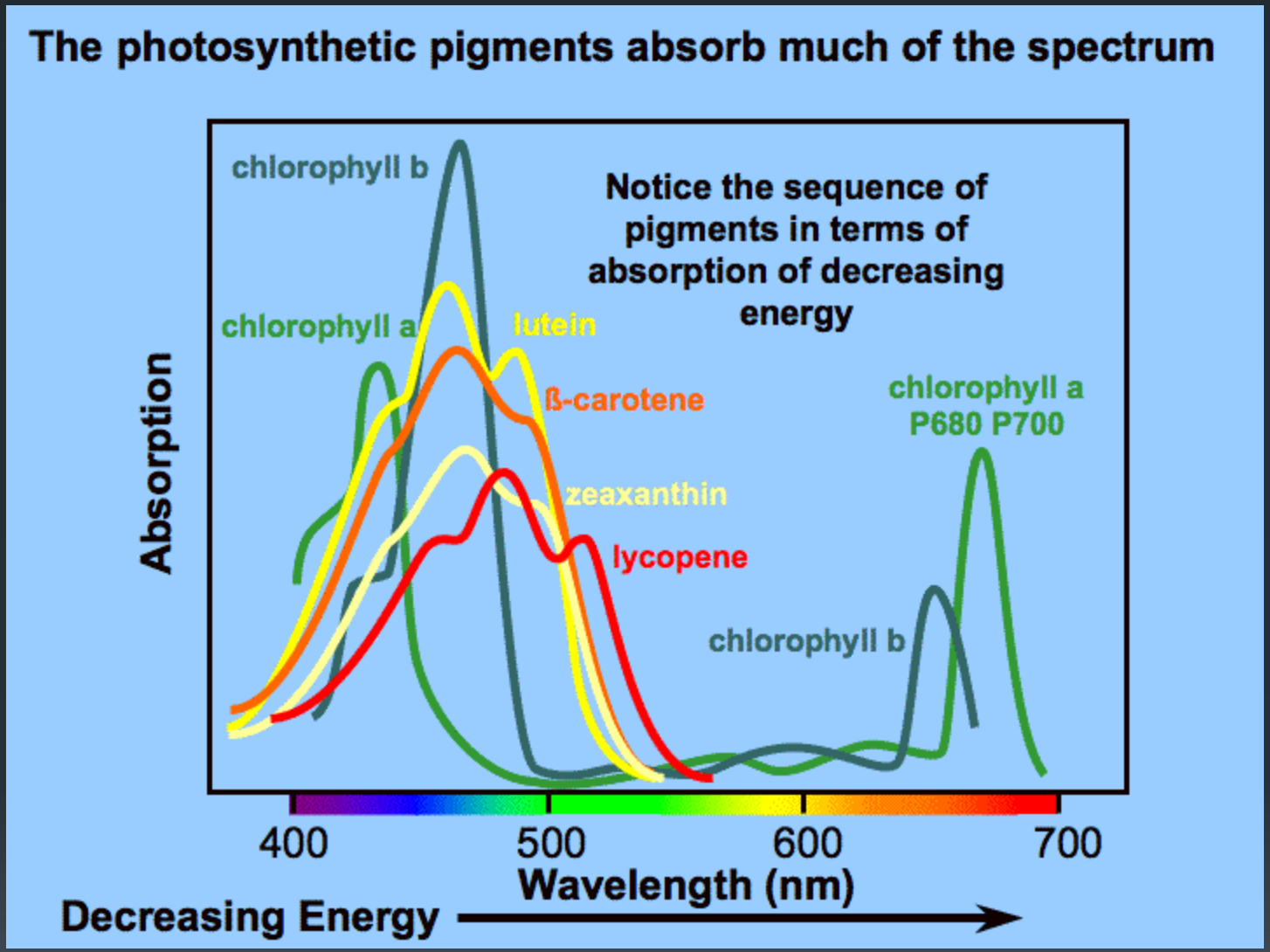
Photosynthetic pigments



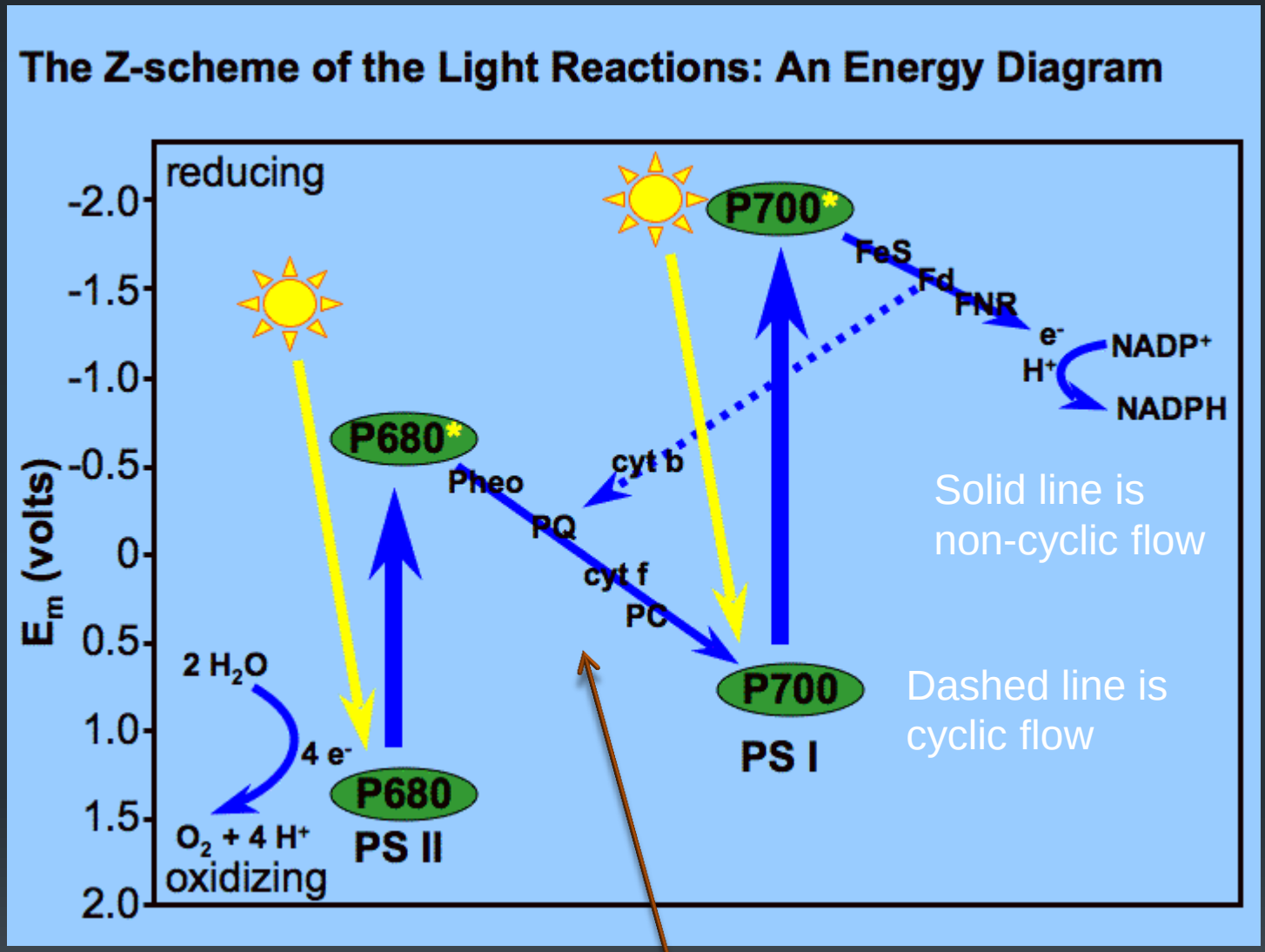
Photosynthetic pigments




Chlorophyll a
Chlorophyll b
ß-Carotene
Zeaxanthin
Photosynthetic pigments are amphipathic
Lutein

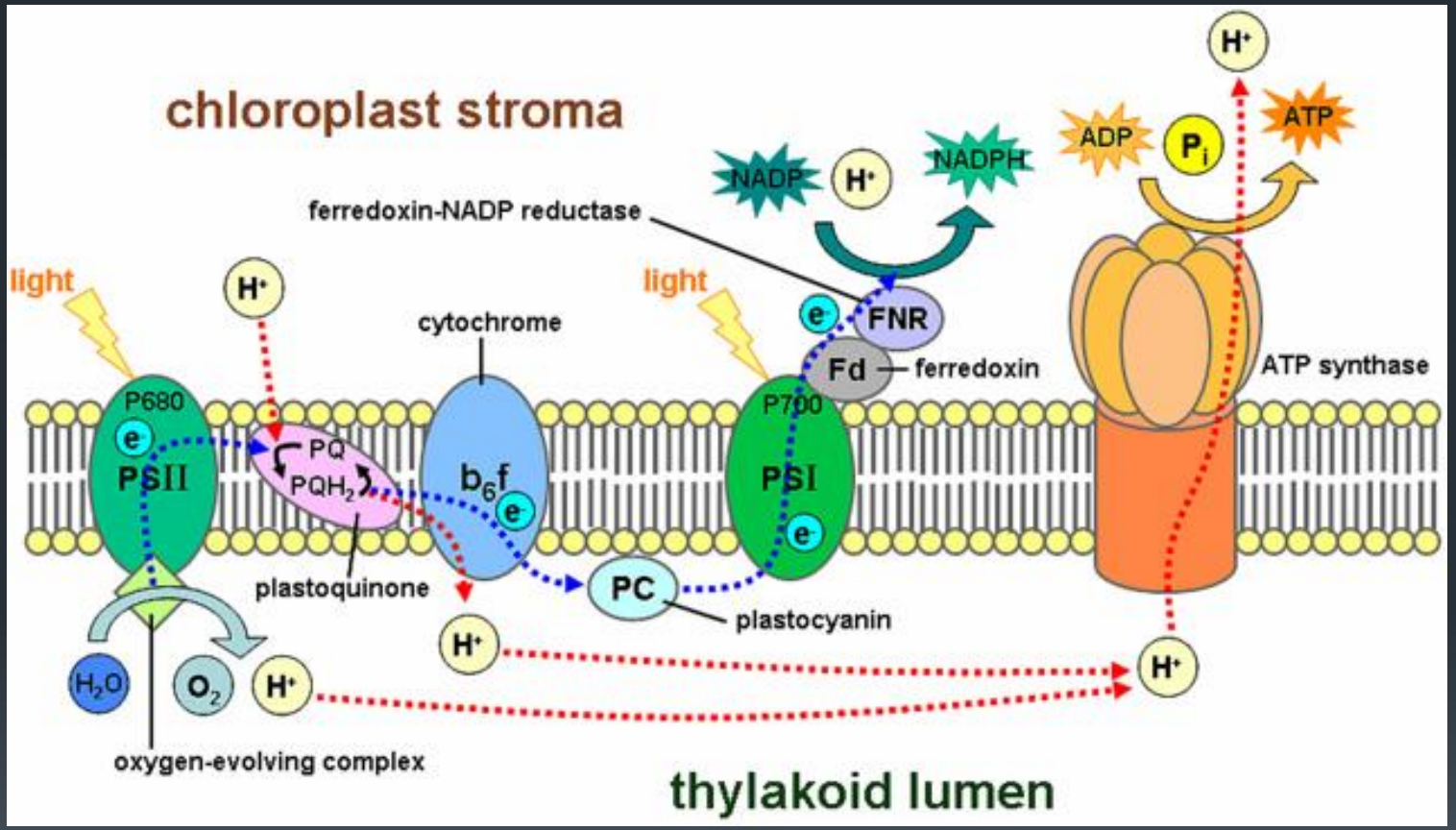


Blue-light is of higher energy than red



Hill Reaction

ETS between PSII and PSI drives photophoshorylation


chloroplast stroma
H+
ADP
Pi
ATP
NADP
H+
NADPH
ferredoxin-NADP reductase
light
H+
cytochrome
light
e
FNR
Fd
ferredoxin
ATP synthase
P680
e
PSII
PQ
PQH2
b6f
e
P700
PSI
e
plastoquinone
PC
plastocyanin
H+
H+
H2O
O2
H+
oxygen-evolving complex
thylakoid lumen

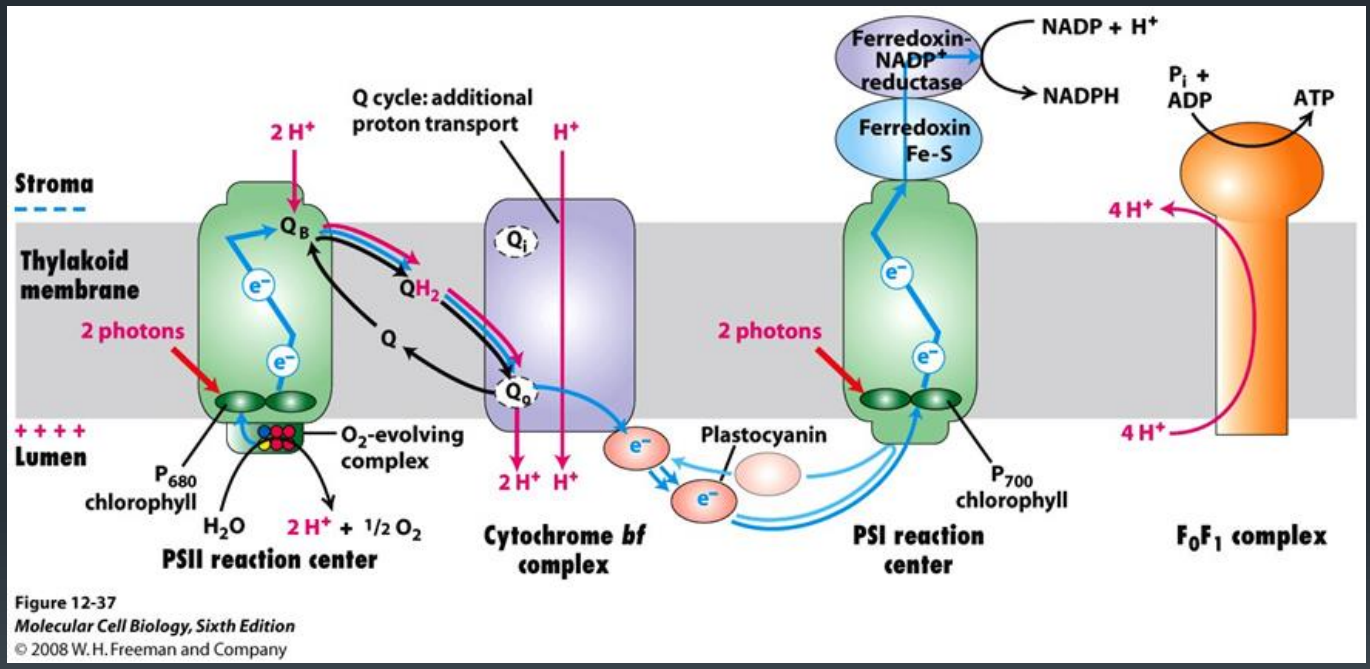
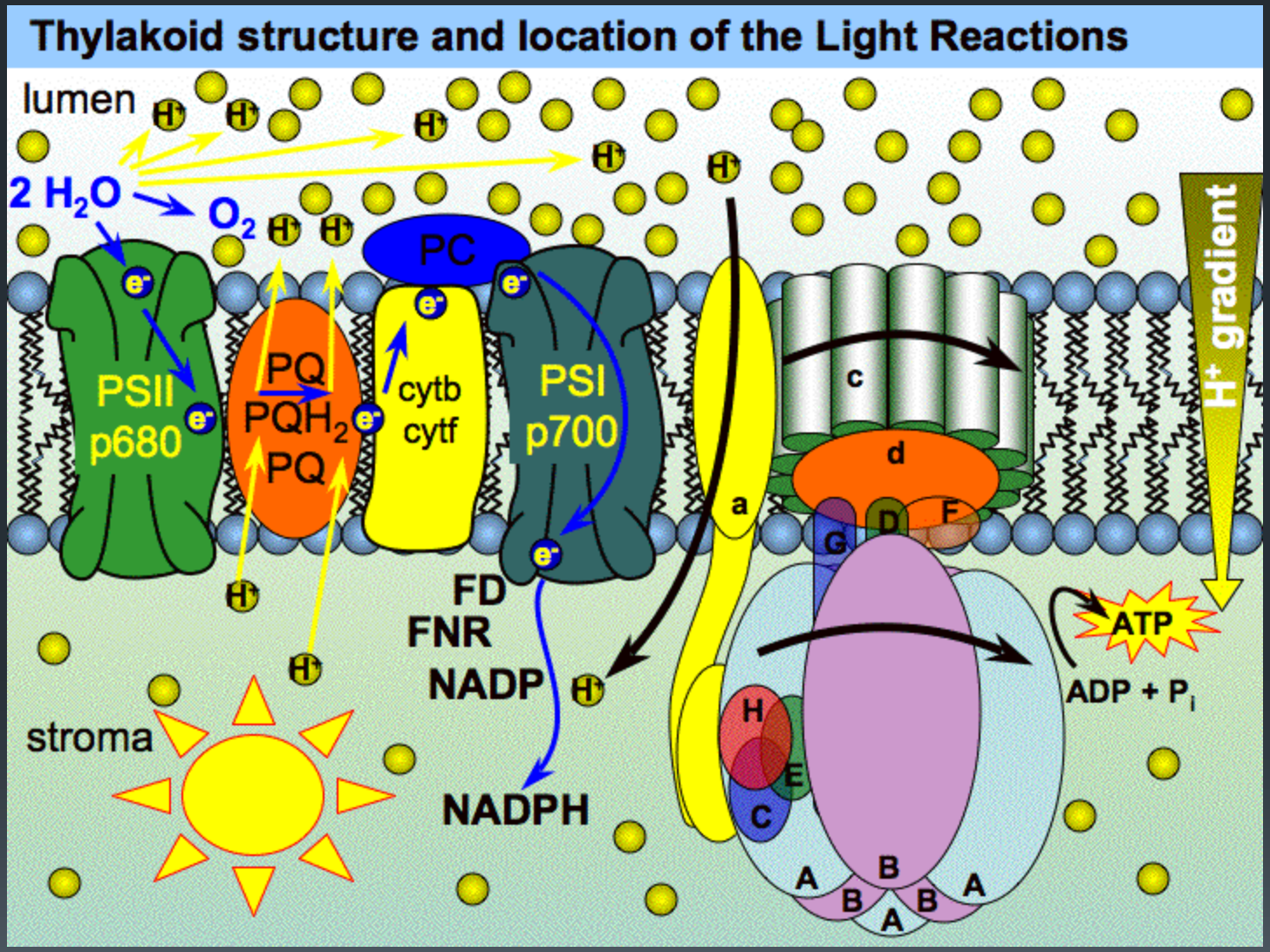
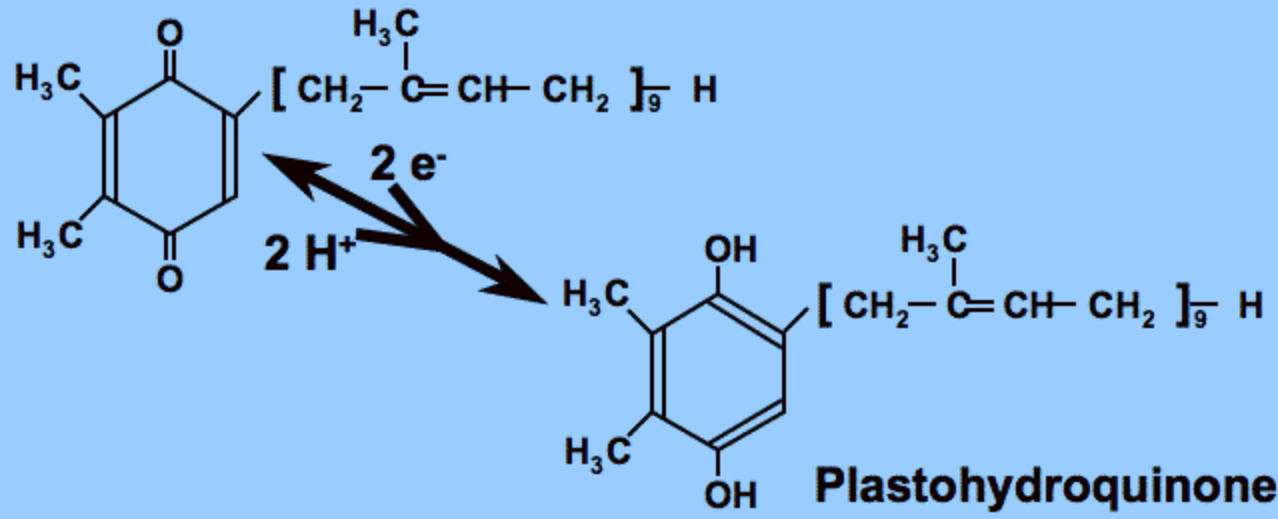


Figure 12-37
Molecular Cell Biology, Sixth Edition


Thylakoid structure and location of the Light Reactions
lumen
2 H2O
O2
PC
PSII
p680
PQ
PQH2
PQ
cytb
cytf
PSI
p700
a
c
d
D
F
G
H+ gradient
FD
FNR
NADP
NADPH
ATP
ADP + Pi
stroma
H
E
C
A
B
A
B
B
A

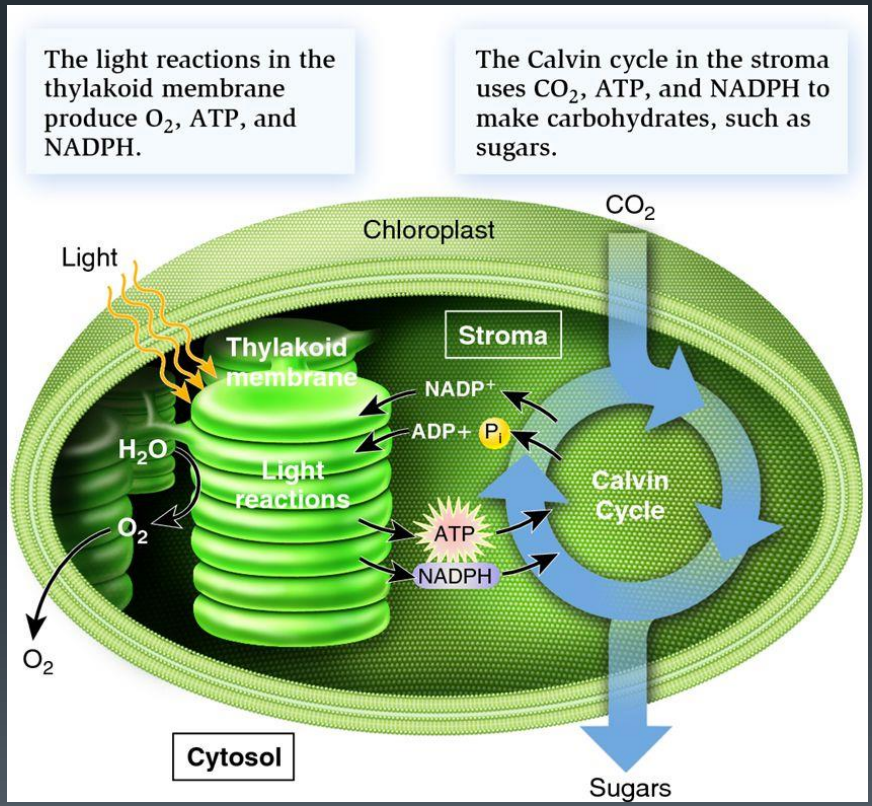
Plastoquinone is a shuttle for protons across the thylakoid membrane

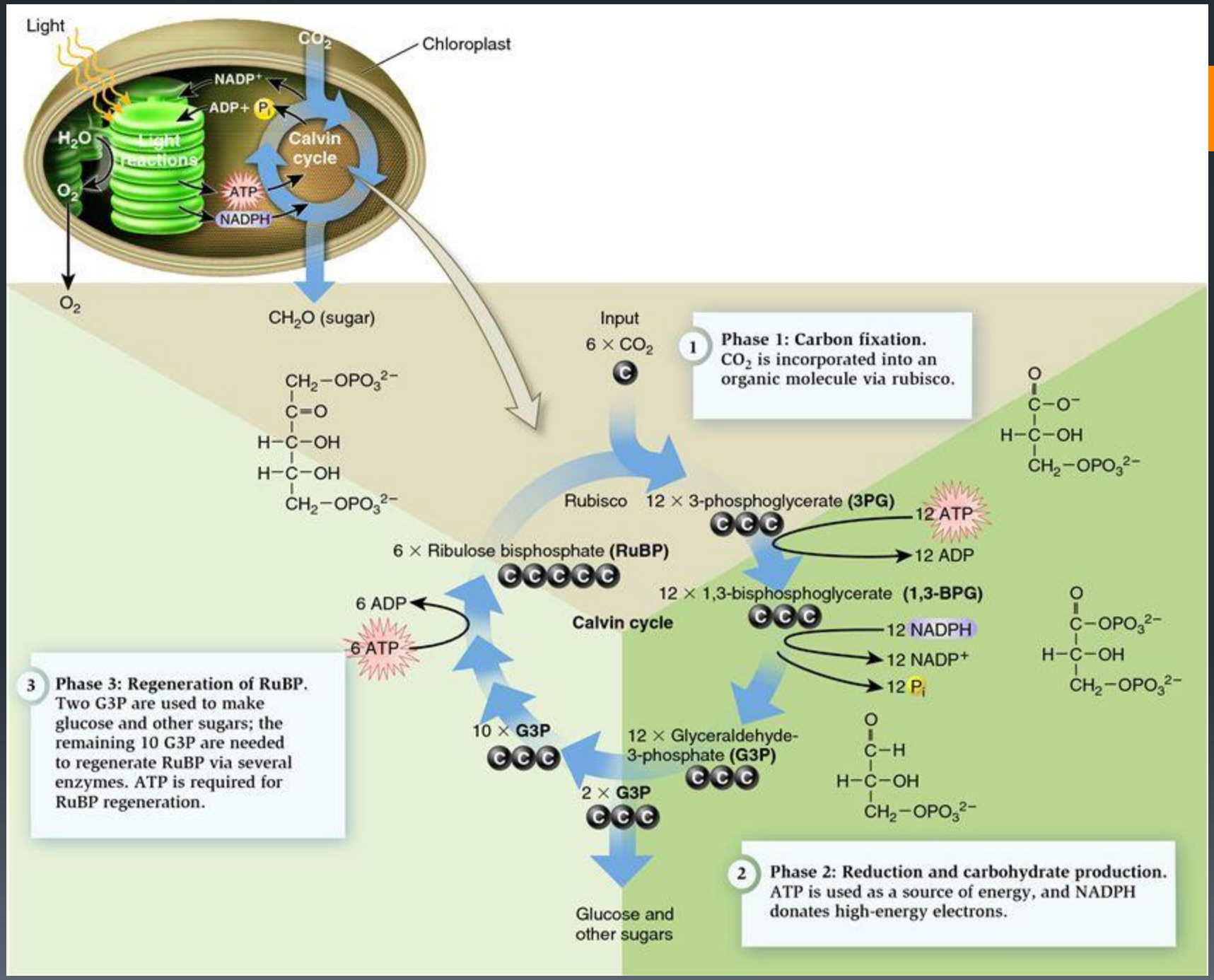
Plastoquinone

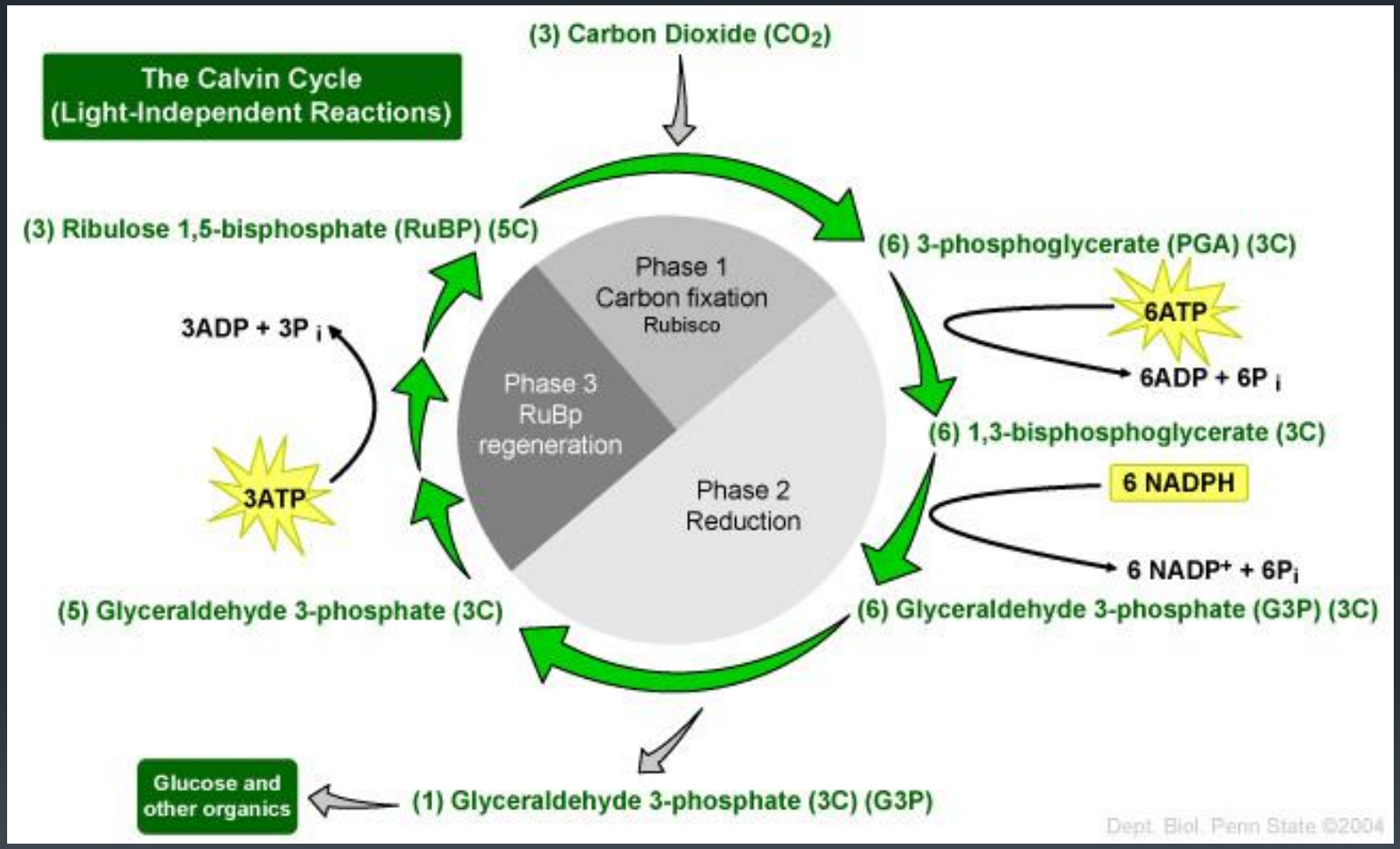


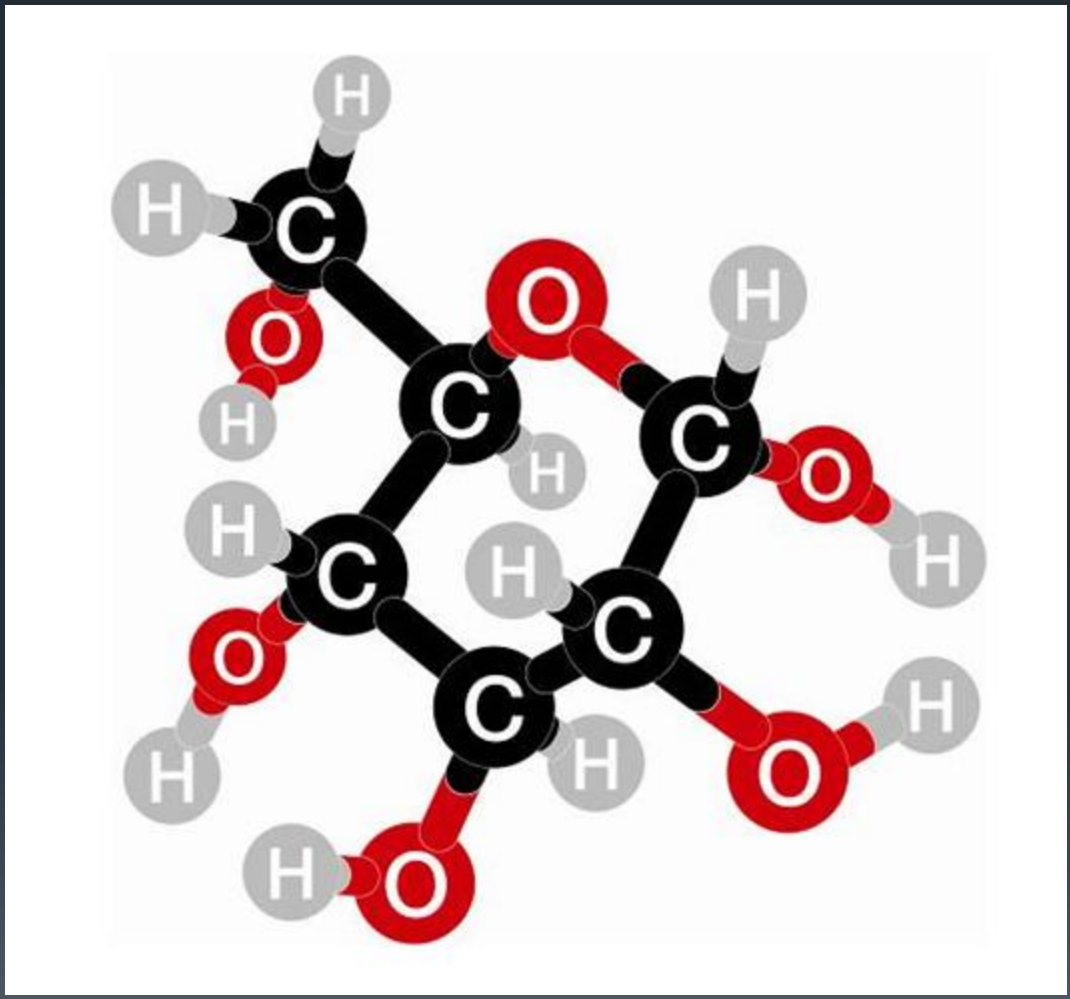
Plastohydroquinone

Light dependent reactions supply ATP and reducing power to the light independent reactions




Light
CO_2
Chloroplast
$NADP^+$
ADP+ P_i
H_2O
Light reactions
Calvin cycle
O_2
ATP
NADPH
O_2
CH_2O (sugar)
Input
6 × CO_2
1 Phase 1: Carbon fixation. CO_2 is incorporated into an organic molecule via rubisco.
Rubisco
12 × 3-phosphoglycerate (3PG)
12 ATP
12 ADP
6 × Ribulose bisphosphate (RuBP)
6 ADP
6 ATP
12 × 1,3-bisphosphoglycerate (1,3-BPG)
Calvin cycle
12 NADPH
12 $NADP^+$
12 P_i
3 Phase 3: Regeneration of RuBP. Two G3P are used to make glucose and other sugars; the remaining 10 G3P are needed to regenerate RuBP via several enzymes. ATP is required for RuBP regeneration.
10 × G3P
12 × Glyceraldehyde-3-phosphate (G3P)
2 × G3P
Glucose and other sugars
2 Phase 2: Reduction and carbohydrate production. ATP is used as a source of energy, and NADPH donates high-energy electrons.


The Calvin Cycle
(Light-Independent Reactions)
(3) Carbon Dioxide (CO_2)
(3) Ribulose 1,5-bisphosphate (RuBP) (5C)
(6) 3-phosphoglycerate (PGA) (3C)
Phase 1
Carbon fixation
Rubisco
Phase 3
RuBp
regeneration
Phase 2
Reduction
6ATP
6ADP + 6P i
3ADP + 3P i
3ATP
(6) 1,3-bisphosphoglycerate (3C)
6 NADPH
6 NADP+ + 6Pi
(5) Glyceraldehyde 3-phosphate (3C)
(6) Glyceraldehyde 3-phosphate (G3P) (3C)
Glucose and other organics
(1) Glyceraldehyde 3-phosphate (3C) (G3P)
Dept. Biol. Penn State ©2004



Glucose is a simple, soluble sugar.

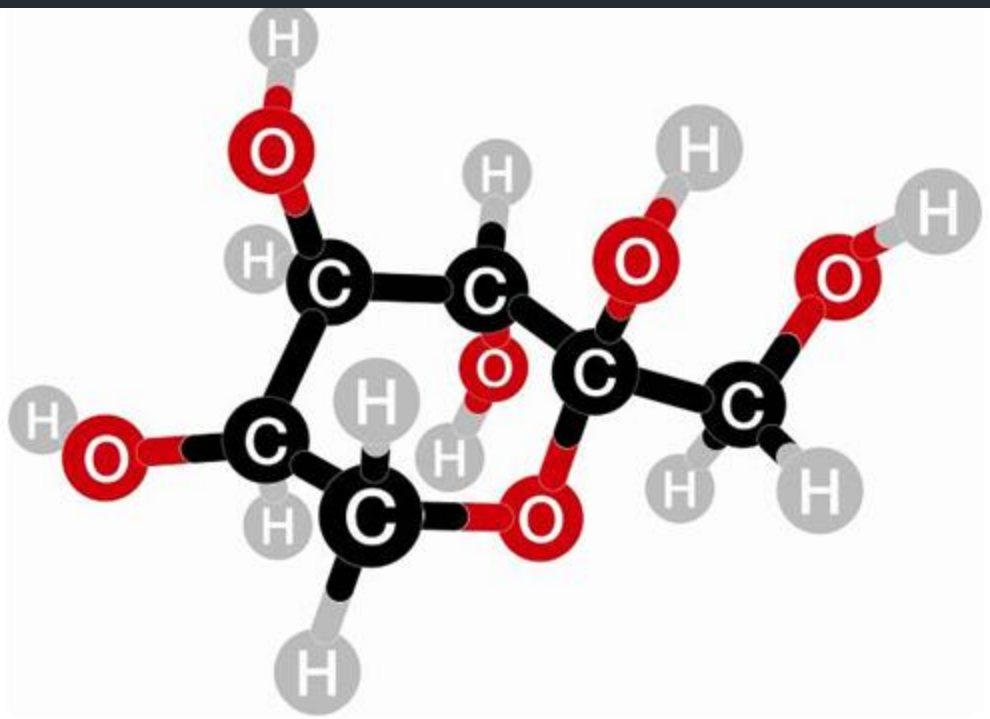
Often incorrectly listed as product of Calvin cycle

Exit Product of Calvin Cycle

- One G3P (Glyceraldehyde-3-phosphate) molecule exits the Calvin cycle
- This is the product of the Calvin cycle
  - This exiting G3P molecule is readily converted to glucose in reactions outside of the Calvin cycle
- The other 5 G3P molecules remain in the Calvin cycle

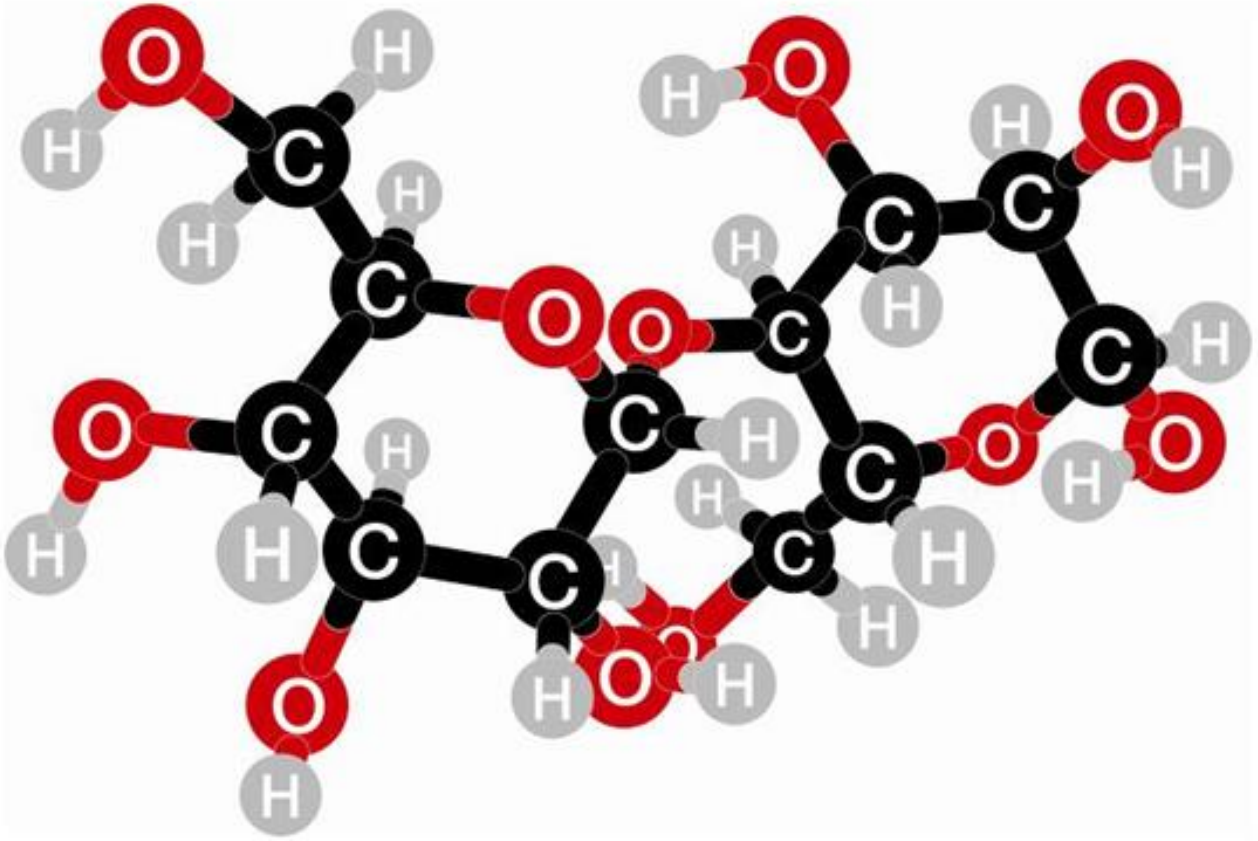
The ultimate product of photosynthesis is the whole plant

- G3P is converted into sugars, starches, proteins, etc.
- G3P is ultimately converted into all of the organic molecules present within the plant
- Photosynthesis produces approximately 155 billion tons of material per year



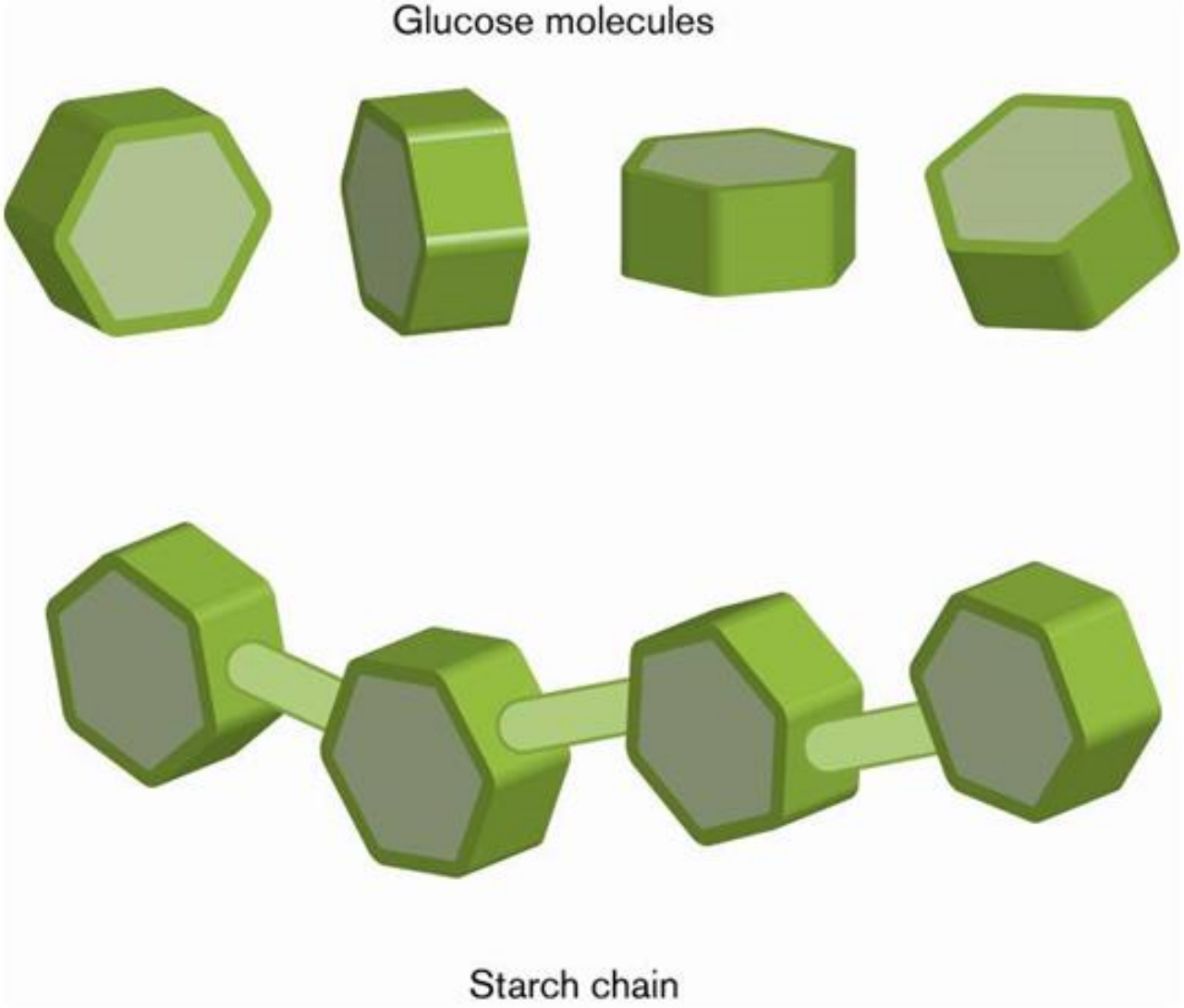
Fructose

Sucrose is made from one molecule of glucose and one of fructose.. The kind of sugar you sprinkle on your cereal or have in your tea.



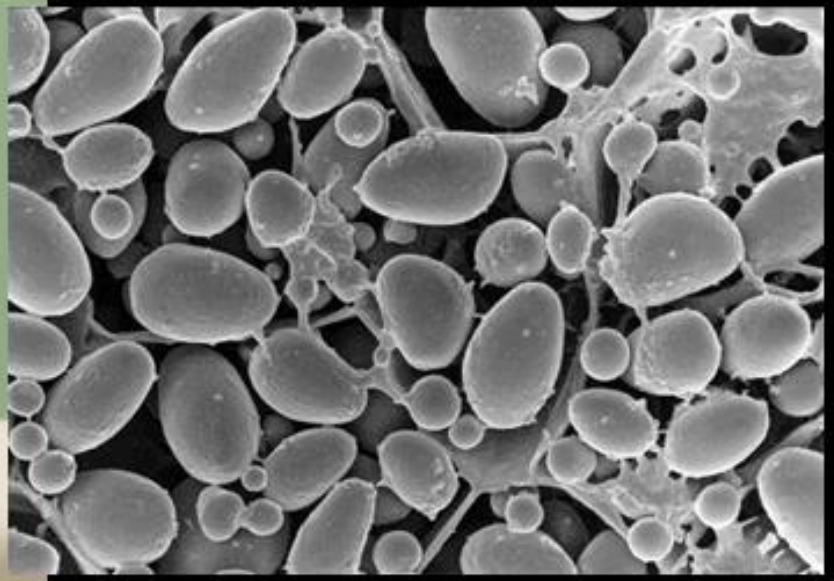
Sucrose

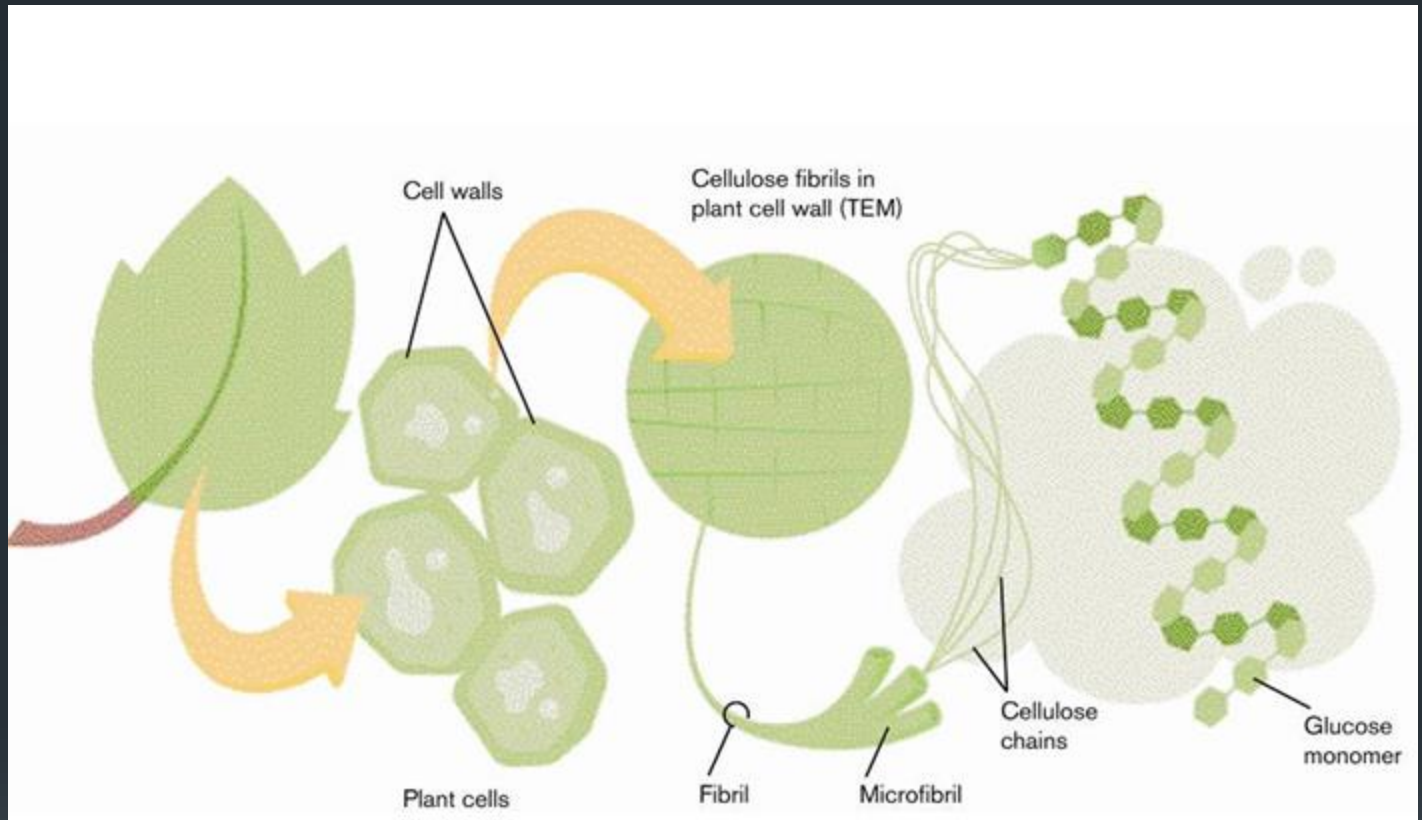
Sucrose is found in almost all plants but it occurs at concentrations high enough for economic recovery in only sugar cane and sugar beet.



Glucose molecules join together to form long chains. One of these polymers is called starch.

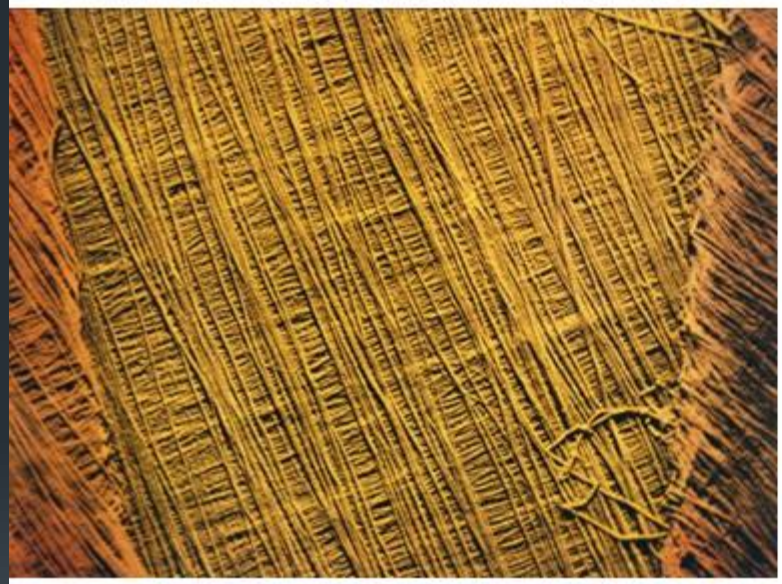
These are starch grains from a potato. You can look at them easily under a microscope just by staining a very thin slice of potato with iodine solution.





Another type of polymer made from glucose molecules is cellulose. Cellulose chains form fibrils that make up the cell wall structure of all plant cells.

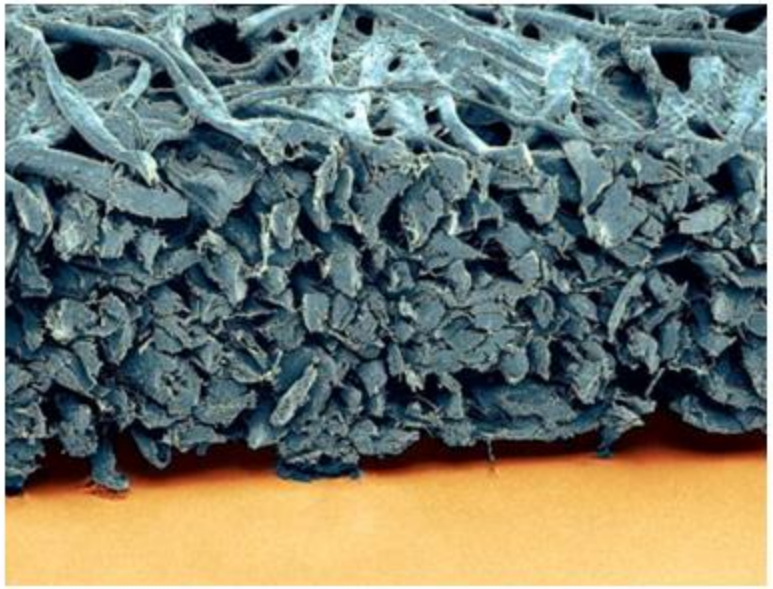
Plant cell wall

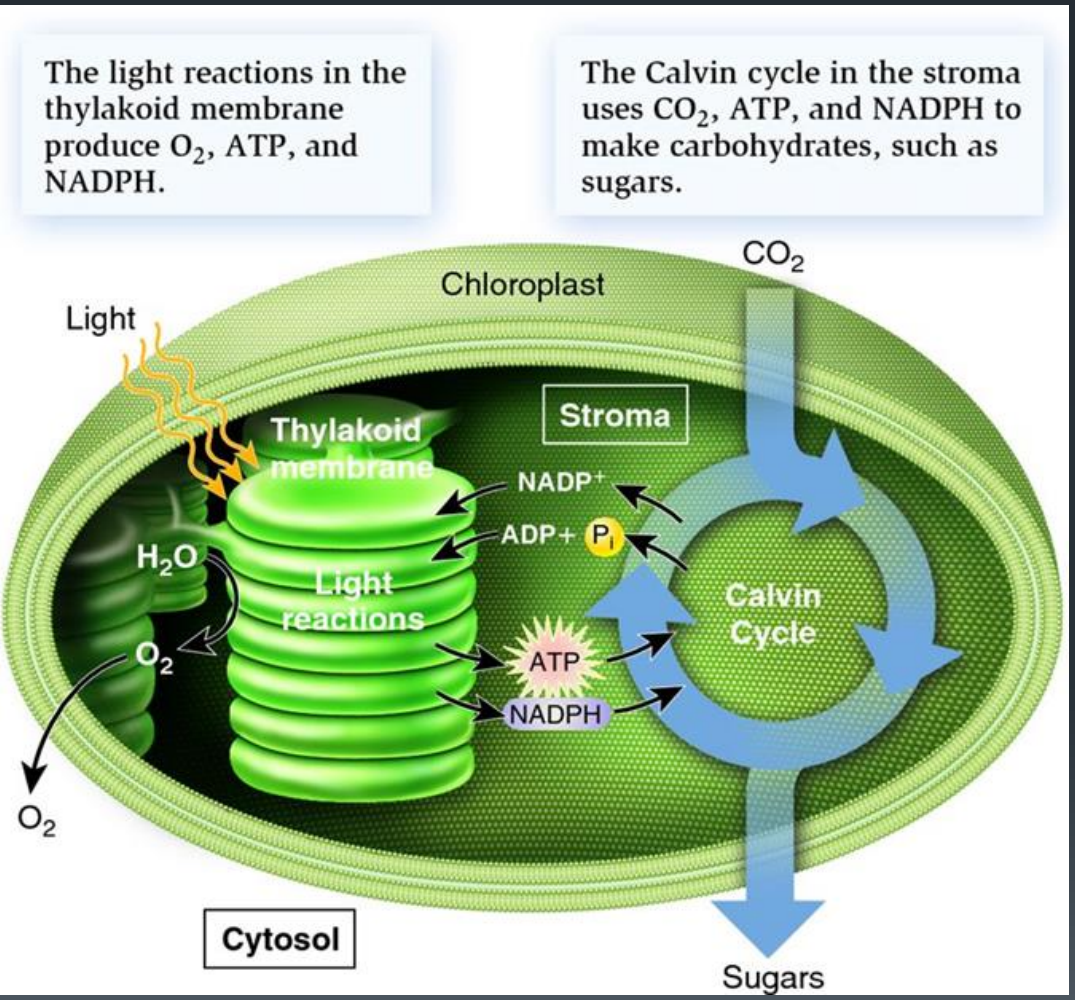


Coloured scanning electron micrograph (SEM) of cellulose microfibrils (strands) in a plant cell wall. Unlike animal cells, plants cells are enclosed in a protective rigid cell wall. The main constituent of the wall is cellulose, a complex polysaccharide that forms microfibrils. Cellulose microfibrils measure between 5 nanometres and 15 nanometres in diameter.

Filter paper

Coloured scanning electron micrograph (SEM) of the cut end of a piece of filter paper showing its many cellulose fibres. Cellulose is a polysaccharide that is the main constituent of all plant tissues and fibres. Filter paper is a porous material used for separating the liquid and solid parts of a suspension and, being made from wood pulp, is almost pure cellulose.





Recap

- 3 CO_2 + 3RuBP → 6 PGA
- 6 PGA → 6 G3P
  - 6 ATP and 6 NADPH spent
  - One G3P removed as product
- 5 G3P → 3 RuBP
  - 3 ATP are spent

- **Overall:**
  3 CO_2 → 1 G3P

- The product of photosynthesis is a sugar – G3P, not glucose
- G3P can be readily converted into many other molecules
  - e.g., Two G3P → glucose

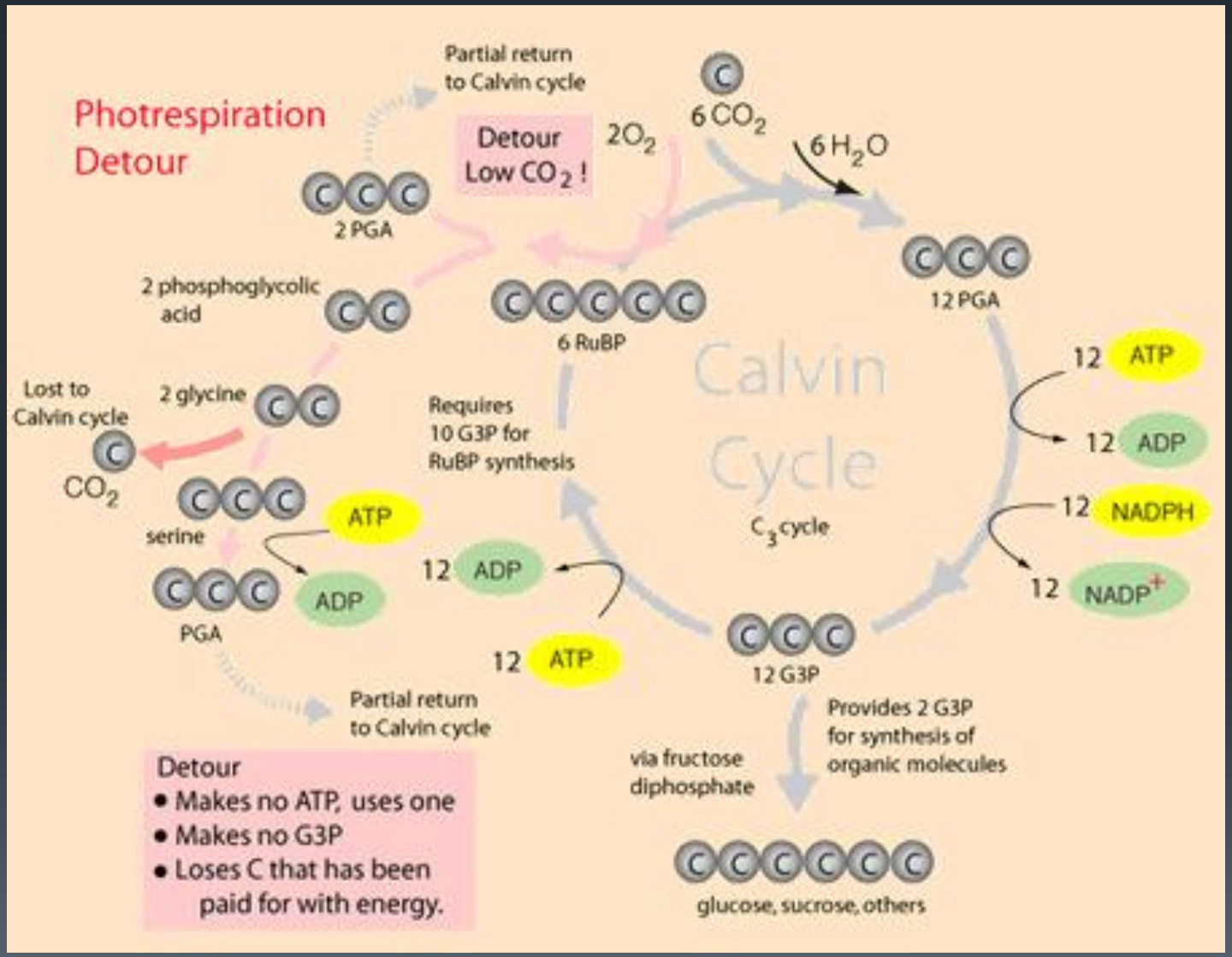
Evolution of Oxygen in Atmosphere

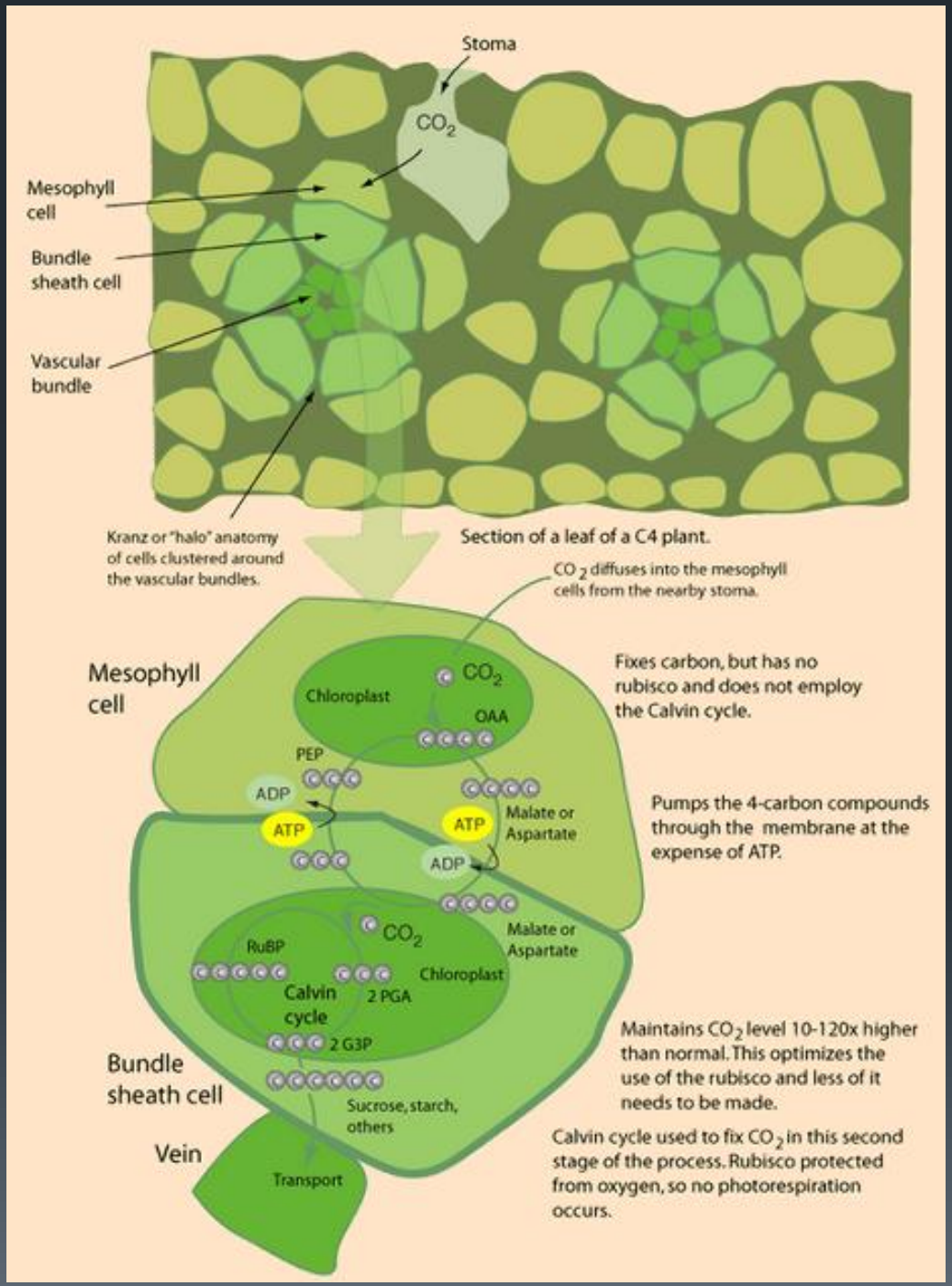
- The early Earth's atmosphere lacked O_2
  - 21% of the Earth's current atmosphere is O_2
- This O_2 is a product of photosynthesis
  - When water is split to yield electrons, O_2 is incidentally formed
  - H_20 à $2H^+ + ½\ O_2 + 2\ e^-$
- This waste product of photosynthesis is critically important to humans and many other species

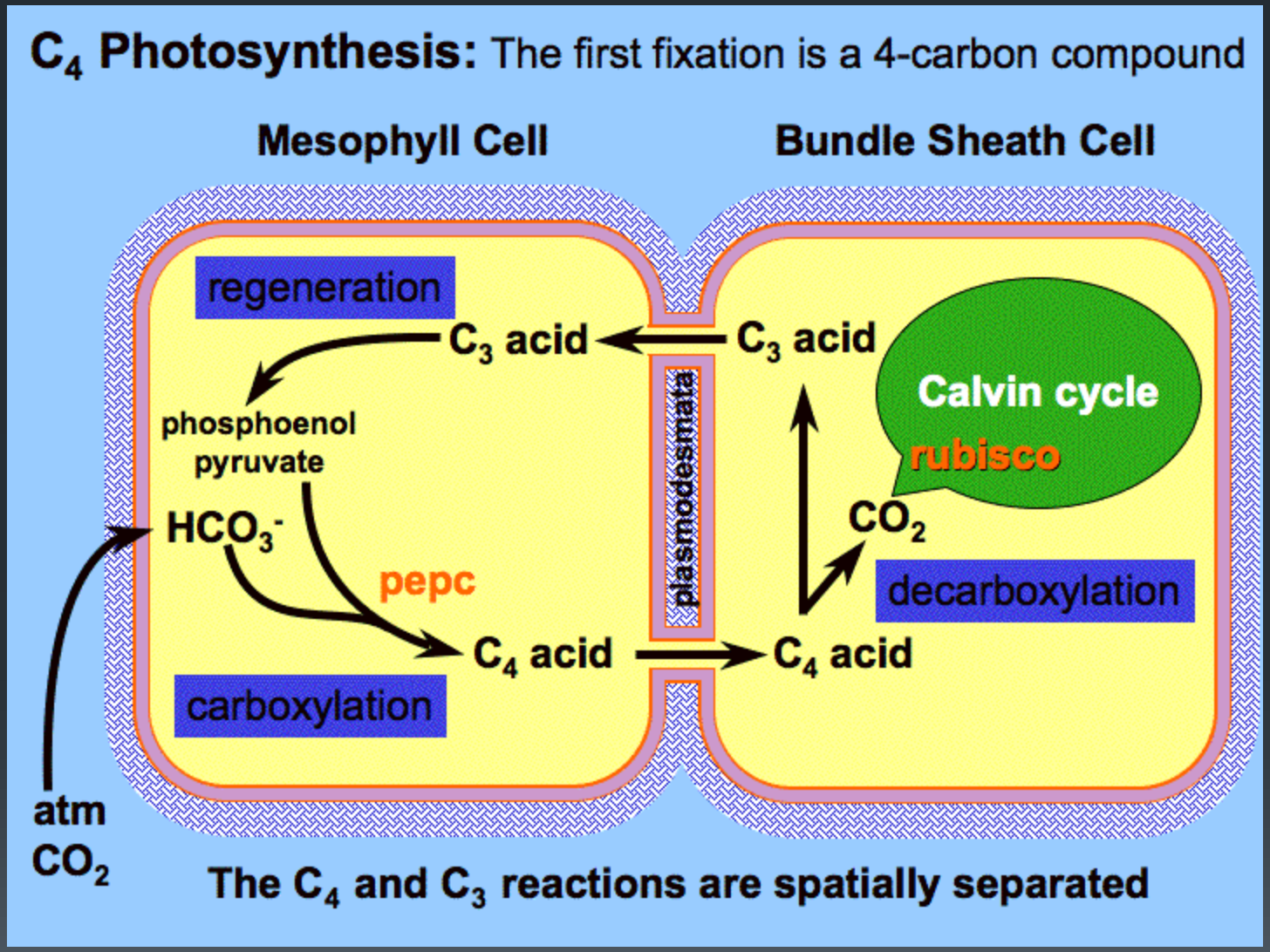
Photosynthetic Machinery

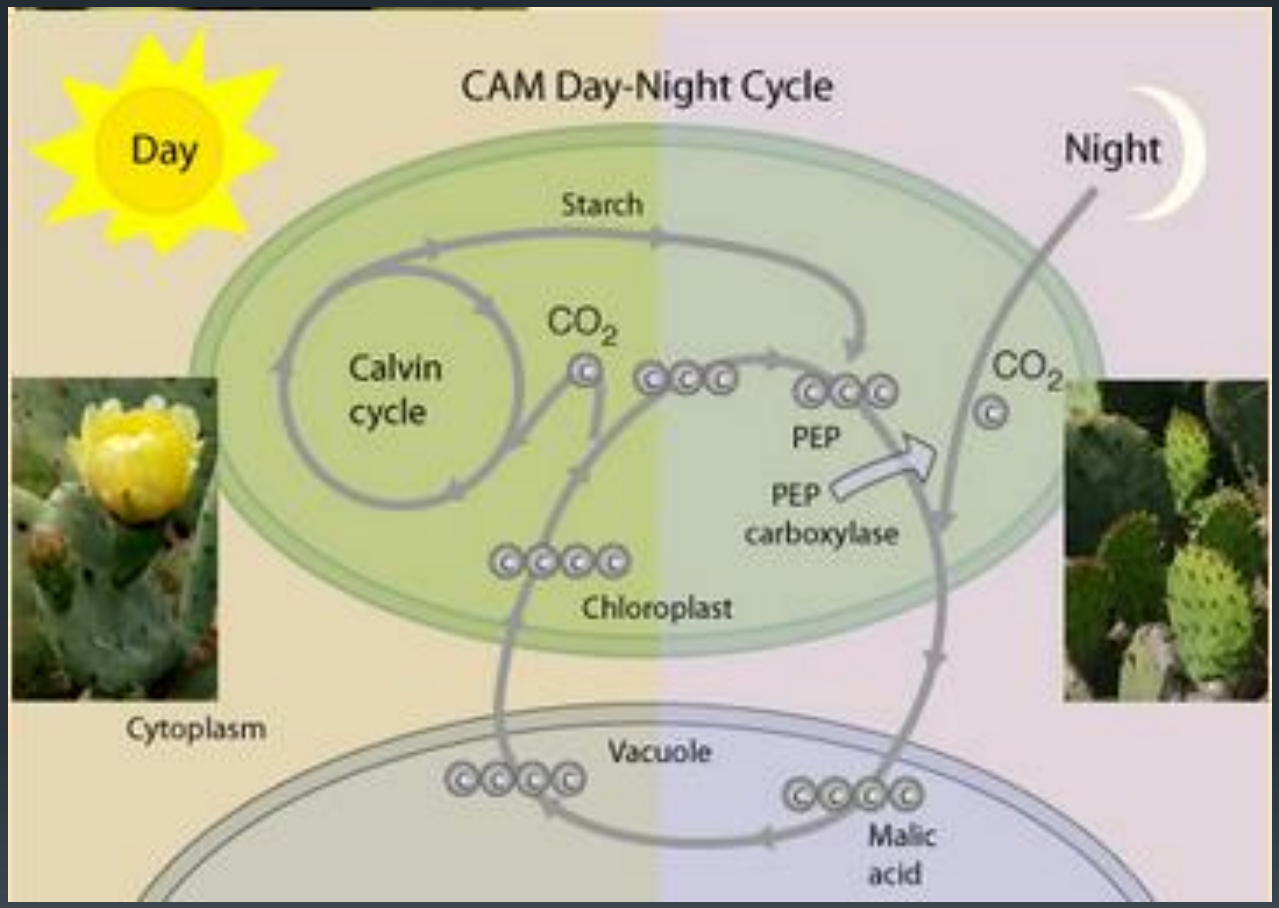
- C3 plants
  - 85% of plant species are C3 plants
  - Cereal grains: wheat, rice, barley, oats, peanuts, cotton, sugar beets, tobacco, spinach, soybeans, and most trees, most lawn grasses such as rye and fescue
- C4 plants
  - 0.4% of known species of plants are C4 plant
  - Corn, sorghum, sugarcane and millet, crabgrass and bermuda grass, many tropical grasses and sedges
- CAM plants
  - 10% of the plant species
  - Cacti, orchids, maternity plant, wax plant, pineapple, Spanish moss, and some ferns, pineapple and Agave

CO_2 levels in chloroplasts below 50 ppm




Stoma
CO_2
Mesophyll cell
Bundle sheath cell
Vascular bundle
Kranz or "halo" anatomy of cells clustered around the vascular bundles.
Section of a leaf of a C4 plant.
CO_2 diffuses into the mesophyll cells from the nearby stoma.
Mesophyll cell
Chloroplast
CO_2
OAA
Fixes carbon, but has no rubisco and does not employ the Calvin cycle.
PEP
ADP
ATP
ATP
Malate or Aspartate
Pumps the 4-carbon compounds through the membrane at the expense of ATP.
ADP
Malate or Aspartate
CO_2
RuBP
Chloroplast
Calvin cycle
2 PGA
2 G3P
Maintains CO_2 level 10-120x higher than normal. This optimizes the use of the rubisco and less of it needs to be made.
Bundle sheath cell
Sucrose, starch, others
Vein
Transport
Calvin cycle used to fix CO_2 in this second stage of the process. Rubisco protected from oxygen, so no photorespiration occurs.


C4 Photosynthesis: The first fixation is a 4-carbon compound
Mesophyll Cell
Bundle Sheath Cell
regeneration
C3 acid
C3 acid
phosphoenol pyruvate
HCO3-
pepc
C4 acid
carboxylation
plasmodesmata
Calvin cycle
rubisco
CO2
decarboxylation
C4 acid
atm CO2
The C4 and C3 reactions are spatially separated


CAM Day-Night Cycle
Day
Night
Starch
CO_2
Calvin cycle
CO_2
PEP
PEP carboxylase
Chloroplast
Cytoplasm
Vacuole
Malic acid

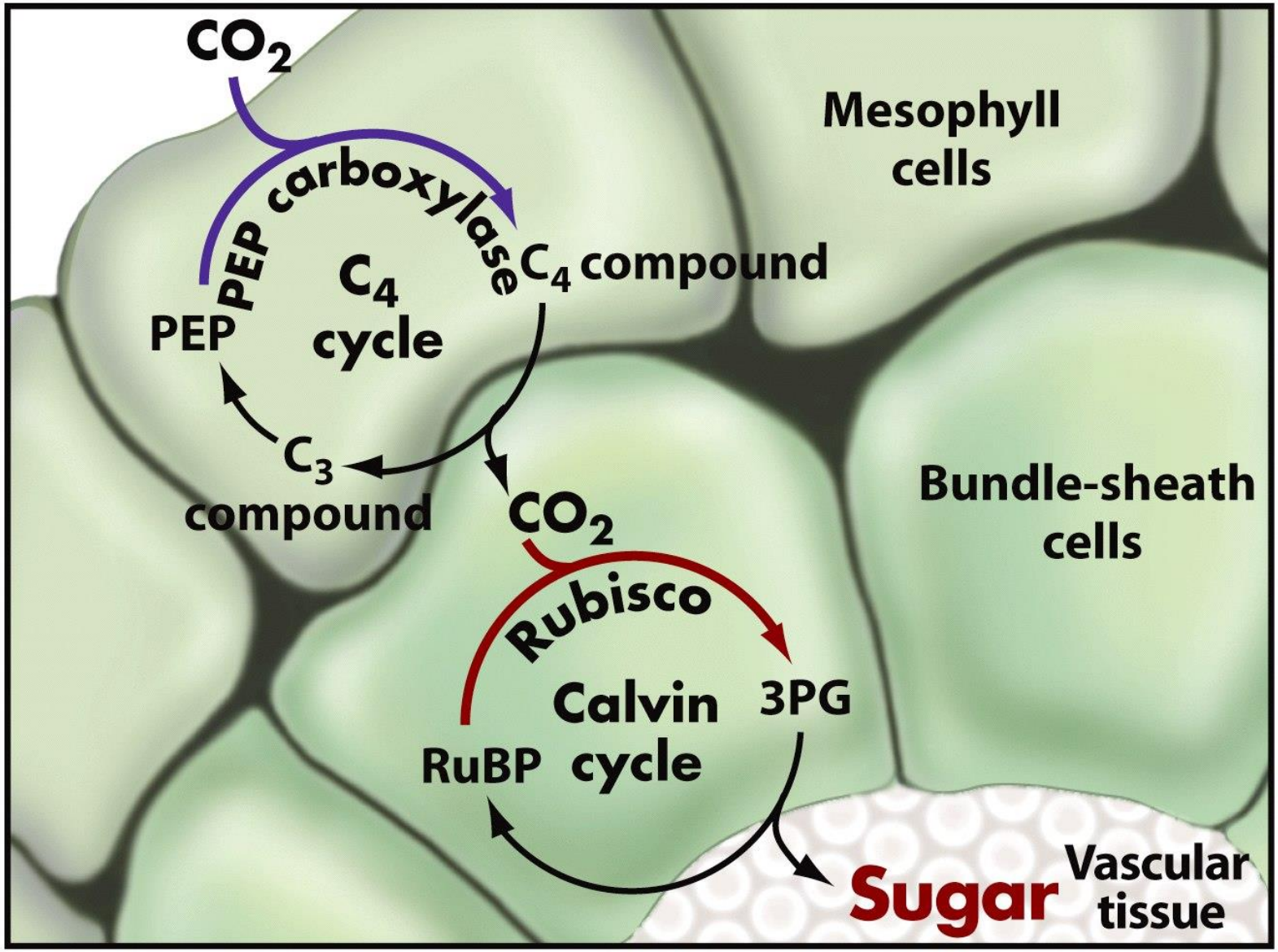
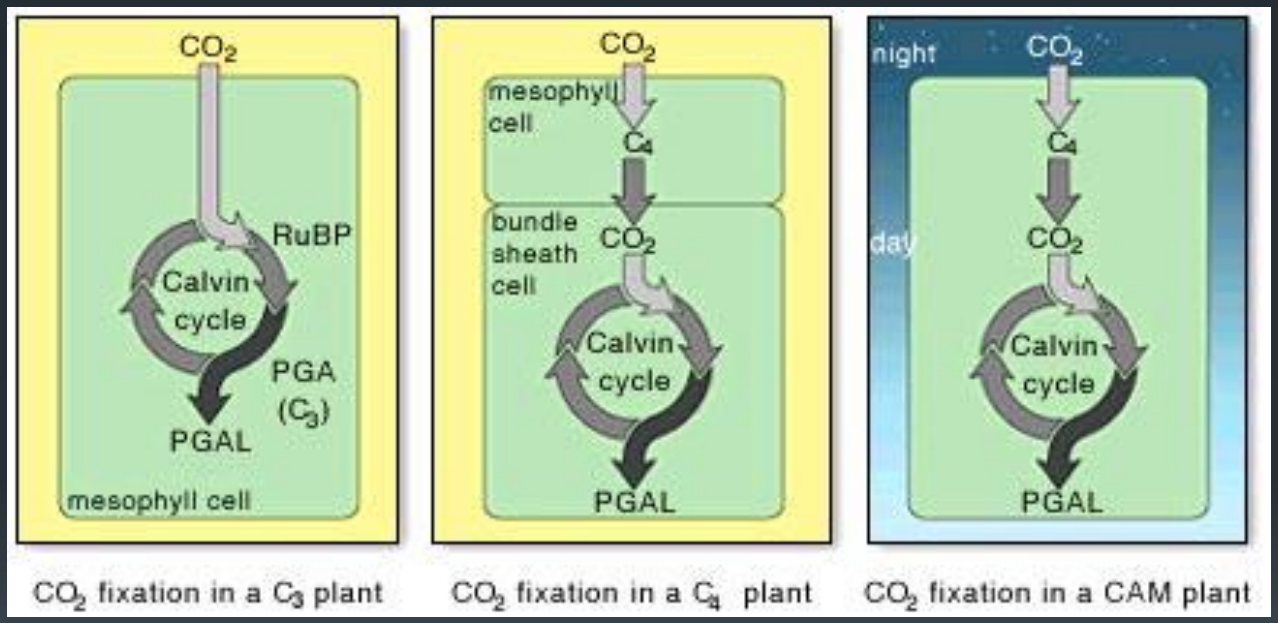


Figure 10-25b Biological Science, 2/e

In Summary:


CO_2
RuBP
Calvin cycle
PGA (C_3)
PGAL
mesophyll cell
CO_2 fixation in a C_3 plant
CO_2
mesophyll cell
C_4
bundle sheath cell
CO_2
Calvin cycle
PGAL
CO_2 fixation in a C_4 plant
night
day
CO_2
C_4
CO_2
Calvin cycle
PGAL
CO_2 fixation in a CAM plant