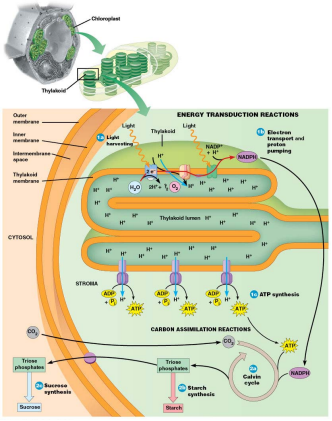

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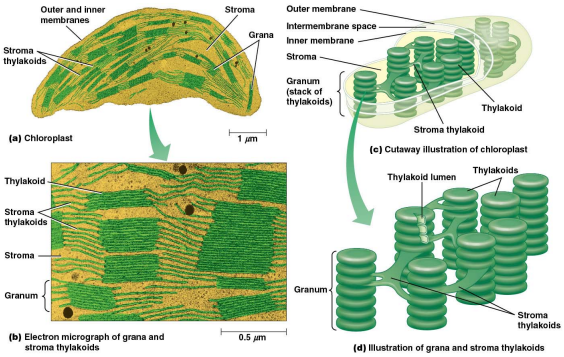

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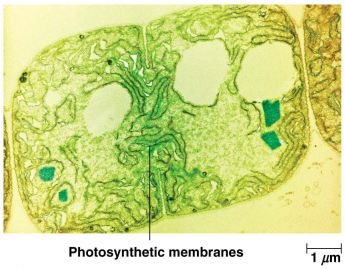

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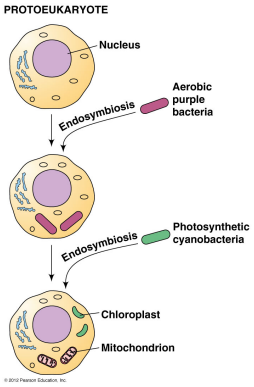

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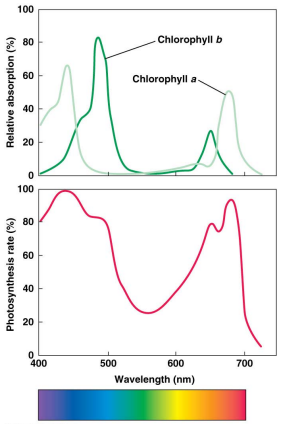

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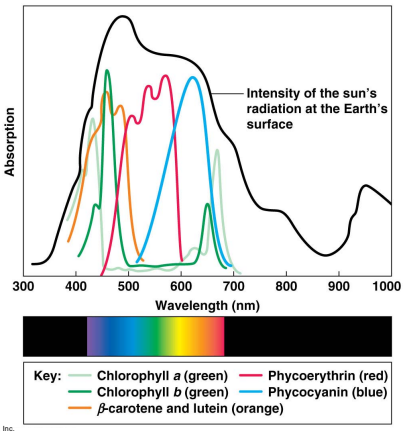

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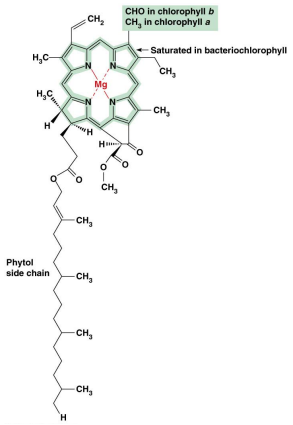

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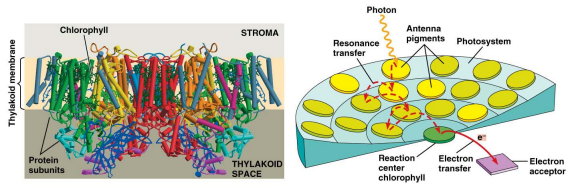

(a) Structure of a photosystem (b) Energy transfer within a photosystem

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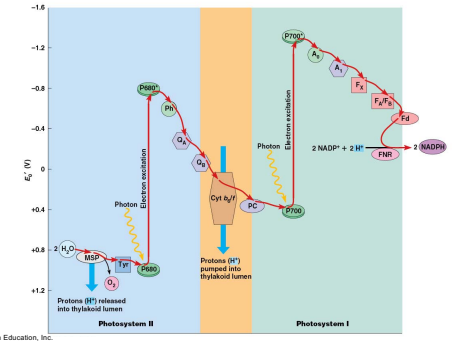
(a) **Photosystem II** removes electrons from water and passes them sequentially to a manganese-stabilizing protein (MSP), a tyrosine residue (Tyr) on protein D1, a special pair of chlorophyll *a* molecules (P680), pheophytin (Ph), and two plastoquinones (Q_A and Q_B). Oxygen is released as water is oxidized.

(b) **The cytochrome b_6/f complex** receives electrons from PSII and passes them to PSI via plastocyanin (PC). Simultaneously, protons are pumped from the chloroplast stroma into the thylakoid lumen.

(c) **Photosystem I** accepts electrons from PC and passes them to ferredoxin (Fd) via another special pair of chlorophyll *a* molecules (P700), a modified chlorophyll *a* molecule (A_0), phylloquinone (A_1), and three iron-sulfur centers (F_X, F_A, and F_B).

(d) **Ferredoxin-NADP⁺ reductase (FNR)** transfers electrons from ferredoxin to NADP.



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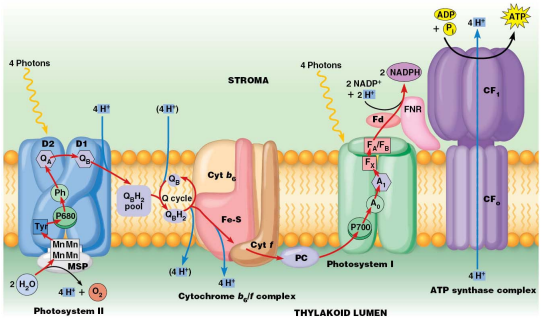
(a) **PSII** includes 25 polypeptides, two of which (D1 and D2) bind chlorophyll P680 and components of the electron transport system. The four manganese atoms help to oxidize water.

(b) **The cytochrome b_6/f complex** contains seven polypeptides and includes two cytochromes (b_6 and f) and an iron-sulfur protein (Fe-S). It transfers electrons from PSII to PSI.

(c) **PSI** contains more than ten polypeptides and binds chlorophyll P700 and several additional electron carriers. Electrons from PSI are used to reduce NADP⁺ to NADPH.

(d) **The ATP synthase complex** acts as a proton channel and uses the electrochemical proton gradient generated by electron transport to synthesize ATP.



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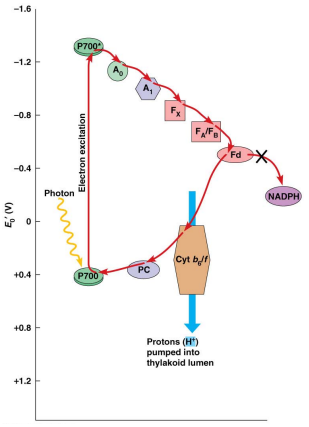

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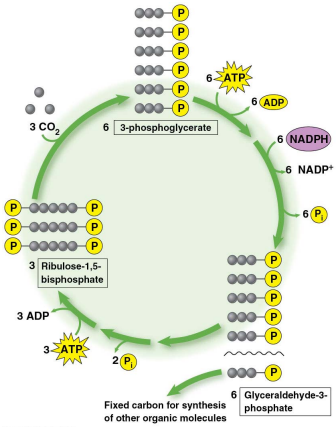

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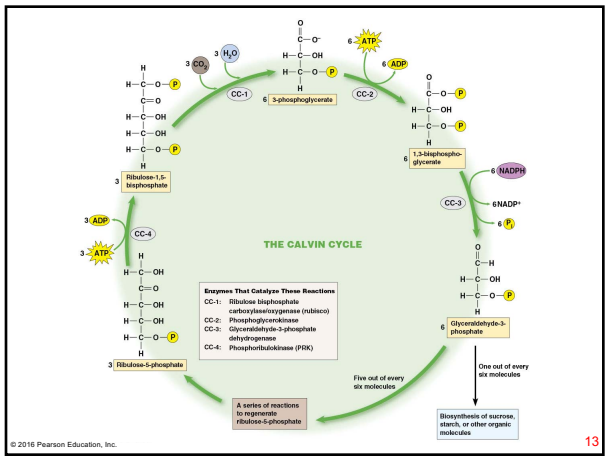
THE CALVIN CYCLE
3 CO2
3 H2O
CC-1
6 3-phosphoglycerate
6 ATP
6 ADP
CC-2
6 1,3-bisphospho-glycerate
6 NADPH
6 NADP+
6 Pi
CC-3
6 Glyceraldehyde-3-phosphate
One out of every six molecules
Five out of every six molecules
Biosynthesis of sucrose, starch, or other organic molecules
A series of reactions to regenerate ribulose-5-phosphate
3 Ribulose-5-phosphate
3 ATP
3 ADP
CC-4
3 Ribulose-1,5-bisphosphate
Enzymes That Catalyze These Reactions
CC-1: Ribulose bisphosphate carboxylase/oxygenase (rubisco)
CC-2: Phosphoglycerokinase
CC-3: Glyceraldehyde-3-phosphate dehydrogenase
CC-4: Phosphoribulokinase (PRK)
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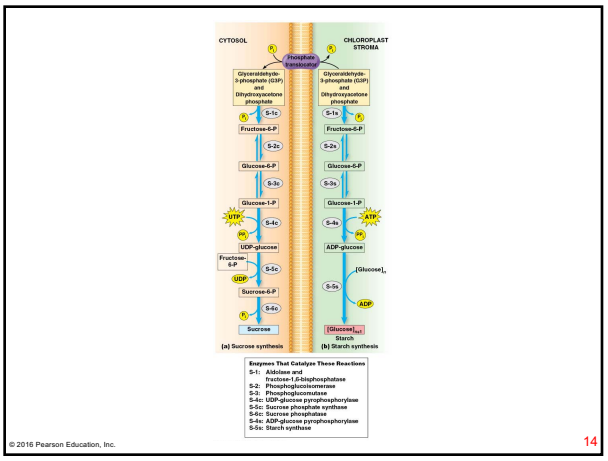
CYTOSOL
CHLOROPLAST STROMA
Phosphate translocator
Glyceraldehyde-3-phosphate (G3P) and Dihydroxyacetone phosphate
S-1c
S-1a
Fructose-6-P
S-2c
S-2a
Glucose-6-P
S-3c
S-3a
Glucose-1-P
UTP
S-4c
S-4a
ATP
UDP-glucose
ADP-glucose
Fructose-6-P
S-5c
UDP
Sucrose-6-P
S-6c
S-5a
ADP
Sucrose
[Glucose]n
[Glucose]n+1
Starch
(a) Sucrose synthesis
(b) Starch synthesis
Enzymes That Catalyze These Reactions
S-1: Aldolase and fructose-1,6-bisphosphatase
S-2: Phosphoglucoisomerase
S-3: Phosphoglucomutase
S-4c: UDP-glucose pyrophosphorylase
S-5c: Sucrose phosphate synthase
S-6c: Sucrose phosphatase
S-4a: ADP-glucose pyrophosphorylase
S-5a: Starch synthase
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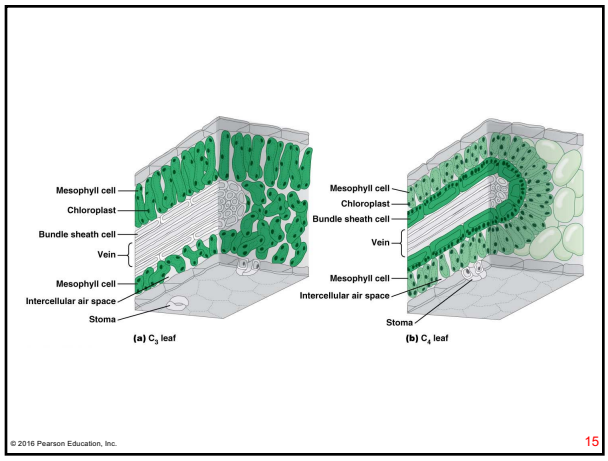
Mesophyll cell
Chloroplast
Bundle sheath cell
Vein
Mesophyll cell
Intercellular air space
Stoma
(a) C3 leaf
Mesophyll cell
Chloroplast
Bundle sheath cell
Vein
Mesophyll cell
Intercellular air space
Stoma
(b) C4 leaf
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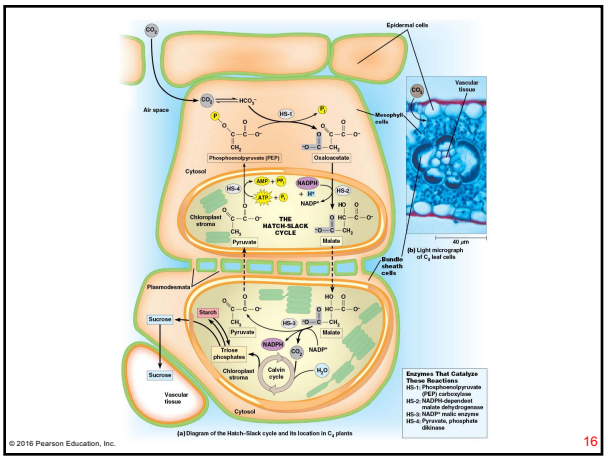
CO2
Epidermal cells
Air space
HCO3−
HS-1
Mesophyll cells
Phosphoenolpyruvate (PEP)
Oxaloacetate
Cytosol
AMP + Pi
ATP + Pi
NADPH + H+
NADP+
HS-4
HS-2
Chloroplast stroma
THE HATCH-SLACK CYCLE
Pyruvate
Malate
Vascular tissue
40 μm
(b) Light micrograph of C4 leaf cells
Bundle sheath cells
Plasmodesmata
Sucrose
Starch
Pyruvate
HS-3
Malate
NADPH
CO2
NADP+
Triose phosphates
Chloroplast stroma
Calvin cycle
H2O
Sucrose
Vascular tissue
Cytosol
(a) Diagram of the Hatch-Slack cycle and its location in C4 plants
Enzymes That Catalyze These Reactions
HS-1: Phosphoenolpyruvate (PEP) carboxylase
HS-2: NADPH-dependent malate dehydrogenase
HS-3: NADP+ malic enzyme
HS-4: Pyruvate, phosphate dikinase
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