Фотосинтез

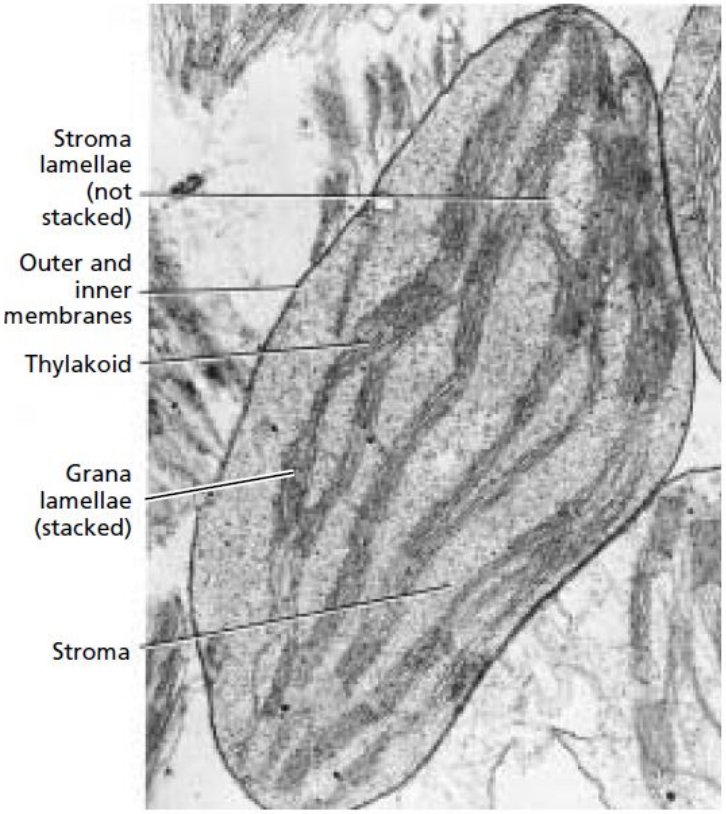
Лекция для студентов 3 курса ОДО биологического факультета

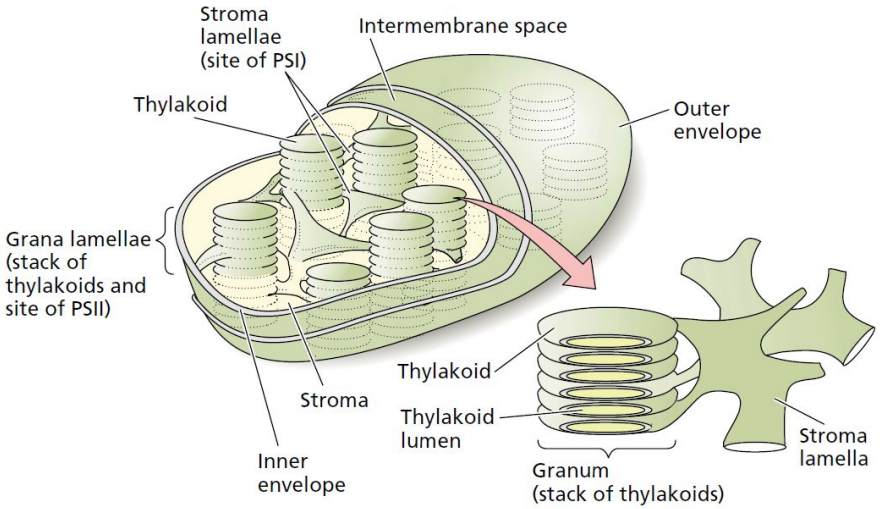
Общее уравнение фотосинтеза

$$6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2$$

Carbon dioxide — Water — Carbohydrate — Oxygen

Строение хлоропласта

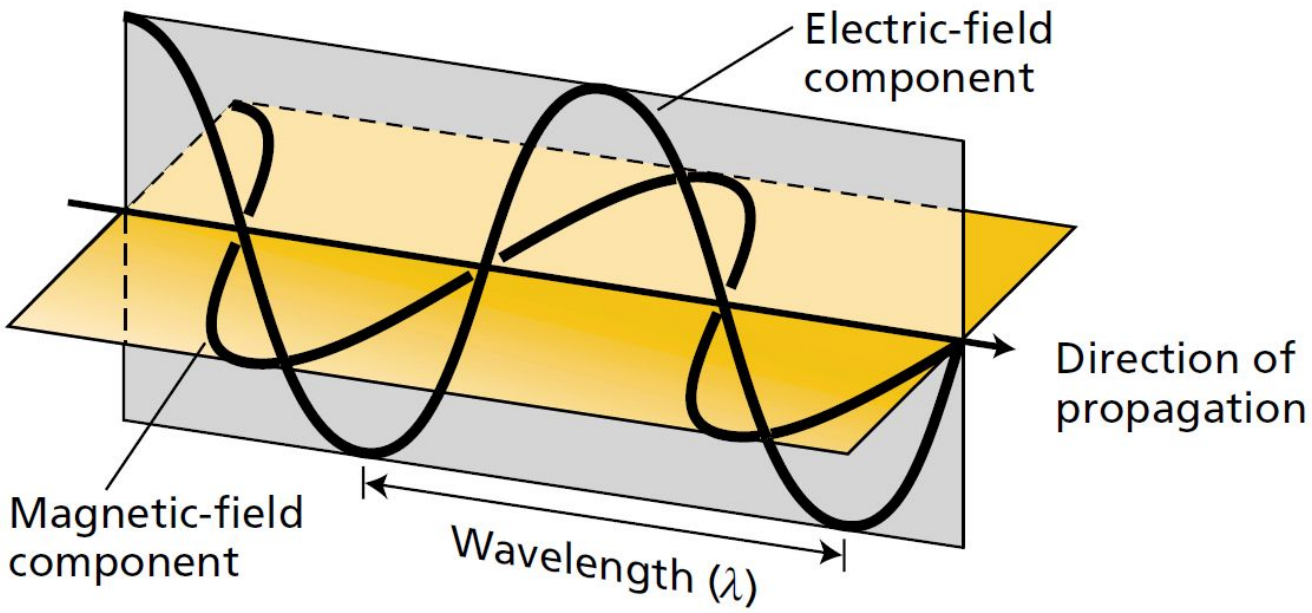




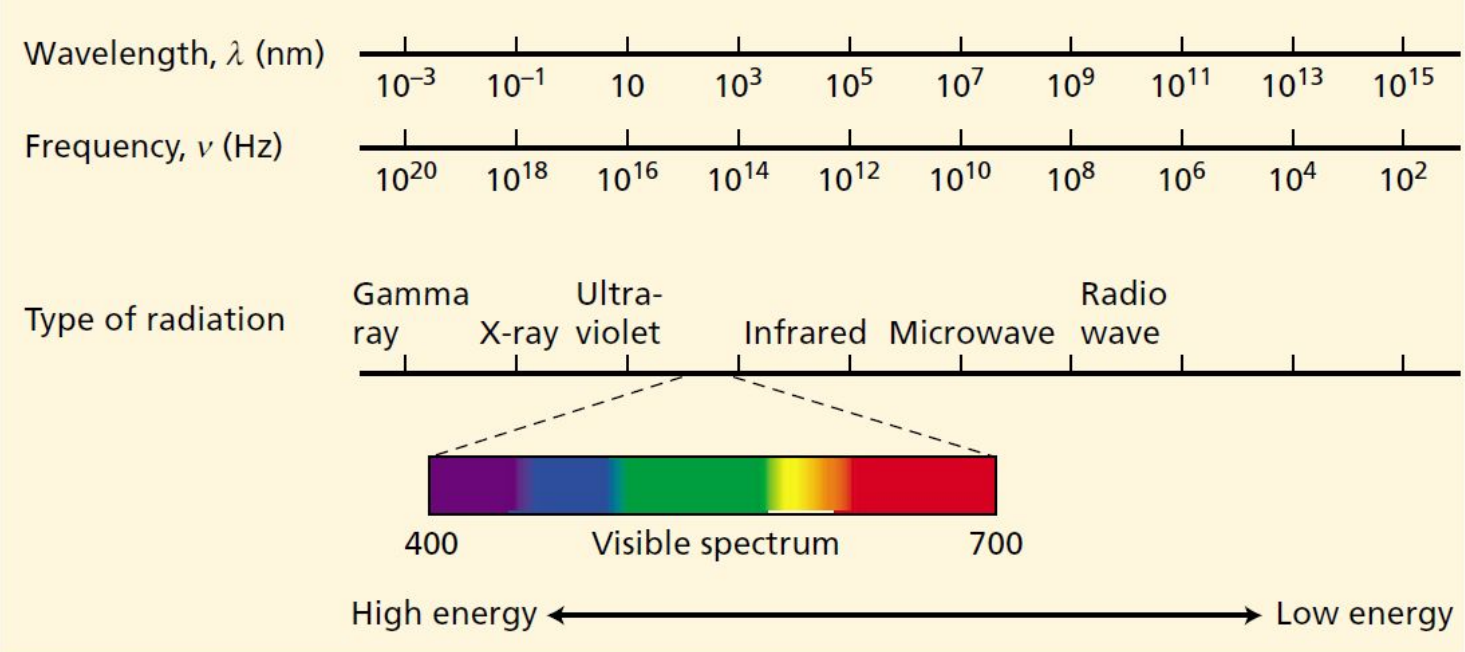
ФОТОСИНТЕЗ.

- Световые реакции

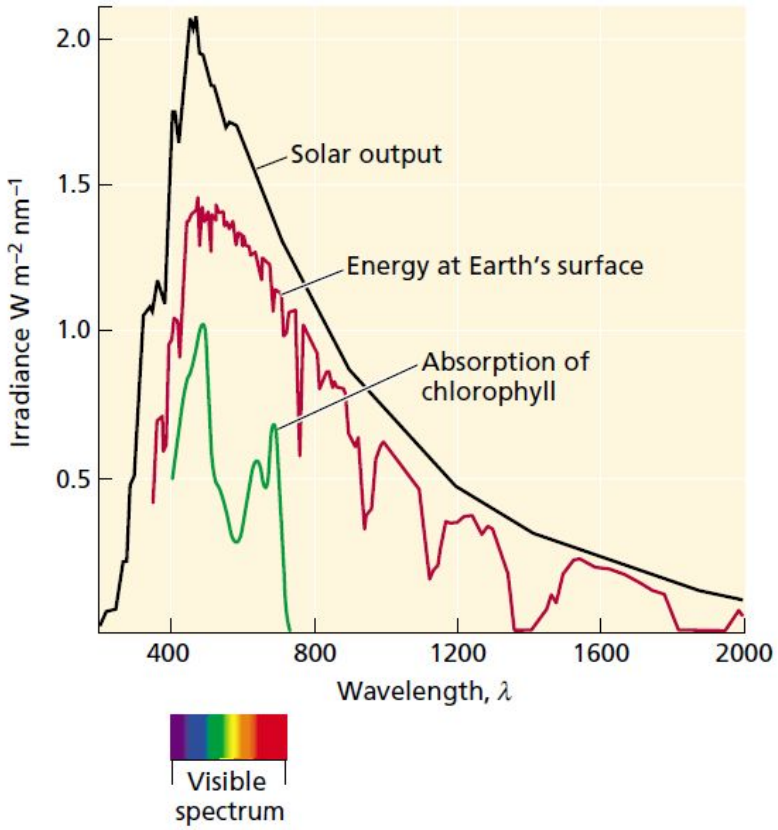
Природа световой энергии



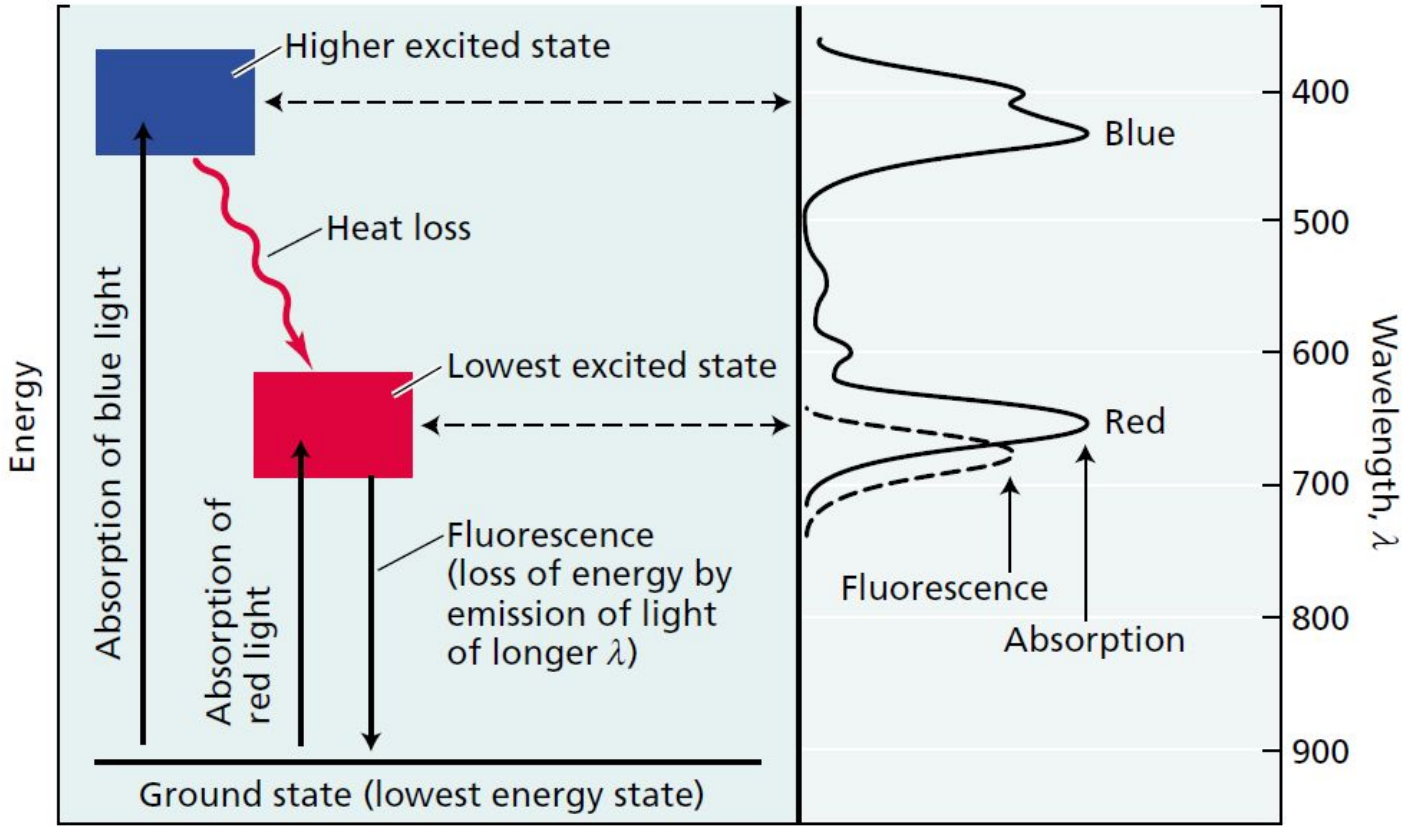
Электромагнитный спектр



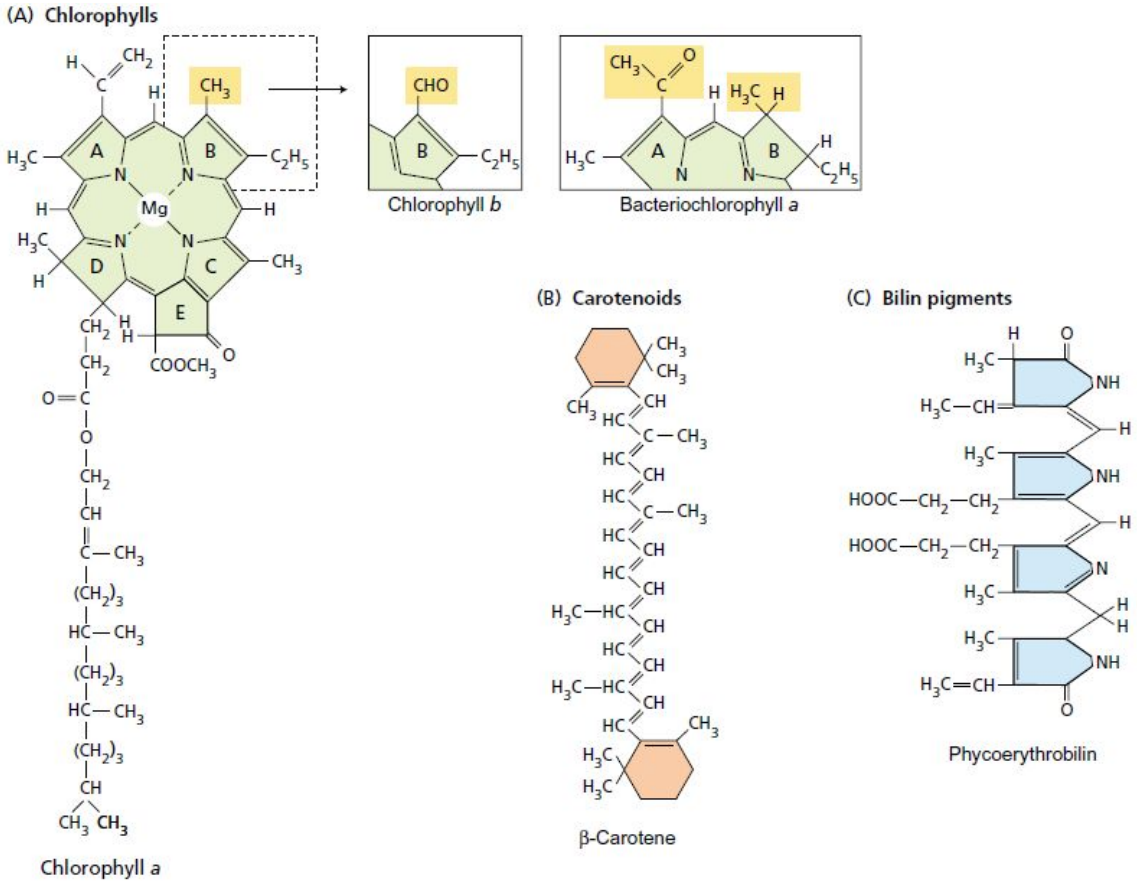
Спектр солнечного излучения и область поглощения хлорофилла



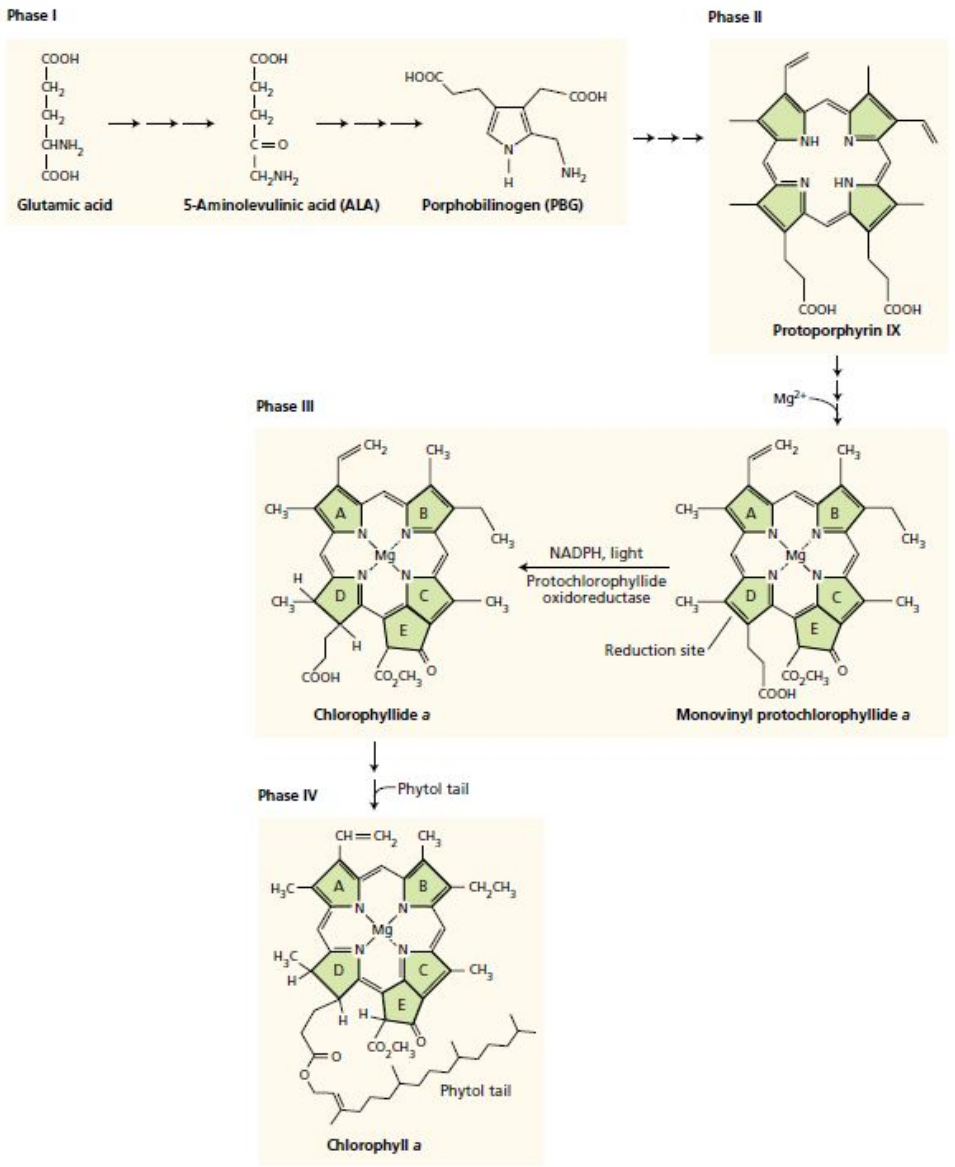
Поглощение и испускание энергии хлорофиллом



Строение фотосинтетических пигментов



Основные этапы синтеза хлорофилла а



Спектры абсорбции некоторых фотосинтетических пигментов

- 1. Бактериохлорофилл a
- 2. Хлорофилл a
- 3. Хлорофилл b
- 4. Фикоэритробиллин
- 5. β-каротин

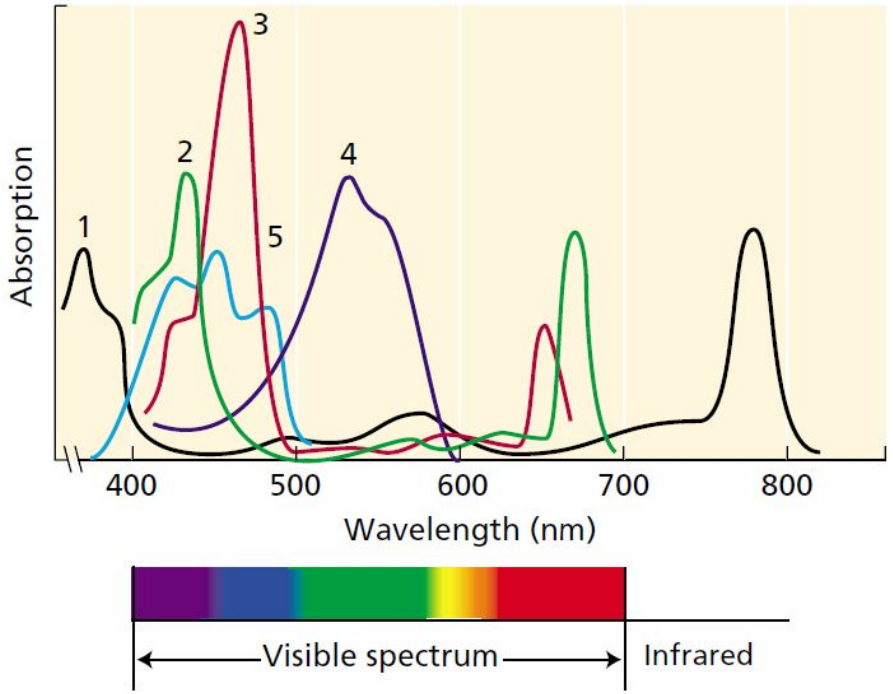
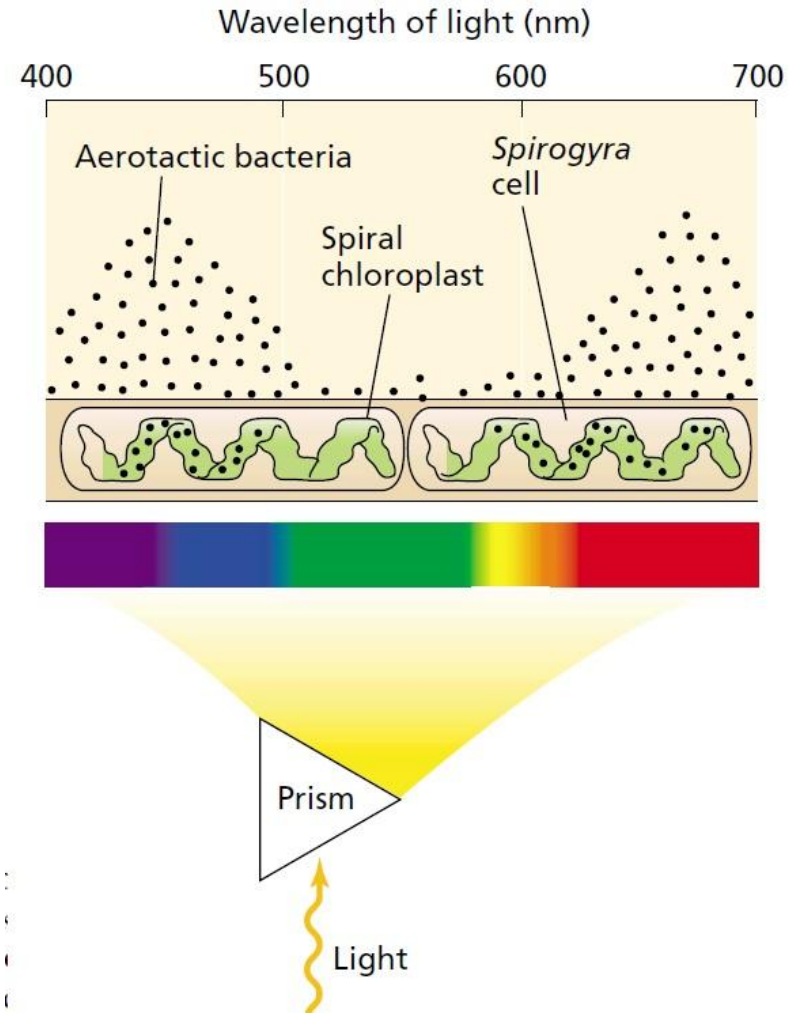
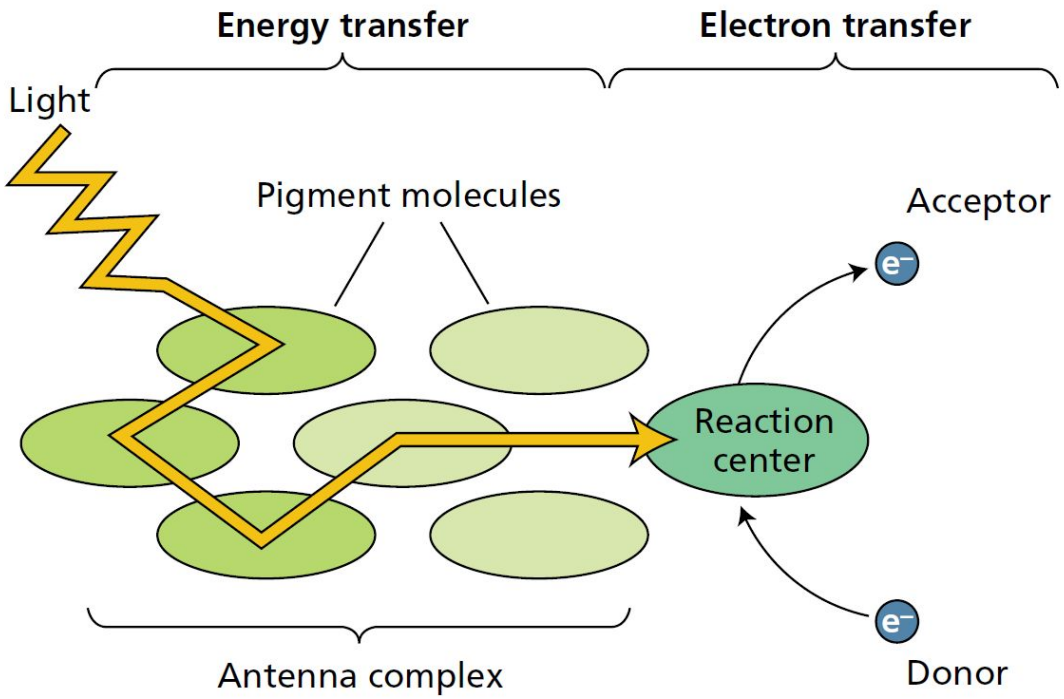


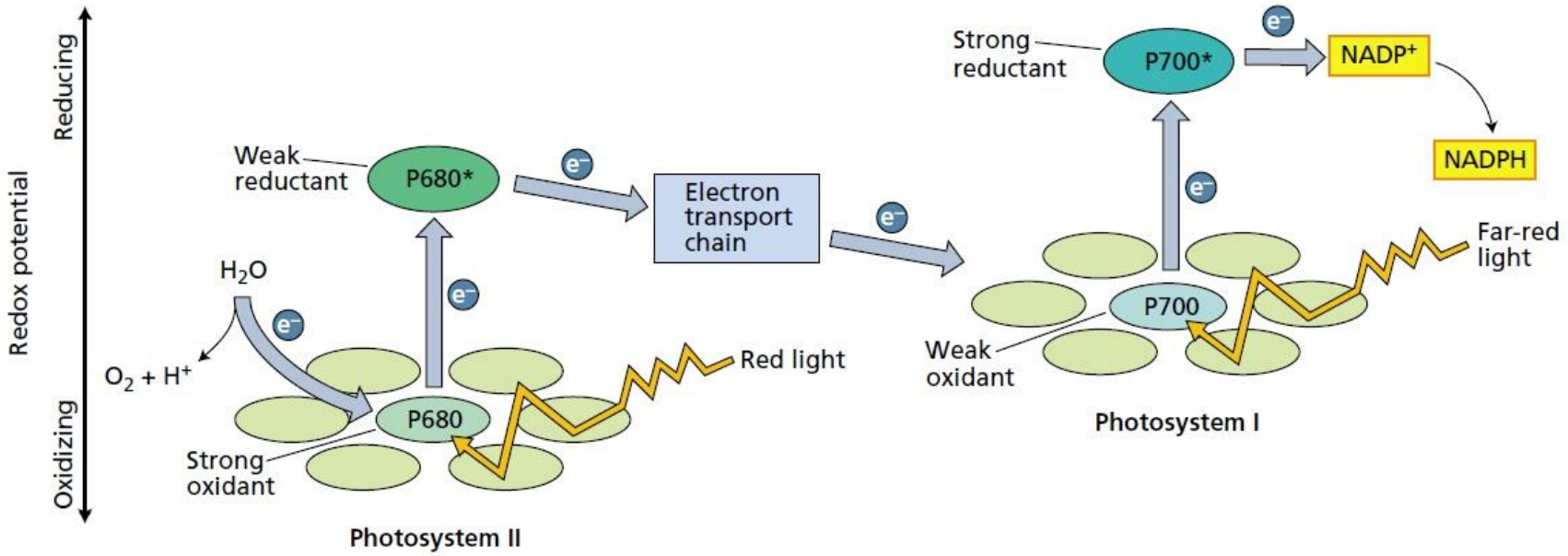
Схема эксперимента Энгельмана



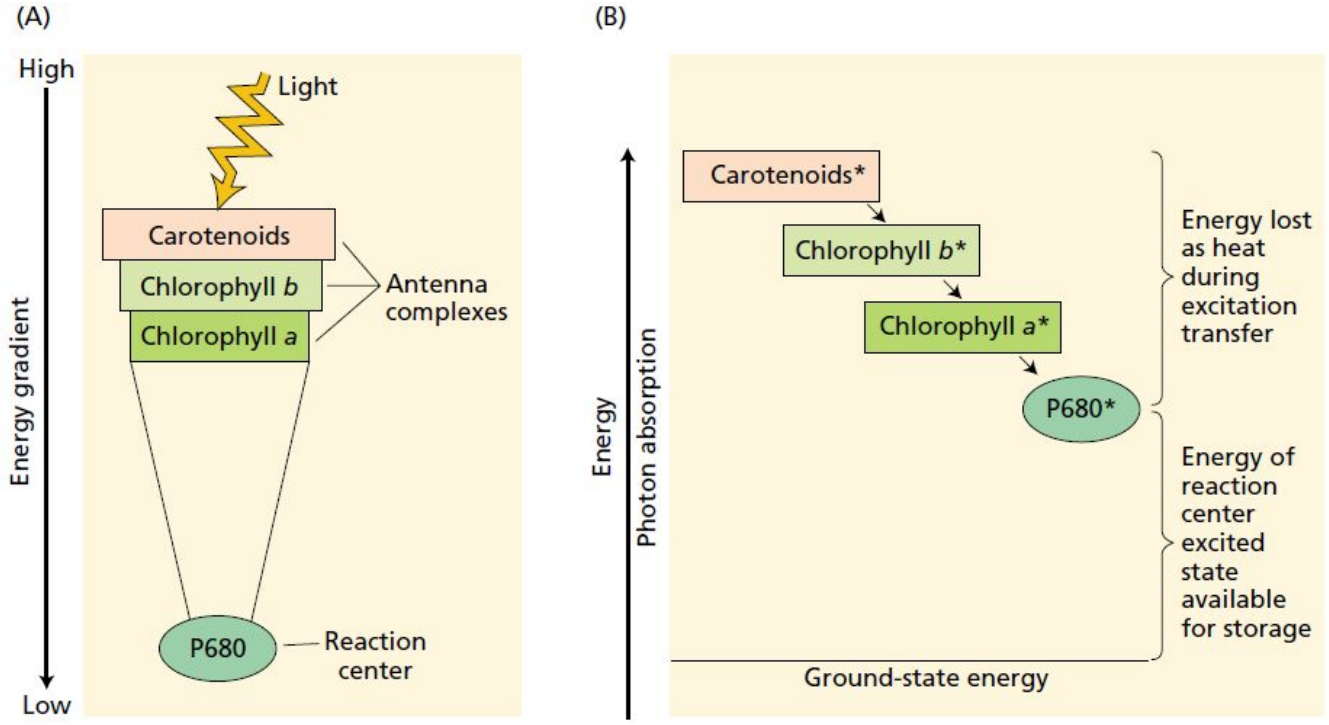
Концепция трансформации энергии света в процессе фотосинтеза



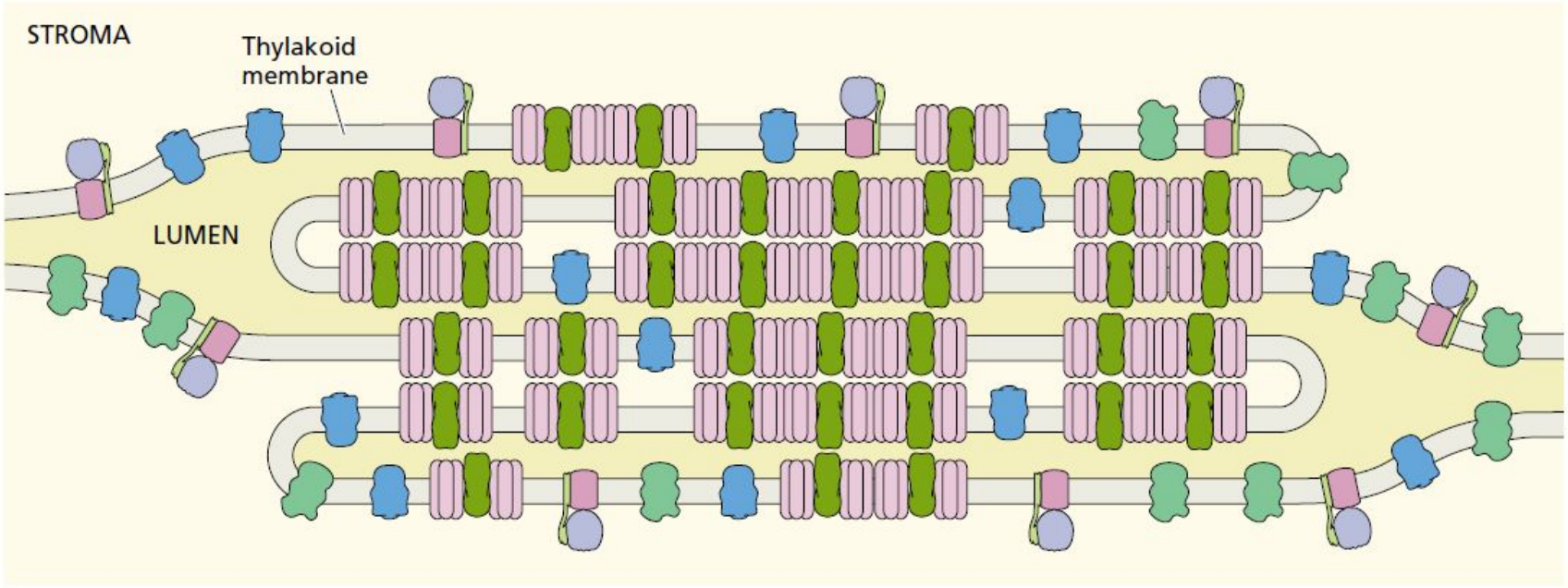
Z-схема фотосинтеза

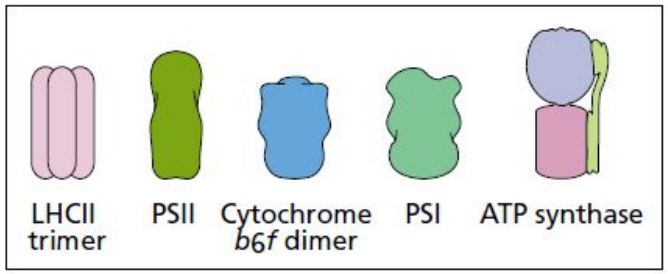


Передача энергии в светособирающем комплексе

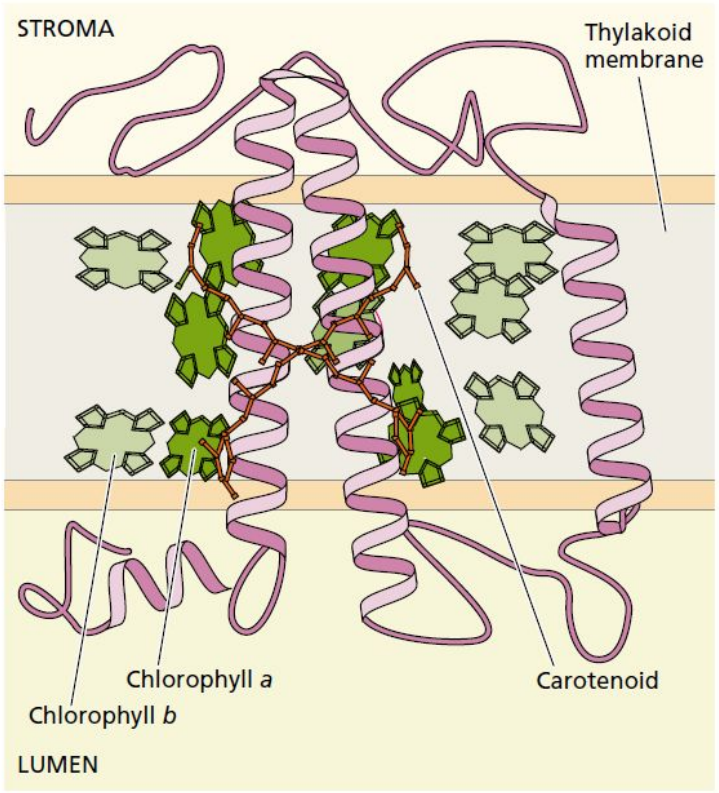


Расположение белковых комплексов в мембране тилакоидов

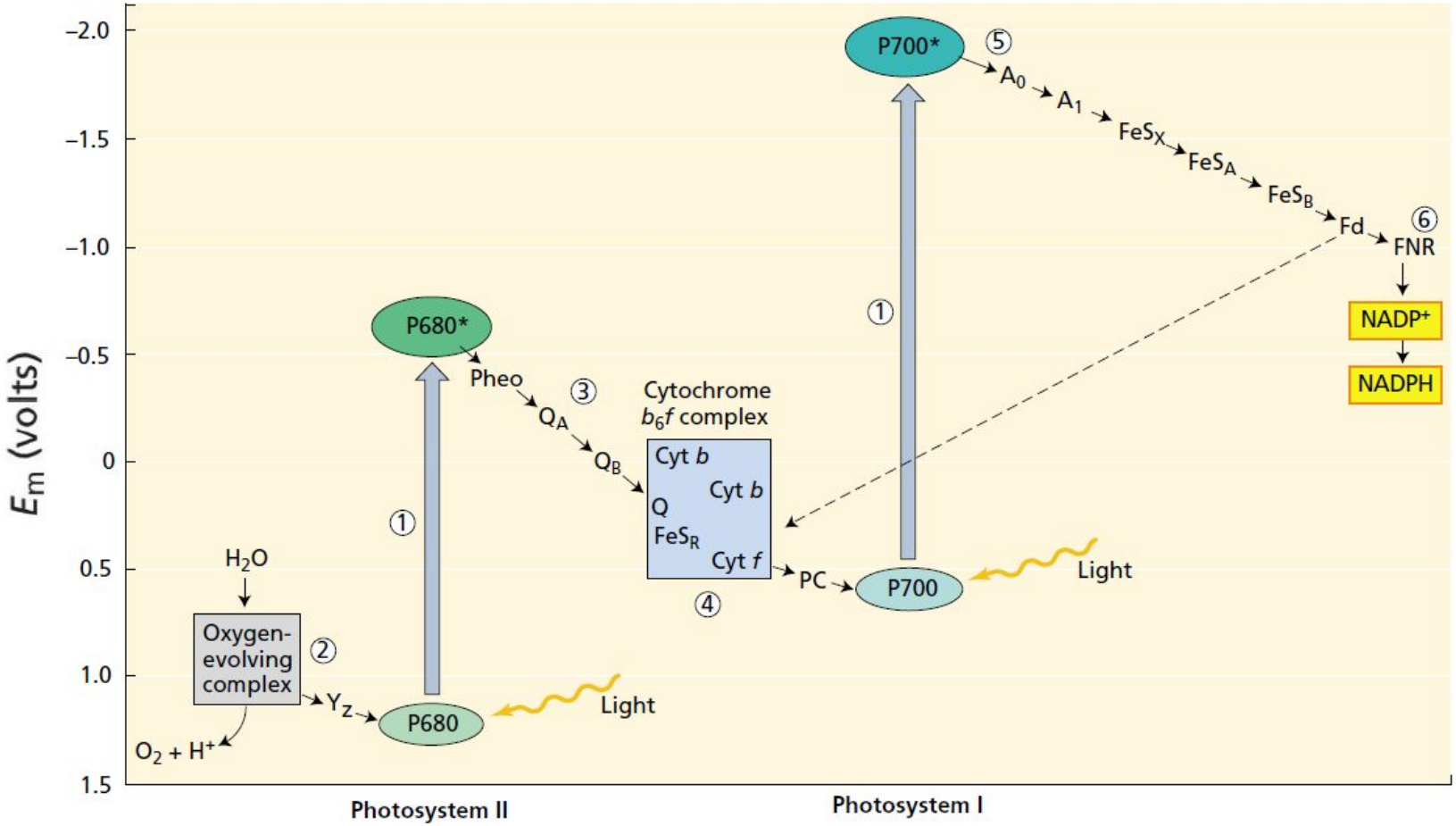




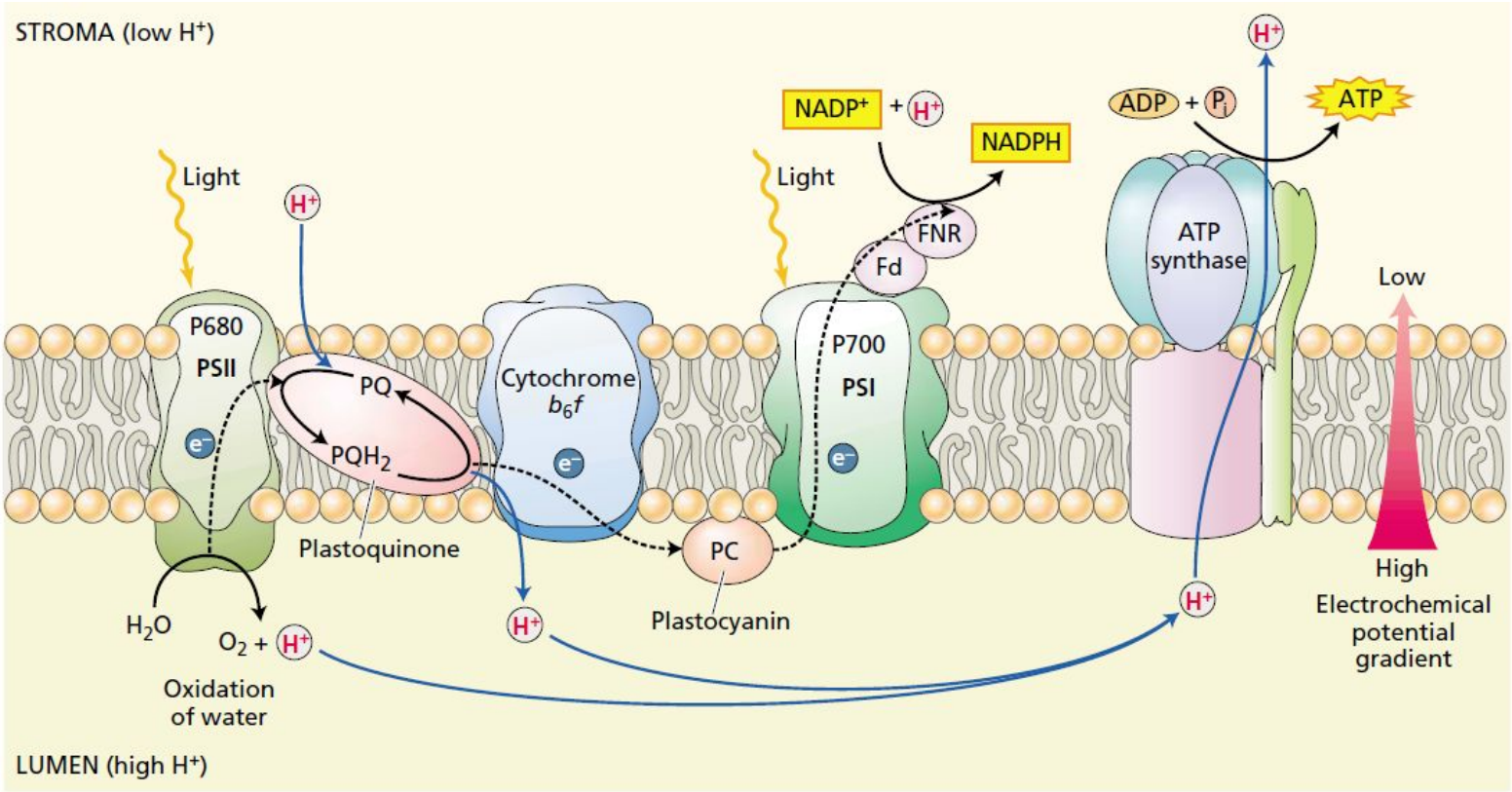
Строение светособирающего комплекса



Z-схема

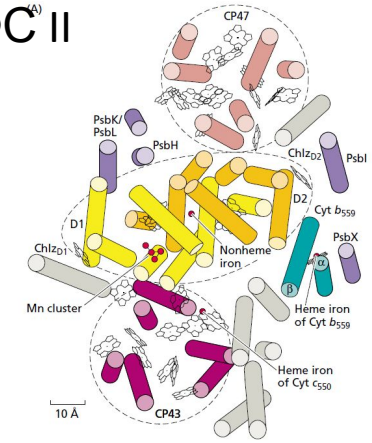

–2.0
–1.5
–1.0
–0.5
0
0.5
1.0
1.5
E_m (volts)
P700*
⑤
A_0
A_1
FeS_X
FeS_A
FeS_B
Fd
⑥
FNR
NADP+
NADPH
①
P680*
Pheo
③
Q_A
Q_B
Cytochrome
b_6f complex
Cyt *b*
Cyt *b*
Q
FeS_R
Cyt *f*
④
PC
P700
Light
H_2O
Oxygen-
evolving
complex
②
Y_Z
P680
Light
$O_2 + H^+$
Photosystem II
Photosystem I

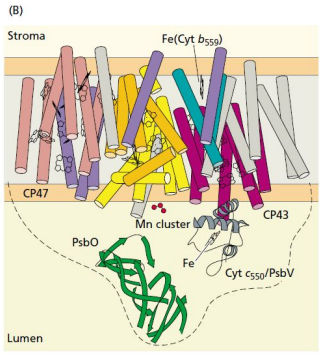
Перенос электронов и протонов по системе белковых компонентов мембраны тилакоида. Синтез АТР

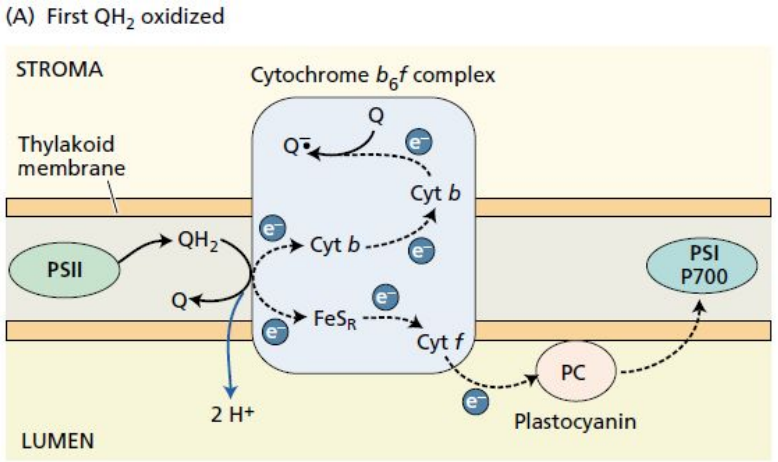


Структура ФСII и ФСI

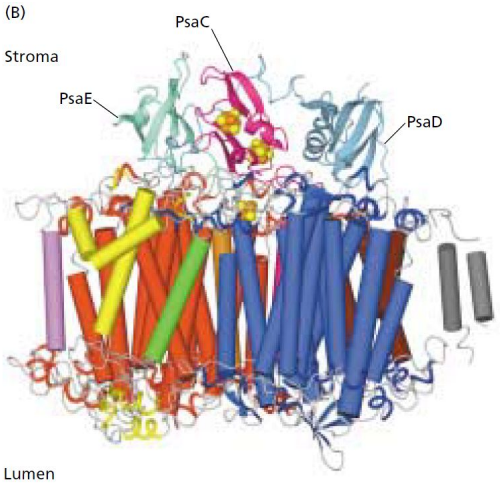
ФС II

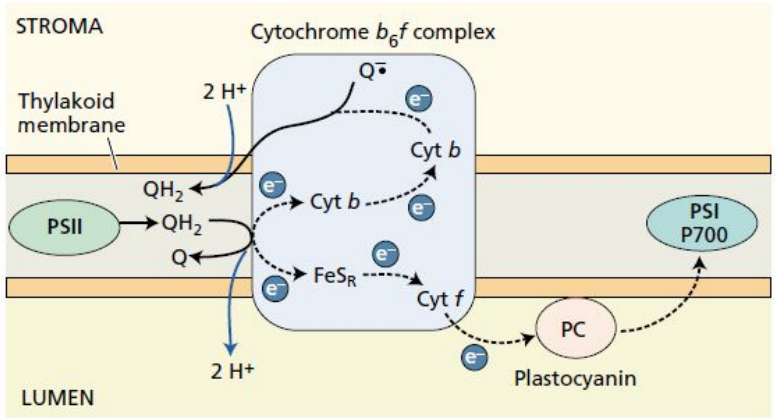




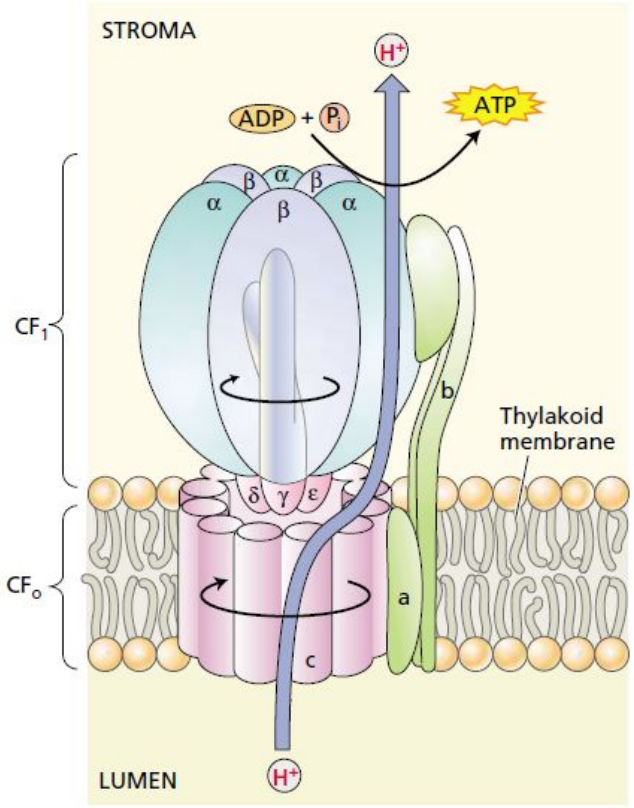


ФС I

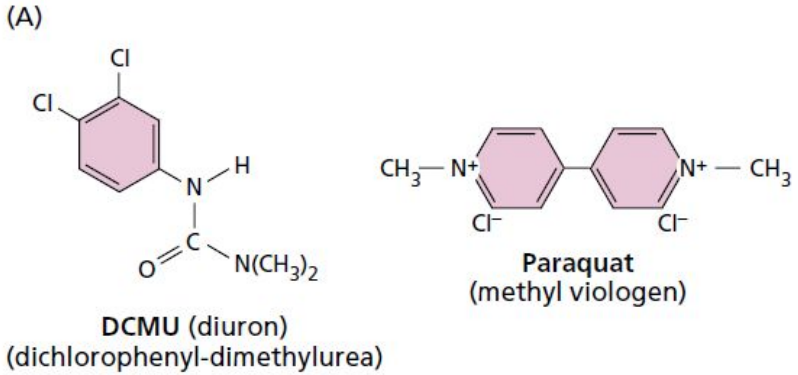


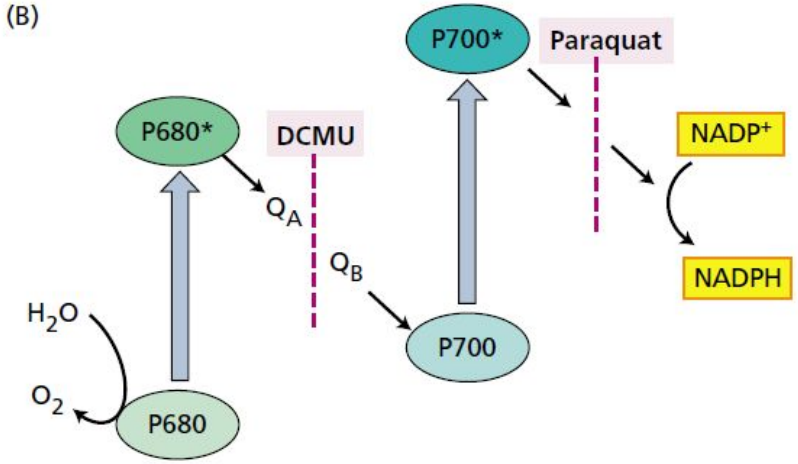


Структура АТРсинтазы



Гербициды, нарушающие транспорт электронов

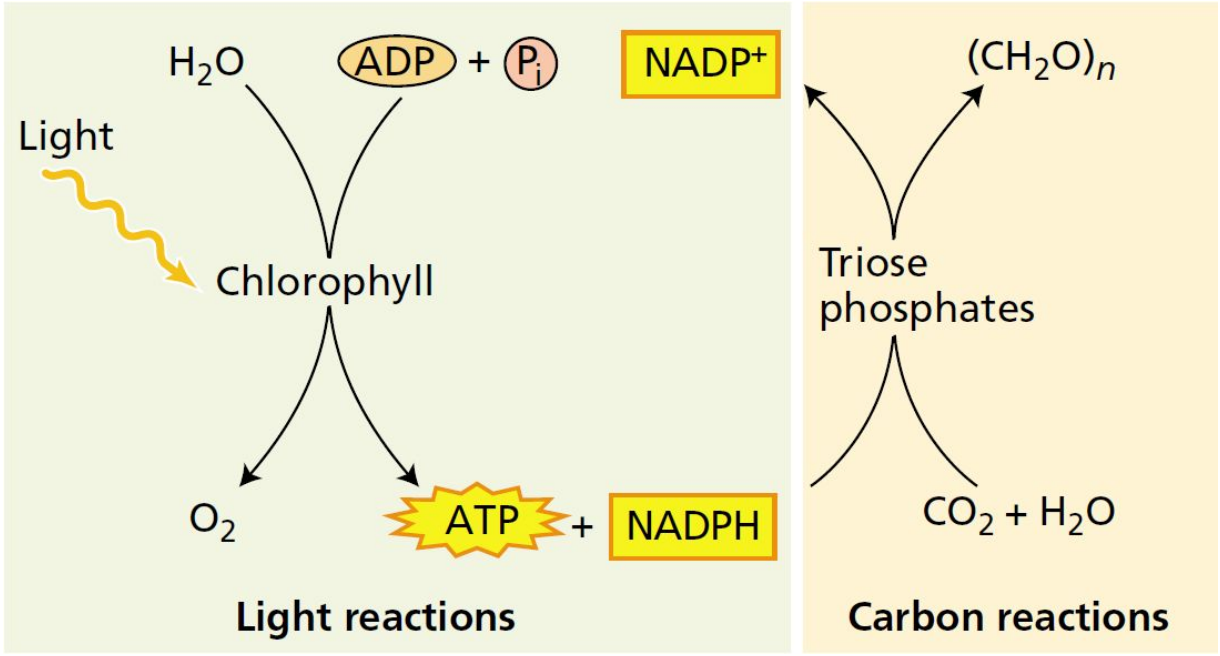




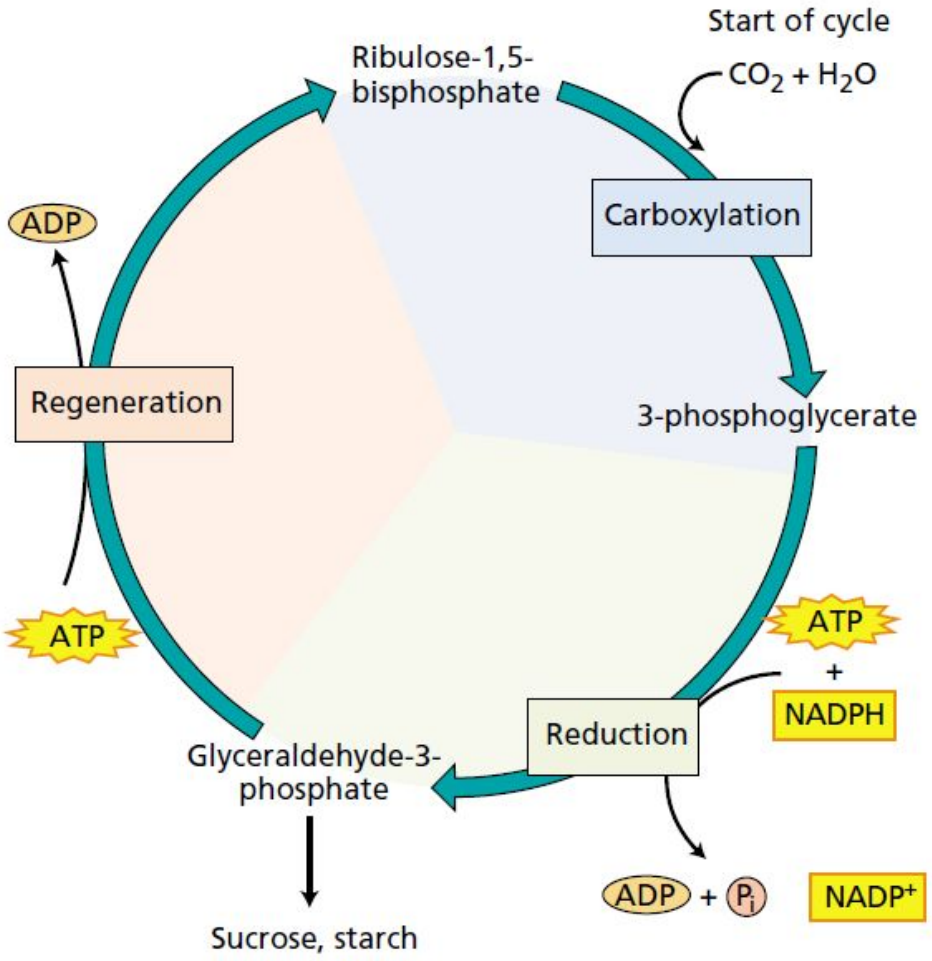
ФОТОСИНТЕЗ

- Темновые реакции

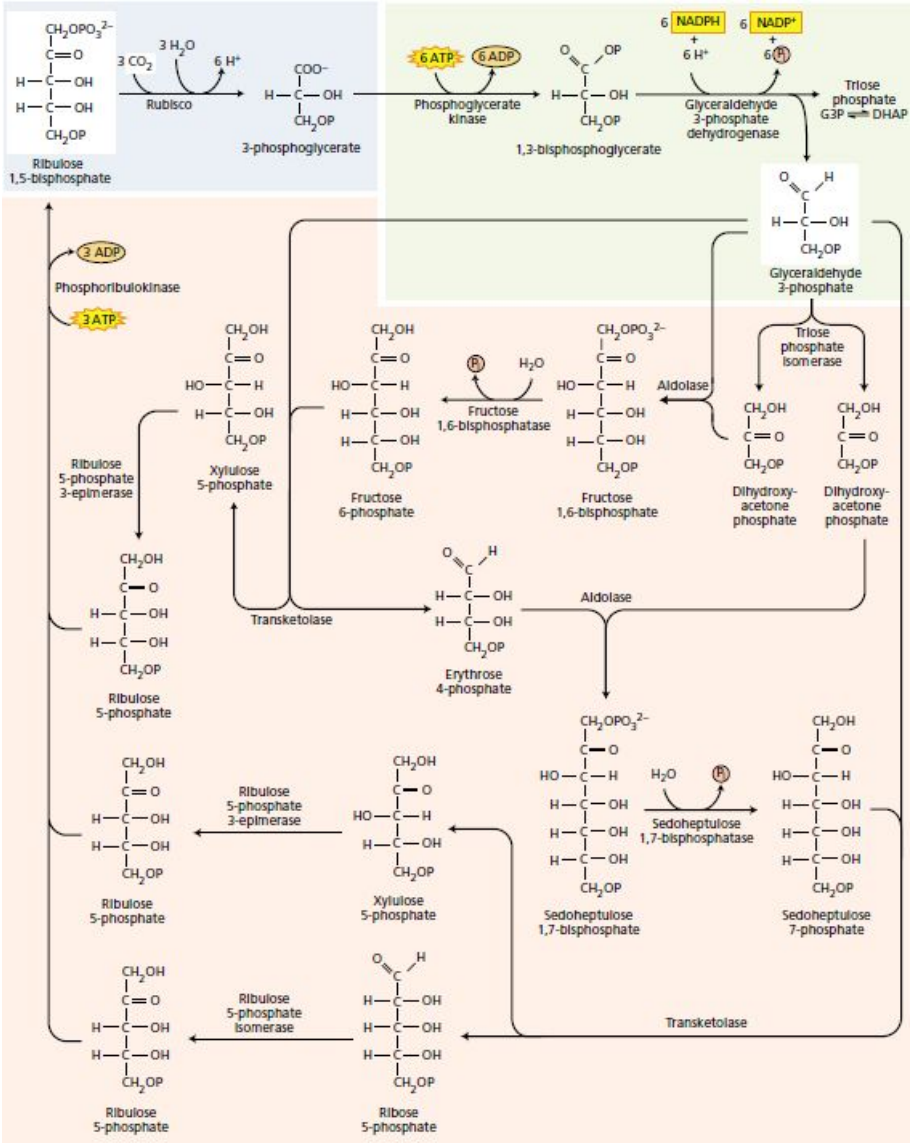
Темновая стадия фотосинтеза



Цикл Кальвина. Основные этапы



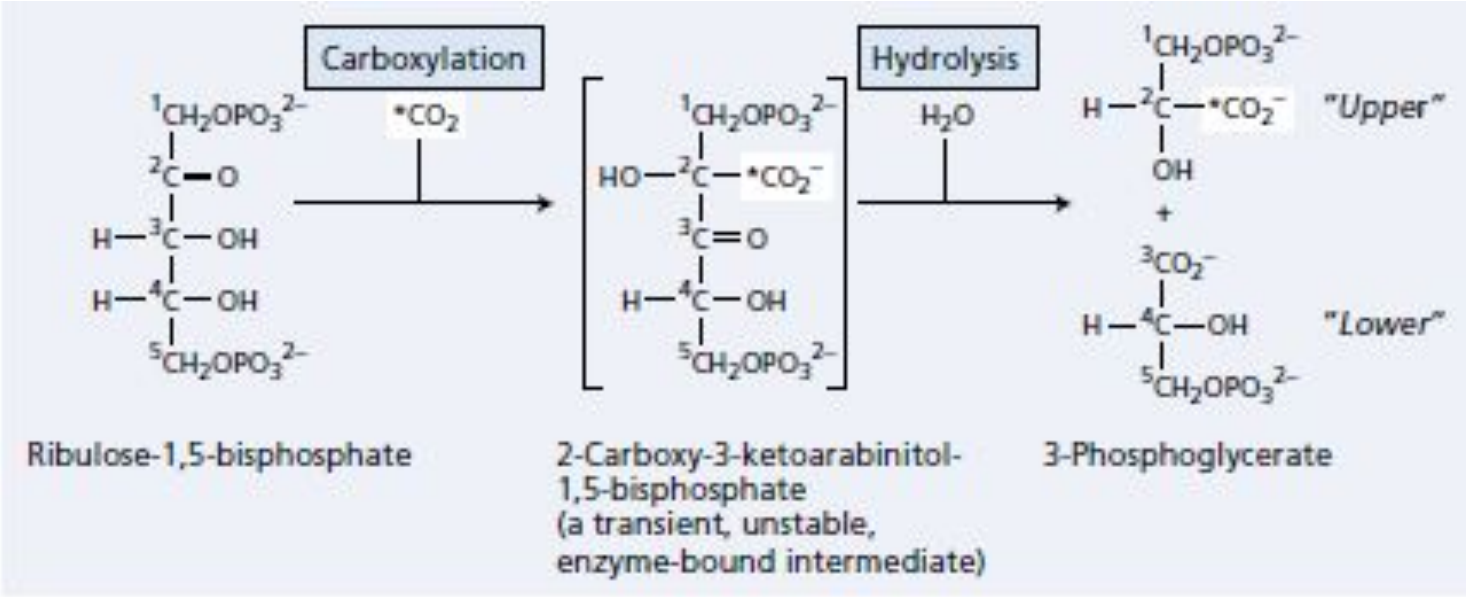
- Цикл Кальвина.
- С3-фотосинтез



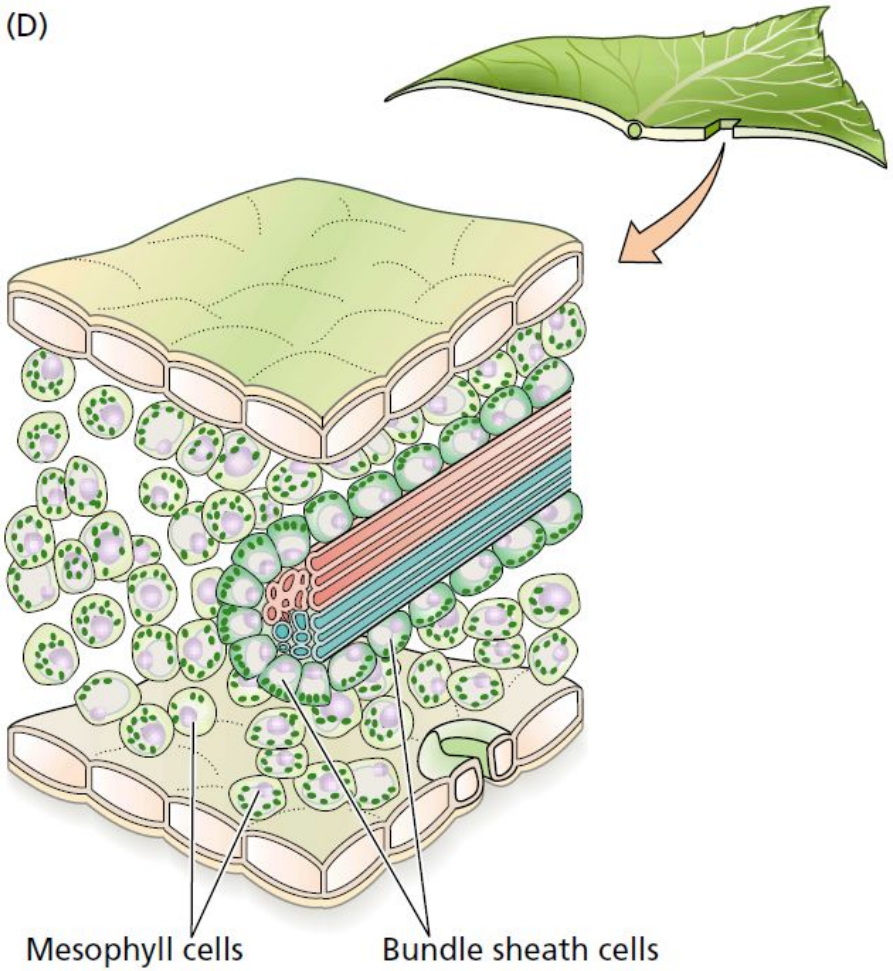
Реакции цикла Кальвина

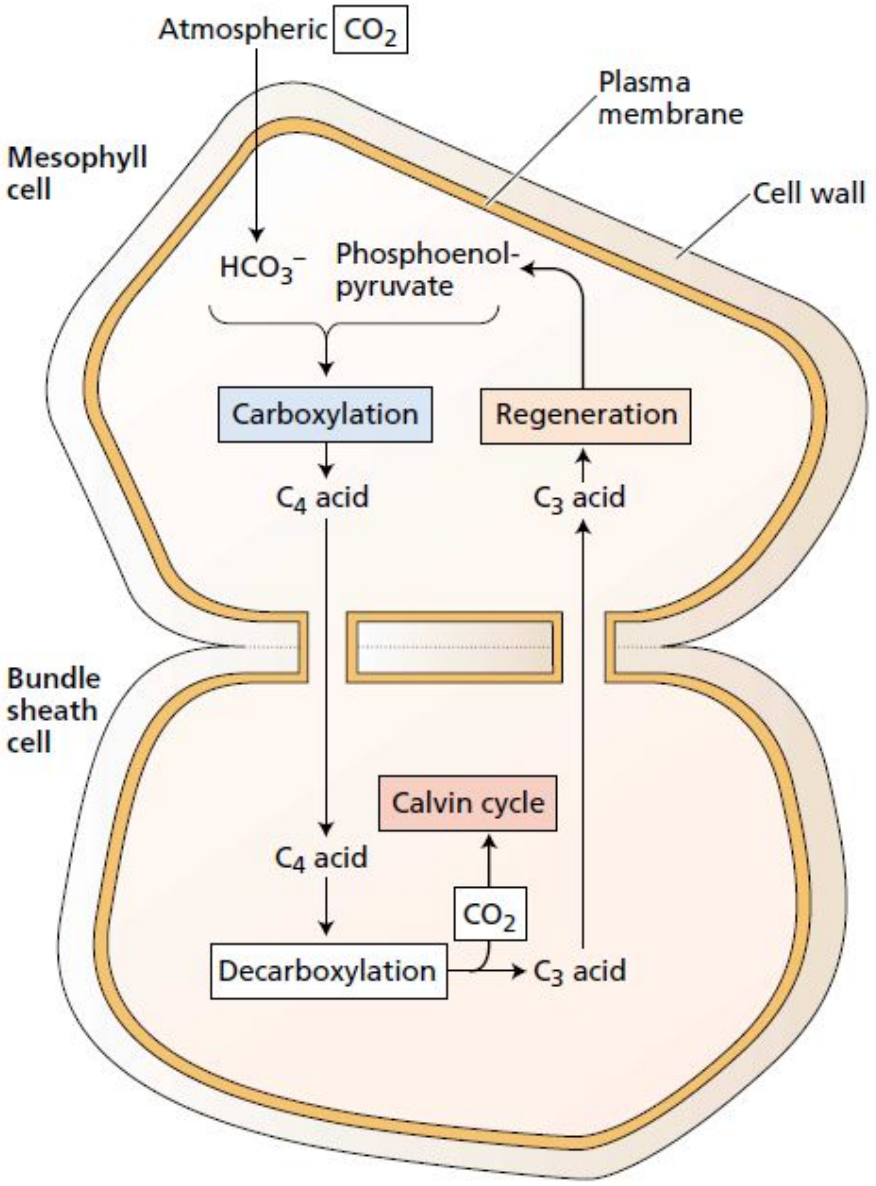
Enzyme	Reaction
1. Ribulose-1,5-bisphosphate carboxylase/oxygenase	6 Ribulose-1,5-bisphosphate + 6 CO_2 + 6 H_2O → 12 (3-phosphoglycerate) + 12 H^+
2. 3-Phosphoglycerate kinase	12 (3-Phosphoglycerate) + 12 ATP → 12 (1,3-bisphosphoglycerate) + 12 ADP
3. NADP:glyceraldehyde-3-phosphate dehydrogenase	12 (1,3-Bisphosphoglycerate) + 12 NADPH + 12 H^+ → 12 glyceraldehye-3-phosphate + 12 $NADP^+$ + 12 P_i
4. Triose phosphate isomerase	5 Glyceraldehyde-3-phosphate → 5 dihydroxyacetone-3-phosphate
5. Aldolase	3 Glyceraldehyde-3-phosphate + 3 dihydroxyacetone-3-phosphate → 3 fructose-1,6-bisphosphate
6. Fructose-1,6-bisphosphatase	3 Fructose-1,6-bisphosphate + 3 H_2O → 3 fructose-6-phosphate + 3 P_i
7. Transketolase	2 Fructose-6-phosphate + 2 glyceraldehyde-3-phosphate → 2 erythrose-4-phosphate + 2 xylulose-5-phosphate
8. Aldolase	2 Erythrose-4-phosphate + 2 dihydroxyacetone-3-phosphate → 2 sedoheptulose-1,7-bisphosphate
9. Sedoheptulose-1,7,bisphosphatase	2 Sedoheptulose-1,7-bisphosphate + 2 H_2O → 2 sedoheptulose-7-phosphate + 2 P_i
10. Transketolase	2 Sedoheptulose-7-phosphate + 2 glyceraldehyde-3-phosphate → 2 ribose-5-phosphate + 2 xylulose-5-phosphate
11a. Ribulose-5-phosphate epimerase	4 Xylulose-5-phosphate → 4 ribulose-5-phosphate
11b. Ribose-5-phosphate isomerase	2 Ribose-5-phosphate → 2 ribulose-5-phosphate
12. Ribulose-5-phosphate kinase	6 Ribulose-5-phosphate + 6 ATP → 6 ribulose-1,5-bisphosphate + 6 ADP + 6 H^+
Net: 6 CO_2 + 11 H_2O + 12 NADPH + 18 ATP → Fructose-6-phosphate + 12 $NADP^+$ + 6 H^+ + 18 ADP + 17 P_i	

Карбоксилирование рибулезо-1,5-дифосфата RUBISCO



Особенности листа С4-растения

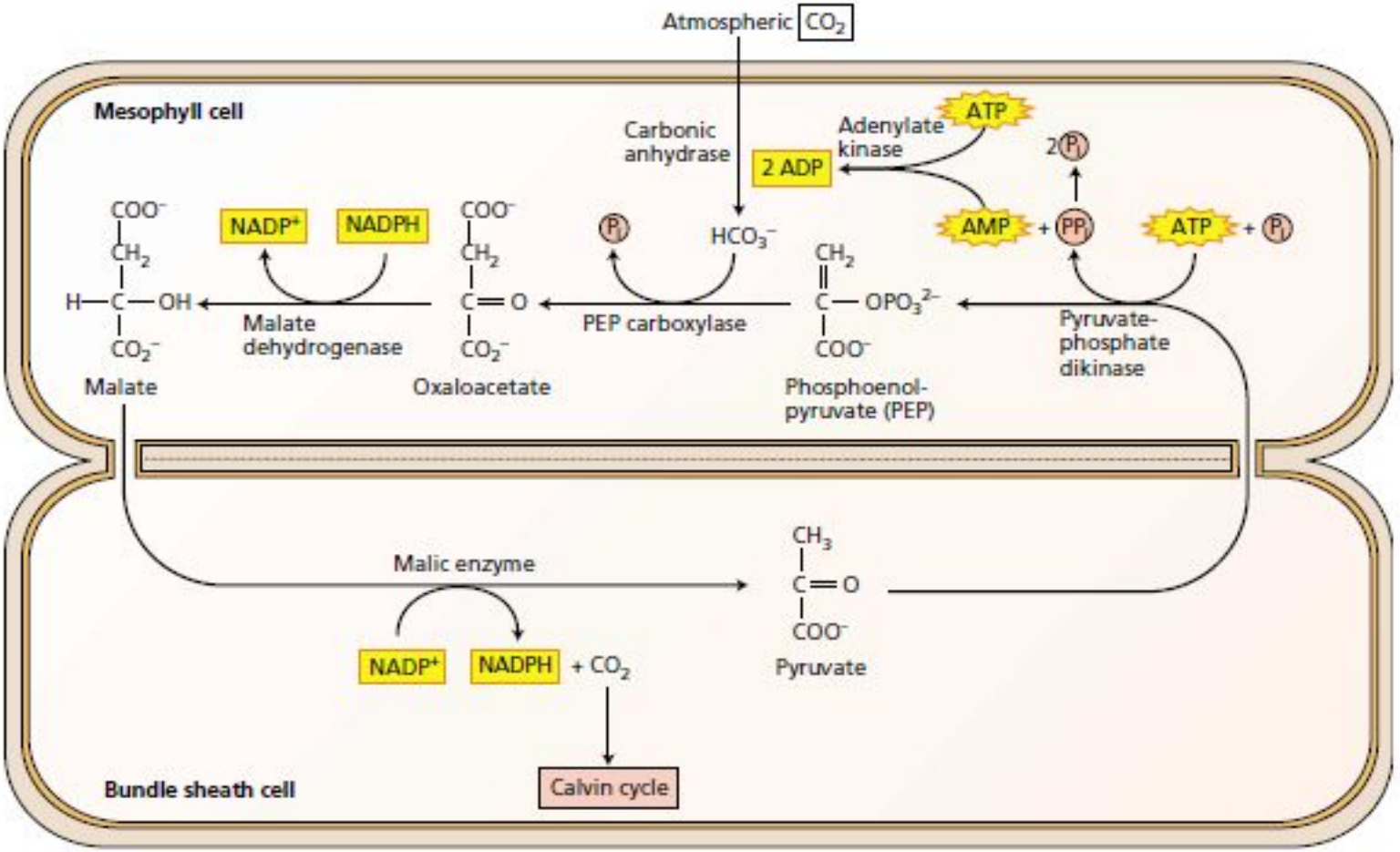



Atmospheric CO_2
Plasma membrane
Mesophyll cell
Cell wall
HCO_3^-
Phosphoenol-pyruvate
Carboxylation
Regeneration
C_4 acid
C_3 acid
Bundle sheath cell
Calvin cycle
C_4 acid
CO_2
Decarboxylation
C_3 acid

Реакции C4-пути ФС

Enzyme	Reaction
1. Phosphoenolpyruvate (PEP) carboxylase	Phosphoenolpyruvate + HCO_3^- → oxaloacetate + P_i
2. NADP:malate dehydrogenase	Oxaloacetate + NADPH + H^+ → malate + $NADP^+$
3. Aspartate aminotransferase	Oxaloacetate + glutamate → aspartate + α-ketoglutarate
4. NAD(P) malic enzyme	Malate + $NAD(P)^+$ → pyruvate + CO_2 + NAD(P)H + H^+
5. Phosphoenolpyruvate carboxykinase	Oxaloacetate + ATP → phosphoenolpyruvate + CO_2 + ADP
6. Alanine aminotransferase	Pyruvate + glutamate ↔ alanine + α-ketoglutarate
7. Adenylate kinase	AMP + ATP → 2 ADP
8. Pyruvate–orthophosphate dikinase	Pyruvate + P_i + ATP → phosphoenolpyruvate + AMP + PP_i
9. Pyrophosphatase	PP_i + H_2O → 2 P_i

C4-путь фотосинтеза

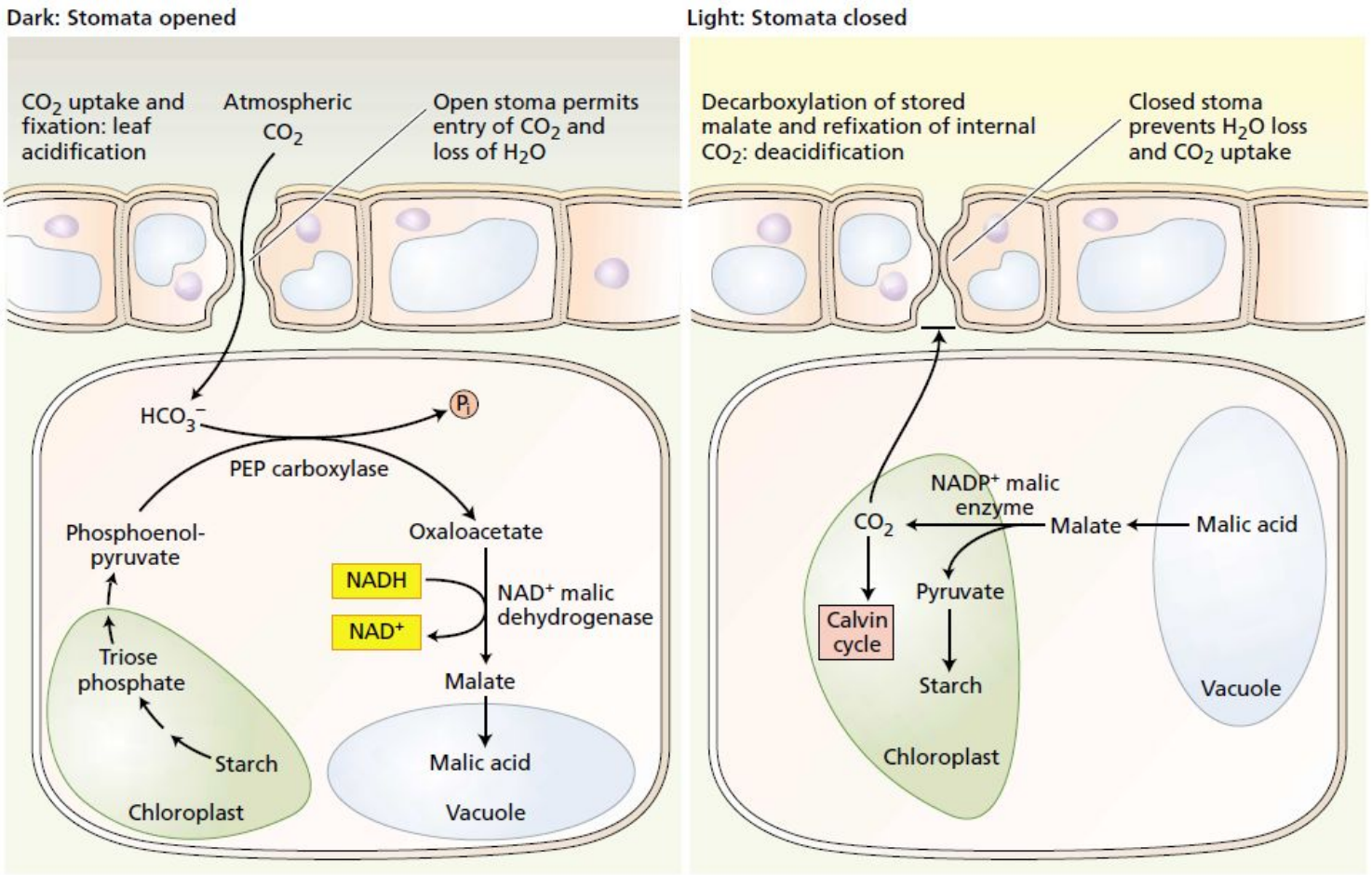


Энергетический обмен С4-пути ФС

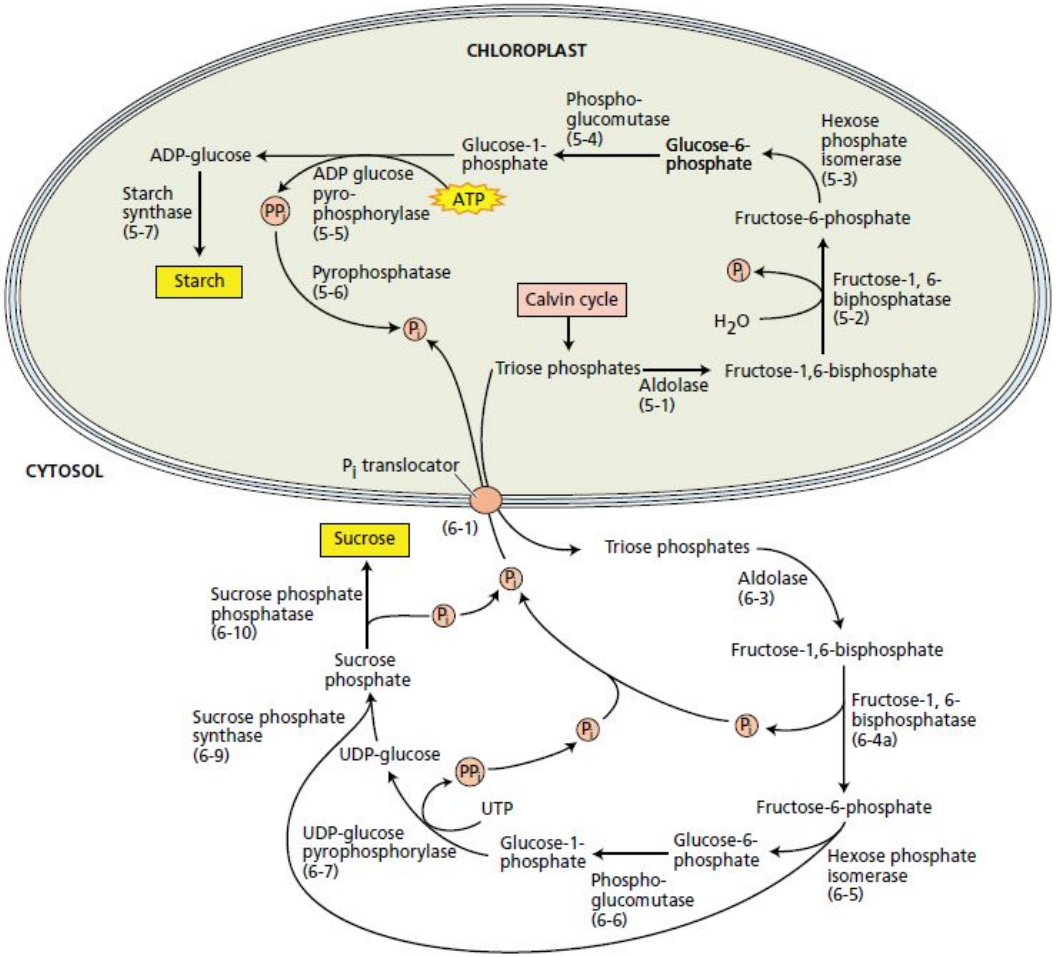
Phosphoenolpyruvate + H_2O + NADPH + CO_2 (mesophyll)	→	malate + $NADP^+$ + P_i (mesophyll)
Malate + $NADP^+$	→	pyruvate + NADPH + CO_2 (bundle sheath)
Pyruvate + P_i + ATP	→	phosphoenolpyruvate + AMP + PP_i (mesophyll)
PP_i + H_2O	→	2 P_i (mesophyll)
AMP + ATP	→	2ADP
Net: CO_2 (mesophyll) + ATP + 2 H_2O	→	CO_2 (bundle sheath) + 2ADP + 2 P_i

Cost of concentrating CO_2 within the bundle sheath cell = 2 ATP per CO_2

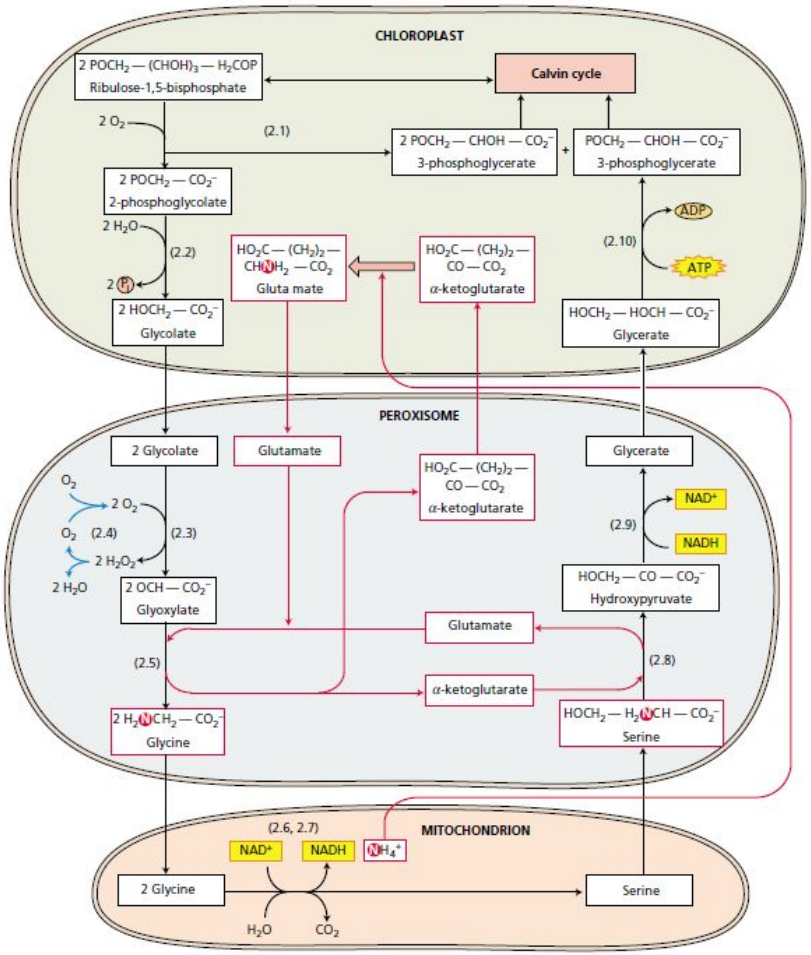
CAM-путь ФС


Dark: Stomata opened
Light: Stomata closed
CO_2 uptake and fixation: leaf acidification
Atmospheric CO_2
Open stoma permits entry of CO_2 and loss of H_2O
Decarboxylation of stored malate and refixation of internal CO_2: deacidification
Closed stoma prevents H_2O loss and CO_2 uptake
HCO_3^-
P_i
PEP carboxylase
Phosphoenol-pyruvate
Oxaloacetate
NADH
NAD^+
NAD^+ malic dehydrogenase
Malate
Triose phosphate
Starch
Chloroplast
Malic acid
Vacuole
$NADP^+$ malic enzyme
CO_2
Malate
Malic acid
Pyruvate
Calvin cycle
Starch
Chloroplast
Vacuole

Синтез крахмала и Сахарозы

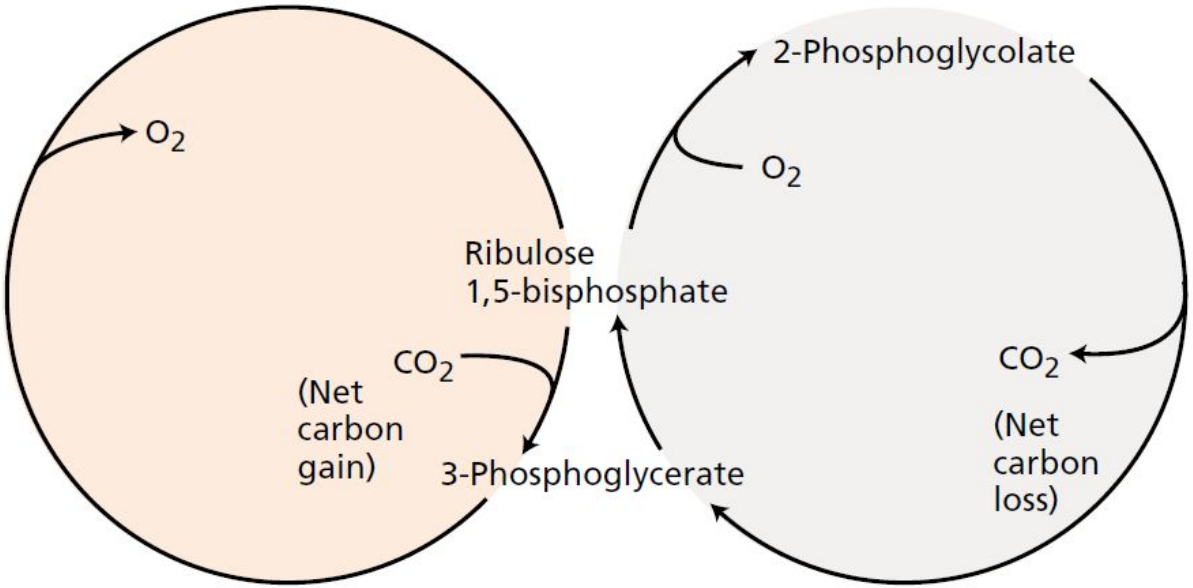


Фотодыхание



Реакции фотодыхания

Enzyme	Reaction
1. Ribulose-1,5-bisphosphate carboxylase/oxygenase (chloroplast)	2 Ribulose-1,5-bisphosphate + 2 O_2 → 2 phosphoglycolate + 2 3-phosphoglycerate + 4 H^+
2. Phosphoglycolate phosphatase (chloroplast)	2 Phosphoglycolate + 2 H_2O → 2 glycolate + 2 P_i
3. Glycolate oxidase (peroxisome)	2 Glycolate + 2 O_2 → 2 glyoxylate + 2 H_2O_2
4. Catalase (peroxisome)	2 H_2O_2 → 2 H_2O + O_2
5. Glyoxylate:glutamate aminotransferase (peroxisome)	2 Glyoxylate + 2 glutamate → 2 glycine + 2 α-ketoglutarate
6. Glycine decarboxylase (mitochondrion)	Glycine + NAD^+ + H^+ + H_4-folate → NADH + CO_2 + NH_4^+ + methylene-H_4-folate
7. Serine hydroxymethyltransferase (mitochondrion)	Methylene-H_4-folate + H_2O + glycine → serine + H_4-folate
8. Serine aminotransferase (peroxisome)	Serine + α-ketoglutarate → hydroxypyruvate + glutamate
9. Hydroxypyruvate reductase (peroxisome)	Hydroxypyruvate + NADH + H^+ → glycerate + NAD^+
10. Glycerate kinase (chloroplast)	Glycerate + ATP → 3-phosphoglycerate + ADP + H^+



Electron transport and the Calvin cycle

C_2 oxidative photosynthetic carbon cycle