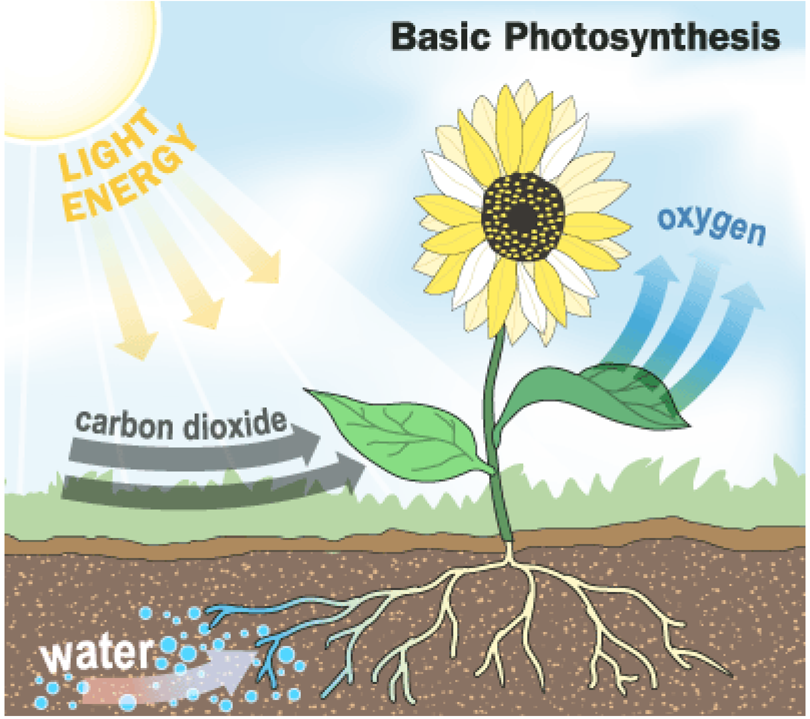
Metabolism III



Aim: understand gluconeogenesis, pentose phosphate pathway, photosynthesis and amino acid synthesis

Anabolism

- From a carbon source and inorganic molecules, microbes synthesize new organelles and cells
  - a lot of energy is required for biosynthesis
- Turnover
  - continual degradation and resynthesis of cellular constituents by nongrowing cells
- Metabolism is carefully regulated
  - rate of turnover to be balanced by rate of biosynthesis
  - in response to organism’s environment

Level of organization	*Examples*
Cells	*Bacteria* *Fungi*
Organelles	*Nuclei* *Mitochondria* *Ribosomes* *Flagella*
Supramolecular systems	*Membranes* *Enzyme complexes*
Maromolecules	*Nucleic acids* *Proteins* *Polysaccharides* *Lipids*
Monomers or building blocks	*Nucleotides* *Amino acids* *Sugars* *Fatty acids*
Precursor metabolites	*Pyruvate* *Acetyl-CoA* *Glucose 6-phosphate*
Carbon source + Inorganic molecules	CO_2, NH_3, H_2O, PO_4^{3-}

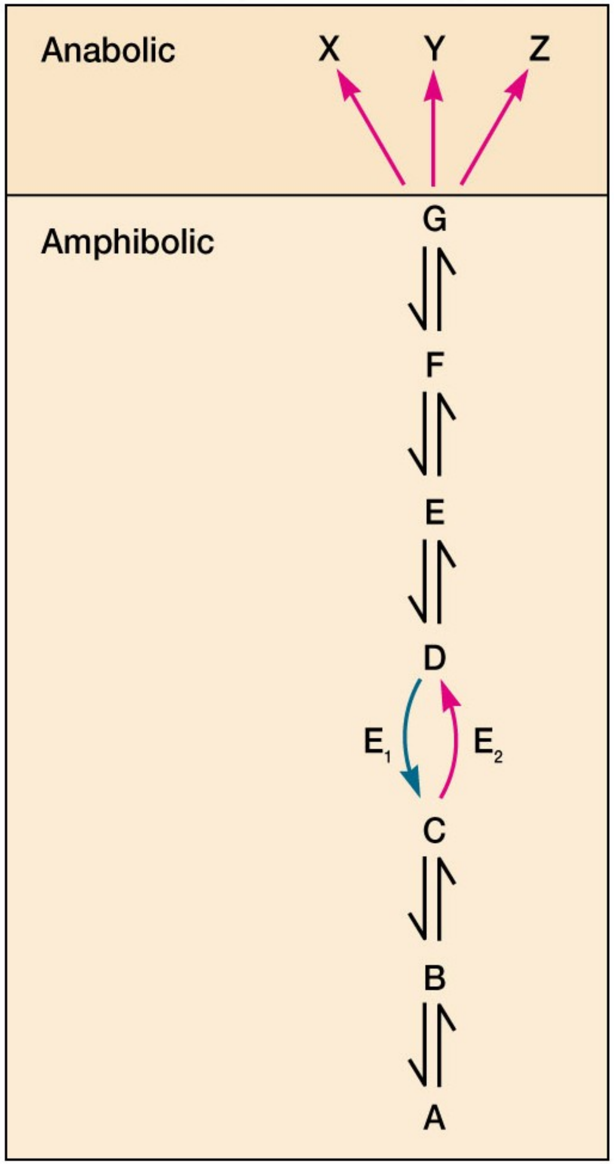
- Macromolecules are synthesized from a few simple structural units (monomers)
  - *saves genetic storage capacity, biosynthetic raw material, and energy*

- Many enzymes are used for both catabolic and anabolic processes
  - *saves materials and energy*

Principles governing biosynthesis

Catabolic and anabolic pathways are not identical, despite sharing many enzymes

– permits independent regulation



To synthesize molecules efficiently, anabolic pathways must operate irreversibly in the direction of biosynthesis

- done by coupling breakdown of ATP to certain reactions in biosynthetic pathways
- drives the biosynthetic reaction to completion

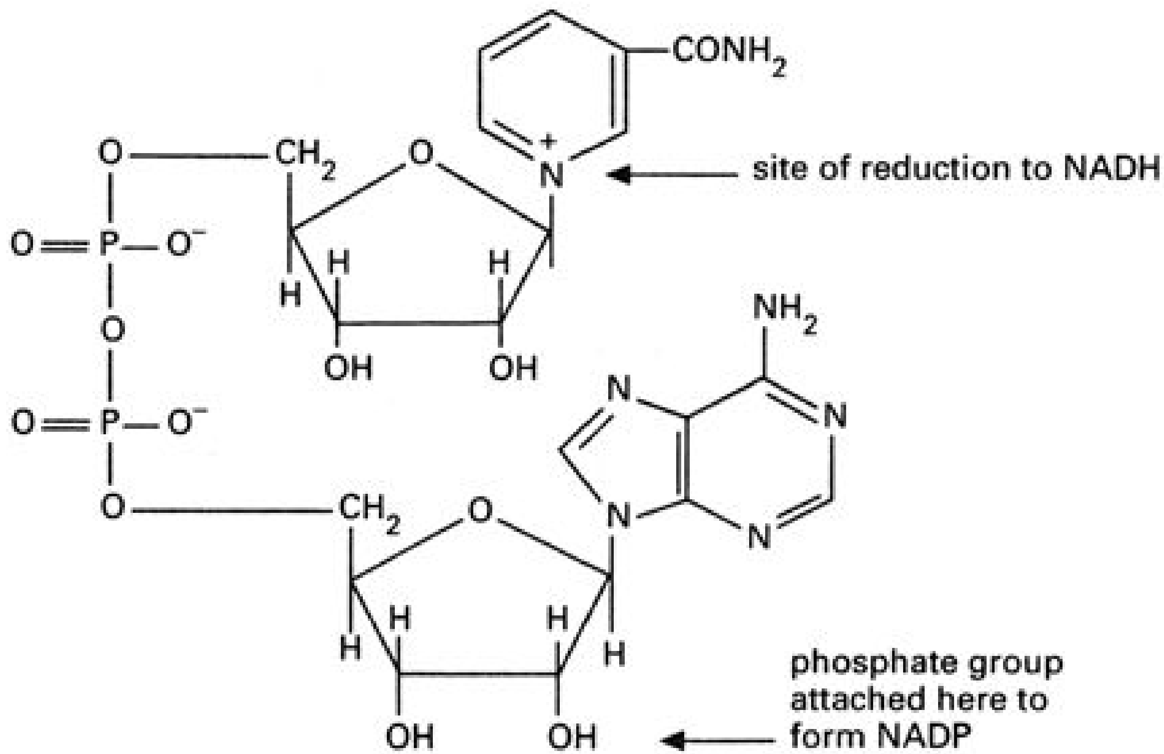
In eucaryotes, anabolic and catabolic reactions located in separate compartments

- allows pathways to operate simultaneously but independently

Catabolic and anabolic pathways use different cofactors

– catabolism produces NADH

– NADPH used as electron donor for anabolism



Synthesis of saccharides

Gluconeogenesis

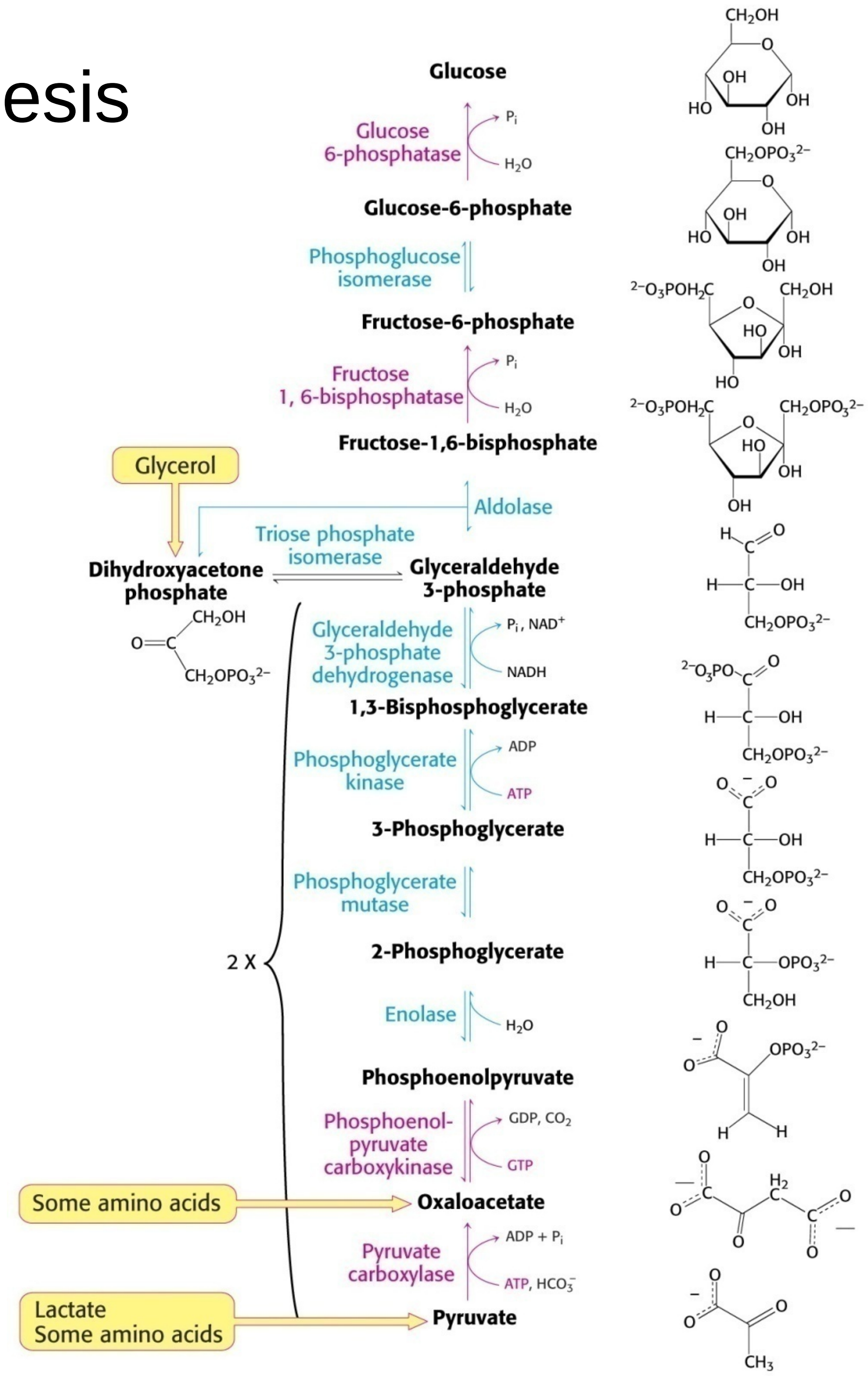
- to synthesize glucose and fructose from noncarbohydrate precursors

Reactions of gluconeogenesis

Glucose is synthesised from glycerol, amino acids and lactate

Reciprocal control of glycolysis and gluconeogenesis

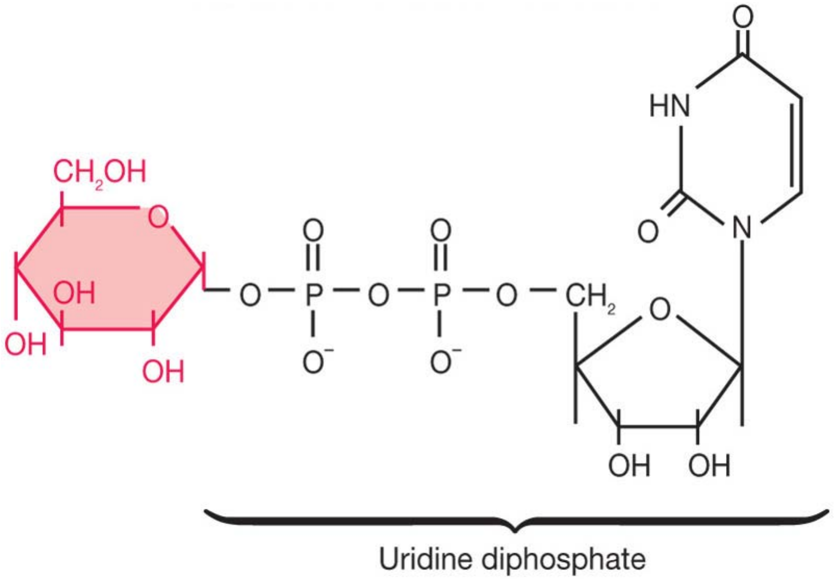
The step between fructose 6-phosphate and fructose1,6-bisphosphate is the most important for the control

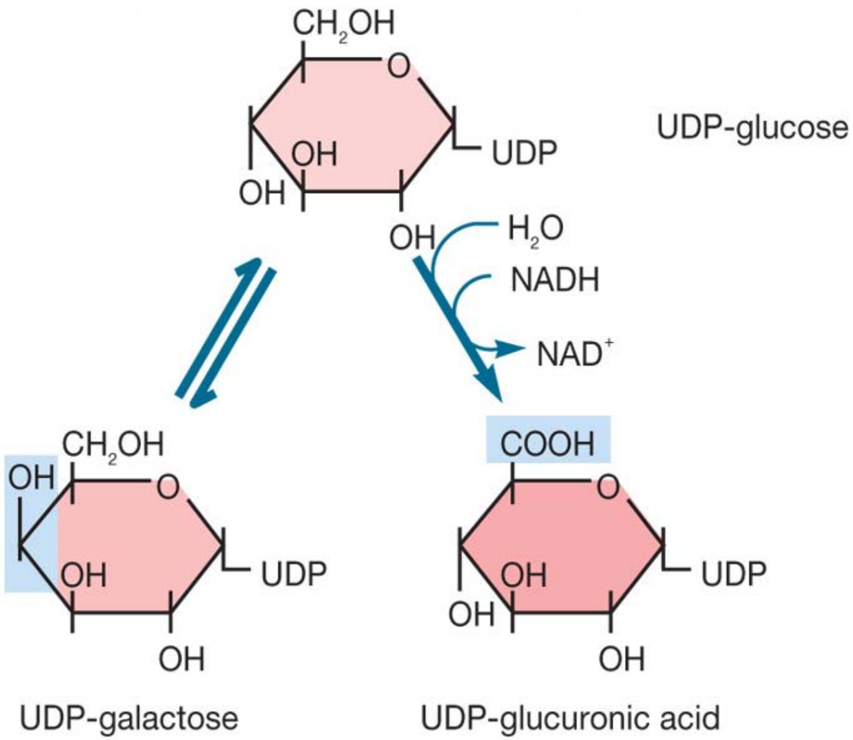


Three steps are different between glycolysis and gluconeogenesis

GLYCOLYSIS	PEP + ADP → Pyruvate + ATP
GLUCONEOGENESIS	Pyruvate + CO_2 + ATP + H_2O → Oxaloacetate + ADP + P_i + $2H^+$
	Oxaloacetate + GTP → PEP + GDP + CO_2
GLYCOLYSIS	Fructose 6-phosphate + ATP → Fructose 1,6-bisphosphate + ADP
GLUCONEOGENESIS	Fructose 1,6-bisphosphate + H_2O → Fructose 6-phosphate + P_i
GLYCOLYSIS	Glucose + ATP → Glucose 6-phosphate + ADP
GLUCONEOGENESIS	Glucose 6-phosphate + H_2O → Glucose + P_i

Some sugars are synthesized while attached to a nucleoside diphosphate such as uridine diphosphate glucose (UDPG)





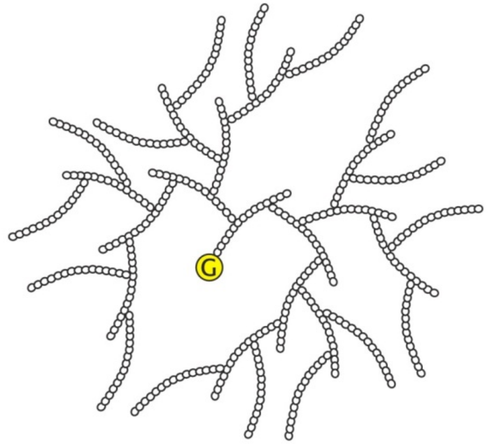
Synthesis of polysaccharides

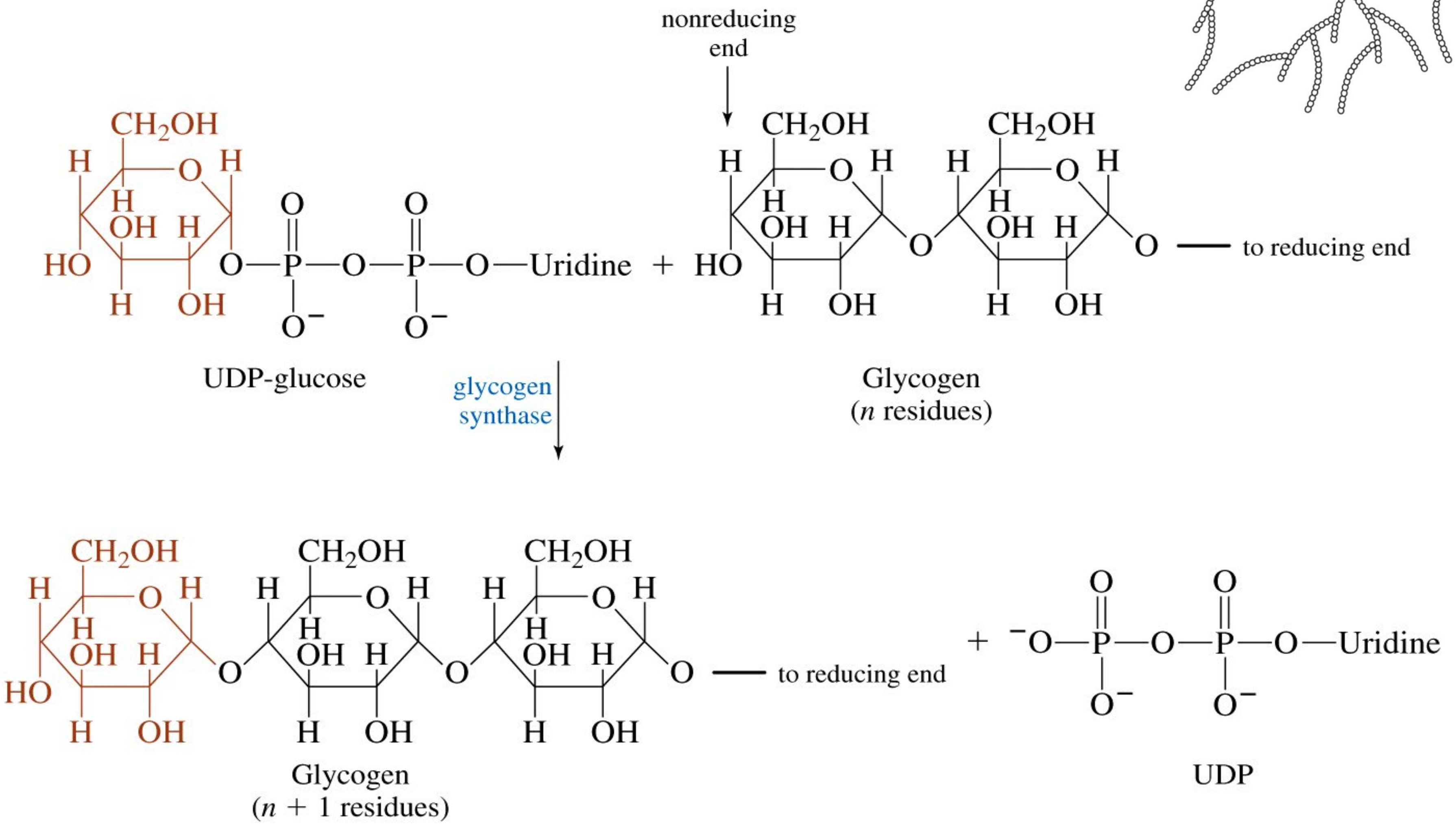
Also involves nucleoside diphosphate sugars

– e.g., starch and glycogen synthesis

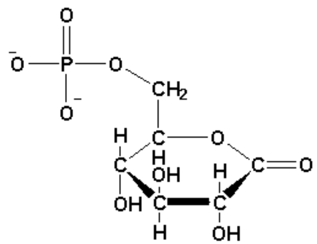
ATP + glucose 1-P $\rightarrow$ ADP-glucose + PP_i

$(glucose)_n$ + ADP-glucose $\rightarrow$ $(glucose)_{n+1}$ + ADP


G


nonreducing
end
UDP-glucose
Uridine
glycogen
synthase
to reducing end
Glycogen
(n residues)
Glycogen
(n + 1 residues)
UDP

Pentose phosphate pathway leads to NADPH and ribose 5-phosphate



NADP → NADPH

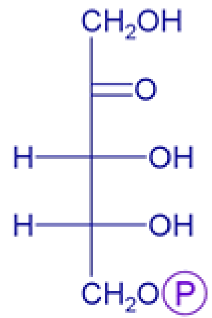
Glucose 6-phosphate —1→ 6-Phosphogluconolactone

H_2O → H^+

6-Phosphogluconolactone —2→ 6-Phosphogluconate

6-Phosphogluconate —3→ (NADP → NADPH)

Ribulose 5-phosphate + CO_2

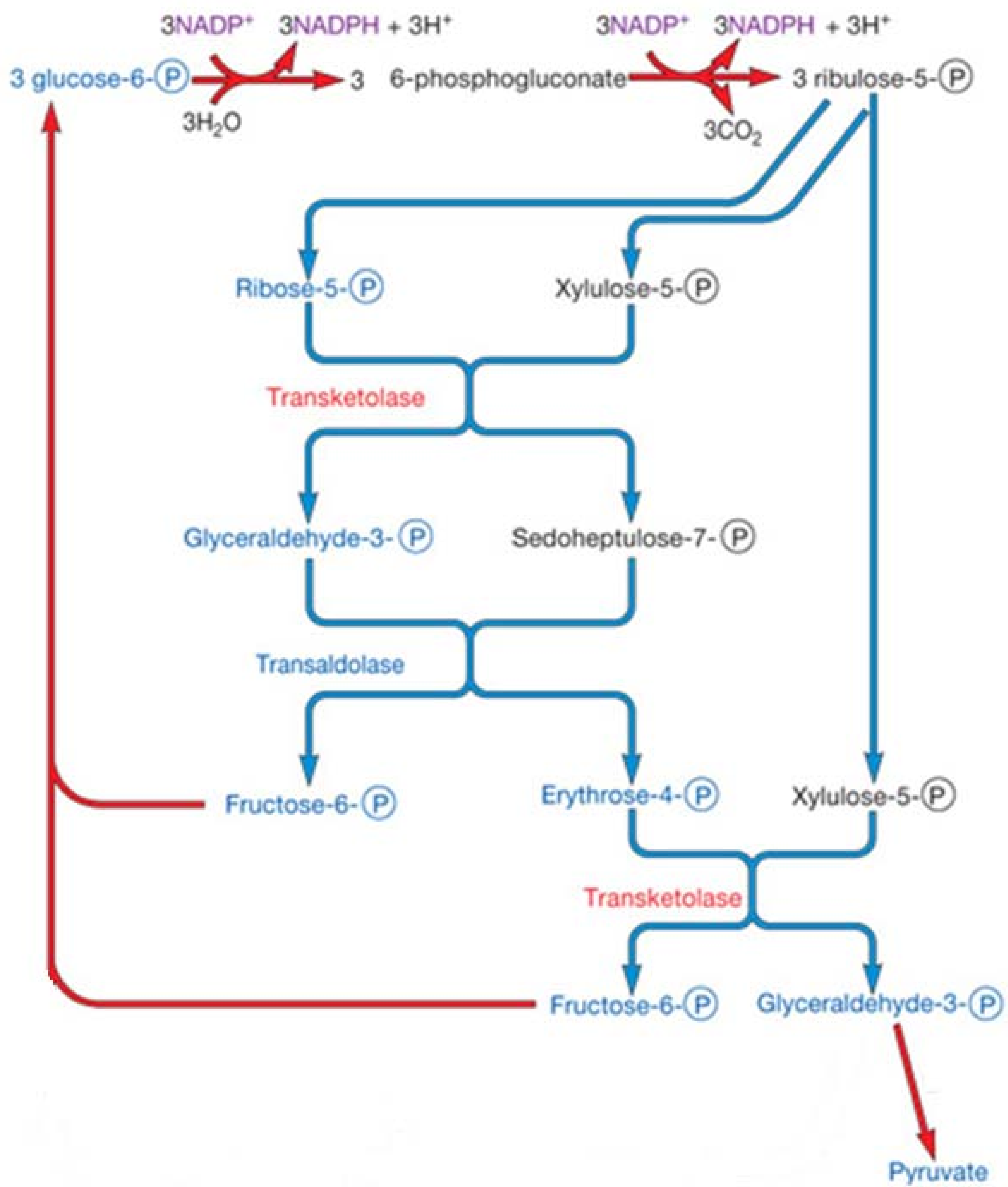


1: Glucose 6-phosphate dehydrogenase
2: Lactonase
3: 6-Phosphogluconate dehydrogenase

Ribulose 5-phosphate ⇌ Ribose 5-phosphate

Glycolysis molecules

3 Ribose 5-phosphate ⇄ 2 fructose 6-phosphate + glyceraldehyde 3-phosphate



3NADP⁺
3NADPH + 3H⁺
3 glucose-6-Ⓟ
3 6-phosphogluconate
$3H_2O$
3NADP⁺
3NADPH + 3H⁺
3 ribulose-5-Ⓟ
$3CO_2$
Ribose-5-Ⓟ
Xylulose-5-Ⓟ
Transketolase
Glyceraldehyde-3-Ⓟ
Sedoheptulose-7-Ⓟ
Transaldolase
Fructose-6-Ⓟ
Erythrose-4-Ⓟ
Xylulose-5-Ⓟ
Transketolase
Fructose-6-Ⓟ
Glyceraldehyde-3-Ⓟ
Pyruvate

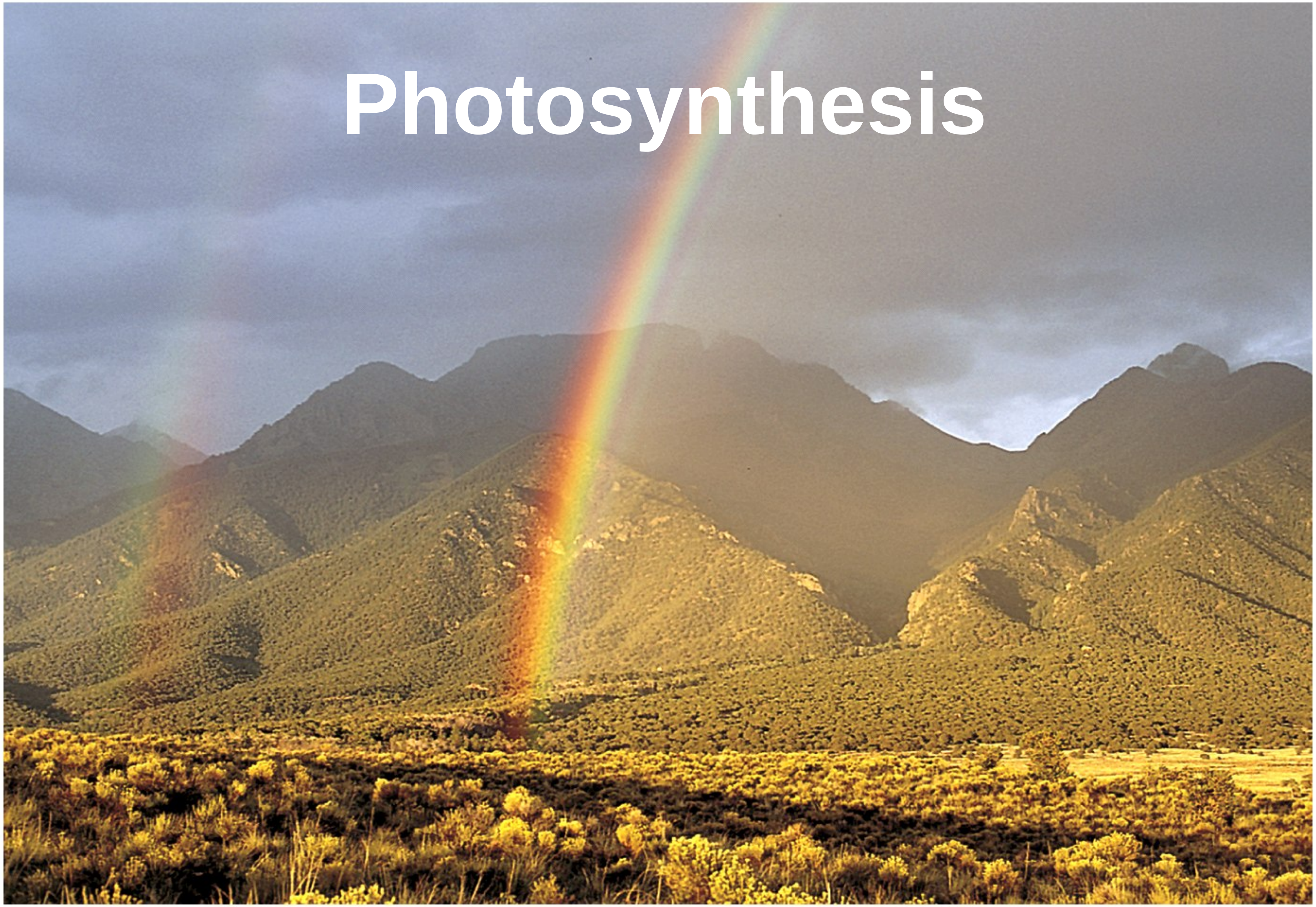
Summary of pentose phosphate pathway

$$\text{Glucose-6-P} + 12\text{NADP}^+ + 7\text{H}_2\text{O}$$

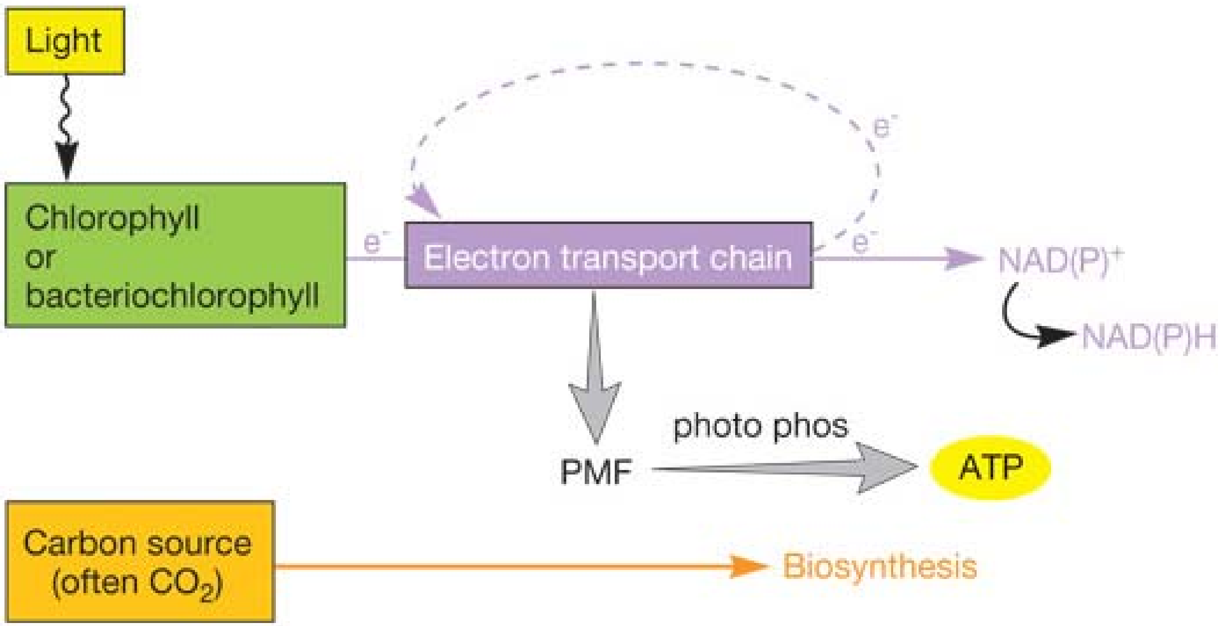
$$\downarrow$$

$$6\text{CO}_2 + 12\text{NADPH} + 12\text{H}^+ + \text{P}_i$$

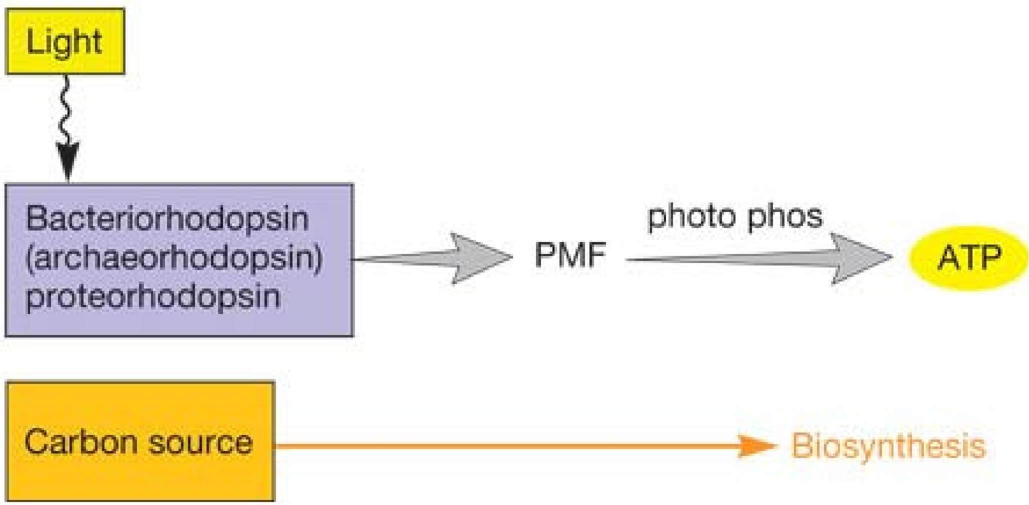
Photosynthesis

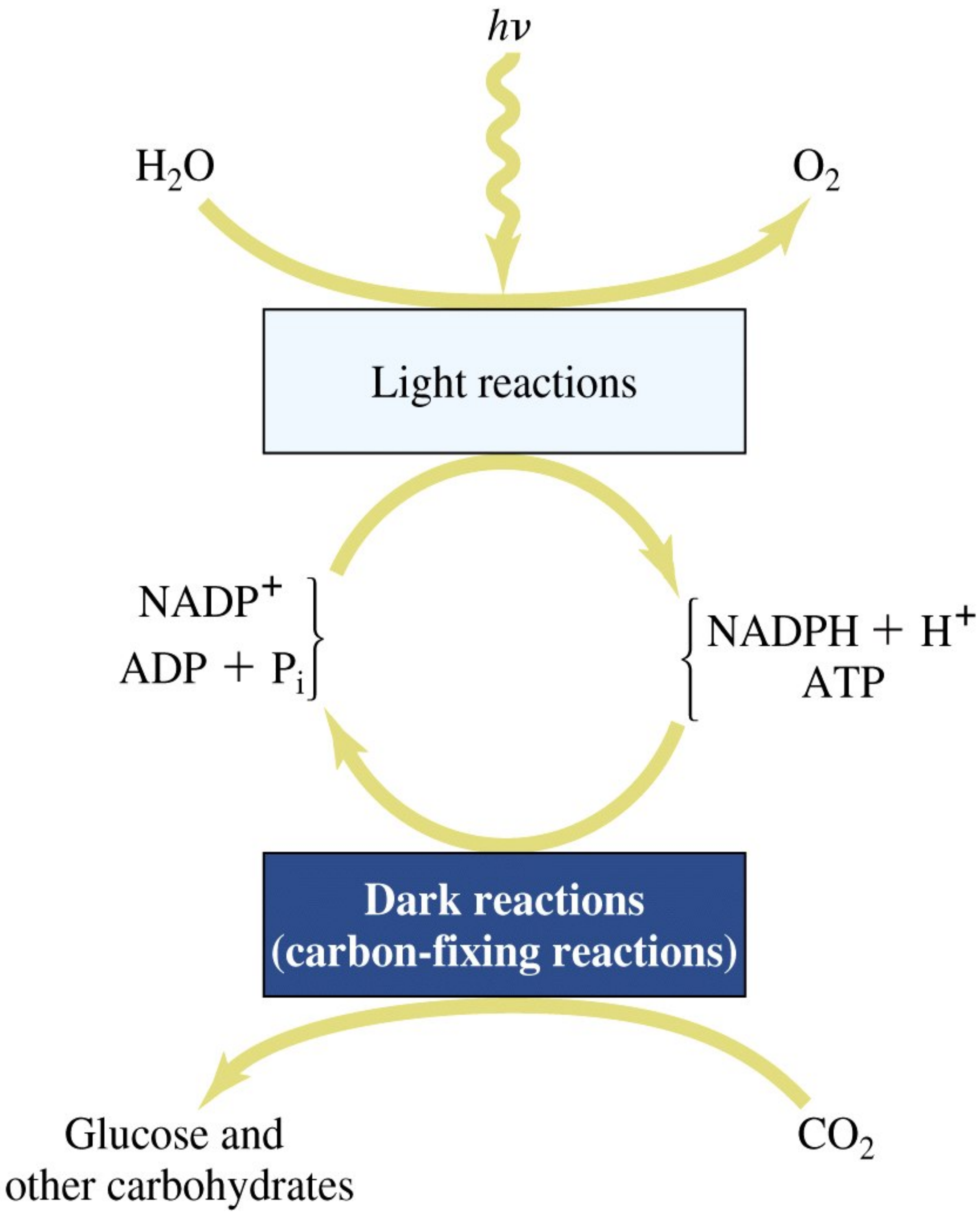


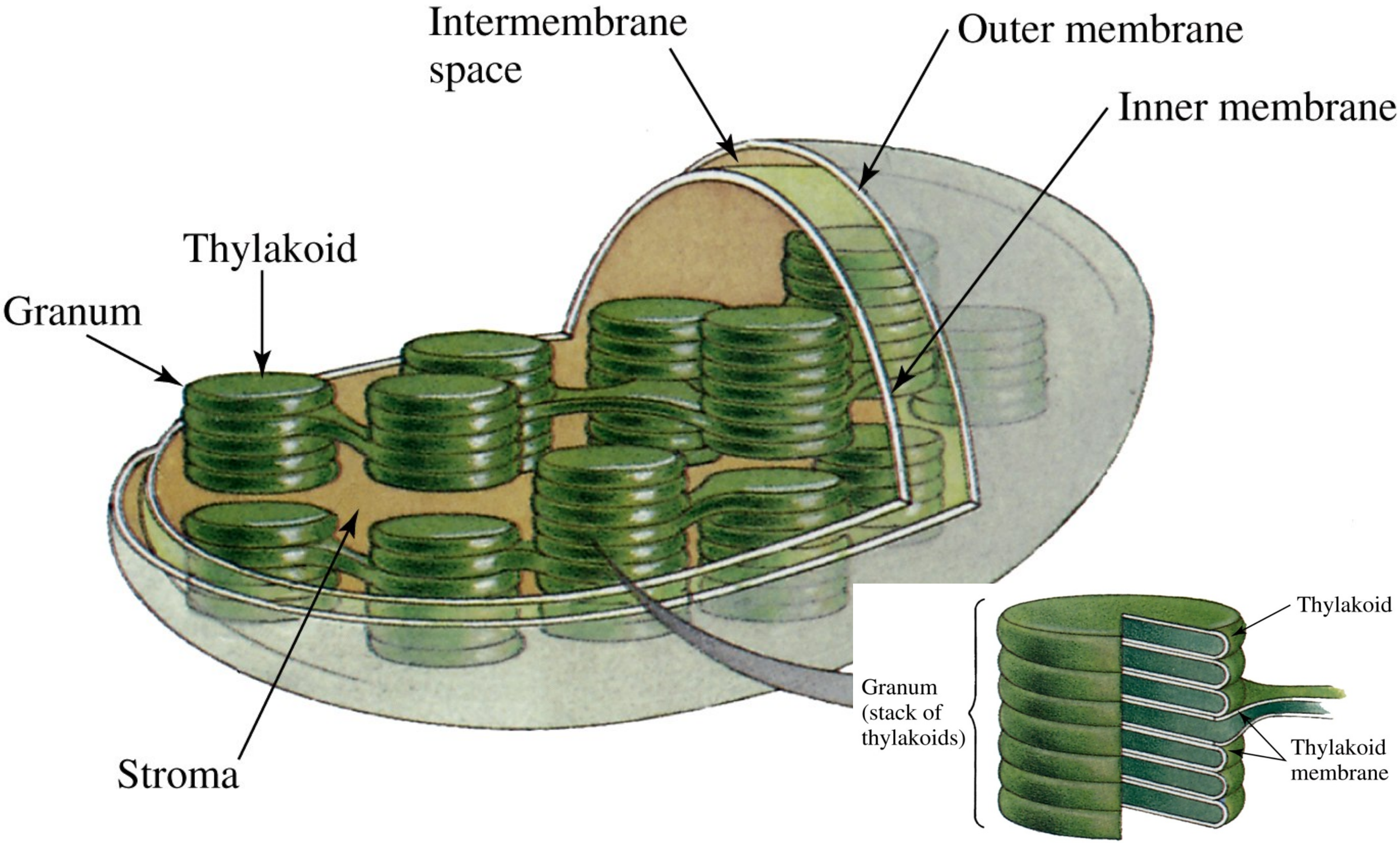
Chlorophyll-based phototrophy



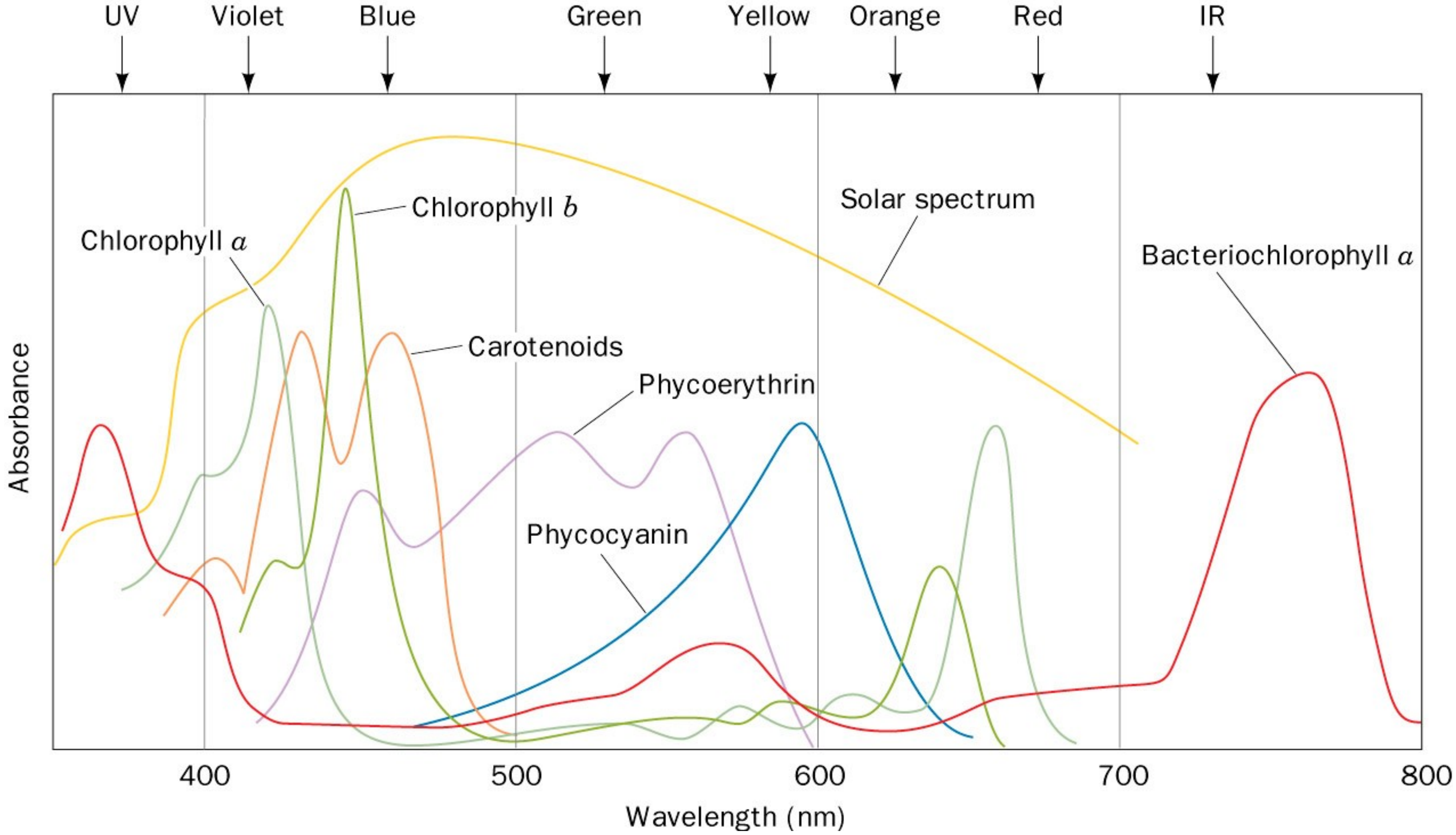
Rhodopsin-based phototrophy




hν
H_2O
O_2
Light reactions
NADP+
ADP + Pi
NADPH + H+
ATP
Dark reactions
(carbon-fixing reactions)
Glucose and
other carbohydrates
CO_2



Intermembrane space
Outer membrane
Inner membrane
Thylakoid
Granum
Stroma
Thylakoid
Granum (stack of thylakoids)
Thylakoid membrane



Absorption spectra of various photosynthetic pigments

The Light Reaction in Oxygenic Photosynthesis

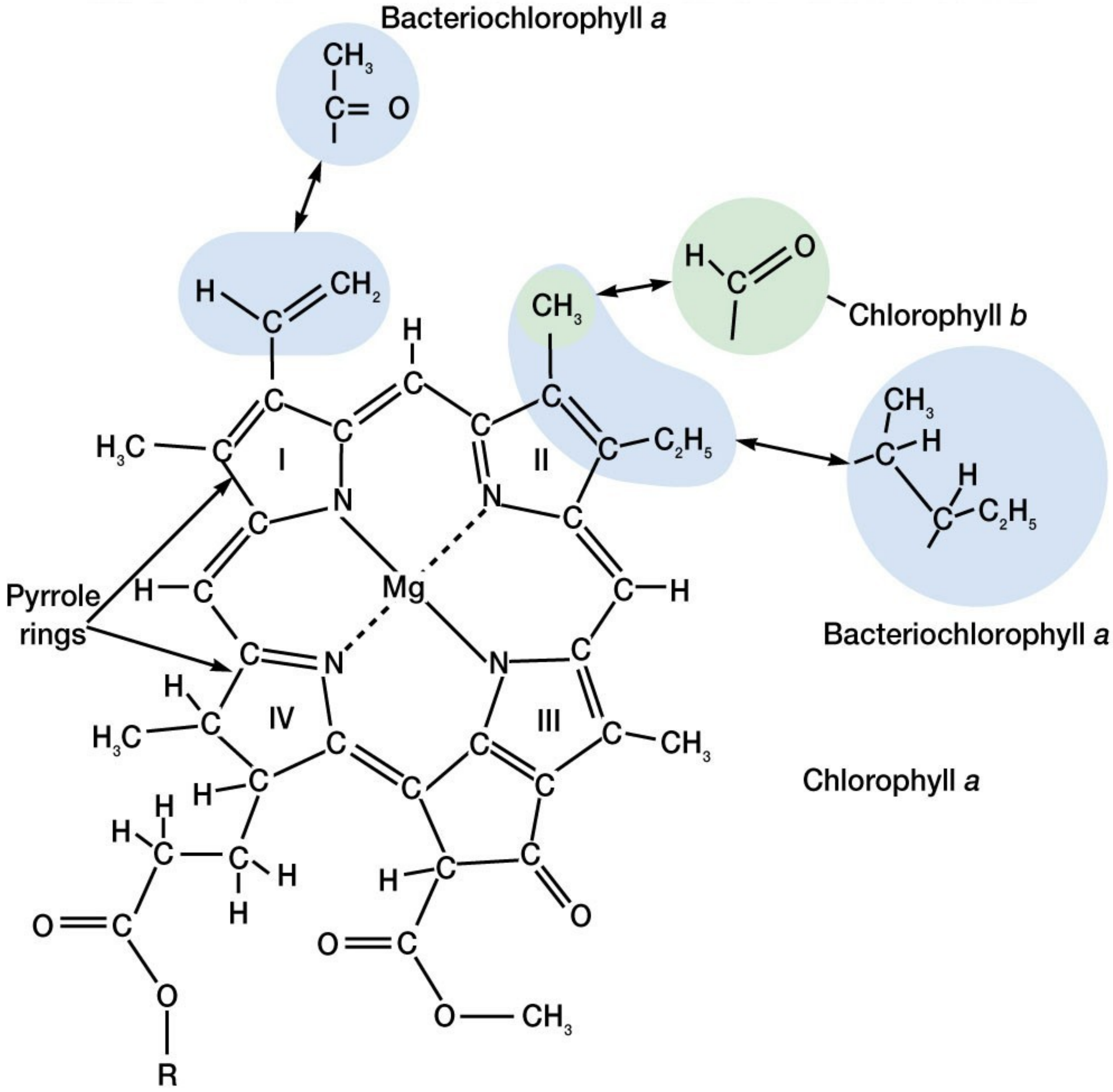
Chlorophylls

– major light-absorbing pigments

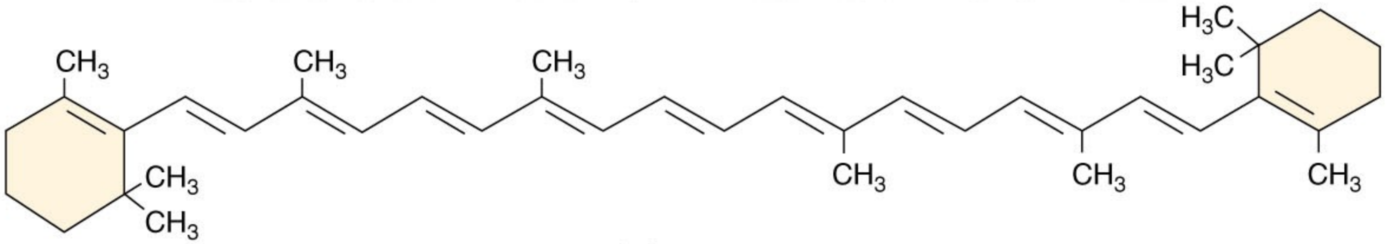
Accessory pigments

– transfer light energy to chlorophylls

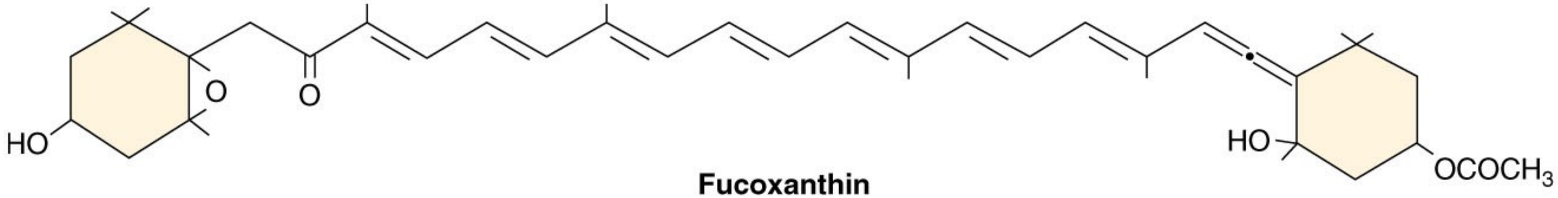
– e.g., carotenoids and phycobiliproteins


Bacteriochlorophyll a
Chlorophyll b
Bacteriochlorophyll a
Chlorophyll a
Pyrrole rings
I
II
III
IV
Mg
N
R

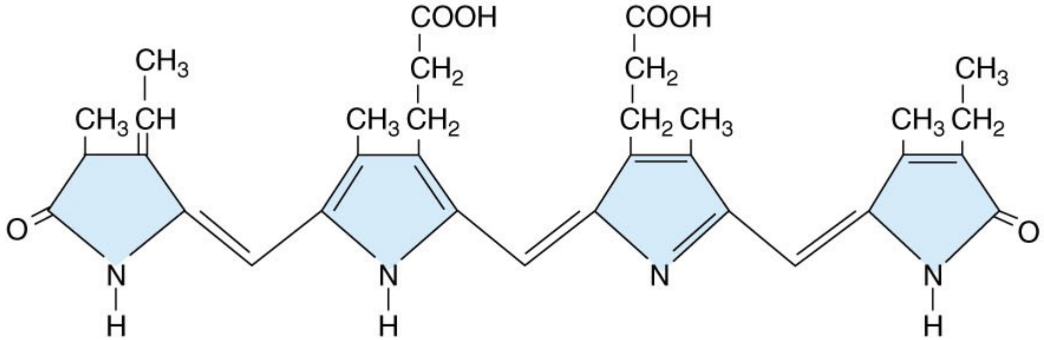
Accessory pigments absorb different wavelengths of light than chlorophylls



β-Carotene



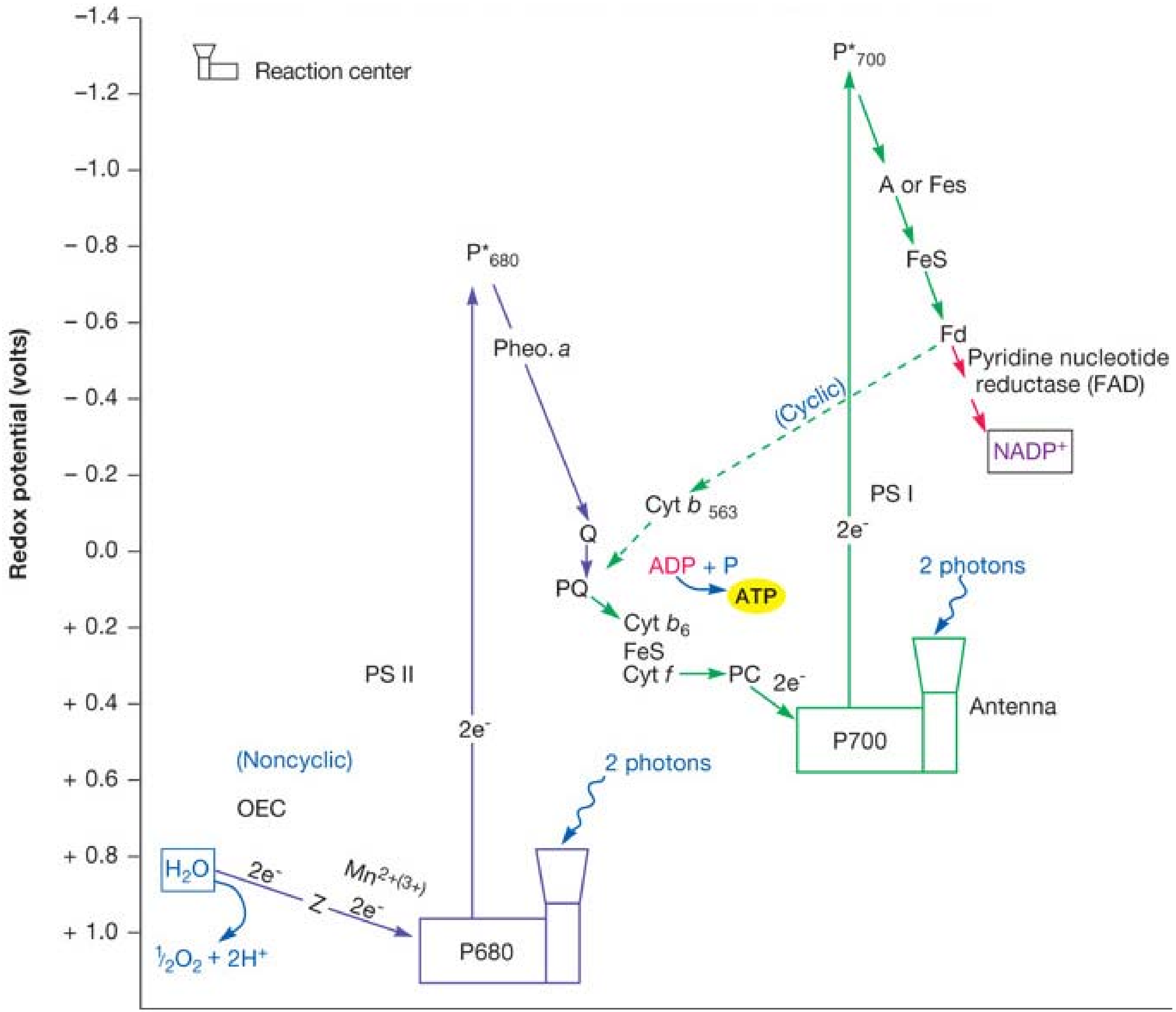
Fucoxanthin



Phycocyanobilin

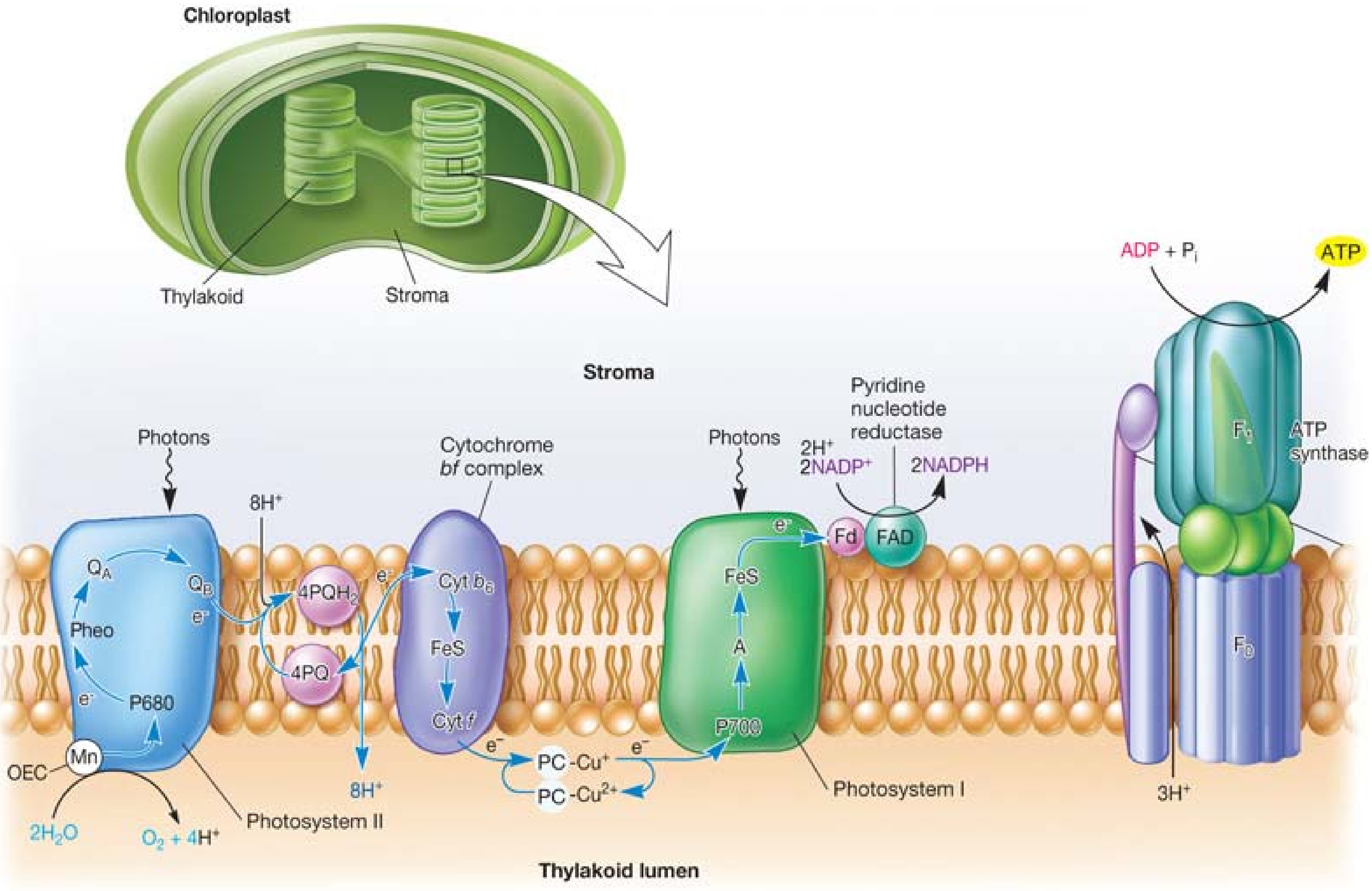
Noncyclic electron flow – ATP + NADPH made

Cyclic electron flow – ATP made (cyclic photophos-phorylation)

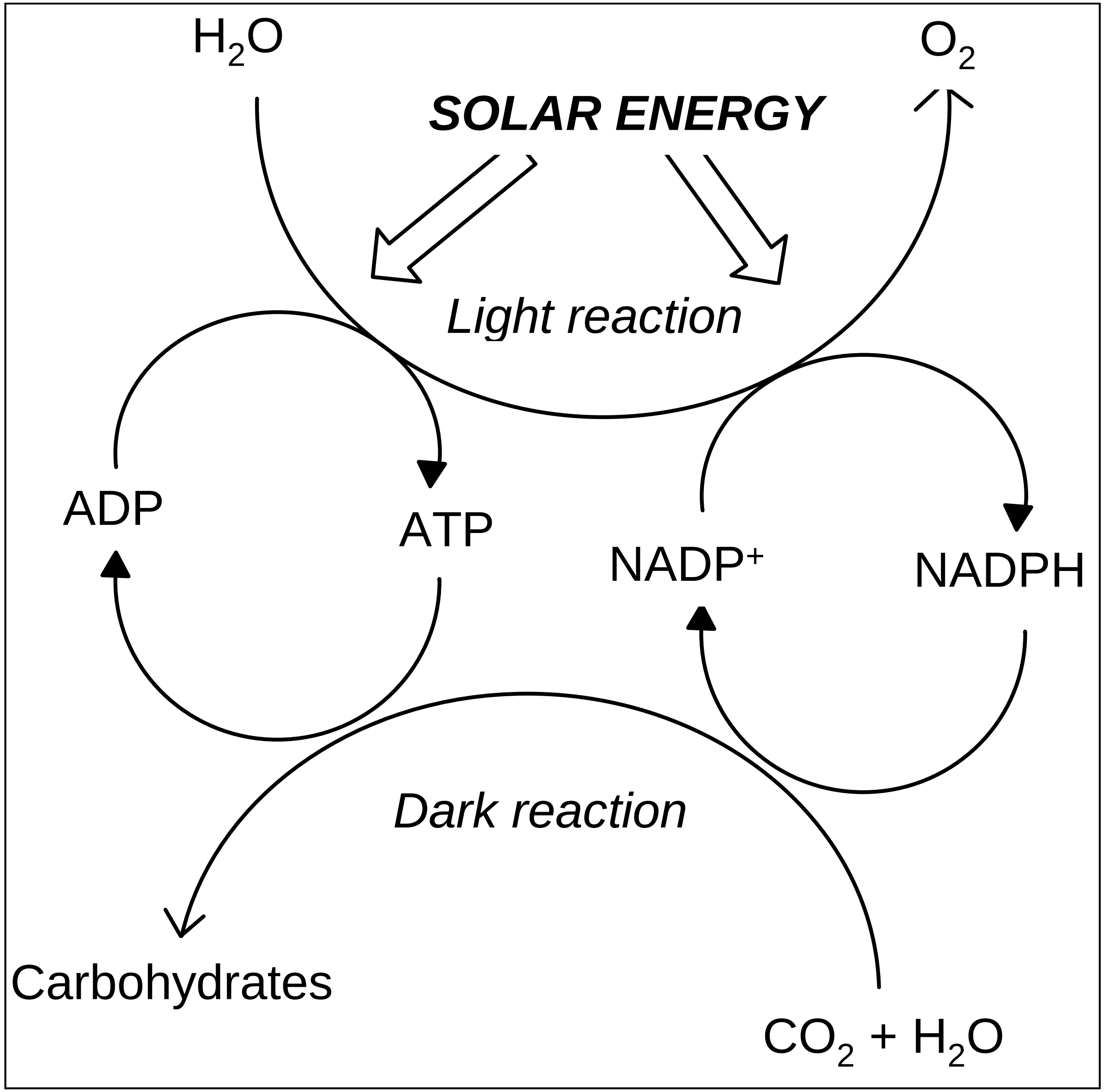


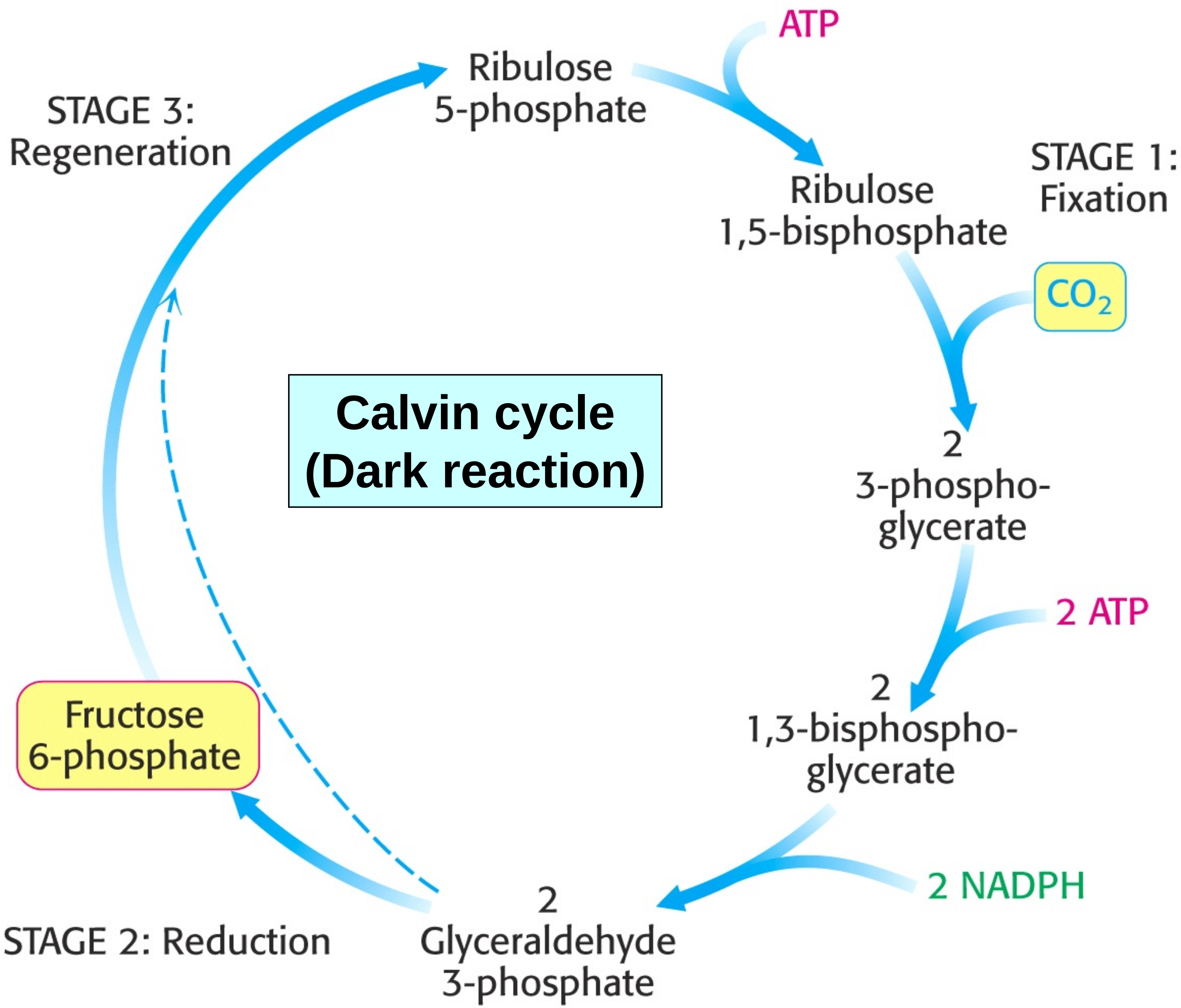
OEC: oxygen evolving complex; Fd: ferredoxin; PQ: plastoquinone; Q: quinone; PC: plastocyanin

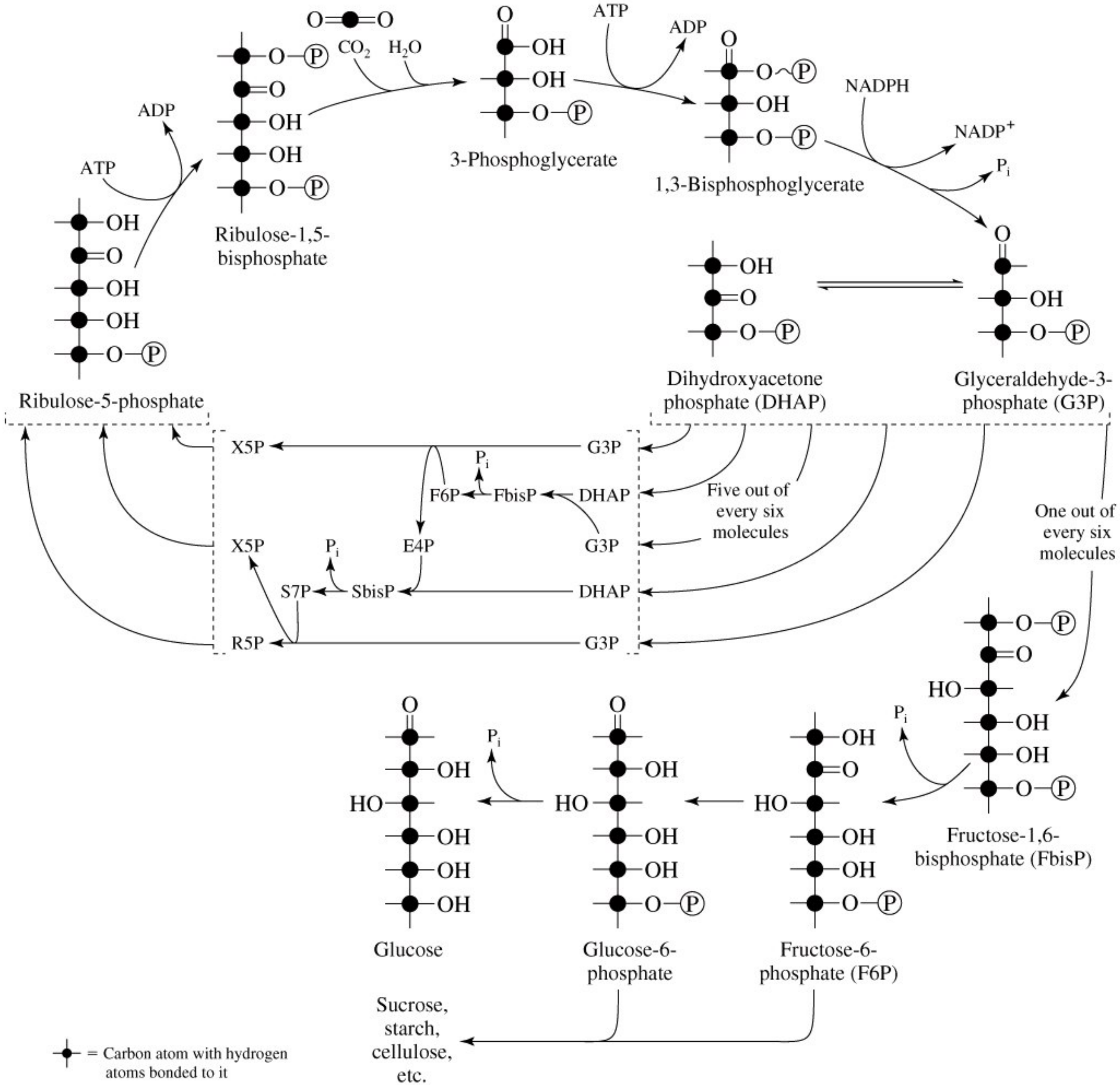
Electron flow → PMF → ATP



Light and dark reactions of photosynthesis




Calvin cycle
(Dark reaction)
ATP
Ribulose
5-phosphate
STAGE 3:
Regeneration
Ribulose
1,5-bisphosphate
STAGE 1:
Fixation
CO_2
2
3-phospho-
glycerate
2 ATP
2
1,3-bisphospho-
glycerate
2 NADPH
Fructose
6-phosphate
2
Glyceraldehyde
3-phosphate
STAGE 2: Reduction



CO2
H2O
3-Phosphoglycerate
ATP
ADP
1,3-Bisphosphoglycerate
NADPH
NADP+
Pi
Ribulose-1,5-bisphosphate
Ribulose-5-phosphate
Dihydroxyacetone phosphate (DHAP)
Glyceraldehyde-3-phosphate (G3P)
X5P
G3P
F6P
FbisP
DHAP
E4P
S7P
SbisP
R5P
Five out of every six molecules
One out of every six molecules
Fructose-1,6-bisphosphate (FbisP)
Fructose-6-phosphate (F6P)
Glucose-6-phosphate
Glucose
Sucrose, starch, cellulose, etc.
= Carbon atom with hydrogen atoms bonded to it

Synthesis of phosphorylated glucose in green plants

$$\text{Glyceraldehyde-3-phosphate} \xrightleftharpoons{\text{isomerase}} \text{dihydroxyacetone phosphate (DHAP)}$$

$$\text{DHAP} + \text{glyceraldehyde-3-phosphate} \xrightleftharpoons{\text{aldolase}} \text{fructose-1,6-bisphosphate}$$

$$\text{Fructose-1,6-bisphosphate} + H_2O \xrightleftharpoons{\text{phosphatase}} \text{fructose-6-phosphate} + P_i$$

$$\text{Fructose-6-phosphate} \xrightleftharpoons{\text{isomerase}} \text{glucose-6-phosphate}$$

$$\text{Glucose-6-phosphate} \xrightleftharpoons{\text{phosphoglucomutase}} \text{glucose-1-phosphate}$$

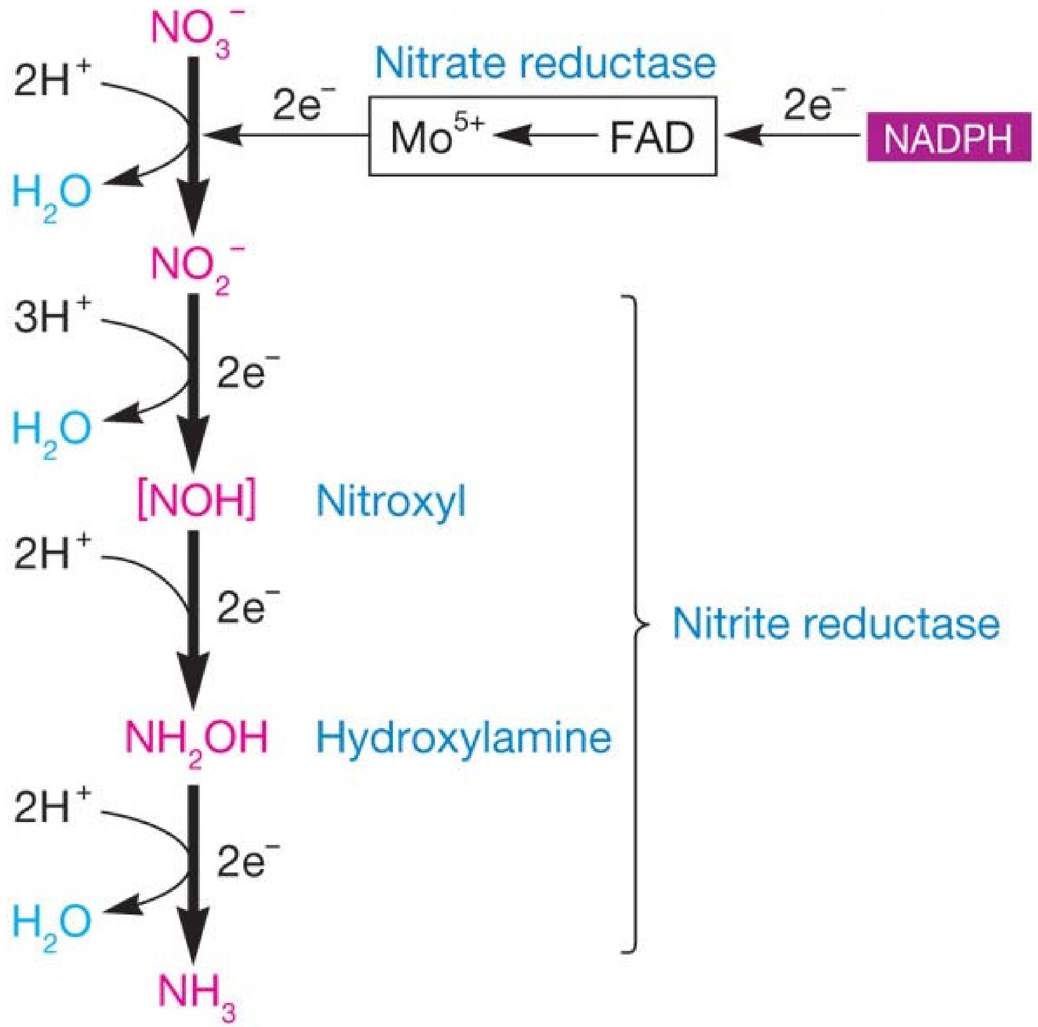
Synthesis of Amino Acids

Nitrogen addition to carbon skeleton is an important step

- potential sources of nitrogen: ammonia, nitrate, or nitrogen
  - most cells use ammonia or nitrate
- ammonia nitrogen easily incorporated into organic material because it is more reduced than other forms of inorganic nitrogen

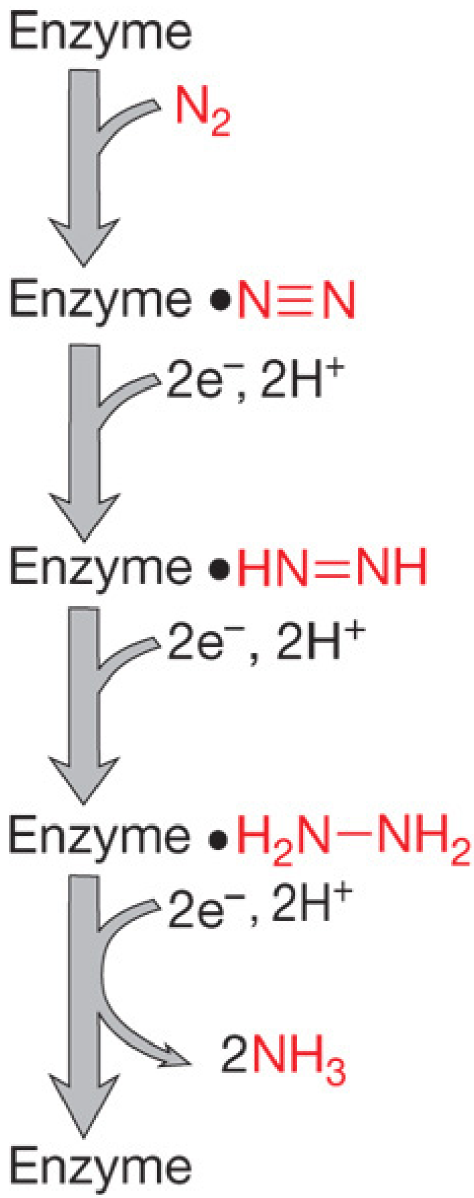
Assimilatory Nitrate Reduction

- used by bacteria to reduce nitrate to ammonia and then incorporate it into an organic form
- nitrate reduction to nitrite catalyzed by nitrate reductase
- reduction of nitrite to ammonia catalyzed by nitrite reductase



Nitrogen Fixation

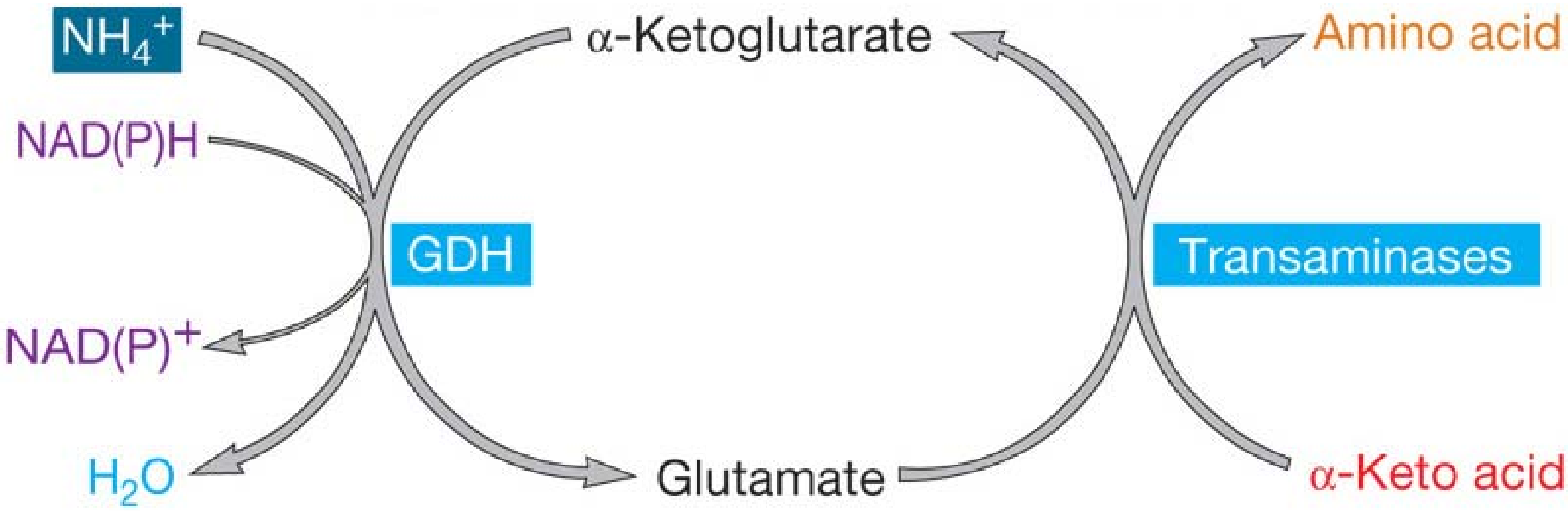
- reduction of atmospheric nitrogen to ammonia
- catalyzed by nitrogenase
  - found only in a few species of procaryotes
- requires large ATP expenditure



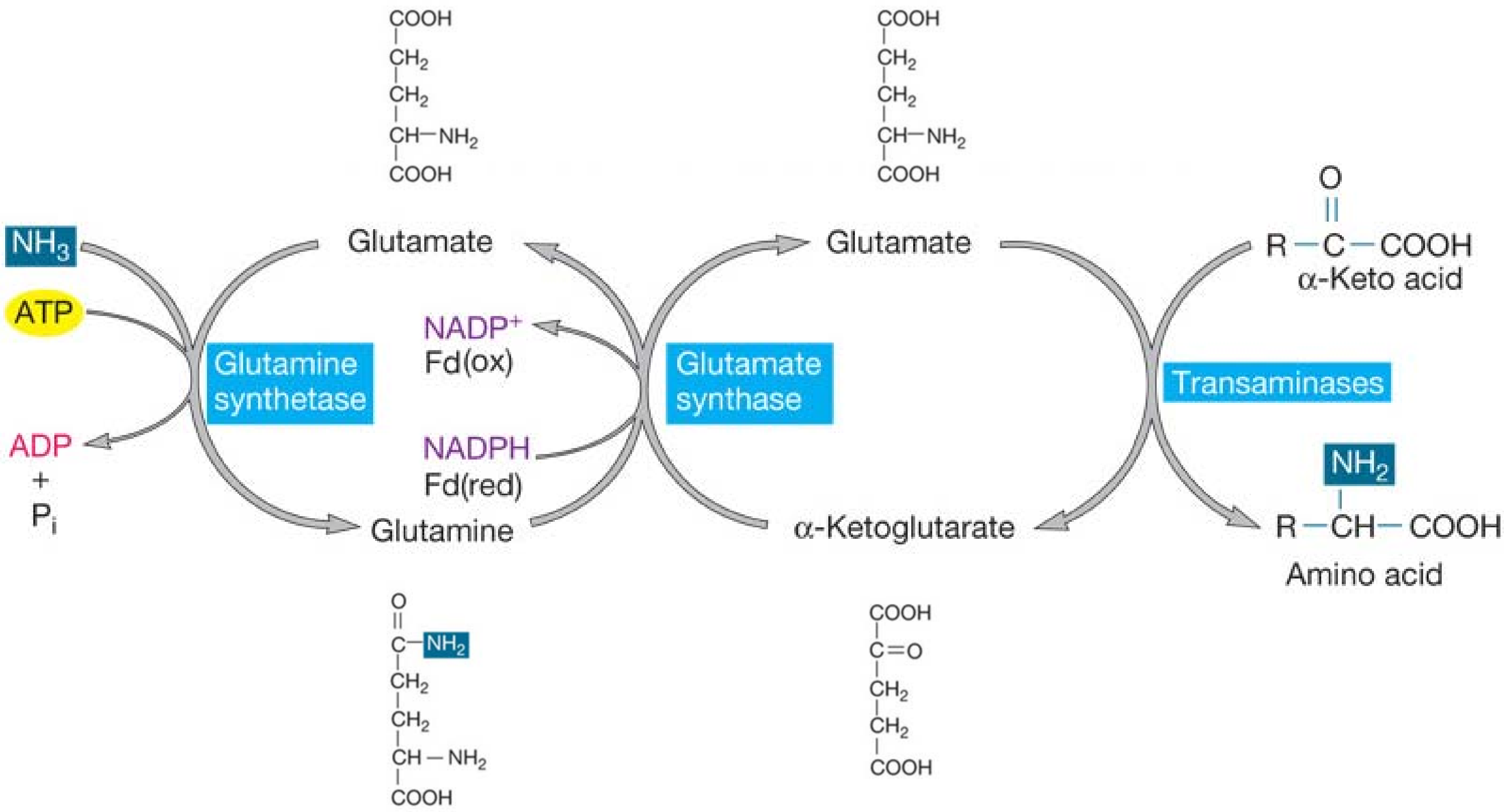
Ammonia Incorporation into Carbon Skeletons

- two mechanisms
  - reductive amination
  - glutamine synthetase-glutamate synthase systems
- once incorporated, nitrogen can be transferred to other carbon skeletons by transaminases

Ammonia Incorporation by reductive amination



Ammonia Incorporation using Glutamine Synthetase and Glutamate Synthase



Summary

- Glucose is synthesized from glycerol, amino acids and lactate in gluconeogenesis
- Pentose phosphate pathway produces NADPH and ribose 5-phosphate
- Photosynthetic organisms absorb and direct solar energy through electron transport chains to synthesize ATP and NADPH. These high-energy products are used for making carbohydrates from CO_2 and H_2O
- Amino acids are synthesized through ammonia incorporation into carbon skeletons