Introduction to Botany. Lecture 6

Alexey Shipunov

Minot State University

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Outline

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Last question

Why did Engelmann decide that photosynthetic pigment has a green color?

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Why did Engelmann decide that photosynthetic pigment has a green color?
Because he saw that oxygen-loving bacteria are concentrating only in places where red and blue light present. It means that pigment of question accepts blue and red so it is green.

Photosynthesis

As a whole I

Blackman

- In 1905, Frederick Blackman discovered that if light intensity is low, increase of temperature has a little effect on the rate of photosynthesis
  1. If light and temperature were *independent*, this could not happen
  2. If temperature and light were *components of the chain*, than light was first and temperature second
- Consequently, photosynthesis has two stages:
  1. Light stage which relates more with light intensity
  2. “Dark” (now called *enzymatic*) stage which relates more with temperature

Light and enzymatic (“dark”) reactions

- Light reactions depend on the light and water, they produce oxygen and energy (in form of ATP)
- Enzymatic reactions depend on carbon dioxide and water, they take energy from light reactions and result in production of carbohydrates

Four equations of photosynthesis

1. $6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$ is *not a formula*, but merely a general description of a process
2. Water molecules arise from both sides, and the better formula is
   $6CO_2 + 12H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6H_2O + 6O_2$
   or even
3. carbon dioxide + hydrogen donor $\xrightarrow{\text{light}}$ carbohydrate + water + oxidized hydrogen donor
4. And the best one is probably
   $CO_2 + H_2O \xrightarrow{\text{light}} \text{carbohydrates} + H_2O + O_2$

Photosynthesis

Light stage: electron transport, synthesis of ATP and NADPH

Participants of light stage

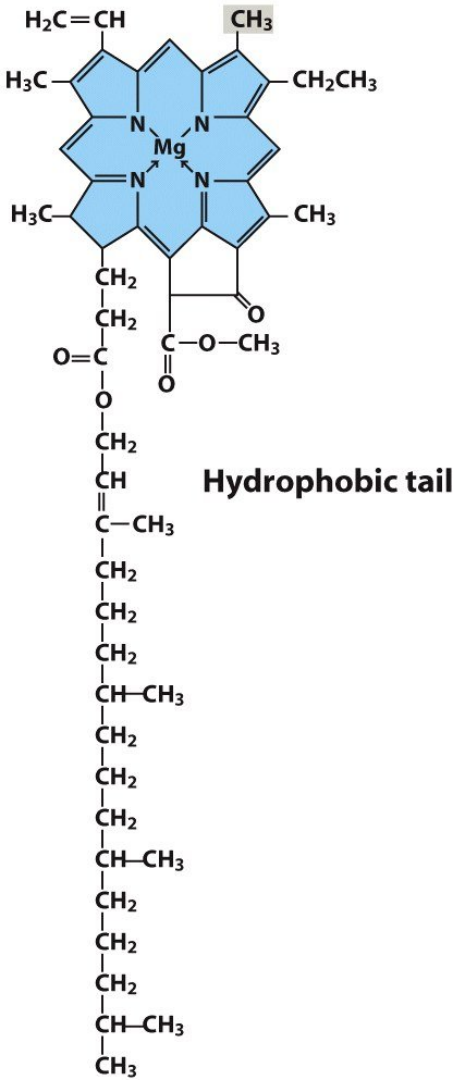
1. Chlorophyll (photosystems II and I)
2. Light
3. Water
4. ATP synthase (ATPase)
5. Protons (H^+)
6. Hydrogen carrier ($NADP^+$)

Where: around thylakoid membrane

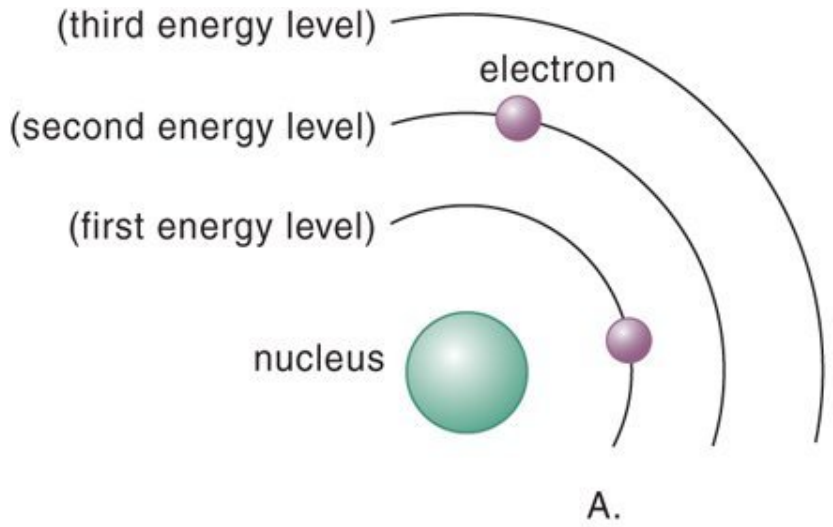
Logic of the light stage

1. To assemble carbon dioxide into sugar, we need ATP
2. To make ATP, we need *electrical current* through the proton pump
3. To make this current, we need the *difference in charge* (voltage difference) between thylakoid and matrix (stroma) compartments
4. To make this difference, we need to *segregate ions*: positively charged (like H^+) will go from outside and stay inside, negatively charged (like e^- and OH^-) will go from inside and stay outside
5. To segregate ions, we need the energy and the energy booster. These are sun rays and chlorophyll

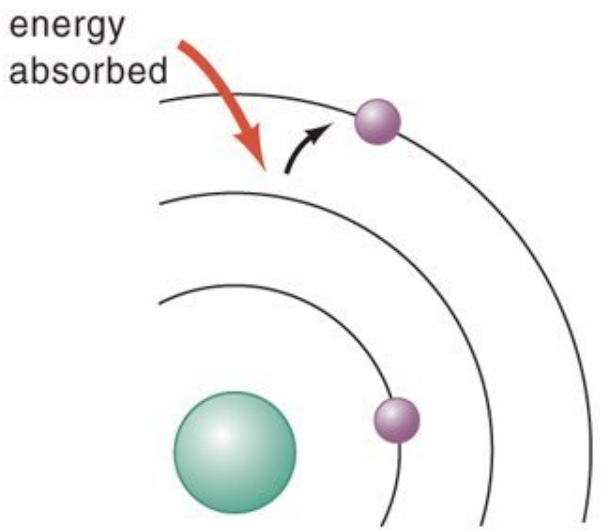
Why chlorophyll is good for the membrane



How chlorophyll works: excitation of the electron

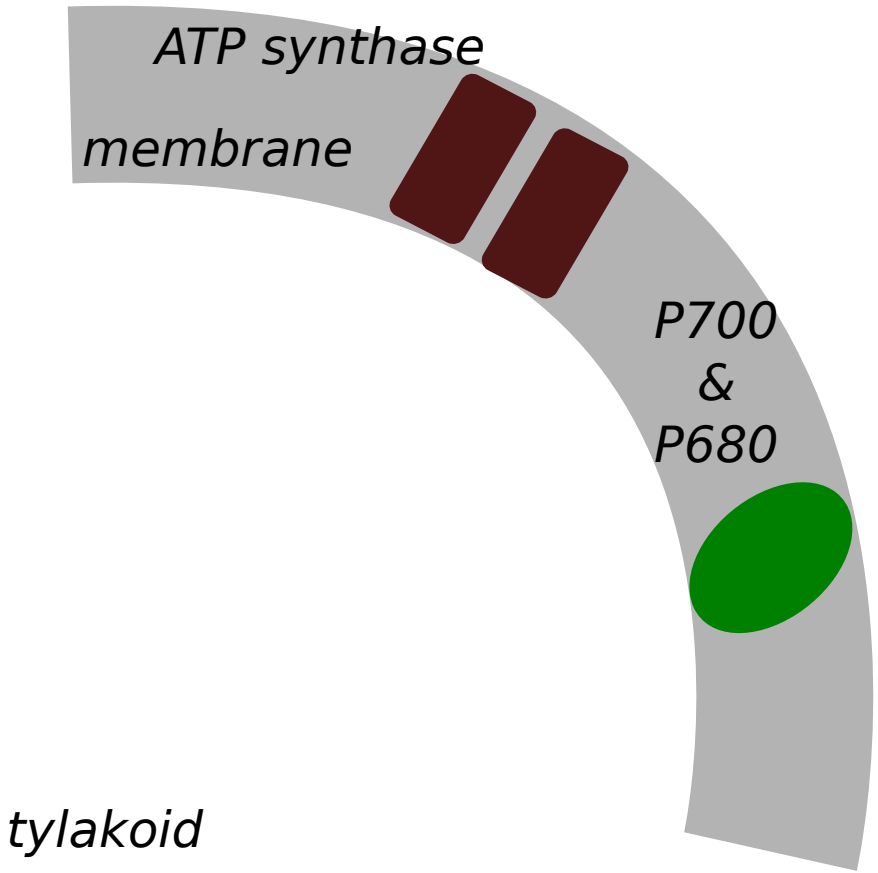


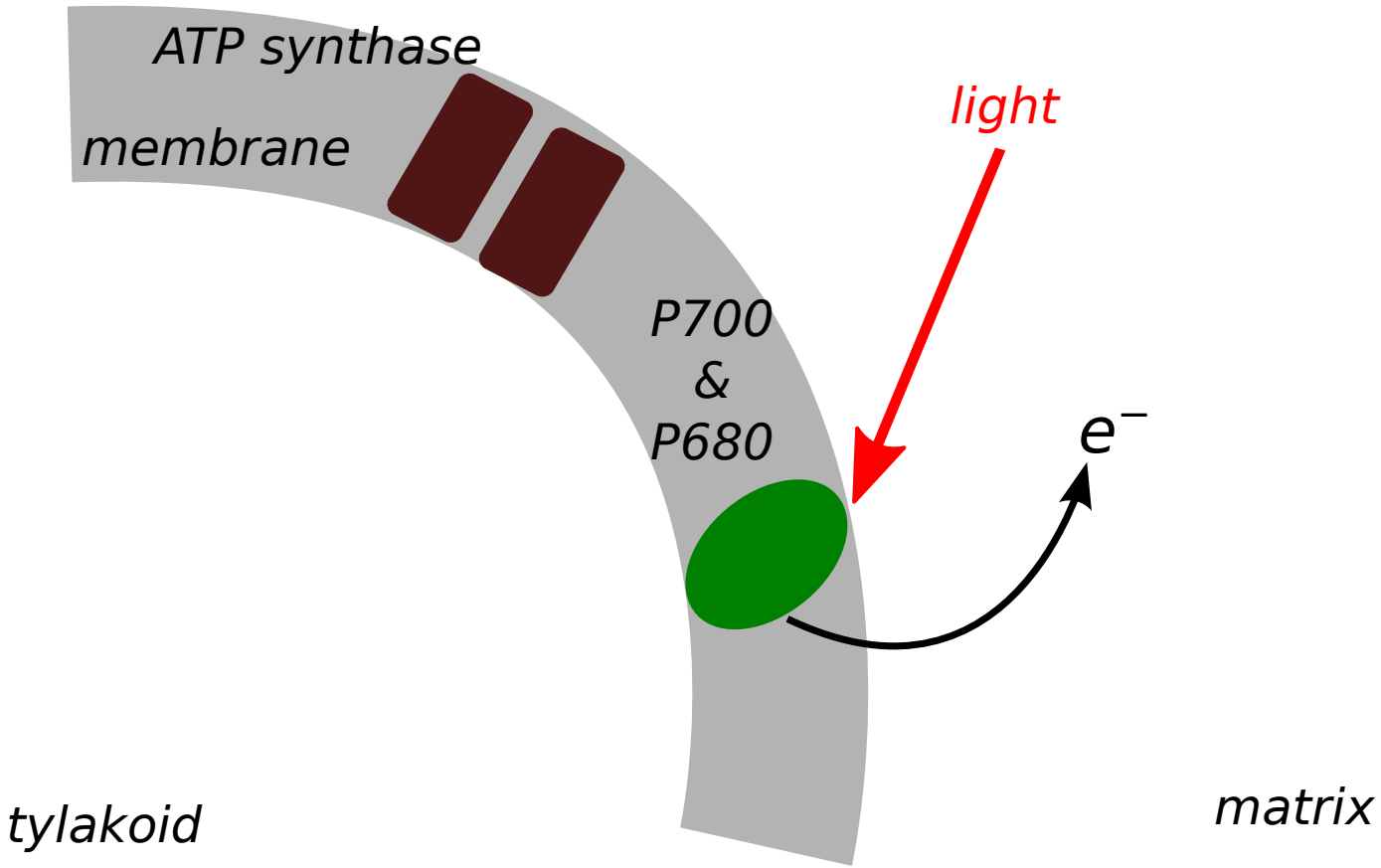
A.

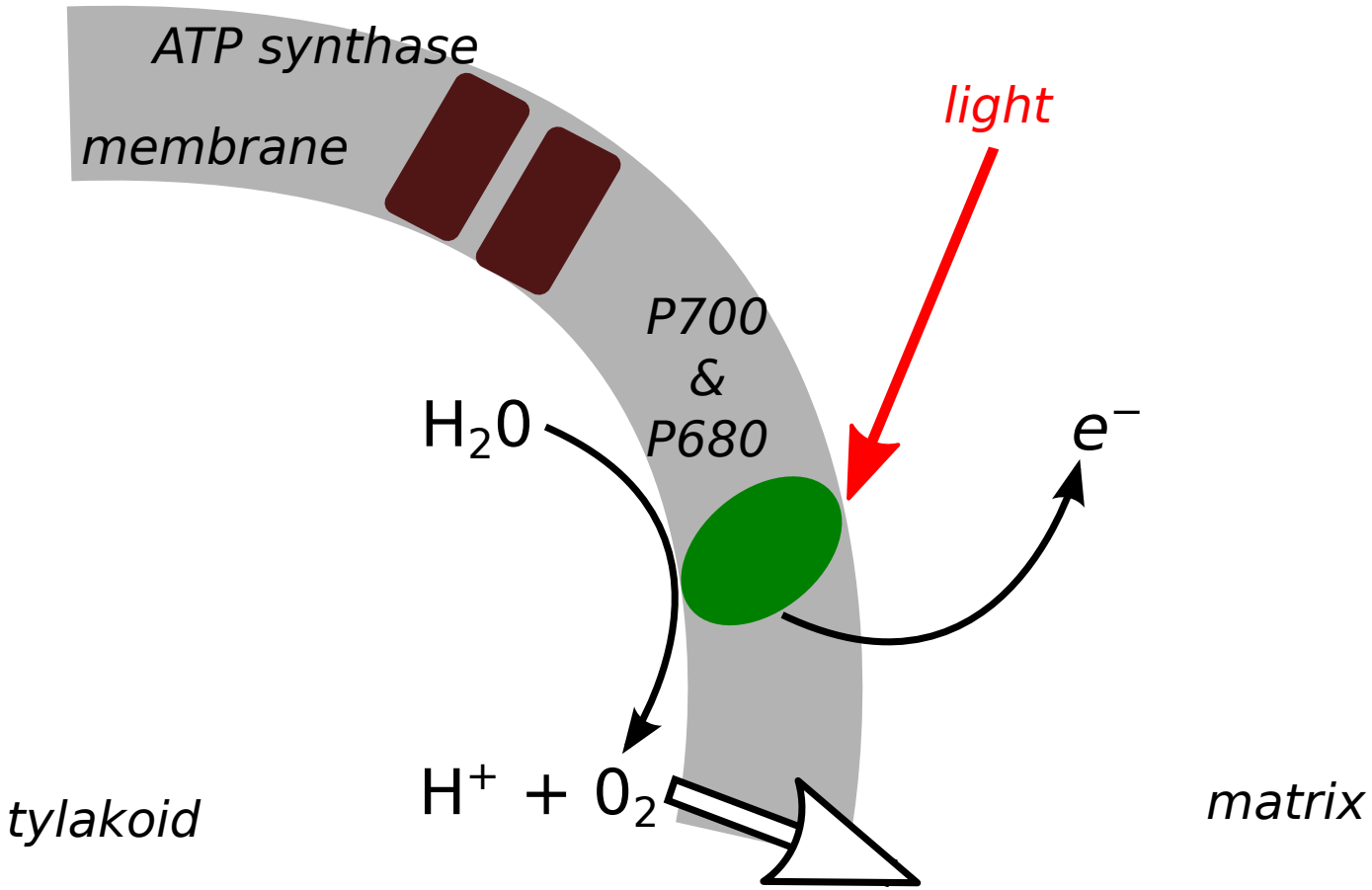


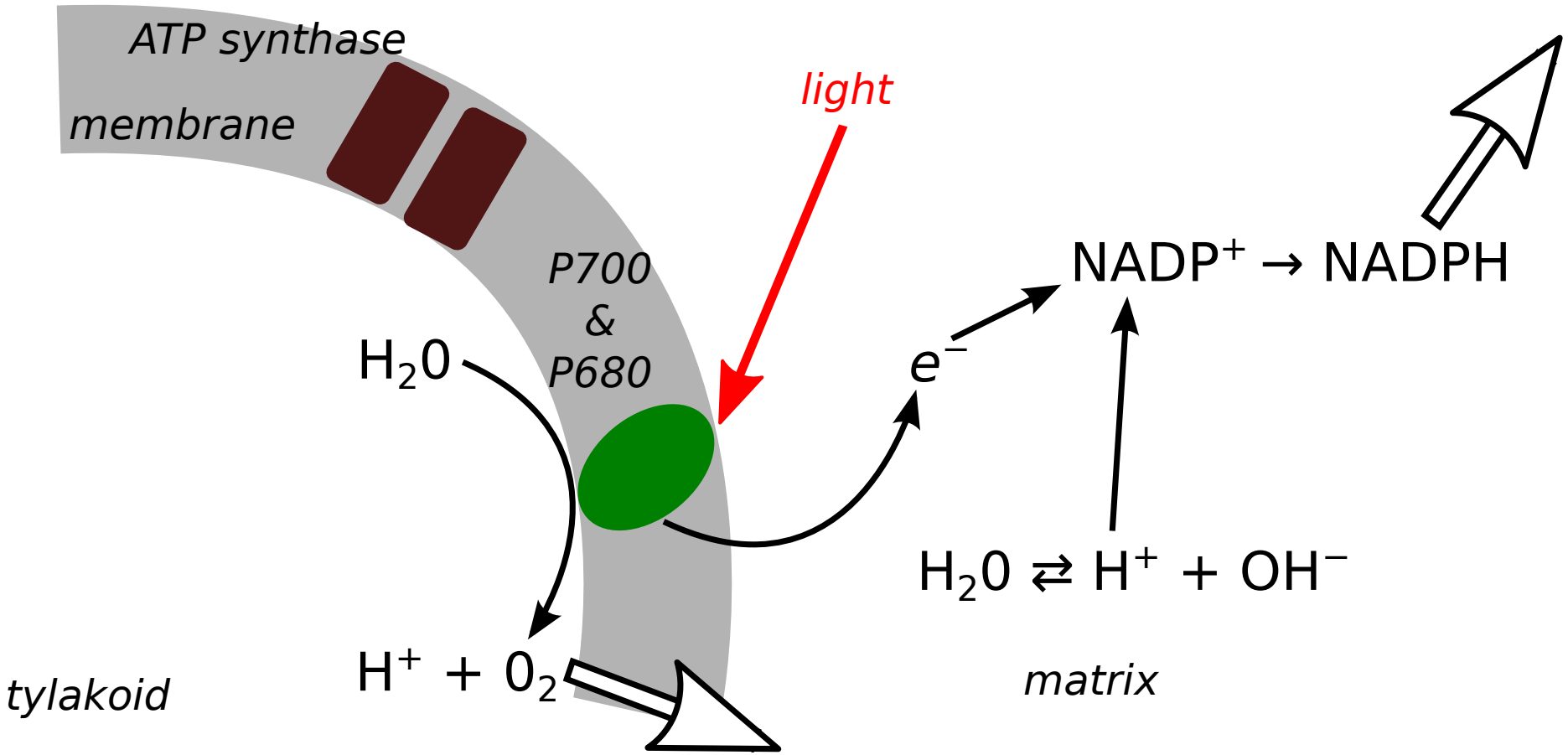
B.

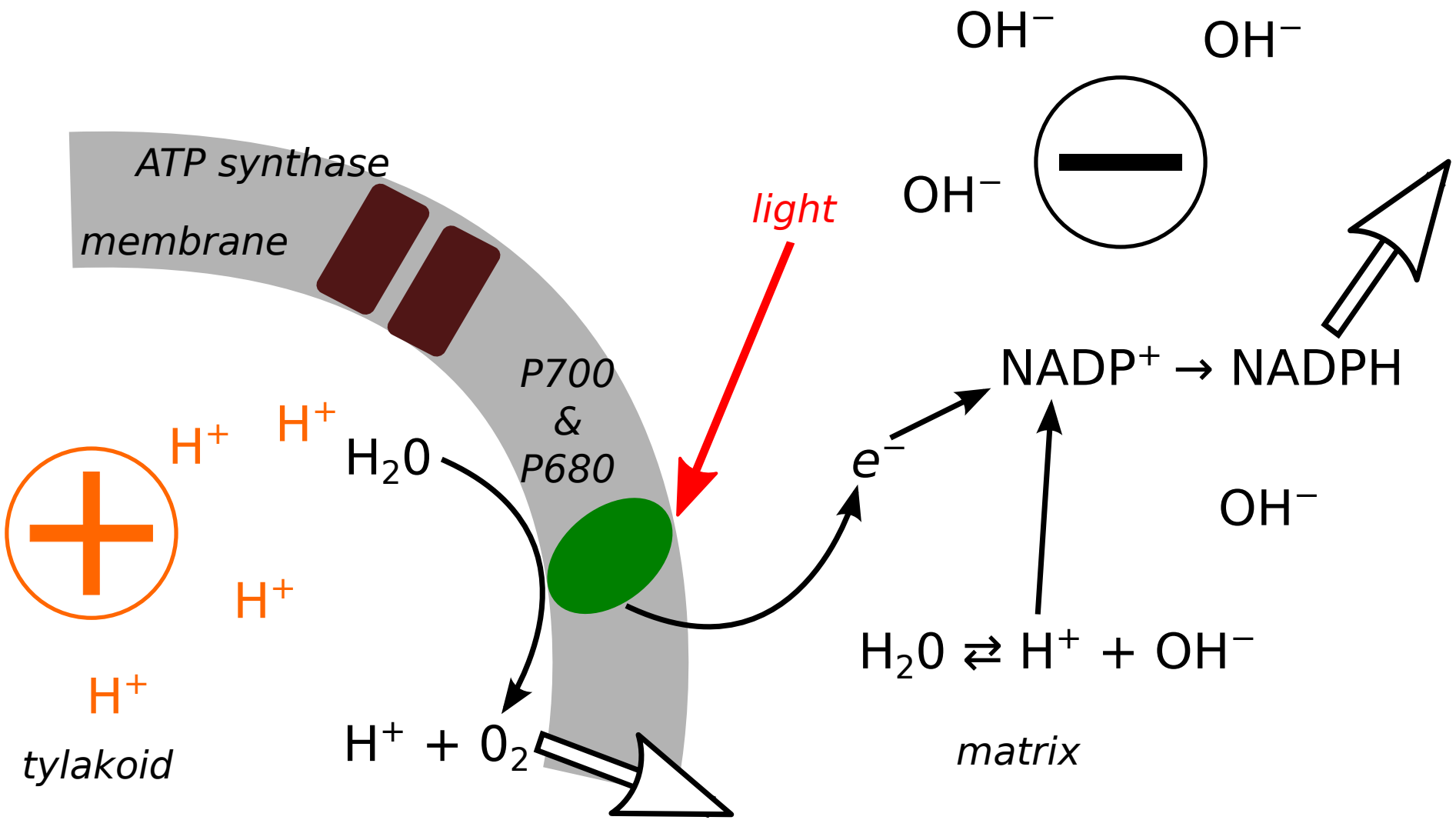
Scheme of light stage

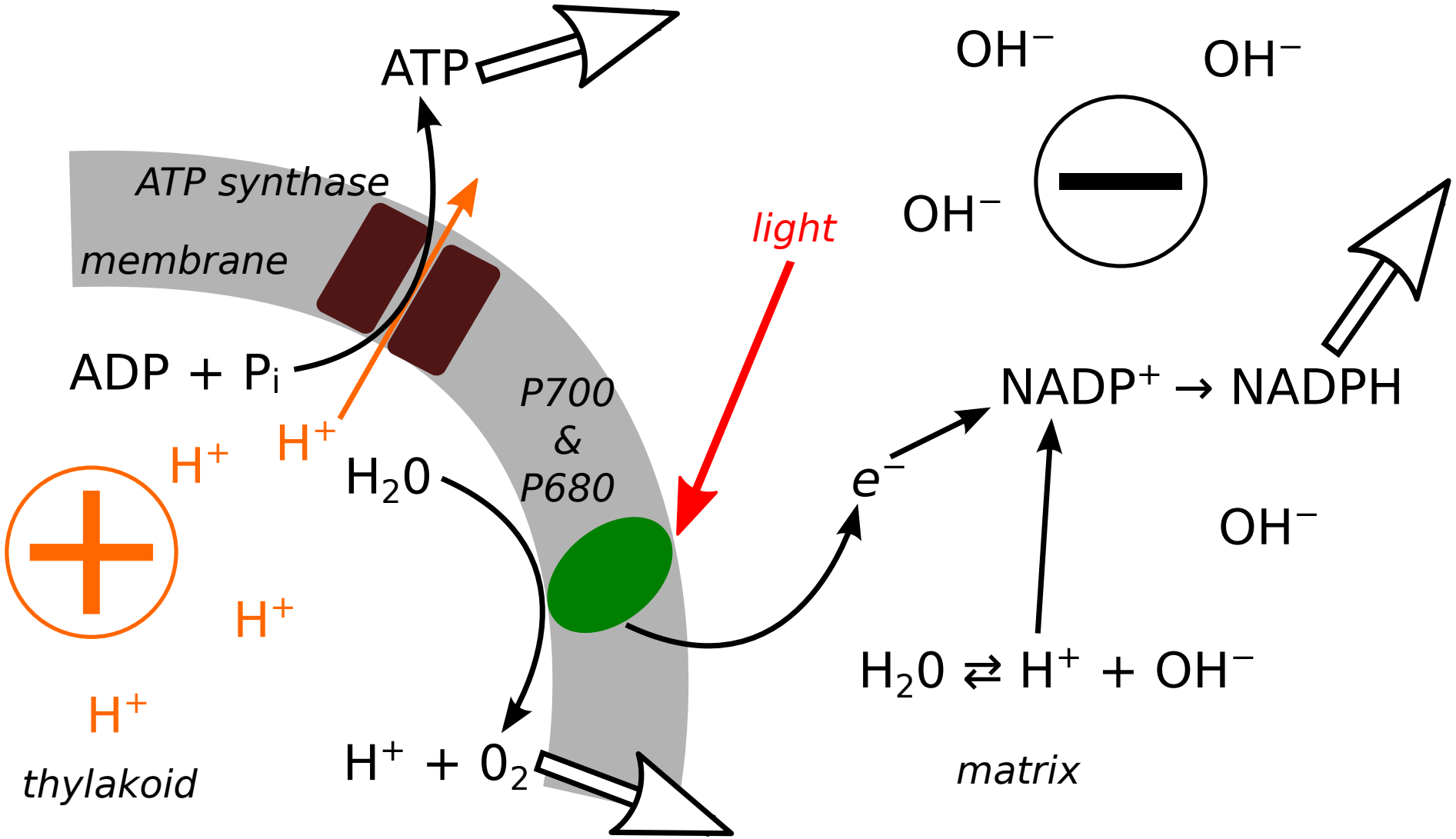

ATP synthase
membrane
P700
&
P680
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
e^-
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
H_2O
e^-
$H^+ + O_2$
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
H_20
e^-
$NADP^+ \rightarrow NADPH$
$H_20 \rightleftarrows H^+ + OH^-$
$H^+ + 0_2$
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
OH^-
OH^-
OH^-
$NADP^+ \rightarrow NADPH$
e^-
OH^-
H^+
H^+
H_20
H^+
H^+
$H_20 \rightleftarrows H^+ + OH^-$
$H^+ + 0_2$
tylakoid
matrix


ATP
ATP synthase
membrane
ADP + Pi
H+
H+
H+
H+
H+
thylakoid
H20
P700
&
P680
light
e−
H+ + 02
OH−
OH−
OH−
NADP+ → NADPH
OH−
H20 ⇄ H+ + OH−
matrix

Main events of light stage

1. Chlorophyll + Light $\longrightarrow$ Electron (e^-) + Chlorophyll$^+$
2. e^- + H^+ (from water) + Hydrogen carrier ($NADP^+$) $\longrightarrow$ NADPH (moves away)
3. $H_2O \longrightarrow H^+$ (accumulates inside) + e^- + O_2
4. H^+ (inside) + OH^- (from water, located outside) $\Longrightarrow$ gradient $\Longrightarrow$ proton pump $\Longrightarrow$ H_2O
   TOGETHER WITH
   ADP + P_i (inorganic phosphate) $\longrightarrow$ **ATP**

Photosystems

- Photosystem II (P_{680}, contains chlorophylls and carotene):
  1. decomposes water;
  2. forwards electron to Photosystem I;
  3. makes proton gradient
- Photosystem I (P_{700}, contains only chlorophylls) makes NADPH

Photosystems movie

Results of the light stage

At the start	At the end
H_2O	H_2O (result of pump) and $\mathbf{O_2}$
Chlorophylls	Chlorophylls
ADP and P_i (inorganic phosphate)	ATP
$NADP^+$	NADPH

Photosynthesis

Enzymatic stage: fixation of carbon dioxide

Participants of enzymatic stage

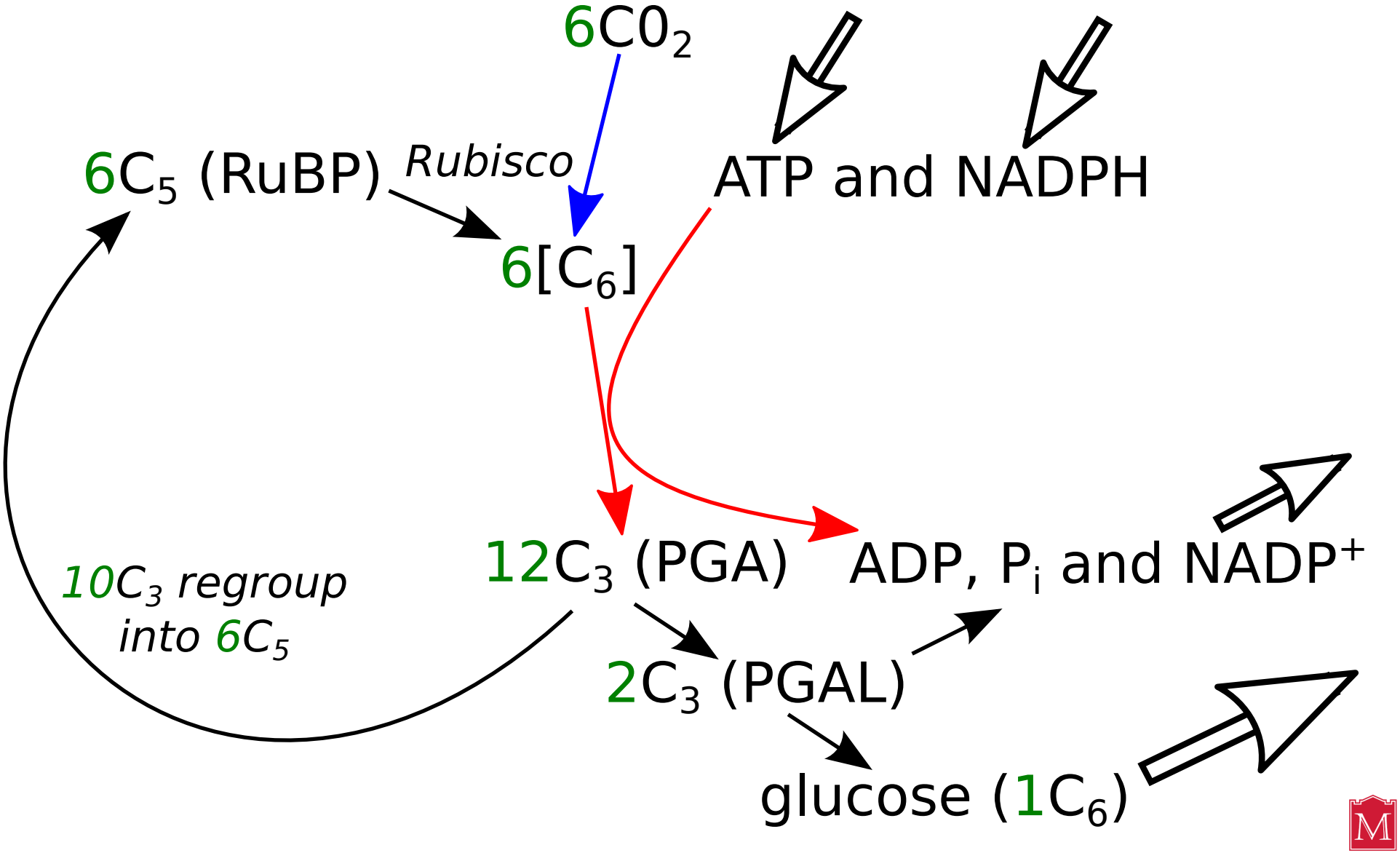
1. Carbon dioxide (CO_2)
2. Hydrogen carrier with hydrogen (NADPH)
3. Source of energy (ATP)
4. Ribulose biphosphate (RuBP, five-C-hydrocarbonate, "C_5")
5. *Rubisco* and other enzymes

Place: in the matrix (stroma) of chloroplast

Main events of enzymatic stage

1. $CO_2 + C_5$ (RuBP, ribulose biphosphate) $\xrightarrow{\text{rubisco}} C_6$
2. $C_6 \longrightarrow 2C_3$ (PGA, phosphoglyceric acid)
3. $C_3 + NADPH + ATP \longrightarrow C_6H_{12}O_6$ (or other organic molecules) + $C_5 + NADP^+ + ADP + P_i$ (inorganic phosphate)
   - Organic molecules are synthesized from C_3 (PGA) through energy-rich **PGAL** (phosphoglyceric aldehyde)

Enzymatic stage: scheme



Results of enzymatic stage

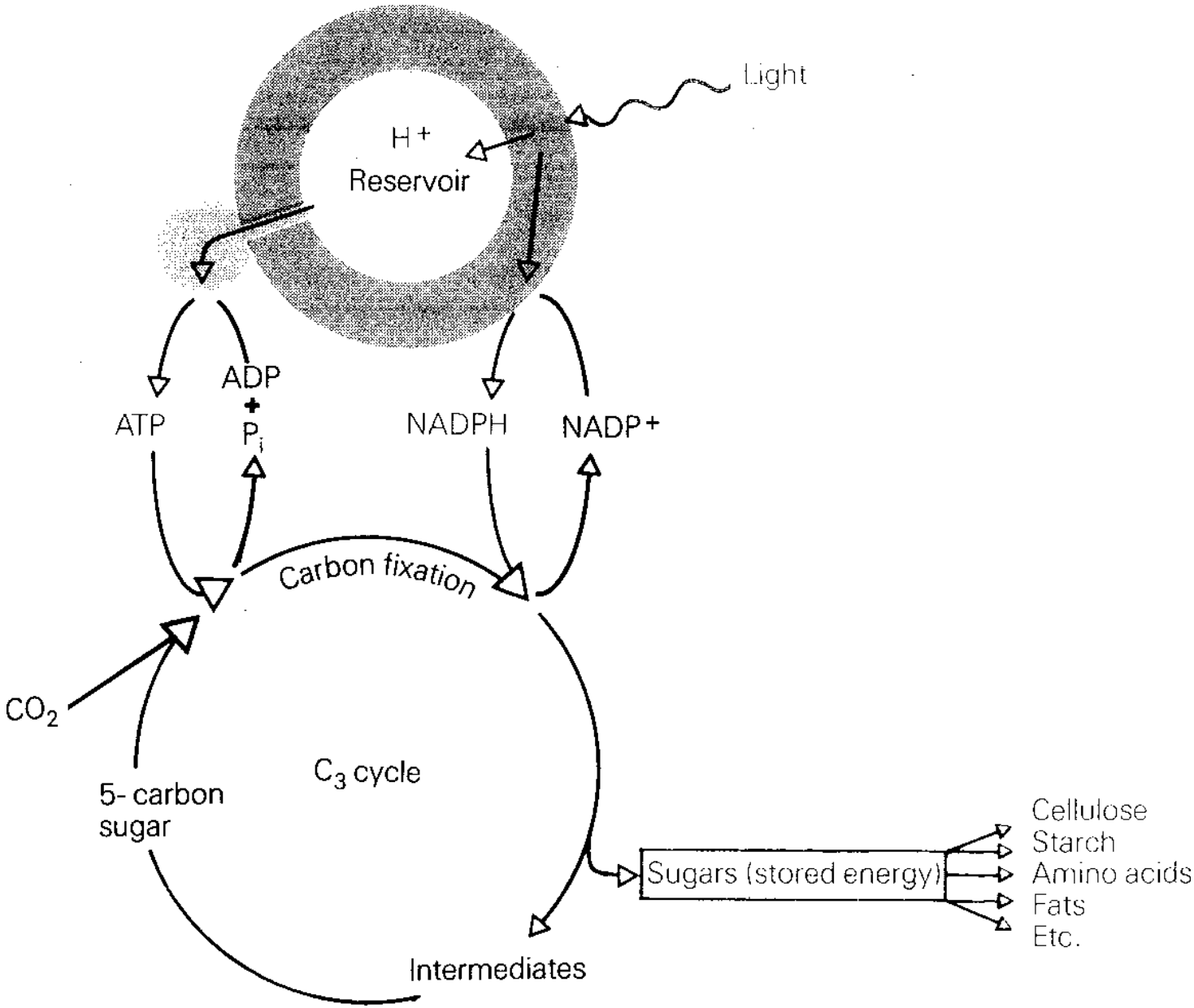
At the start	At the end
CO_2	$C_6H_{12}O_6$ (or other organic molecules)
NADPH	$NADP^+$ (and H to organic molecules)
ATP	ADP and P_i (inorganic phosphate)
C_5	C_5
Rubisco	Rubisco

The other names for enzymatic stage are “Calvin cycle” and “C_3 cycle”

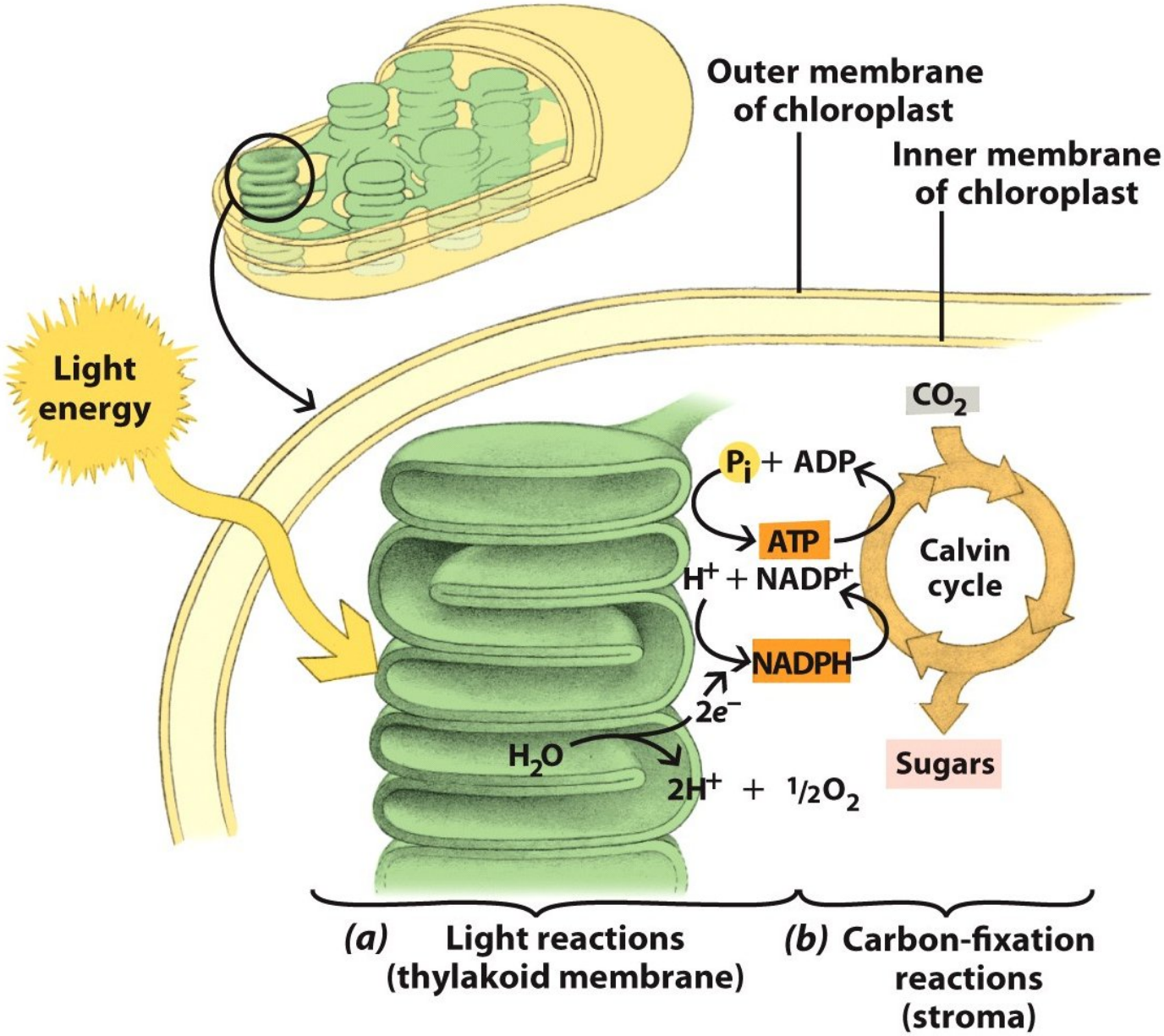
Photosynthesis

As a whole II

Overview of photosynthesis



Photosynthesis in the cell



Photosynthesis movie

Summary

- **Photosynthesis** is a sum of light-dependent and light-independent reactions
- **Light stage** of photosynthesis results in accumulation of energy and hydrogen, and release of oxygen
- **Enzymatic stage** of photosynthesis results in synthesis of organic molecules

For Further Reading

A. Shipunov.
Introduction to Botany [Electronic resource].
2015.
Mode of access:
http://ashipunov.info/shipunov/school/biol_154