Introduction to Botany: BIOL 154
Study guide for Exam 1

Alexey Shipunov

Lectures 2–6

Contents

Outline

1 Questions and answers

Previous final question: the answer

Why plants are important?

- Regulate the flow of energy from Sun to us
- Produce oxygen
- Synthesize medicine

  etc.

Web site (again)

Shipunov, A. Introduction to Botany [Electronic resource]. 2010—onwards.
Mode of access: http://herba.msu.ru/shipunov/school/biol_154/index.htm

BIOL 154: Introduction to Botany

Class materials:

- Syllabus (PDF, 0.2 Mb)
- All points and grades* (Excel, 0.1 Mb)

- Lecture 1 (PDF, 0.3 Mb)
- ~~Lecture 2 (PDF, 0.3 Mb)~~

Folders:

- Old lectures (2010)
- Old lectures (2011)
- Old lectures (2012)
- Old lectures (2013)

Your graded answers are in the box outside my office door (room 229)

2 Plants: definition

2.1 Plants$_1$ and plants$_2$

Plants$_1$ and plants$_2$

- Plants$_1$ are all green photosynthetic organisms
- Plants$_2$ are "typical plants" (better definition follows)

The nature of two definitions

- Plants$_1$—ecological definition (based on the role in nature)
- Plants$_2$—taxonomic definition (based on the evolution)

Plants$_1$ is about ecology

Plants$_1$ are *photosynthetic organisms*:

$$H_2O + CO_2 + \text{light} \rightarrow \text{organic compounds} + O_2$$

Some plants$_1$ could taxonomically be bacteria or even animals!

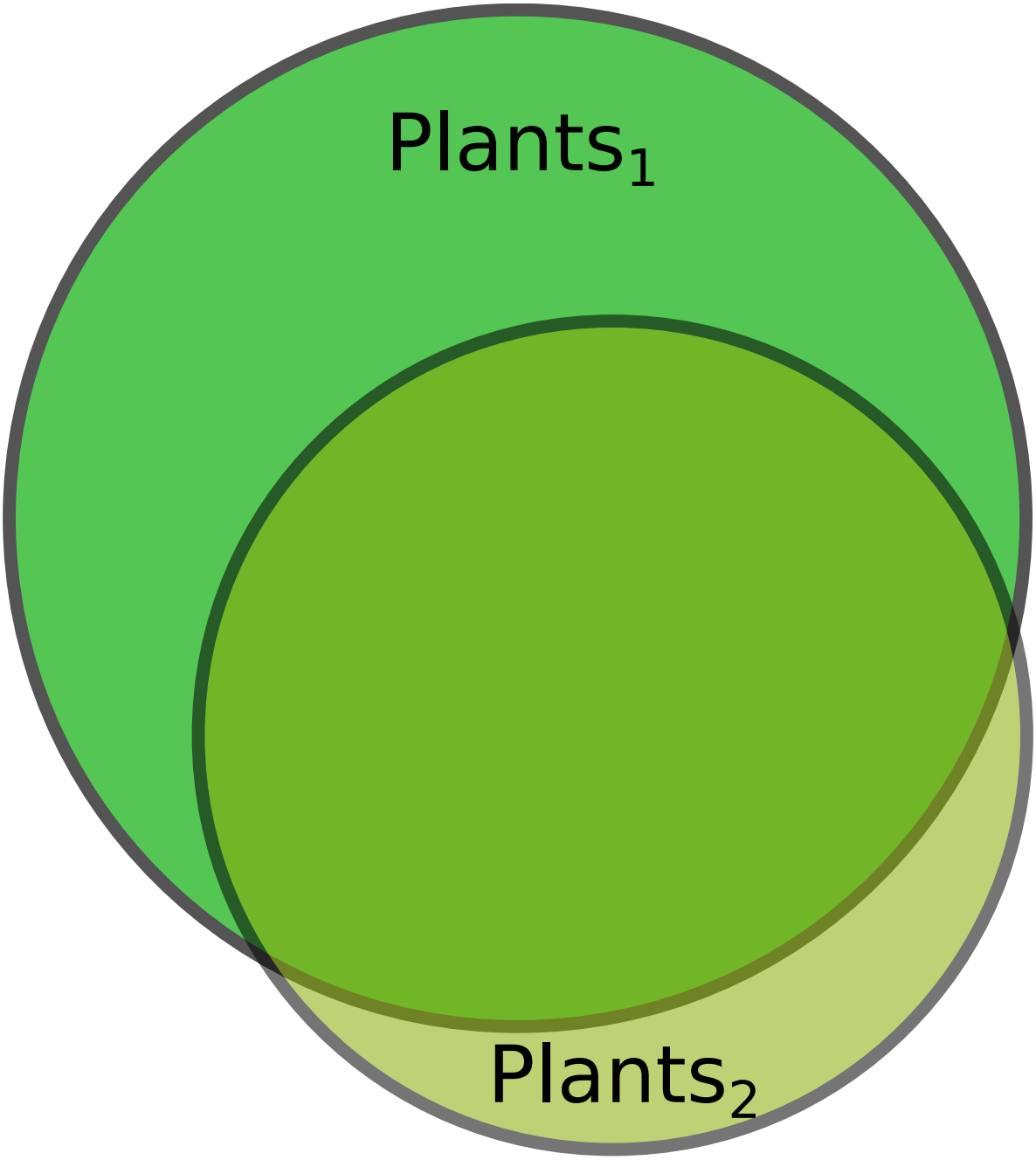
Green slugs

Green slugs obtain chloroplasts from algae, but keep them all their life, feed from them and even use chloroplast genes.

Green *Hydra*

No mouth!

Plants$_1$ and plants$_2$ are similar but not the same



3 Plants in general

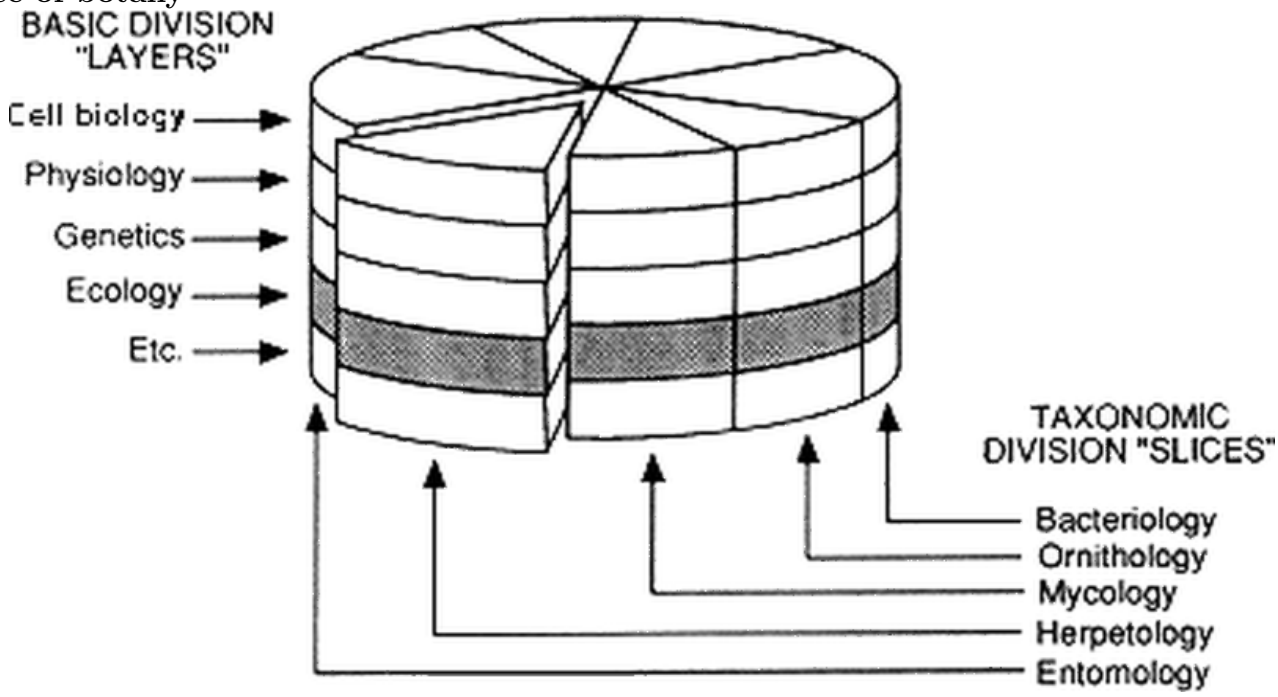
3.1 Levels of organization

Levels of organization

- Ecosystems OR Taxa
- Populations
- Organisms
- Organs
- Tissues

- Cells
- Organelles
- Molecules

Place of botany



Layered cake of biology (Odum, 1971): botany is a "slice science"

3.2 Taxonomy

Ranks

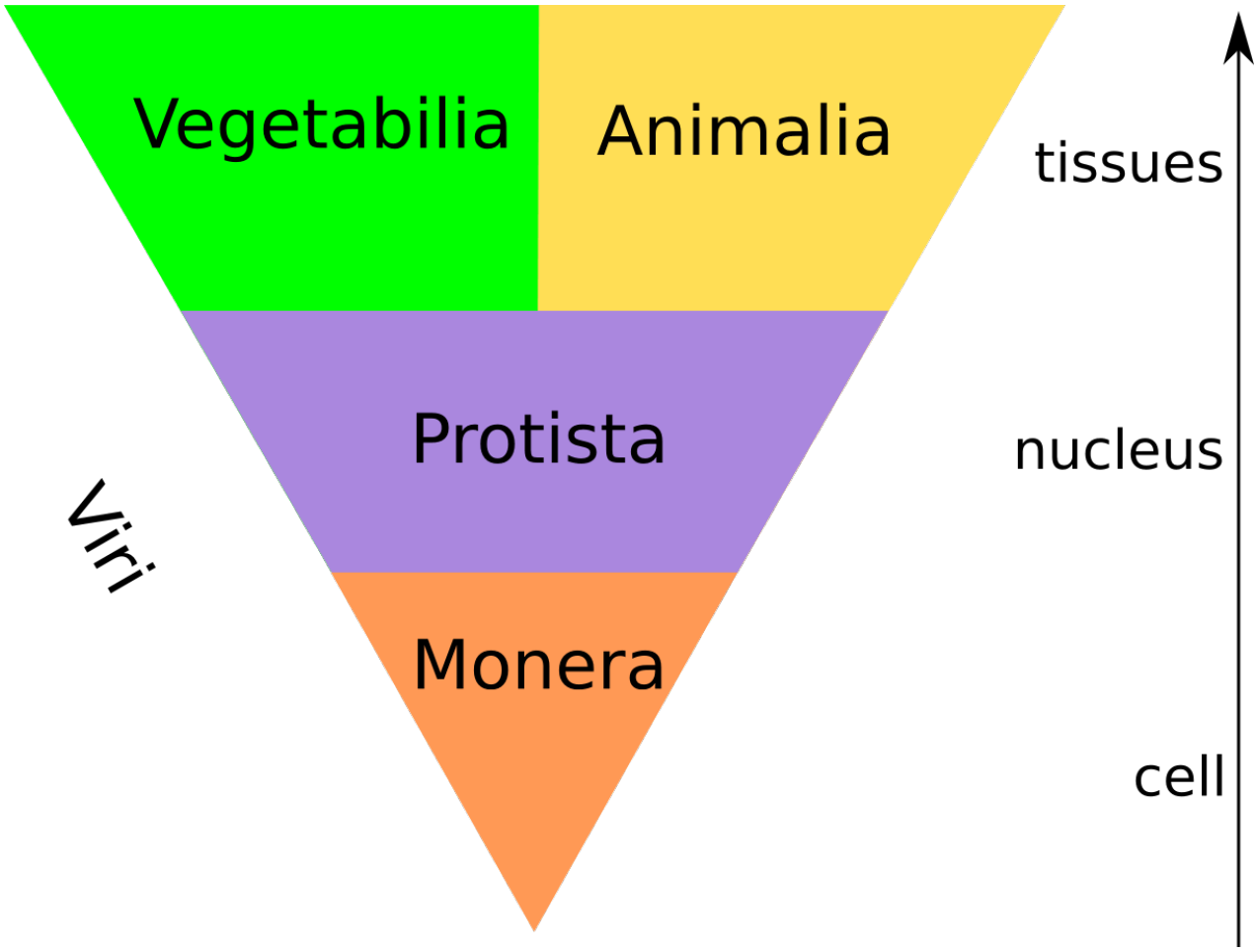
Most scientists accept seven main ranks:

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

Names

- Names of species are binomials like *Solanum tuberosum* (potato)
- Names of other ranks are uninomials like **Vegetabilia** (plant kingdom)

Pyramid of life



Questions about pyramid

What is Monera? Prokaryotes: (1) Bacteria and (2) Archaea

What is Protista? Eukaryotes without tissues

Where are eukaryotes? Protista, Vegetabilia and Animalia

Where are fungi? They belong to different protists

Where are plants$_2$? Vegetabilia

Where are plants$_1$? It is not applicable here

Why are two groups on one level? Vegetabilia and Animalia both have tissues but obtained them for the radically different purposes. Animals acquired *kinoblast* and *phagocytoblast* **to hunt and digest**, and plants have *epidermis* and *photosynthetic tissue* **to survive on land**.

Plants$_1$ and plants$_2$ (updated)

- Plants$_1$ are all photosynthetic organisms
- Plants$_2$ are **Vegetabilia**: multi-tissued, terrestrial, primarily photosynthetic eukaryotes

4 Ways of life

4.1 Energy and food

Ways of life

- How to obtain energy?
  1. From sun light: **phototrophy**
  2. From chemical reactions with inorganic matter ("rocks"): **lithotrophy**
  3. From breaking organic molecules into inorganic (typically, carbon dioxide and water): **organotrophy**
- How to obtain building blocks?
  1. From assimilation of carbon dioxide: **autotrophy**
  2. From other living beings: **heterotrophy**

Six life styles and taxonomy

	Phototrophs	**Lithotrophs**	**Organotrophs**
Autotrophs	Plants_1: some Monera, some Protista, most of Vegetabilia	Some Monera	Some Monera
Heterotrophs	Some Monera	Some Monera	Majority of Animalia and many Protista and Monera

Final question (1 point)

What is the difference between plants_1 and plants_2?

Summary

- "Plants" have **two definitions**
- **Botany** is a "slice science" which covers multiple **levels of organization**

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

[2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 1.*

Outline

5 Questions and answers

Previous final question: the answer

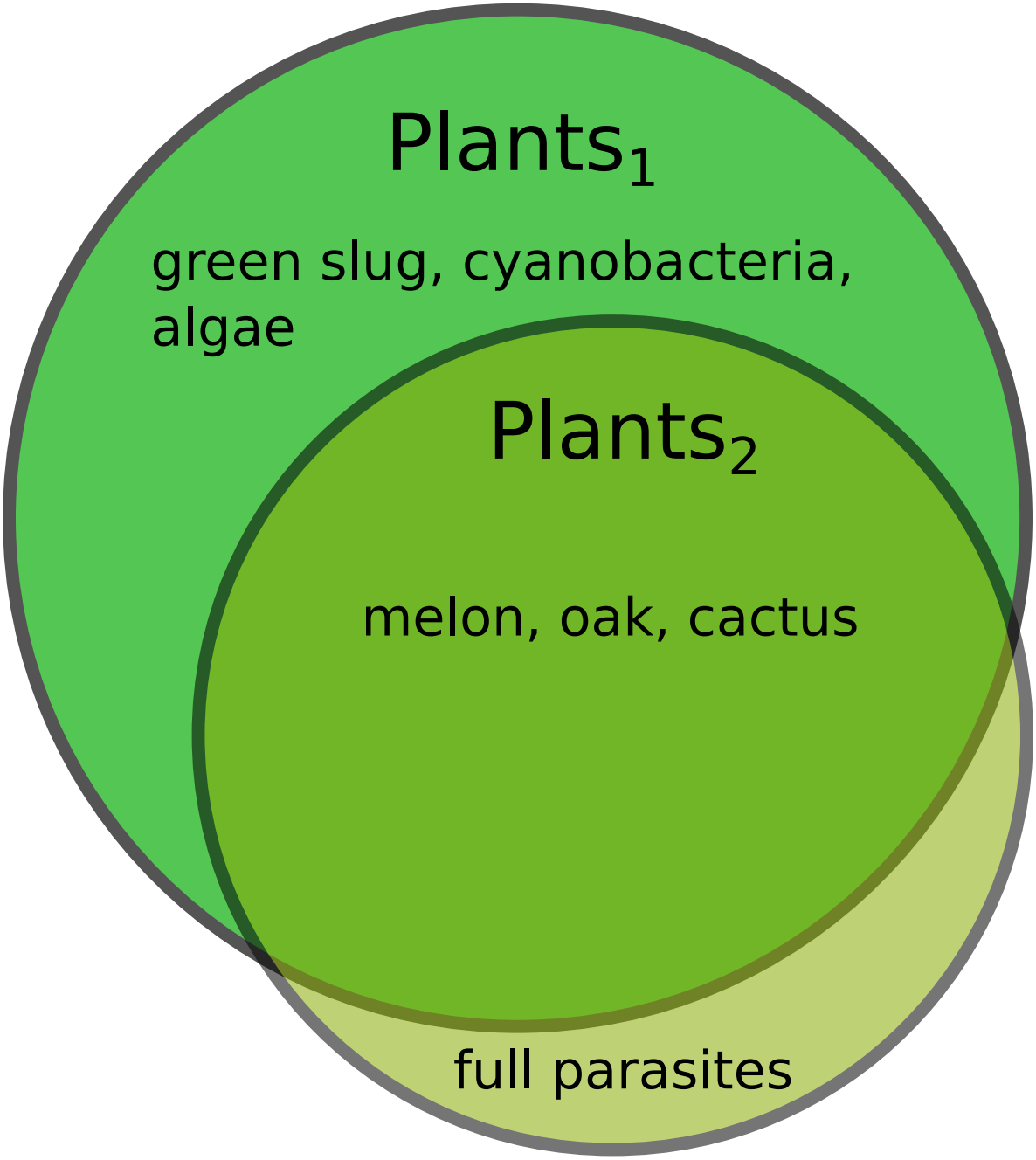
What is the difference between plants$_1$ and plants$_2$?

- Plants$_1$ are all photosynthetic organisms whereas plants$_2$ are only part of them
- Plants$_2$ is a taxonomic (evolutionary, phylogenetic) definition based on having leaves, stems, tissues etc. They are **Vegetablia** kingdom.
- Some Animalia could be plants$_1$ but not plants$_2$

6 Ways of life

6.1 Energy and food

Plants$_1$ and plants$_2$: examples



Plants$_1$, plants$_2$ and life styles

- Plants$_1$ are **photoauthotrophs**
- Plants$_2$ are photoauthotrophs too but there are exceptions: **fully parasitic plants**. Formally, many parasitic plants are plants$_2$ but not plants$_1$
- Carnivorous plants (like sundew or Venus flycatcher) are all photoautotrophs! They "eat" animals to obtain fertilizers: nitrogen and phosphorous.

Pterospora

Mycoparasite

Hydnora

Root parasite

Pilostyles

Internal parasite

Dodder

Stem parasite

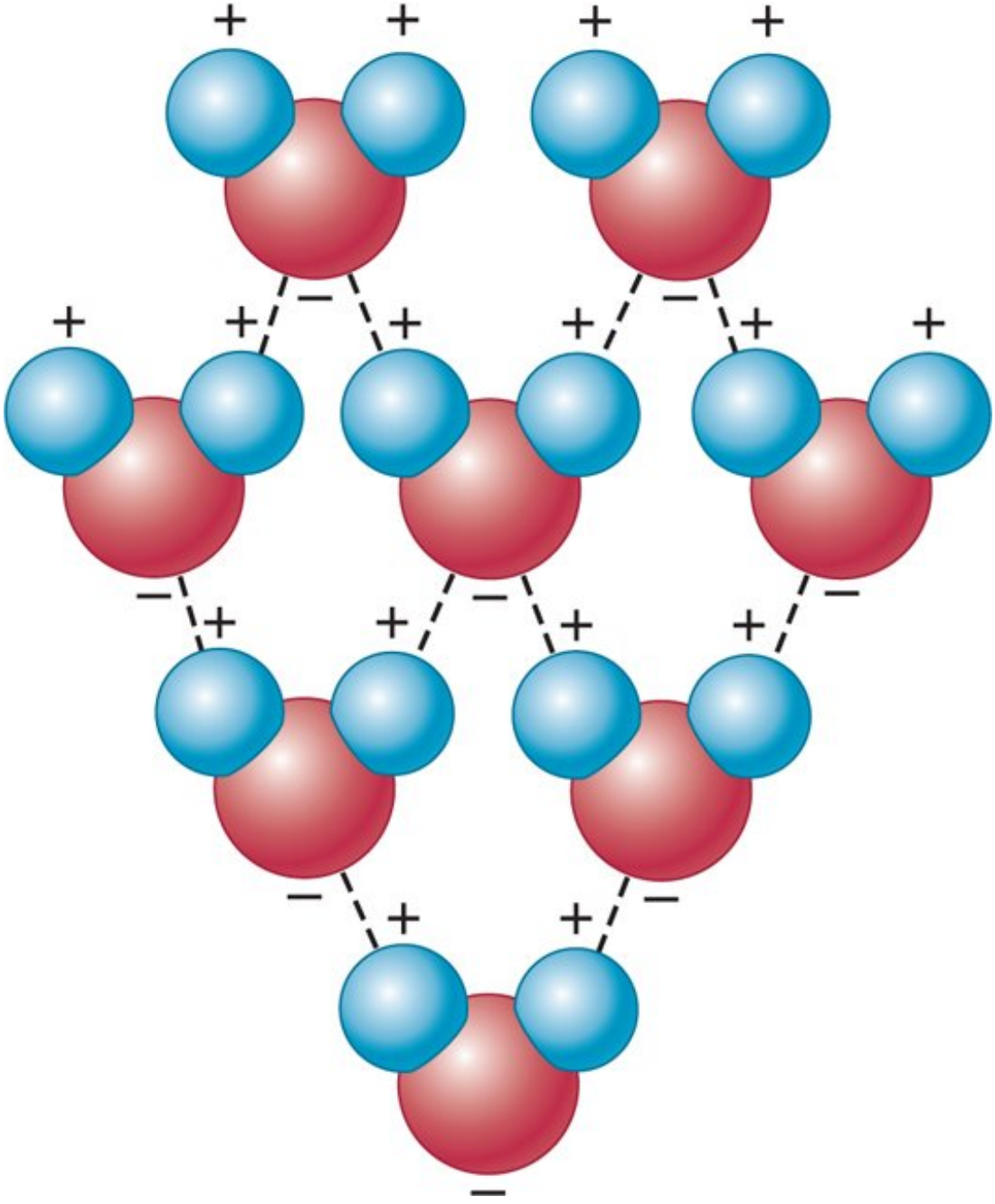
7 Photosynthesis

7.1 Chemistry of life

Very basics of chemistry

- Atoms
  - Protons
  - Neutrons
  - Electrons
- Atomic weight
- Isotopes
- Elements
- Periodic table: rows and columns
- Chemical bonds: ionic, covalent, hydrogen
- Valence and group
- Molecules
- Molecular weight

Water with hydrogen bonds



Final question (2 points)

What is molecular weight of sulfuric acid, H_2SO_4?

Summary

- Some plants$_2$ are formally not plants$_1$: fully parasitic plants
- "Carnivorous" plants are not carnivores
- We will need to know multiple chemical terms (see in the lecture)

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

[2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 2*.

Outline

8 Questions and answers

Previous final question: the answer

What is molecular weight of sulfuric acid, H_2SO_4?

- H_2SO_4 weight $= 2 \times 1 + 32 + 16 \times 4 = 98$
- "98" what? Units of atomic mass, Dalton, "Da", 1/12 of carbon-12 (^{12}C) isotope weight.

Very basics of chemistry

- Atoms
  - Protons
  - Neutrons
  - Electrons
- Atomic weight
- Isotopes
- Elements
- Periodic table: rows and columns
- Chemical bonds: ionic, covalent, hydrogen
- Valence and group
- Molecules
- Molecular weight

9 Photosynthesis

9.1 Chemistry of life

Acids and bases

- Acids: take out H^+ (proton), like
  $HCl \rightarrow H^+ + Cl^-$
- Bases: take out OH^- (hydroxyl)
  $NaOH \rightarrow Na^+ + OH^-$

Molar mass and molar concentration

- Molar mass is a gram equivalent of molecular mass
- For example, molecular mass of salt (NaCl) is $23 + 35$[1] $= 58$ Da. We take "Da" out and replace it with "g" (grams). Therefore, 1 mole of salt is 58 g.
- Every mole contains $6.02214078 \times 10^{23}$ molecules (Avogadro's number)
- Concentration is the density of dissolved substance
- In water solution, 1 M (1 molar) concentration of salt means that in 1 liter of distilled water 58 g of salt was diluted
- If we take half of this water, colcentration will still be 1 M whereas amount of diluted salt will decrease twice

Concentration of protons, and pH and acidity

- If concentration of protons is 0.1 M (1×10^{-1}, 0.1 g of protons in 1 l of water), this is an extremely acidic solution
- In distilled water, concentration of protons is equal to 1×10^{-7} (0.0000001) M
- This is because water molecules can (rarely) dissociate: $H_20 \rightarrow H^+ + OH^-$
- pH of distilled water is equal to $-\log(10^{-7}) = -(-7) = 7$
- pH of the extremely acidic solution (first example) is 1

9.2 Molecules of life

Organic chemistry: chemistry of carbon

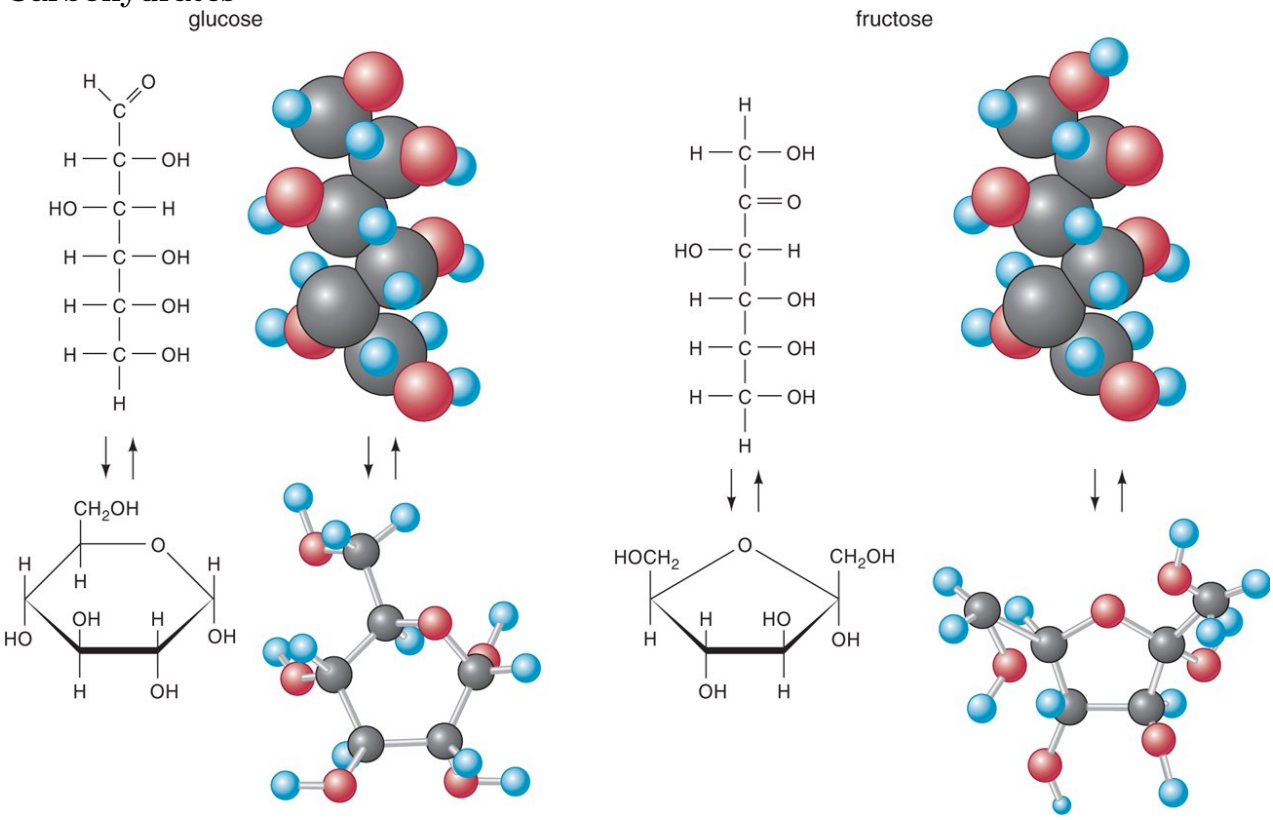
- Carbon skeleton
- And H, O, N, P, S

[1] If we accept that atomic mass of chlorine in 35.

Four types of biomolecules

- Lipids: hydrophobic
- Carbohydrates (sugars): multiple $-$OH groups
- Amino acids: N + C + O and hydrogen
- Nucleotides: cycle with nitrogen (heterocycle), sugar and phosphoric acid

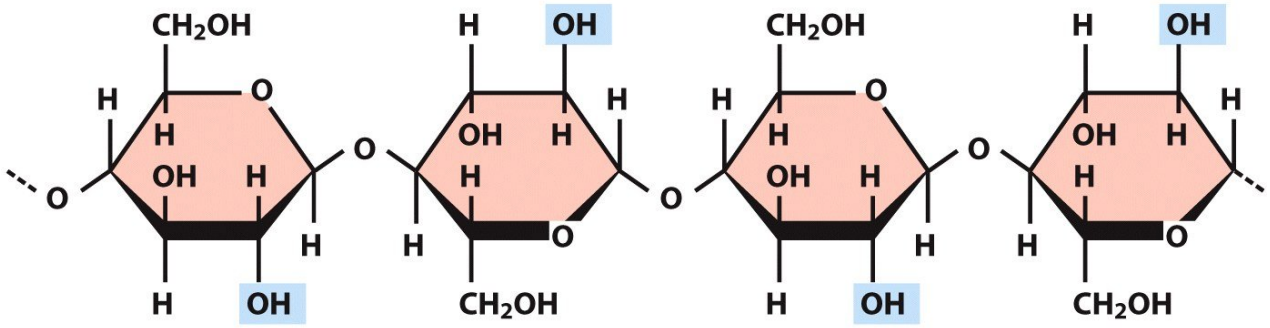
Carbohydrates

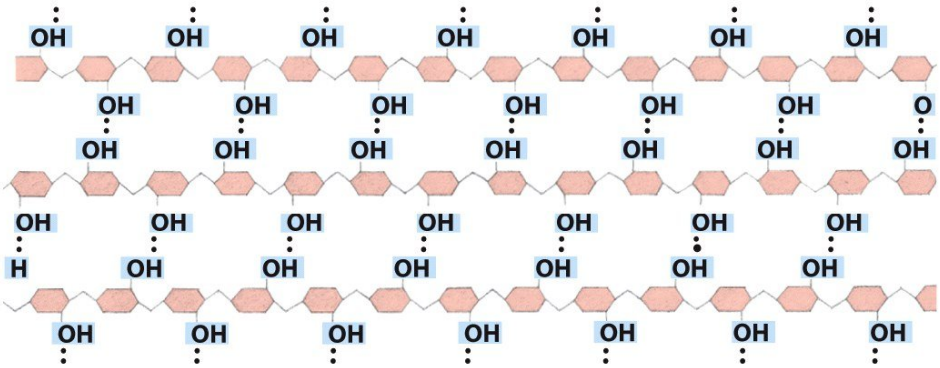


Organic polymers

- Polymeric carbohydrates: polysaccharides (like cellulose and starch)
- Polymeric amino acids: proteins
- Polymeric nucleotides: nucleic acids (DNA and RNA)

Cellulose





Final question (2 points)

Name six biogenic elements.

Summary

- Main biogenic elements: C, H, O, N, P
- Most important bonds: covalent and hydrogen
- Most important monomers: lipids, carbohydrates, amino acids, nucleotides
- Most important polymers: polysaccarides, proteins, nucleic acids

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

[2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 2*.

Outline

10 Questions and answers

Previous final question: the answer

Name six biogenic elements.

- Carbon (C)
- Hydrogen (H) and oxygen (O)
- Nitrogen (N), phosphorous (P), sulfur (S)

There are other essential elements (Na, K, Ca, Cl) but they are not biogenic since they do not participate in making molecules with carbon skeleton (organic molecules).

11 Photosynthesis

11.1 History of photosynthesis studies

van Helmont

- Johannes van Helmont (17th century) rejected the idea that plans take most of their biomass from soil
- Willow (*Salix* sp.) tree of 2.27 kg grew to 67.7 kg in five years, but weight of soil decreased only by 57 g
- van Helmont concluded that plants take most of their weight from water

Pristley

- Famous Joseph Pristley in 1772, made series of experiments with mouse, candle and sprig of mint (*Mentha* sp.)
- Mouse behave similar to candle, they both "spent" air
- Plant revives the air for both candle and mouse

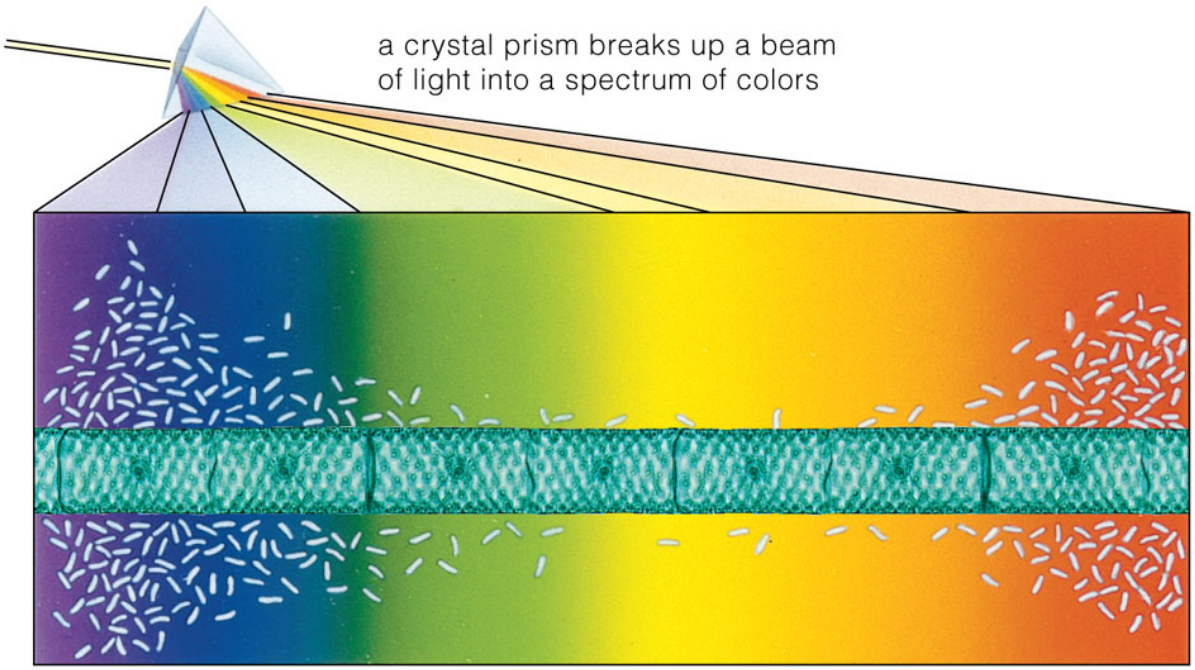
Further history

- Jan Ingenhousz (1779–1796) and Jean Senebier (1780) found that:
  - Only in day time the air is reviving
  - CO_2 is assembled
- Antoin-Laurent Lavoiser (1783) found that the "revived air" is a separate gas, **oxygen**

Engelmann

- Thomas Engelmann in 1884 found that *Spirogyra* alga produce oxygen mostly in blue and red parts of spectrum
- Therefore, the key photosynthetic pigment should accept blue and red rays and reflect green rays
- Chlorophyll fits best to this description

Experiment of Engelmann



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$CO_2 + H_2O \xrightarrow{\text{light}}$carbohydrates + $H_2O + O_2$

11.2 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

Final question (2 points)

Which conclusions can be drawn from Pristley's experiments? Please list more than one.

Summary

- From 17th century, in constantly become clear that plants make their biomass from light, water and carbon dioxide
- **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

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

[2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 2 and 10*.

Outline

12 Questions and answers

Previous final question: the answer

Which conclusions can be drawn from Pristley's experiments? Please list more than one.

- Mouse and candle both "spend good air"
- Plant revives the air

13 Photosynthesis

13.1 Light stage: electron transport, synthesis of ATP and NADPH

Participants of light stage

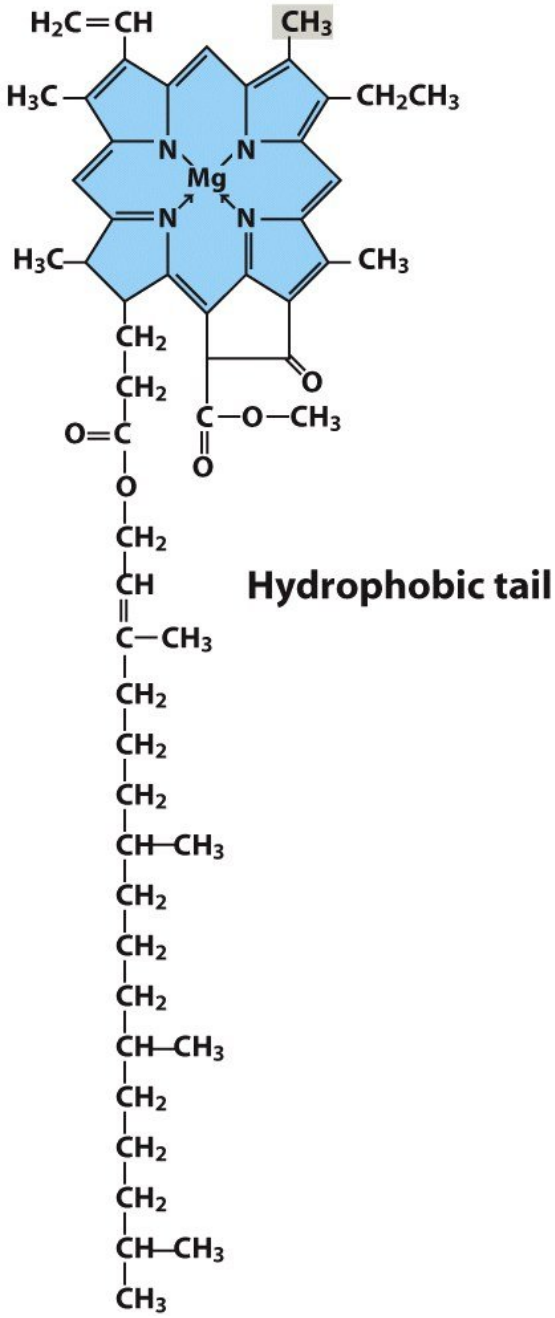
1. Chlorophyll (photosystems II and I)
2. Light
3. Water
4. ATP synthase (ATPase)
5. Protons (H^+)
6. Hydrogen carrier ($NADP^+$)

Where: around thylakoid membrane

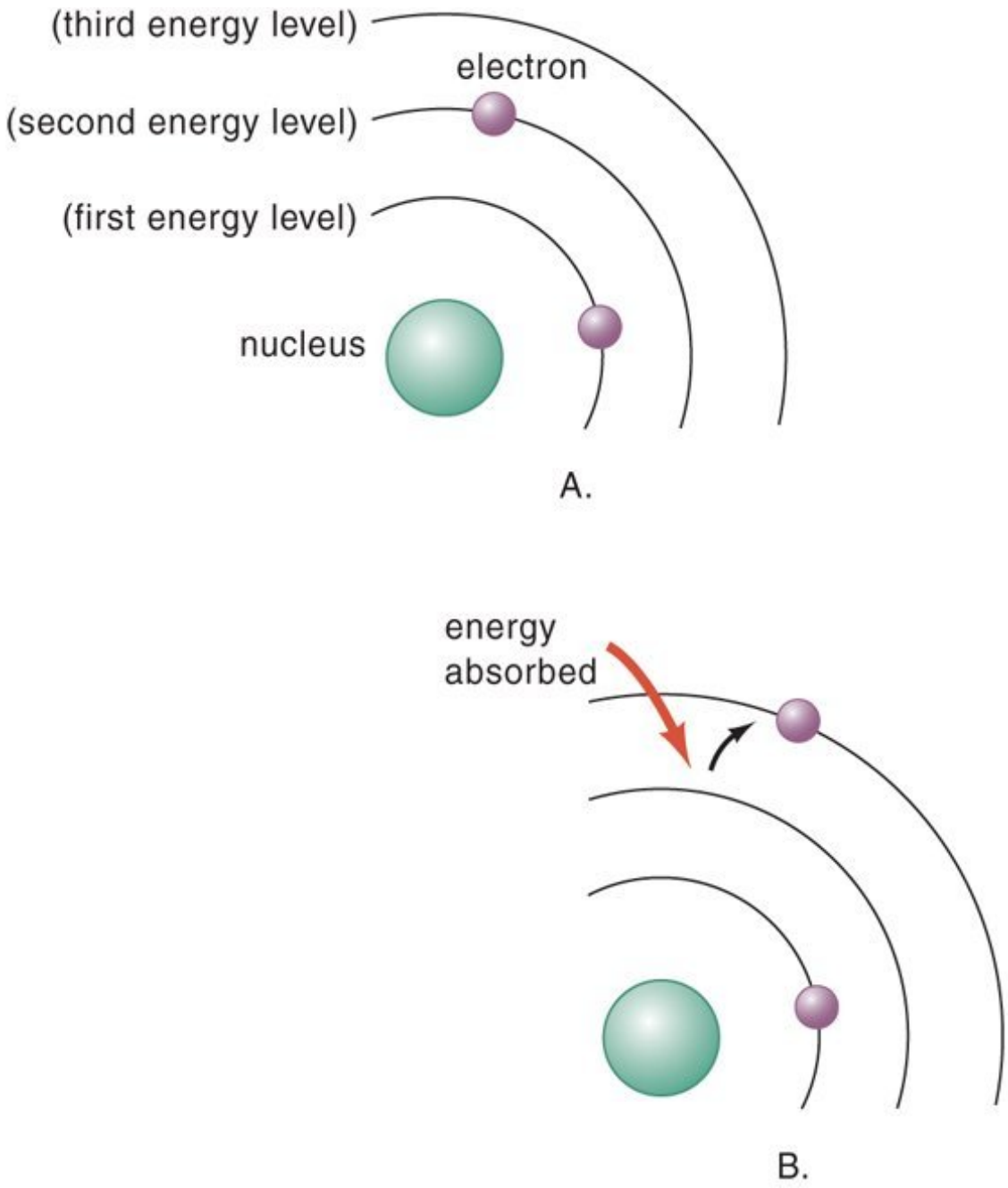
Logic of the light stage

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

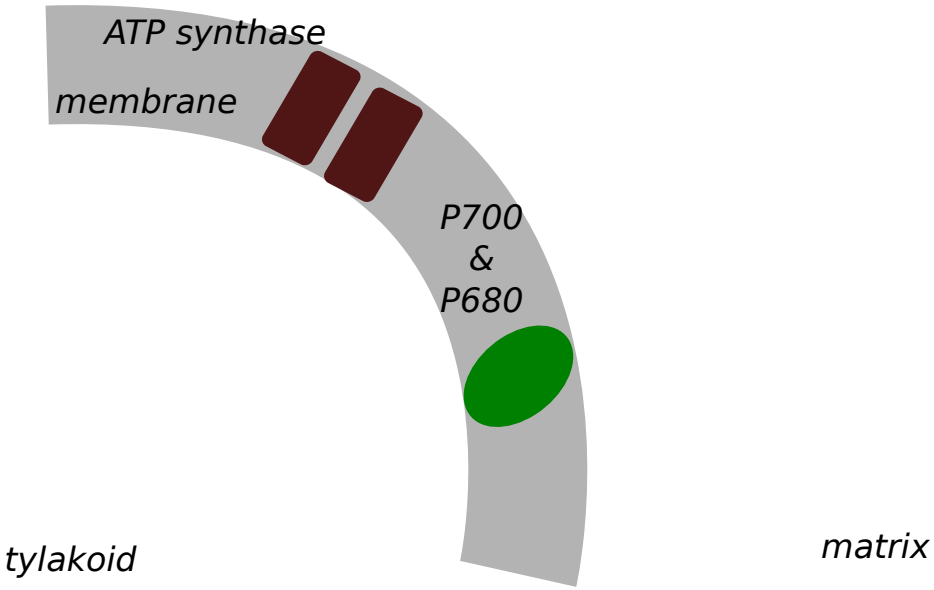
Why chlorophyll is good for the membrane

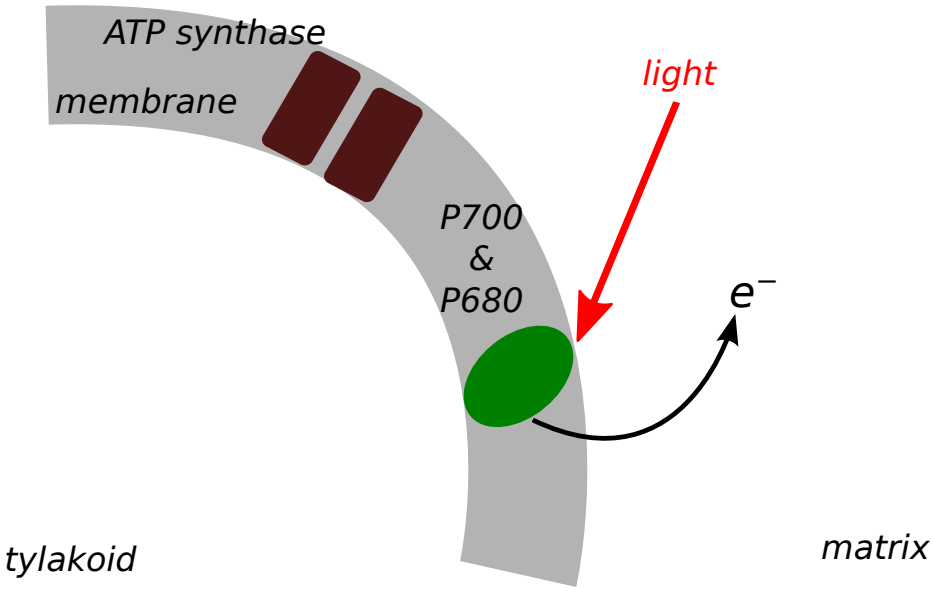


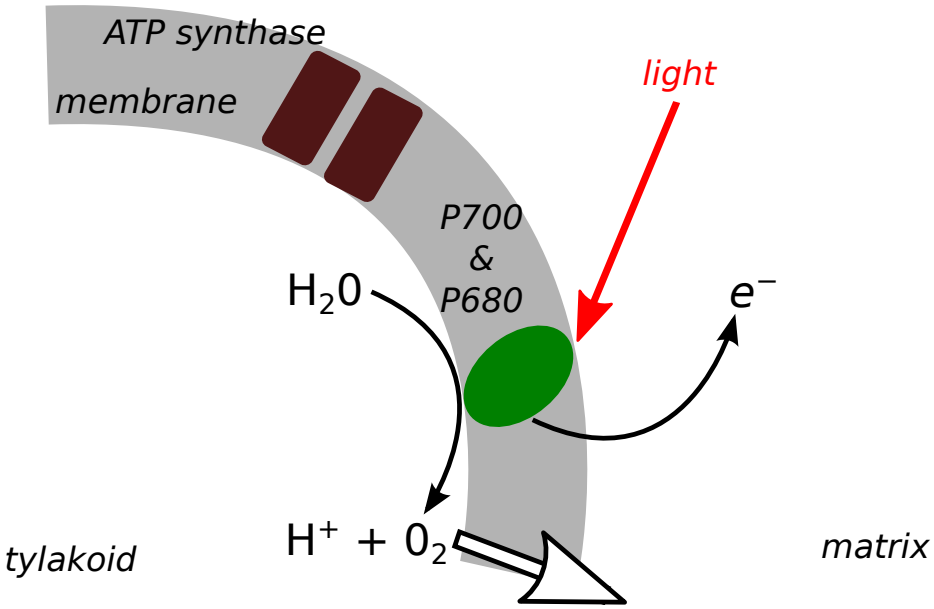
How chlorophyll works: excitation of the electron

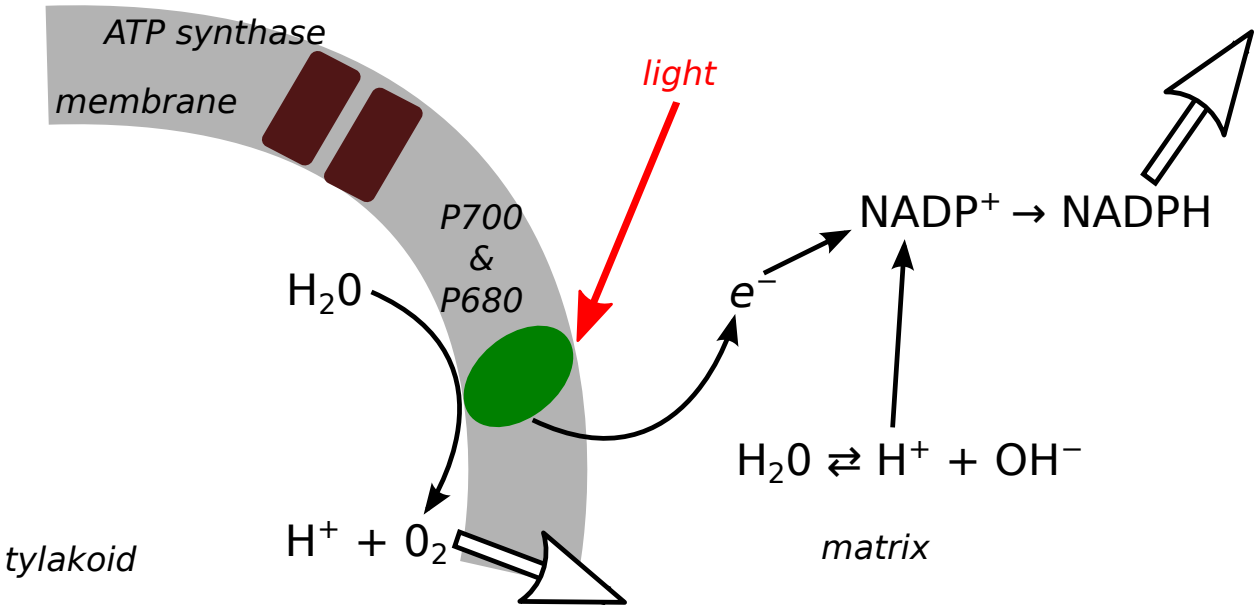


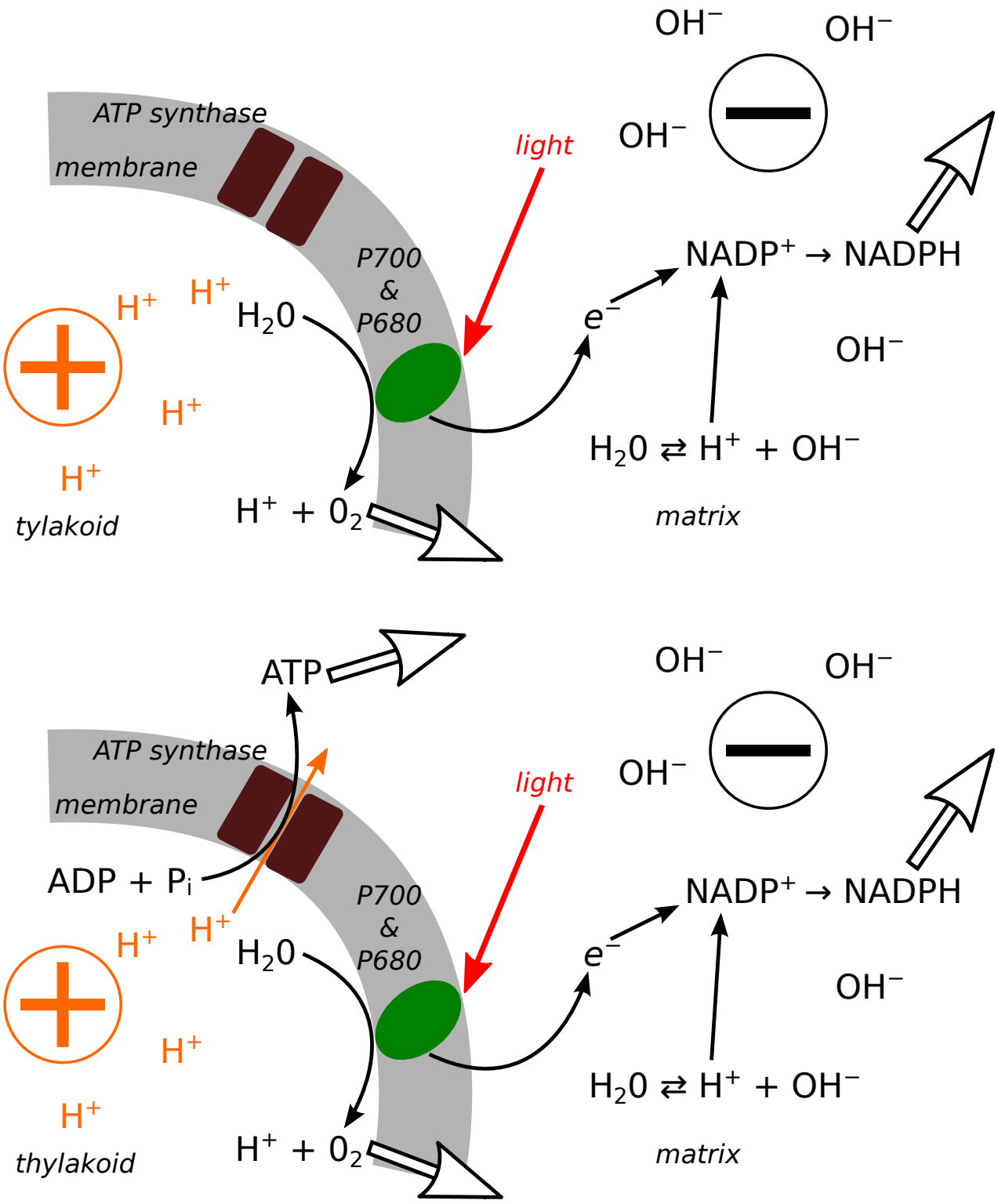
Scheme of light stage


ATP synthase
membrane
P700
&
P680
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
e⁻
tylakoid
matrix


ATP synthase
membrane
light
P700
&
P680
H_20
e^-
$H^+ + 0_2$
tylakoid
matrix


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



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

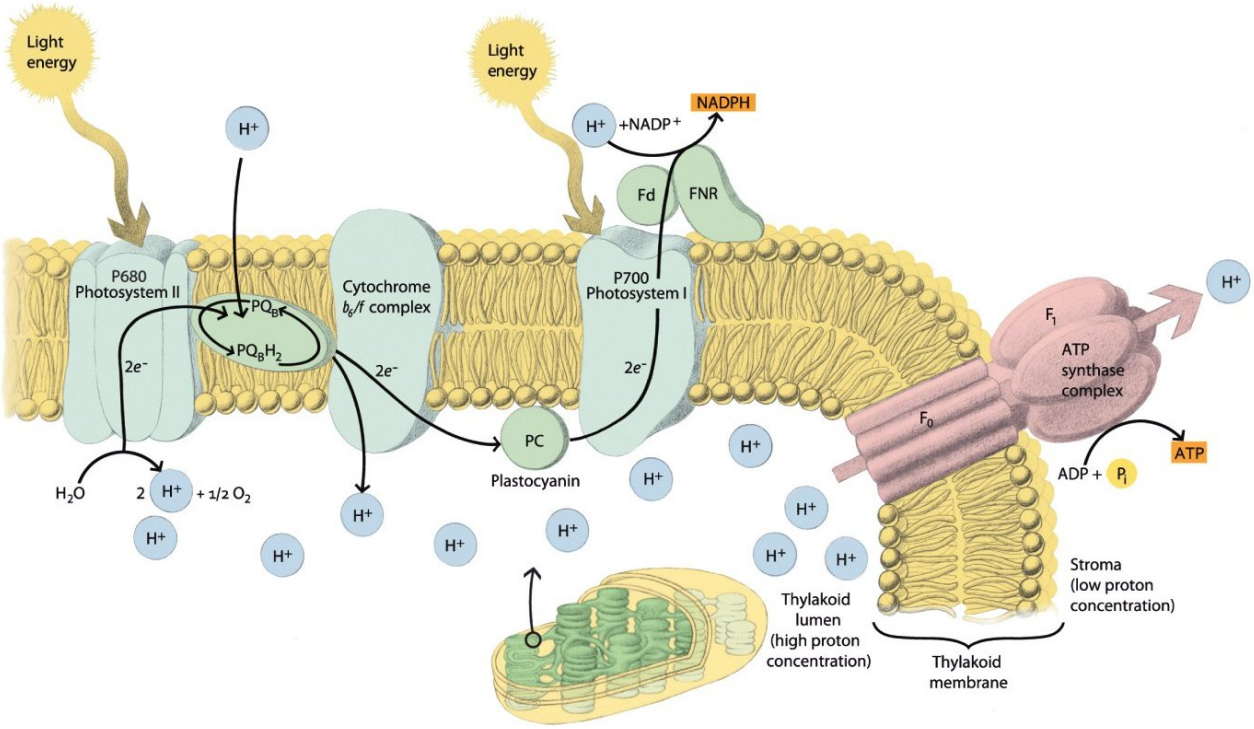
4. H^+ (inside) + OH^- (from water, located outside) $\Longrightarrow$ gradient $\Longrightarrow$proton pump $\Longrightarrow$ H_2O TOGETHER WITH ADP + P_i (inorganic phosphate) $\longrightarrow$ **ATP**

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

Scheme of light stage, now with both photosystems



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

13.2 Enzymatic stage: fixation of carbon dioxide

Participants of enzymatic stage

1. Carbon dioxide (CO_2)

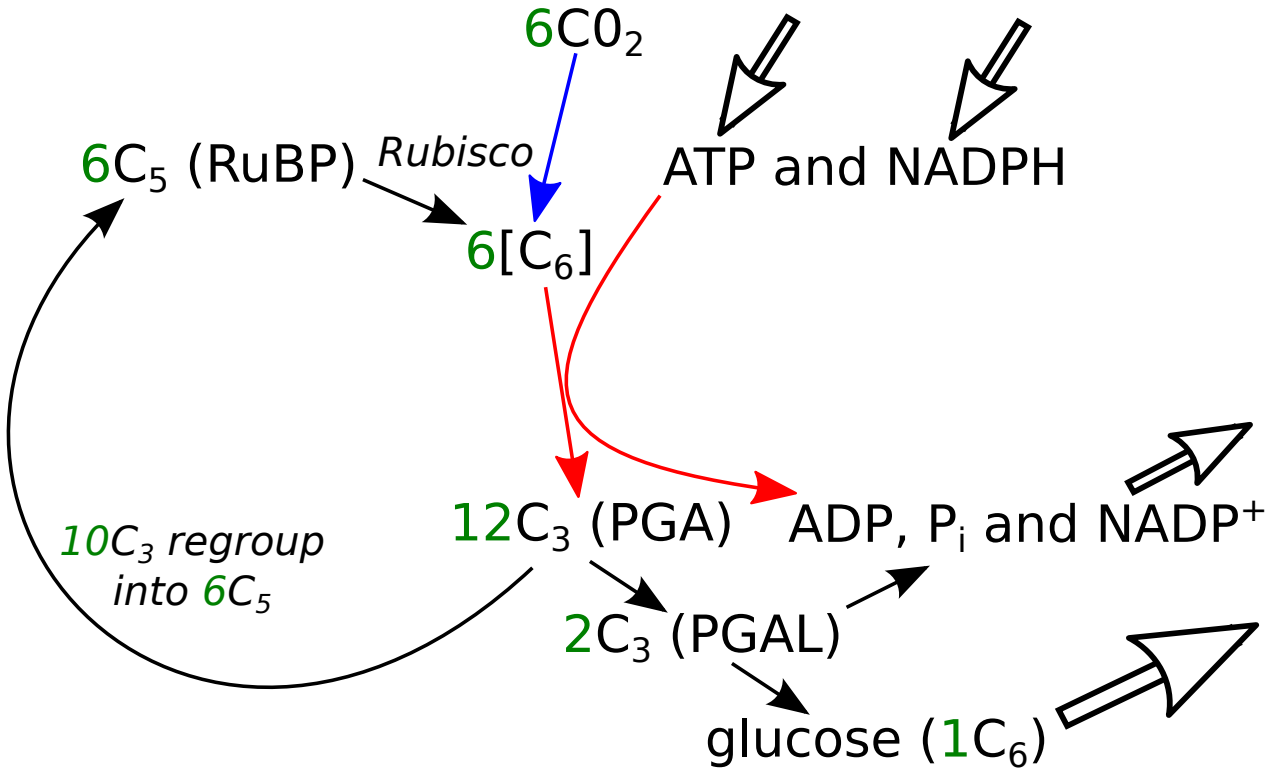
2. Hydrogen carrier with hydrogen (NADPH)
3. Source of energy (ATP)
4. Ribulose biphosphate (RuBP, five-C-hydrocarbonate, "C_5")
5. *Rubisco* and other enzymes

Place: in the matrix (stroma) of chloroplast

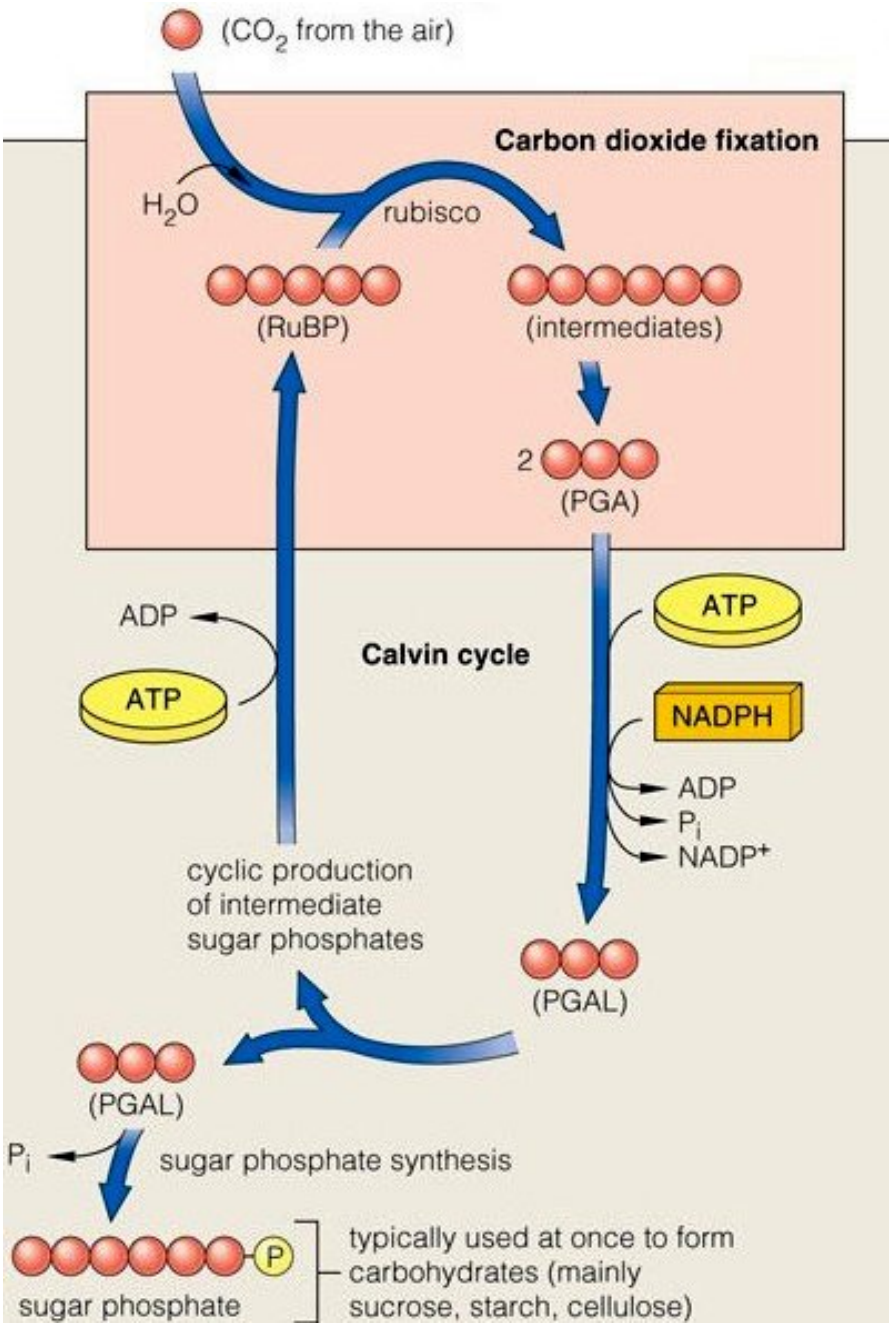
Main events of enzymatic stage

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



Enzymatic stage

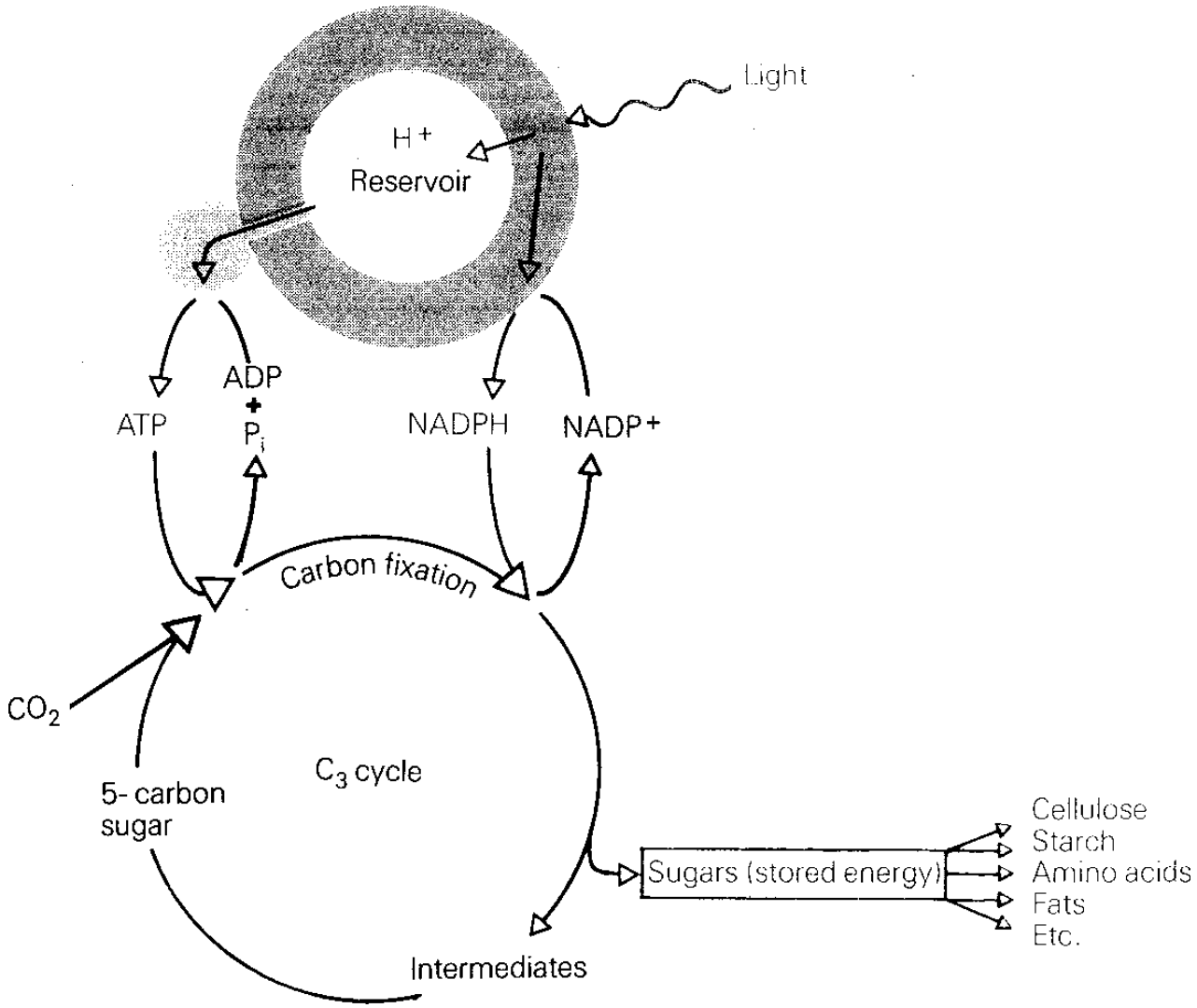


Results of enzymatic stage

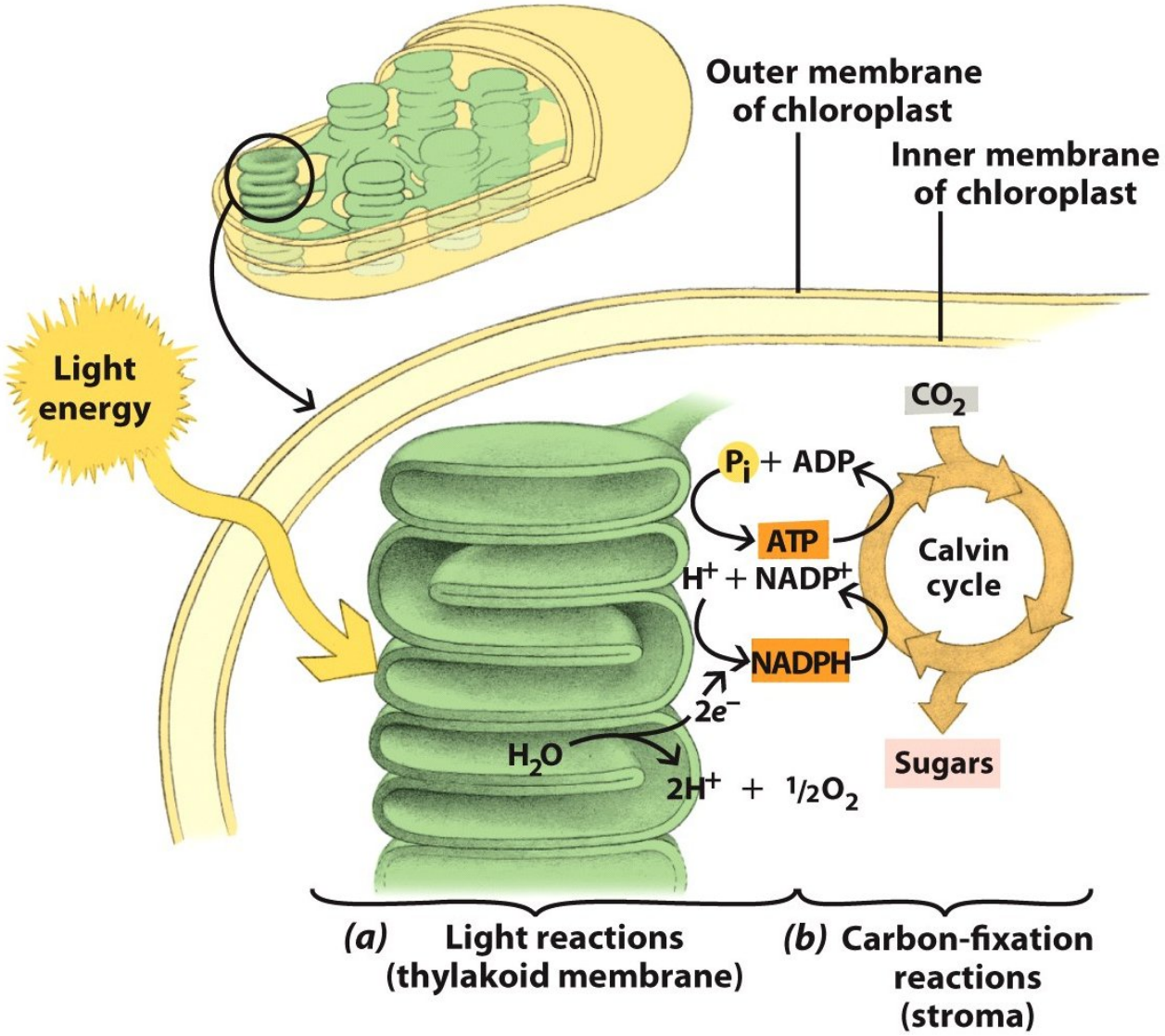
At the start	At the end
CO_2	$C_6H_{12}O_6$ (or other organic molecules)
NADPH	$NADP^+$ (and H to organic molecules)
ATP	ADP and P_i (inorganic phosphate)
C_5	C_5
Rubisco	Rubisco

The other names for enzymatic stage are "Calvin cycle" and "C_3 cycle"

Overview of photosynthesis



Photosynthesis in the cell



Photosynthesis movie

Final question (4 points)

Which photosystem is responsible for every product of the light stage?

At the end	Photosystem ...
H_2O (result of pump) and $\mathbf{O_2}$	...
Chlorophylls	...
ATP	...
NADPH	...

Summary

- **Photosynthesis** is a sequence 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

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

[2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 2 and 10*.