# Introduction to Botany: BIOL 154
# Study guide for Exam 1

Alexey Shipunov

Lectures 2–6

**Outline**

## Contents

# 1 Questions and answers

**Previous final question: the answer**

Why plants are important?

- Oxygen
- Food and food chains
- Medicine

  etc.

# 2 Course in general

## 2.1 Grading

**Exams**

- Normally, exam is based on the question sheet and takes 50 minutes.
- However, several slots will be available for the other type of exam based on electronic essay.

# 3 Plants: definition

## 3.1 Plants$_1$ and plants$_2$

**Plants$_1$ and plants$_2$**

- Plants$_1$ are all photosynthetic organisms
- Plants$_2$ are organisms with stem and leaves (better definition will follow)

**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!

# 4 Plants in general

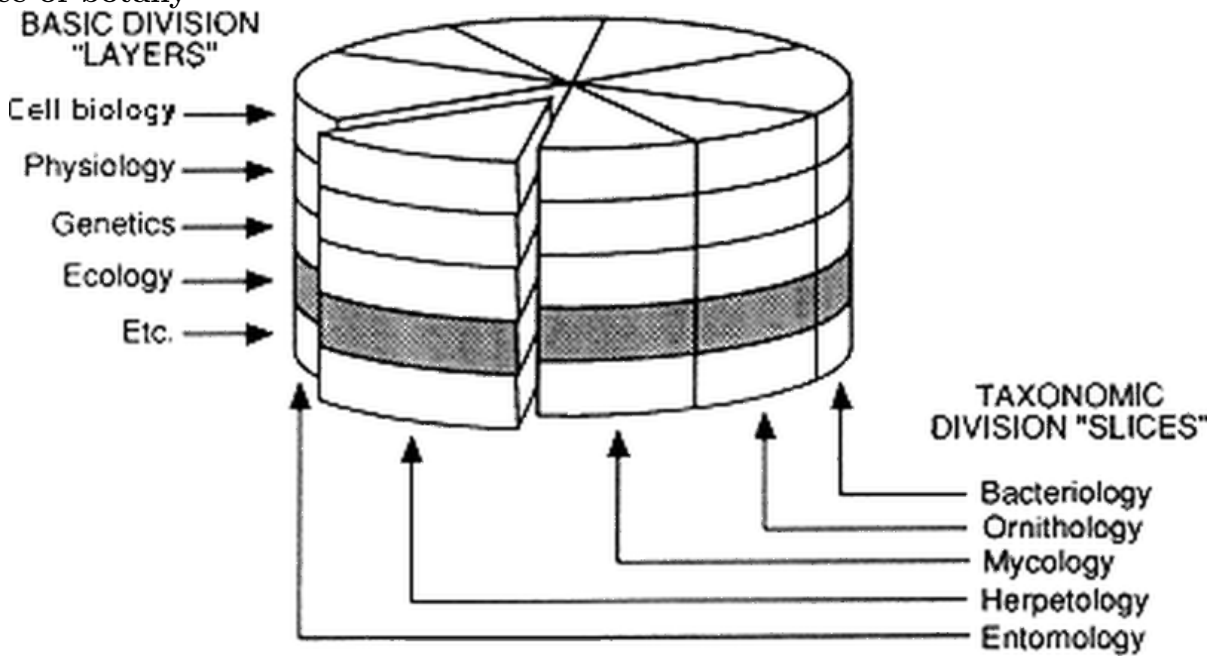
## 4.1 Levels of organization

**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"

## 4.2 Taxonomy

**Ranks**

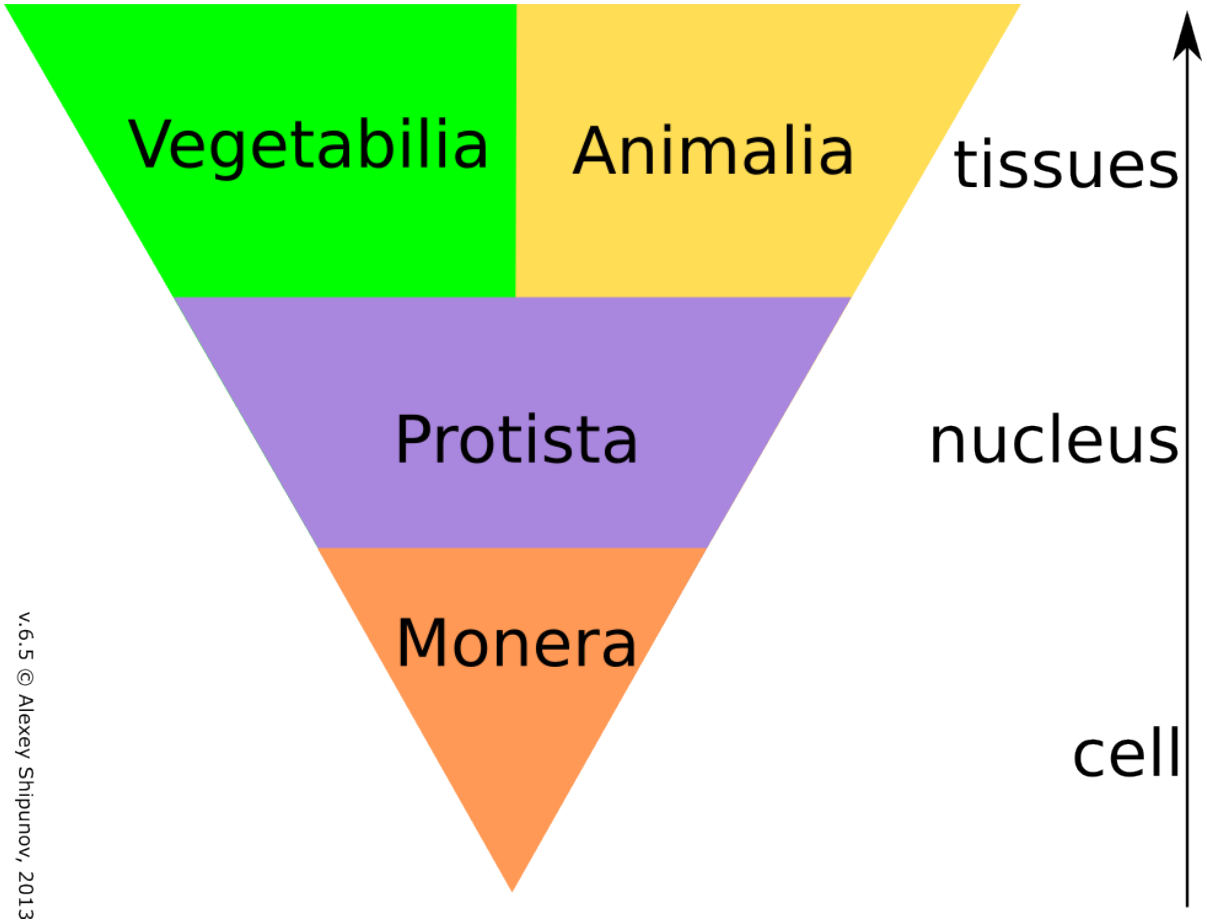
Most scientists accept seven main ranks:

- 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 viruses?** They are not a group but "shatters of evolutionary explosions"

**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

# 5 Ways of life

## 5.1 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** | $\text{Plants}_1$: some Monera, some Protista, most of Vegetabilia | Some Monera | Some Monera |
| **Heterotrophs** | Some Monera | Some Monera | Majority of Animalia and many Protista |

**Final question (1 point)**

What is the difference between $\text{plants}_1$ and $\text{plants}_2$?

**Summary**

- "Plants" have **two definitions**
- **Botany** as a "slice science" 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**

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# 6 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$_2$

# 7 Ways of life

## 7.1 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**

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

- Plants$_1$ are **photoauthotrophs**
- Plants$_2$ are photoauthotrophs too but there are exceptions: **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

# 8 Photosynthesis

## 8.1 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

**Final question (2 points)**

What is molecular weight of sulfuric acid, $H_2SO_4$?

**Summary**

- Some plants2 are not plants1: parasitic plants
- Carnivorous plants are not carnivores

**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**

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# 9 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? Dalton, 1/12 of carbon-12 isotope.

# 10 Photosynthesis

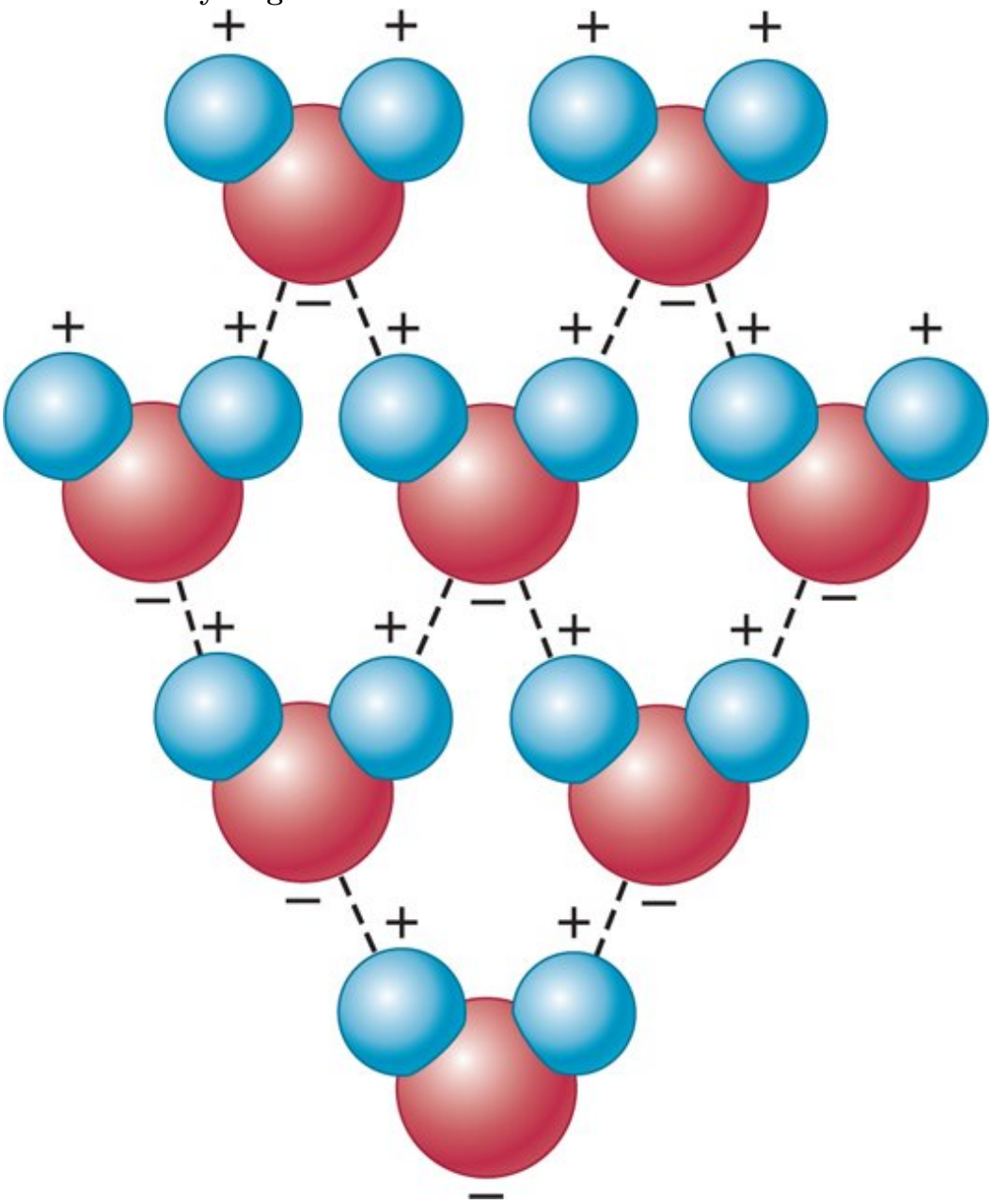
## 10.1 Chemistry of life

**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**



**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] $= 58$. Therefore, 1 mole of salt is 58 g
- Every mole contains $6.02214078 \times 10^{23}$ molecules (Avogadro's number)
- In water solution, 1 M (1 molar) concentration of salt means in 1 liter of distilled water 58 g of salt was diluted

**Concentration**

- Amount of dissolved substance
- If concentration of protons is 0.1 M ($1 \times 10^{-1}$, 0.1 g of protons in 1 l of water), this is an extremely acidic solution
- In distilled water, concentration of protons equal to $1 \times 10^{-7}$ (0.0000001) M
- This is because water molecules can also (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

## 10.2 Molecules of life

**Organic chemistry: chemistry of carbon**

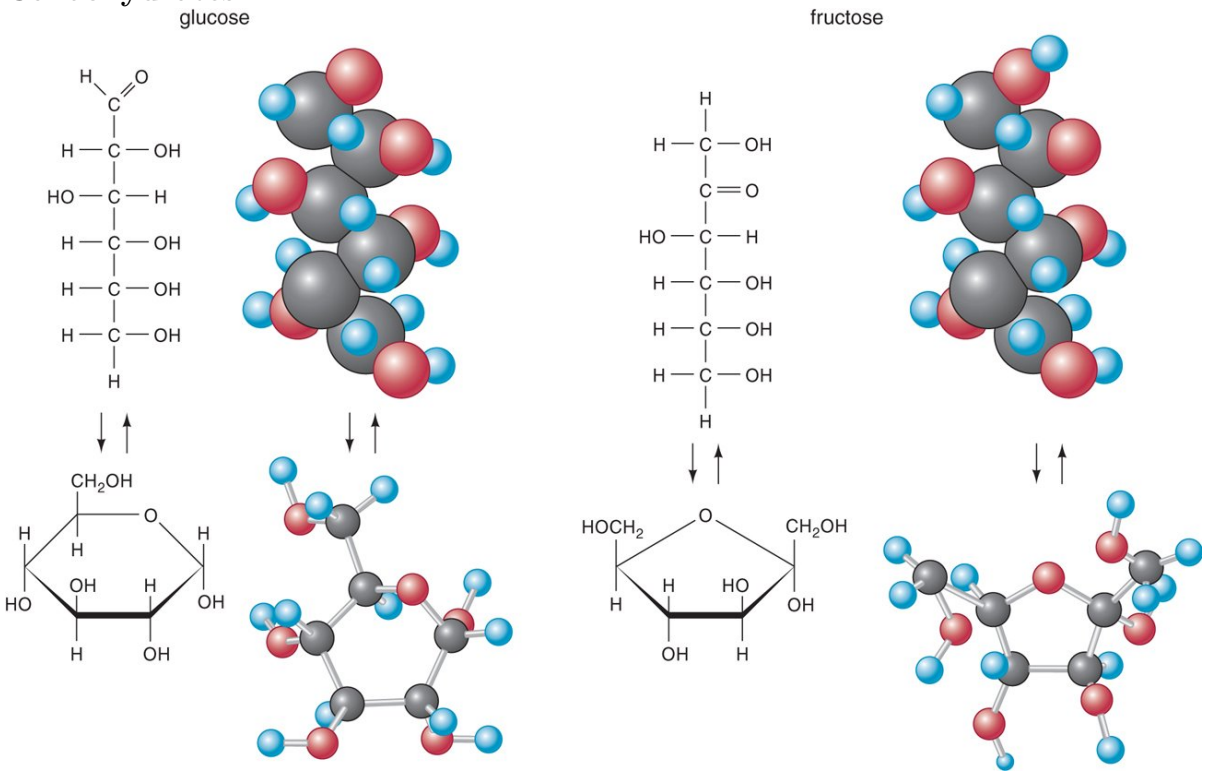
- Carbon skeleton
- And H, O, N, P, S

**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

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

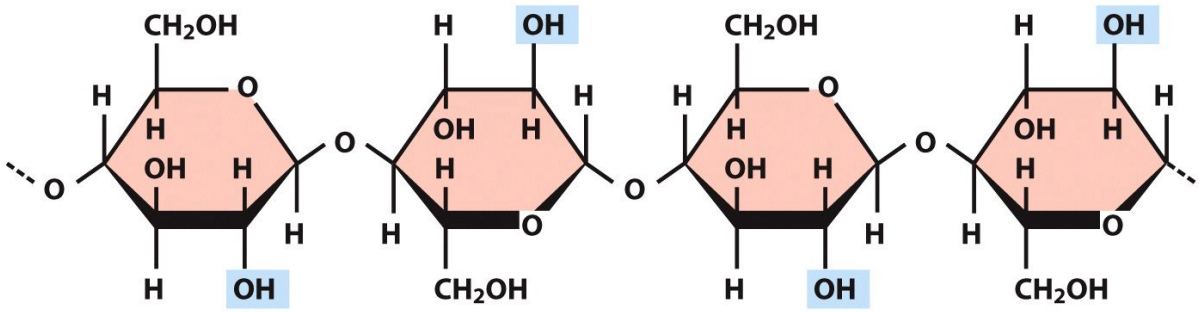
## Carbohydrates




## Organic polymers

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

## Cellulose




## 10.3 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

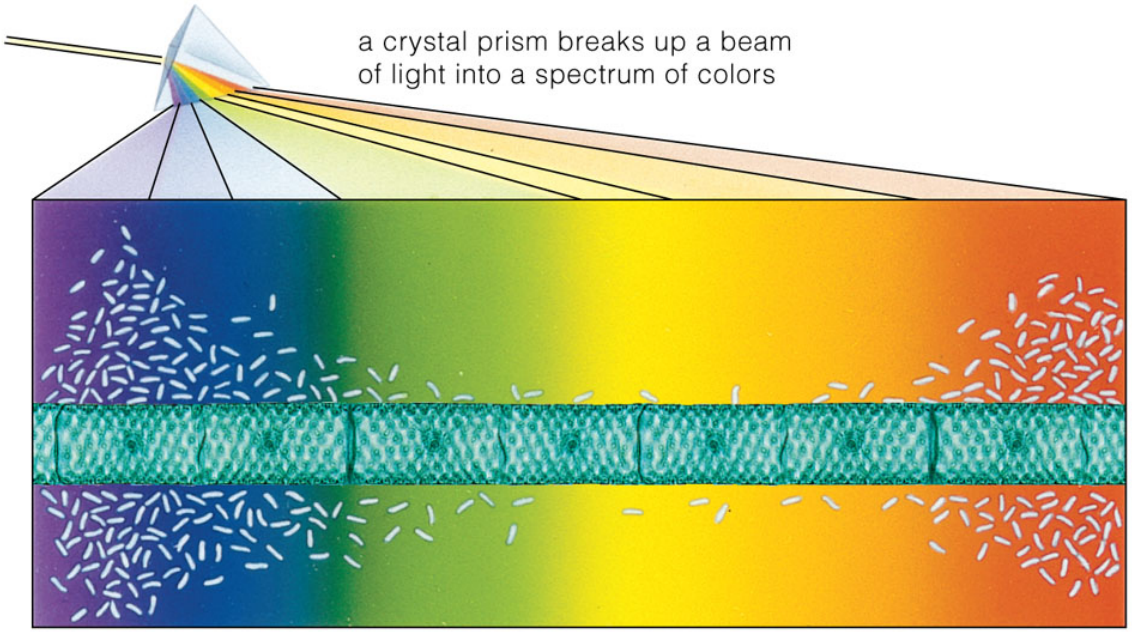
– $CO_2$ is assembled

- 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**






**Final question (2 points)**

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

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

**For Further Reading**

# References


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

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**Outline**

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# 11 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

# 12 Photosynthesis

**Blackman**

- In 1905, Frederick Blackman discovered that if light intensity is low, increase of temperature has a little effect on the rate if 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 + $H_2O$ + $O_2$

## 12.1 Light stage: electron transport, synthesis of ATP and NADPH

**Participants of light stage**

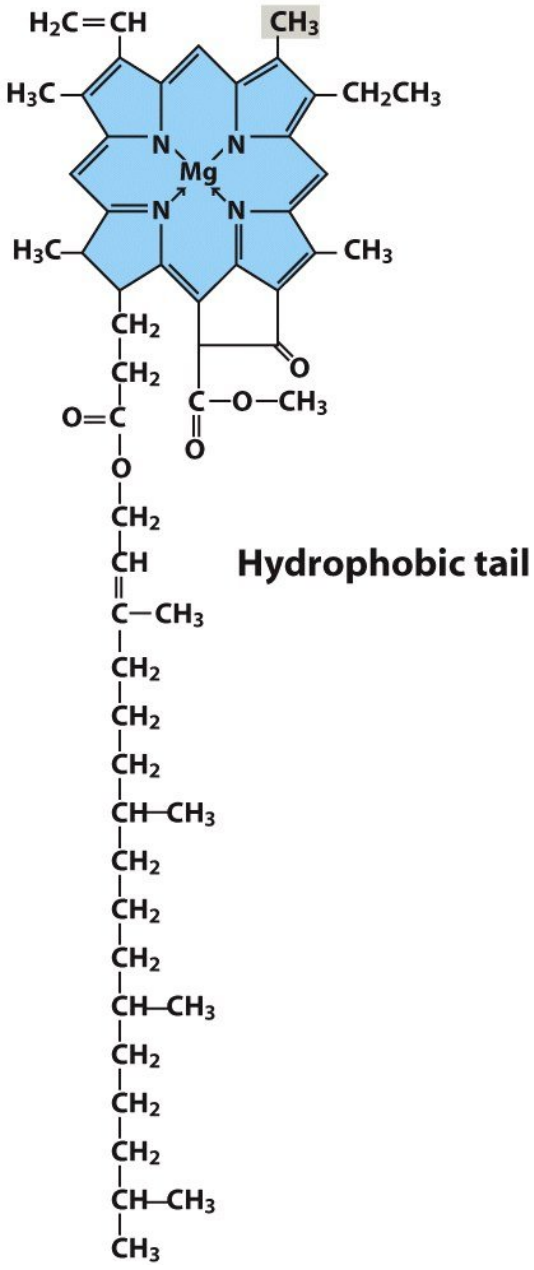
1. Chlorophyll (photosystems II and I)
2. Light
3. Water
4. ATP synthase (ATPase)
5. Protons ($H^+$)
6. Hydrogen carrier ($NADP^+$)

**Where**: around thylakoid membrane

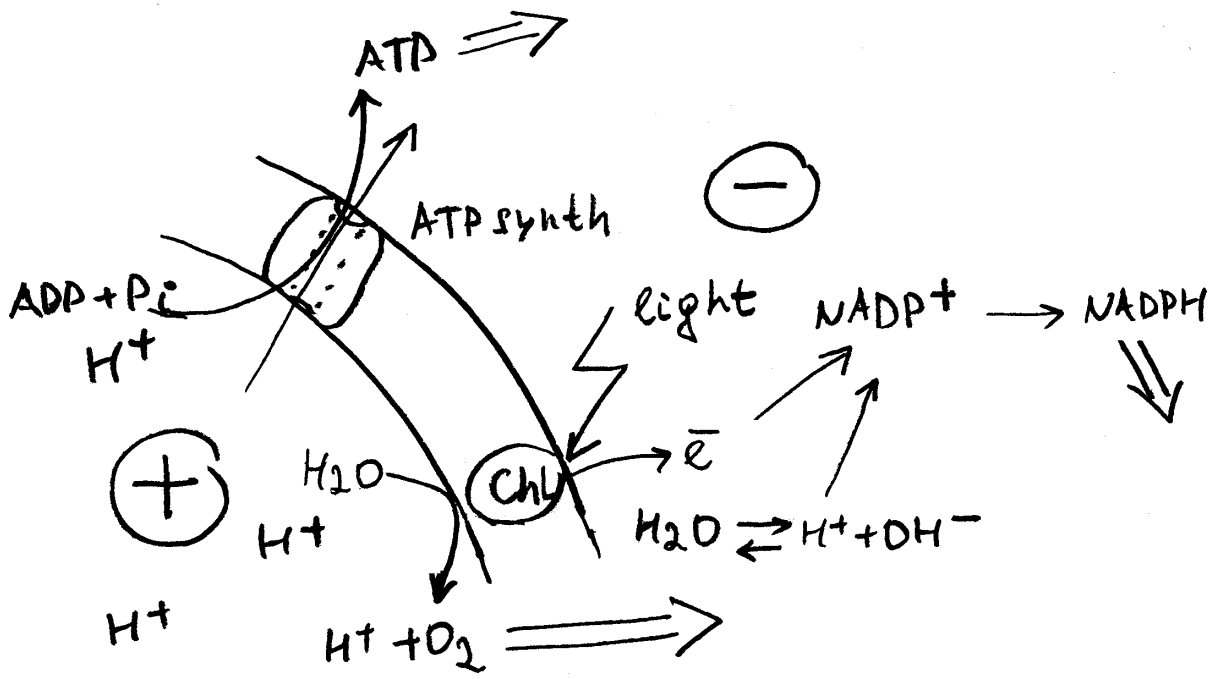
**Logic of the light stage**

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 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**



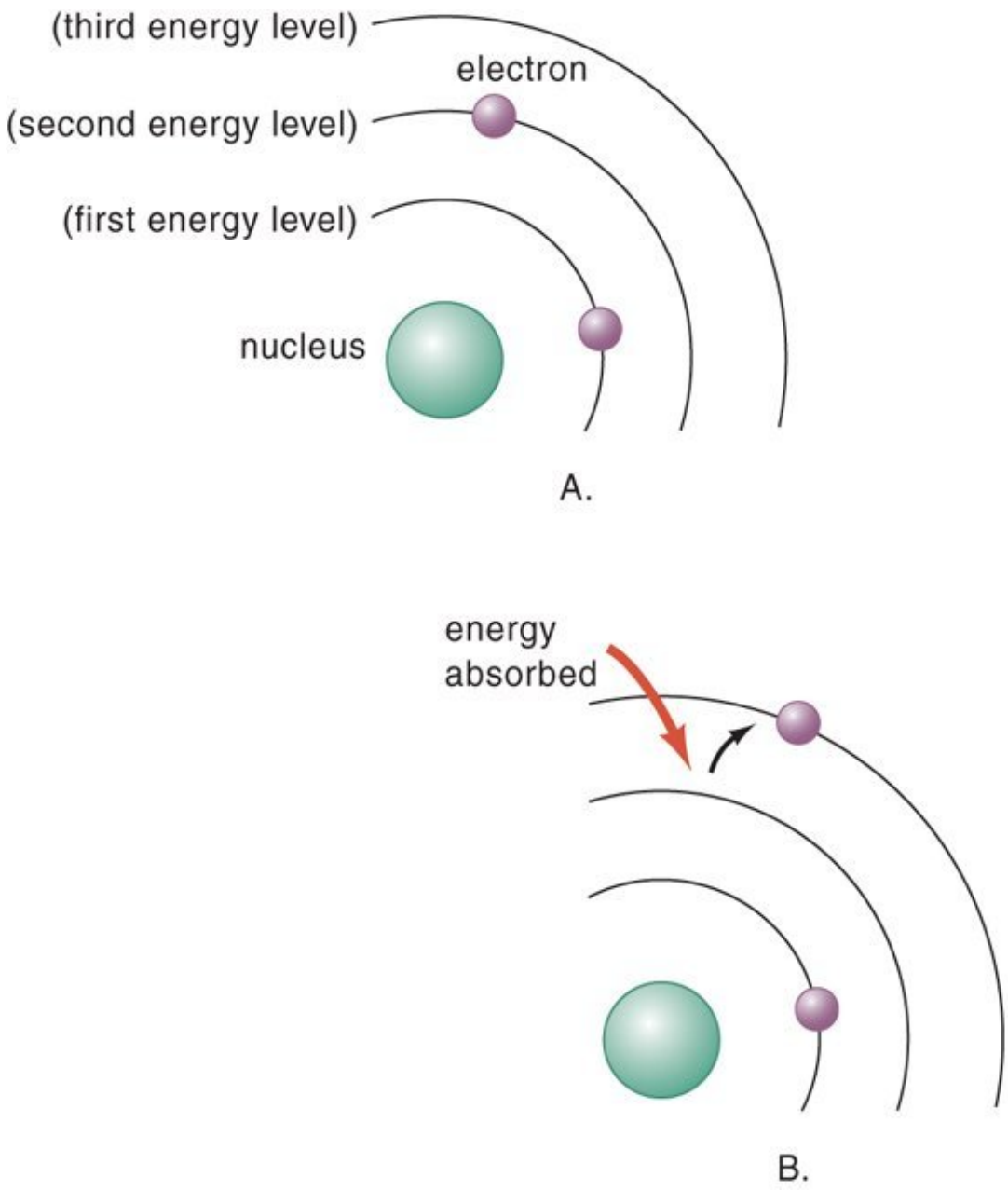

*Scheme of light stage*




**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**

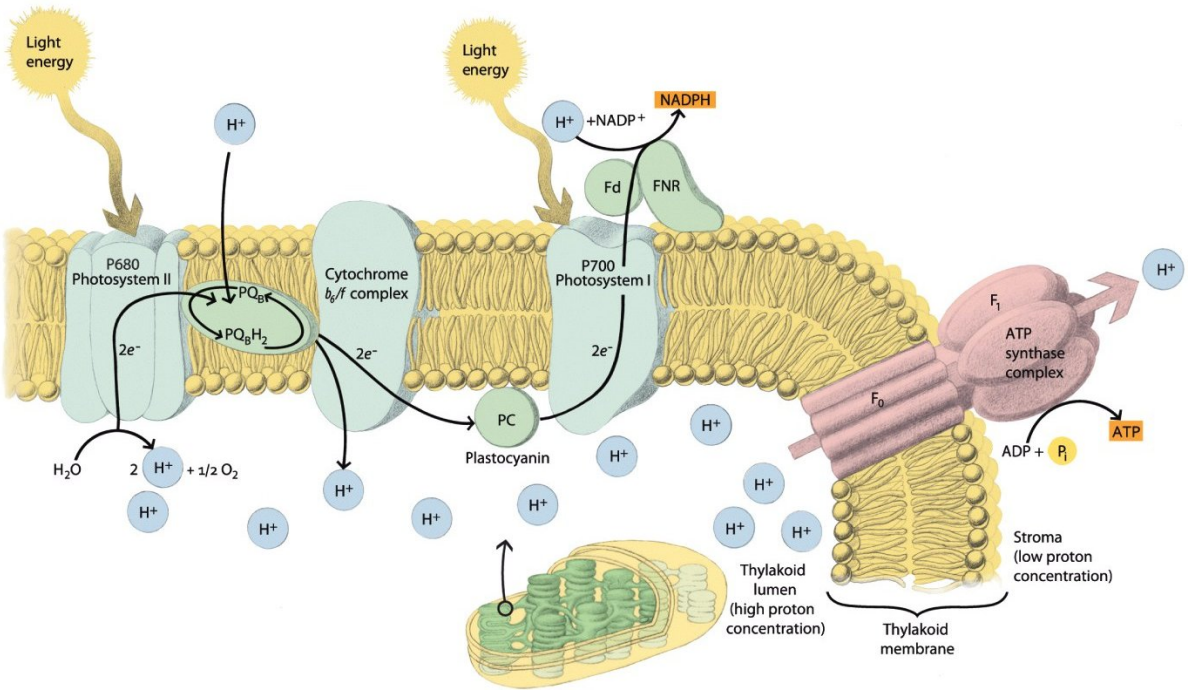
**How chlorophyll works: excitation of the electron**




**Photosystems I and II**

- Photosystem II ($P_{680}$, contains chlorophylls and carotene) decomposes water and forwards electron to Photosystem I ($P_{700}$, contains only chlorophylls)
- Photosystem II ($P_{680}$) splits water, makes proton gradient and then ATP
- Photosystem I ($P_{700}$) makes NADPH

**Two photosystems and main events of light stage**




**Results of the light stage**

| At the start | At the end |
|---|---|
| $H_2O$ | $H_2O$ (result of pump) and **$O_2$** |
| Chlorophylls | Chlorophylls |
| ADP and $P_i$ (inorganic phosphate) | ATP |
| $NADP^+$ | NADPH |

**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 **$O_2$** | ... |
| Chlorophylls | ... |
| ATP | ... |
| NADPH | ... |

**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

**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**

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# 13 Questions and answers

**Previous final question: the answer**

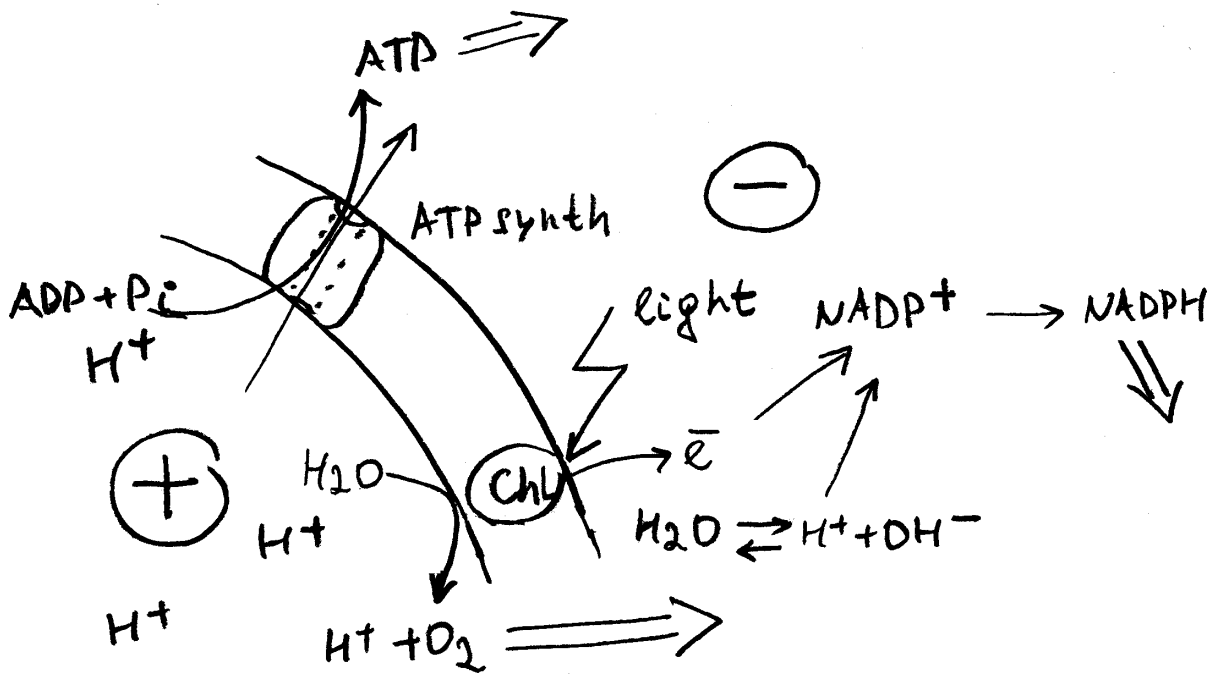
Which photosystem is responsible for every product of the light stage?

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

Photosystems movie

**Results of the light stage**

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




## 13.1 Enzymatic stage: fixation of carbon dioxide

**Participants of enzymatic stage**

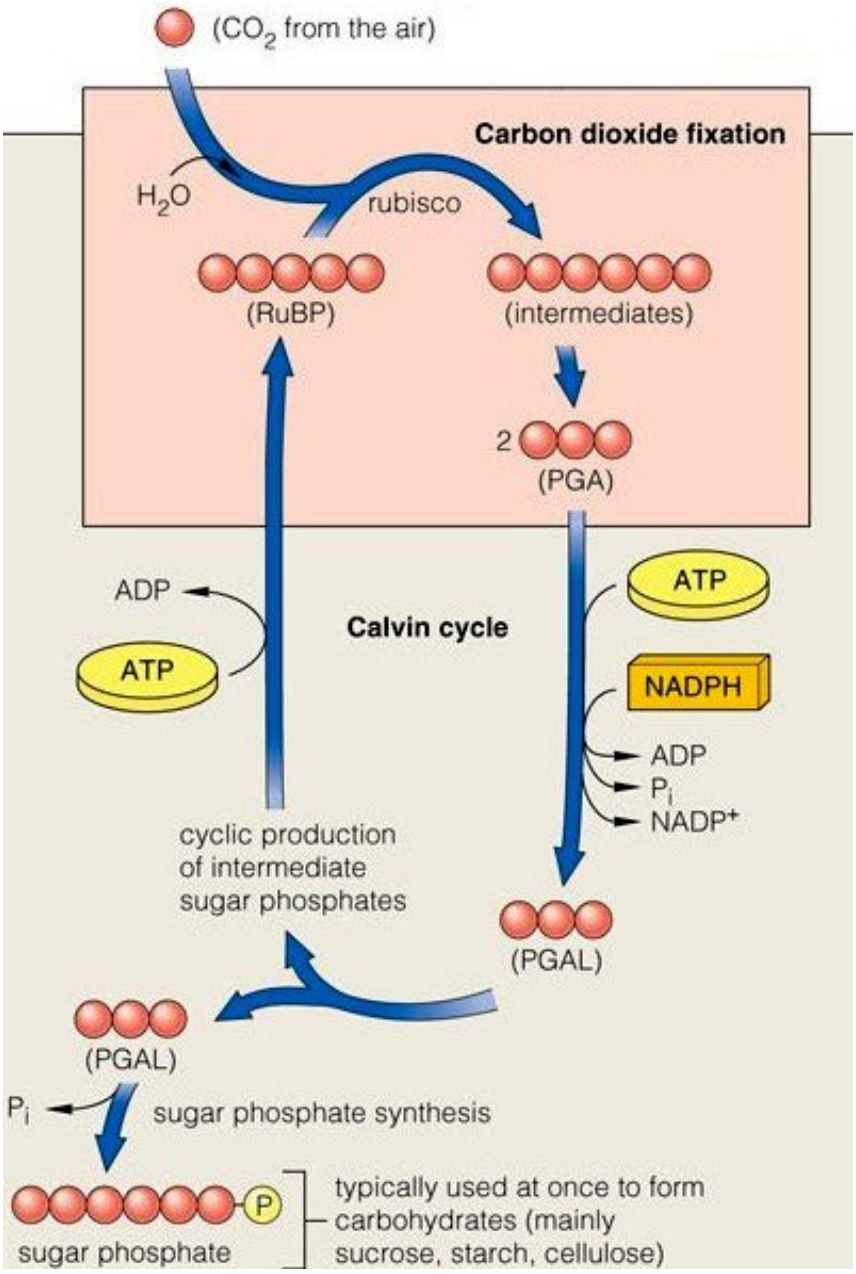
1. Carbon dioxide ($CO_2$)
2. Hydrogen carrier with hydrogen (NADPH)
3. Source of energy (ATP)
4. Ribulose biphosphate (RuBP, five-C-hydrocarbonate, "$C_5$")
5. *Rubisco* and other enzymes

**Place**: in the 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)
4. Processes above are **Calvin ($C_3$) *cycle***, because PGA and PGAL (both $C_3$) are its most important components

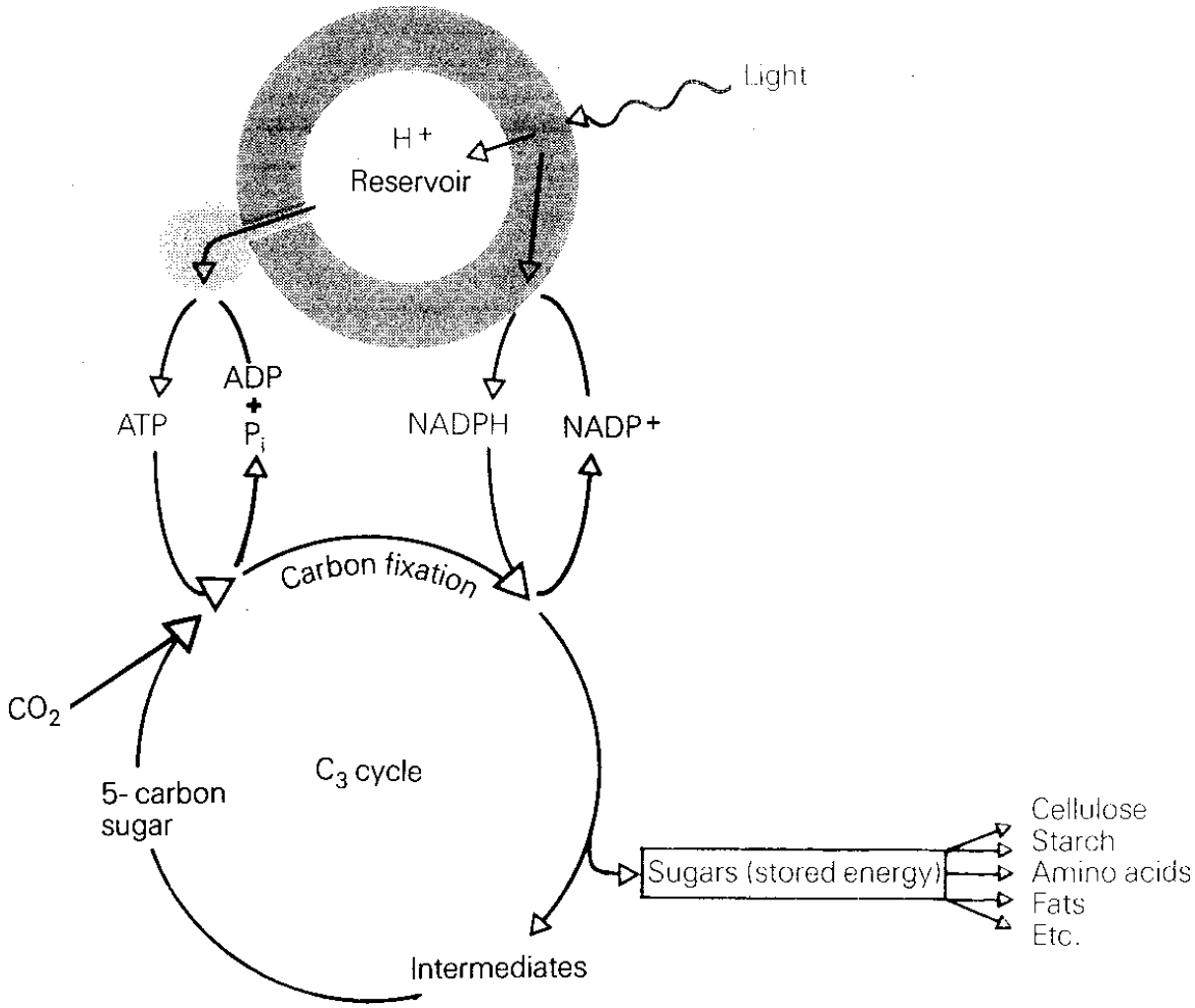
**Calvin ($C_3$) cycle**



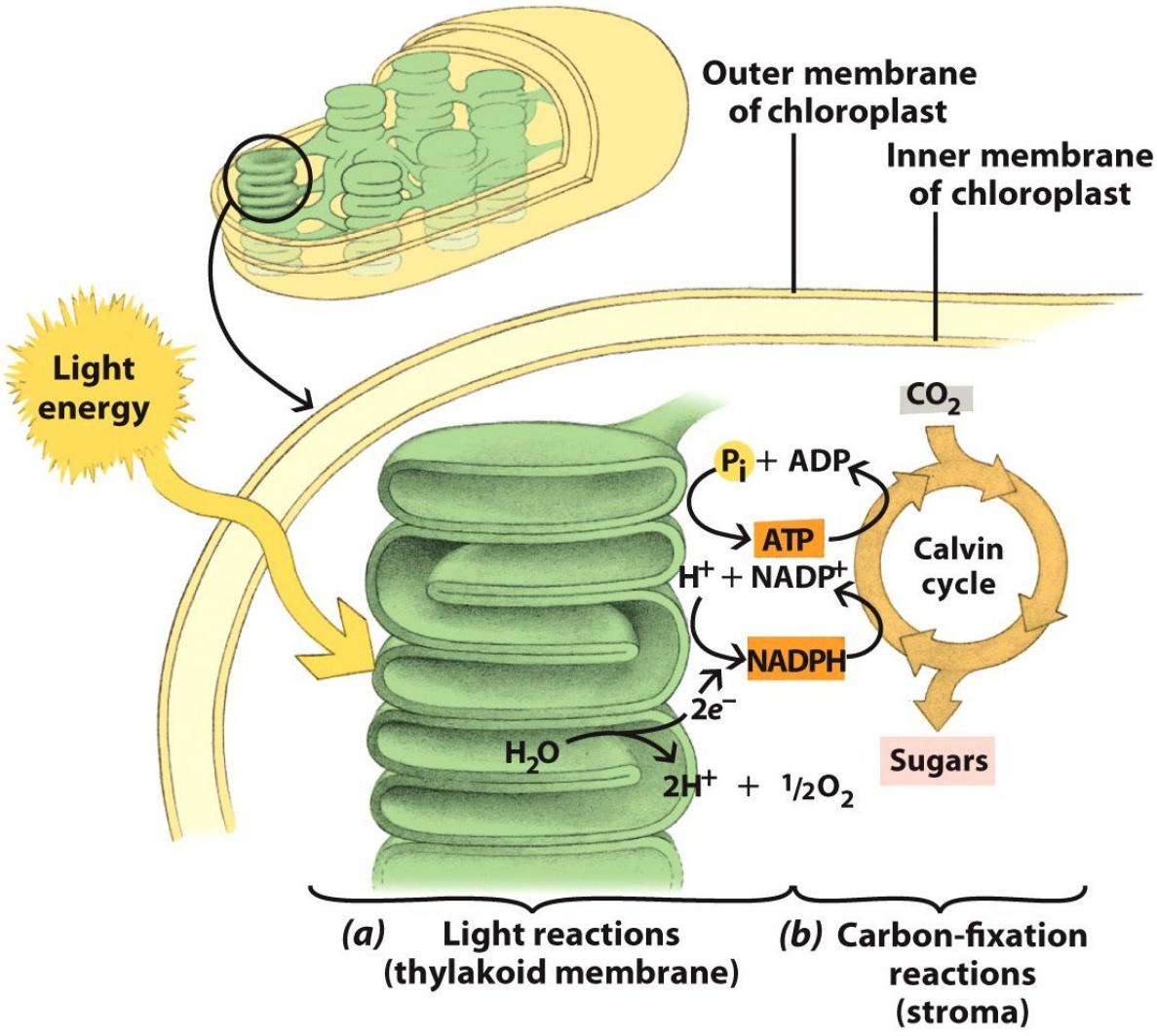

**Results of enzymatic stage**

| 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 |

**Overview of photosynthesis**




**Photosynthesis in the cell**




Photosynthesis movie

**Final question (2 points)**

What is wrong in this picture?

| Before photosynthesis | After photosynthesis |
|---|---|
| $H_2O$ | $O_2$ |
| $NADP^+$ | NADPH |
| $CO_2$ | $C_6H_{12}O_6$ (or other organic molecules) |

**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**

# References

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[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*.