# Contents





# Definition of photosynthesis

**"Process by which plants, algae and some bacteria use the energy of sunlight to drive the synthesis of organic molecules from carbon dioxide and water"**

**Photosynthesis converts the electromagnetic energy of sunlight into chemical bond energy in the cell**

**Plants obtain all the atoms they need from inorganic sources:**

- **carbon from atmospheric carbon dioxide**
- **hydrogen and oxygen from water**
- **nitrogen from ammonia and nitrates in the soil**
- **other elements needed in smaller amounts from inorganic salts in the soil**

**Plants use the energy they derive from sunlight to build these atoms into sugars, amino acids, nucleotides, and fatty acids**

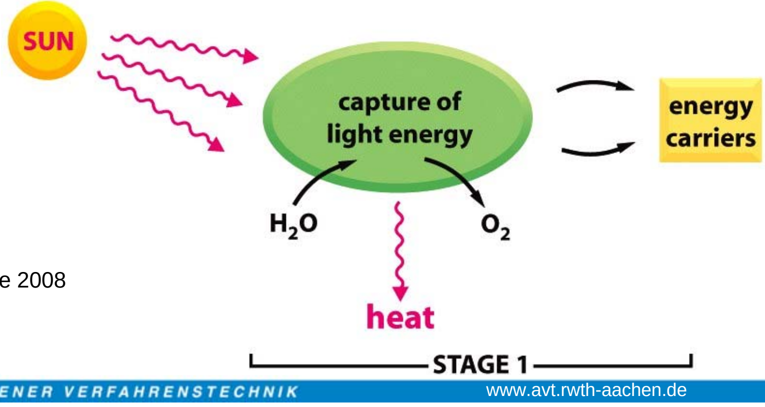
# Photosynthesis – an overview

The reactions of photosynthesis take place in two stages:

**First Stage**:

Energy from sunlight is captured and transiently stored as chemical bond energy in specialized small molecules that act as carriers of energy and reactive chemical groups: ATP and NADPH

molecular oxygen derived from the splitting of water by light is released as a waste product of this first stage.

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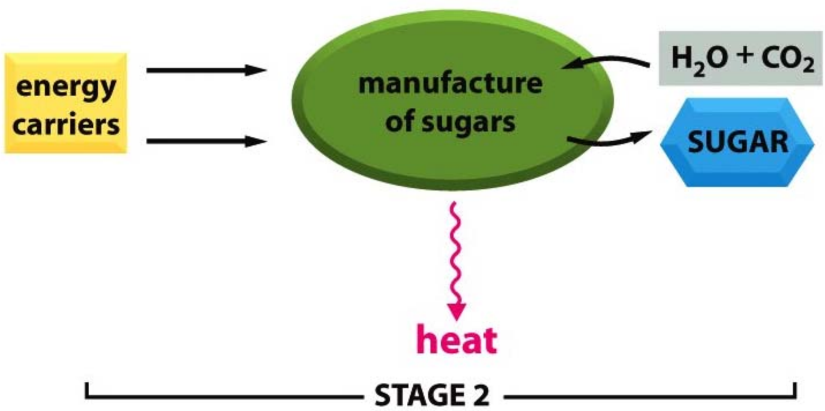
# Photosynthesis – an overview

**Second Stage**:

Energy carriers ATP and NADPH are used to help drive a carbon fixation process in which sugars are manufactured from $CO_2$ and $H_2O$

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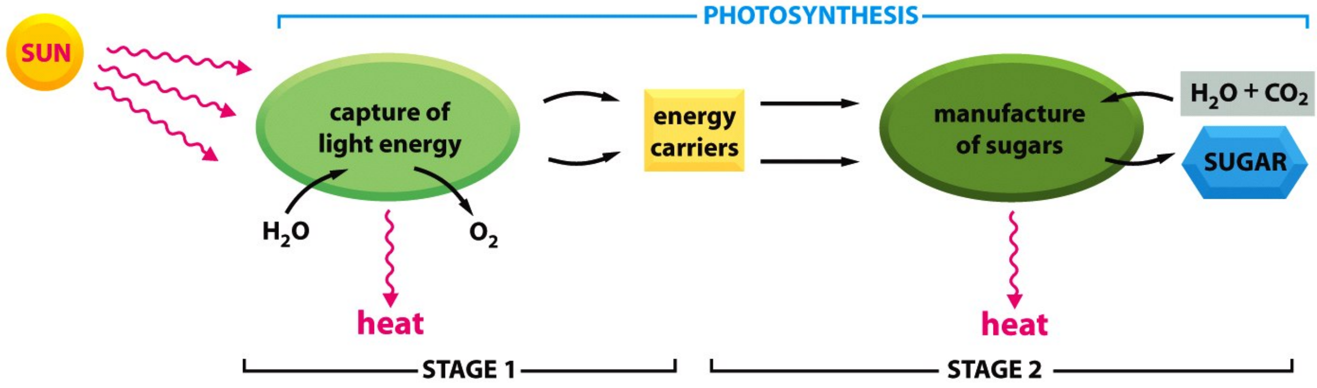
# Photosynthesis – an overview




**net result of the entire process of photosynthesis:**

**light energy + $CO_2$ + $H_2O$ → sugars + $O_2$ + heat energy**

from Garland Science 2008



# Photosynthesis – an overview

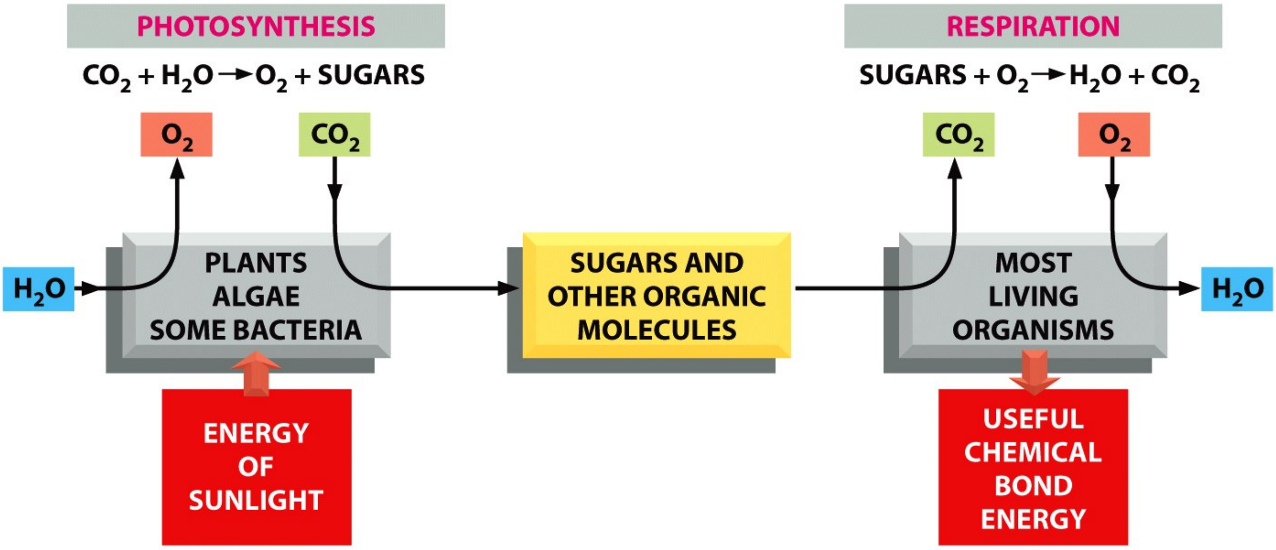
A cell is able to obtain energy from sugars or other organic molecules by allowing their carbon and hydrogen atoms to combine with oxygen to produce $CO_2$ and $H_2O$.

This process is called **respiration**.

Photosynthesis and respiration are complementary processes:

- Photosynthesis uses the energy of sunlight to produce sugars and other organic molecules.
- Respiration is a process that uses $O_2$ to form $CO_2$ from the same carbon atoms that had been taken up as $CO_2$ and converted into sugars by photosynthesis.

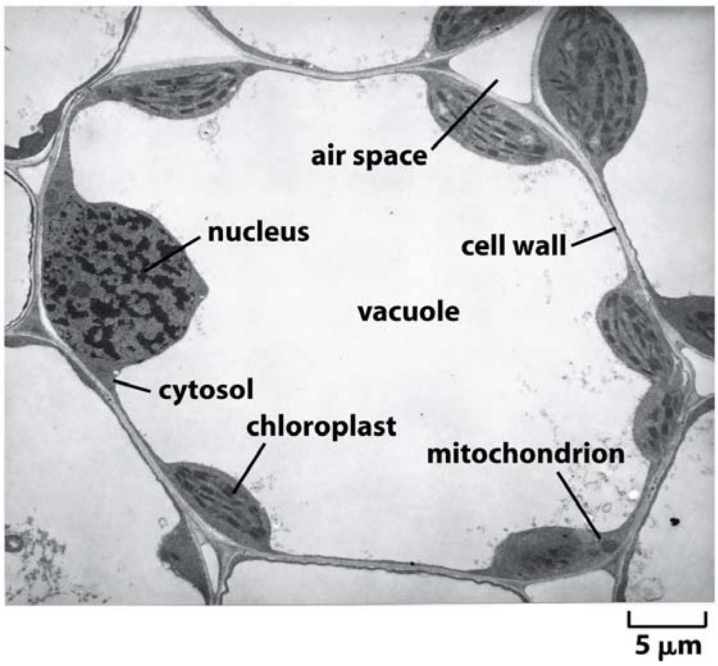
# Photosynthesis – an overview





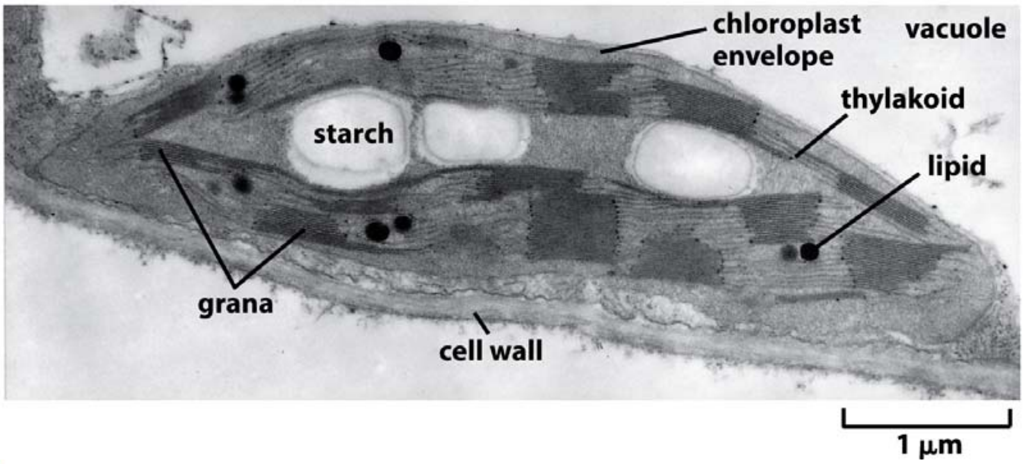

# Chloroplasts

- Photosynthesis occurs in specialized intracellular organelle – the **chloroplast**
- Chloroplasts perform photosynthesis during the daylight hours.
- Photosynthetic cells use the immediate products of photosynthesis, NADPH and ATP, to produce many organic molecules.



# Chloroplasts contain…

- a highly permeable outer membrane
- a much less permeable inner membrane, in which membrane transport proteins are embedded
- these membranes form the **chloroplast envelope**
- the inner membranes surrounds a large space called the **stroma**

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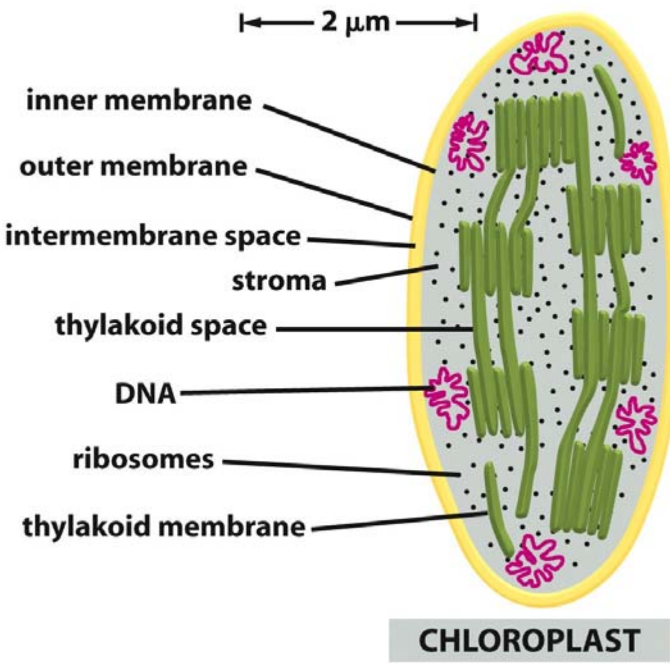
# Chloroplasts

- electron-transport chains, photosynthetic light-capturing systems, and ATP synthase are contained in the **thylakoid membrane**
- that is a third distinct membrane that forms a set of flattened disc like sacs, the **thylakoids**
- the lumen of thylakoids is connected and thereby defining a third internal compartment called **thylakoid space**

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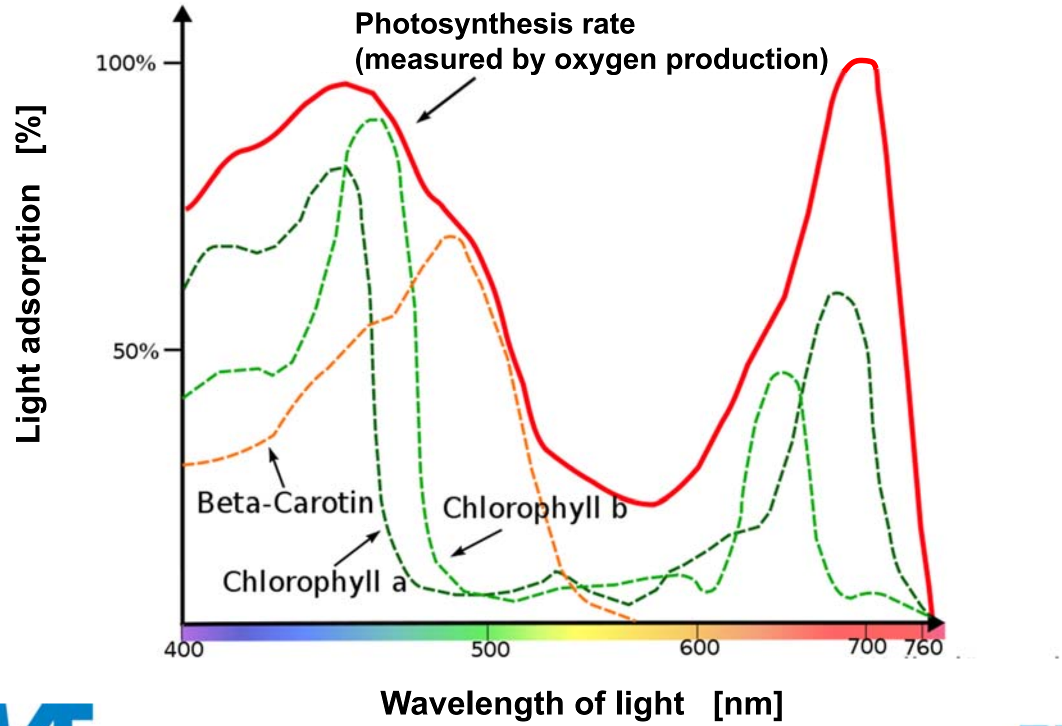
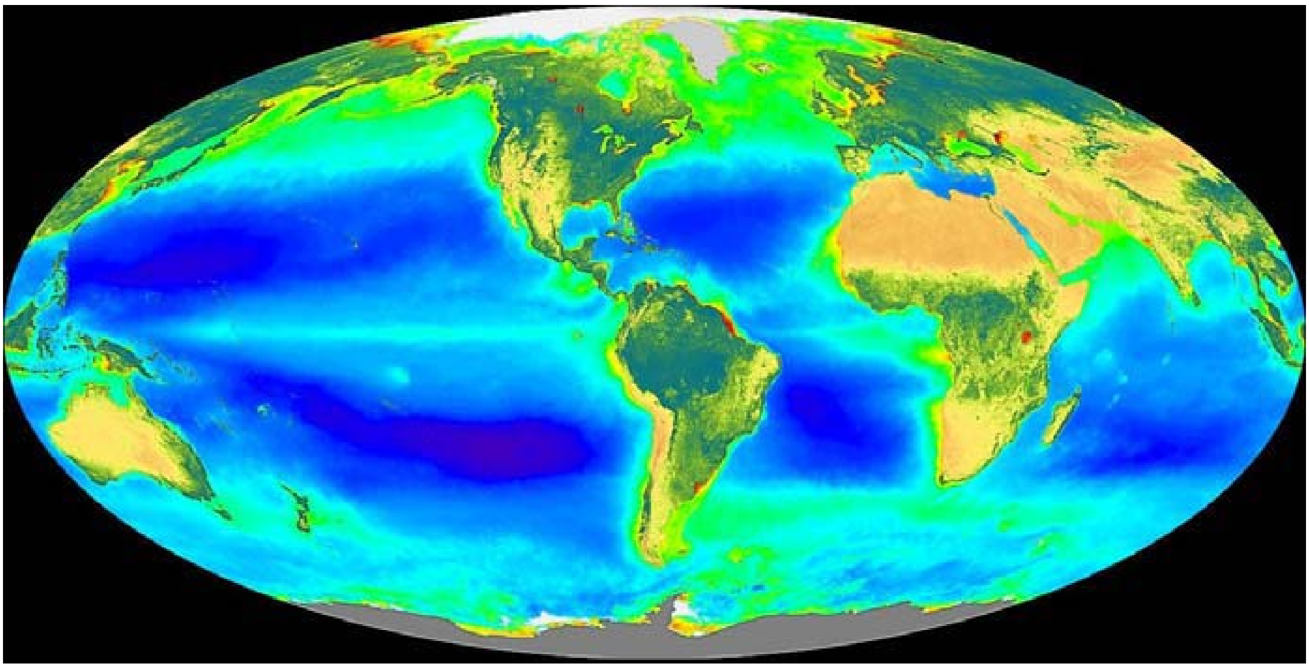
# Adsorption properties of Chloropyll




Source: Wikipedia



# Distribution and amount of Chlorophyll in the biosphere



Ocean: Chlorophyll *a* Concentration (mg/m3) 0.01 0.01 1.0 10 60

years 1997/98

Land: Normalized Difference Vegetation Index minimum maximum

# Efficiency of photosynthesis

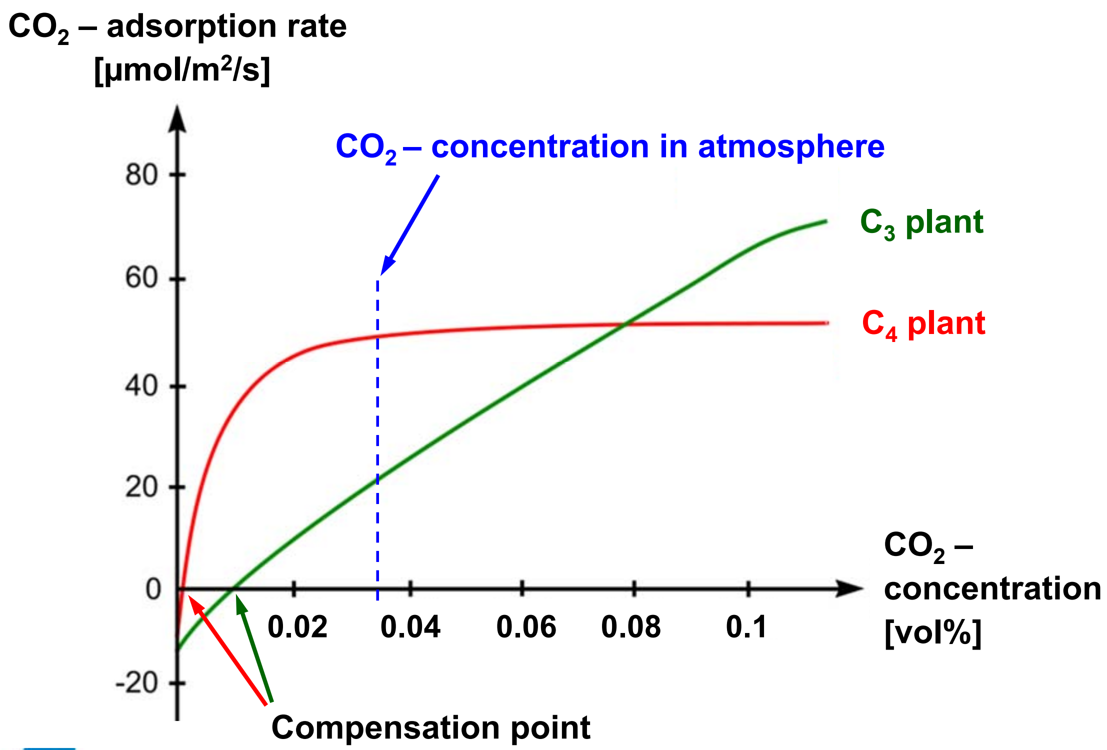
**.. related to total solar irradiance on the surface of the earth**

- Total solar irradiance: 100 %
- Thereof part of the irradiance in the wavelength range ( $\lambda$ = 360 - 720 nm) utilizable by the photosynthesis: 43 %
- Thereof adsorption by terrestrial plants with optimal orientation of the leaves: 80 %
- thereof photon yield of the photosynthesis: 23 %
- Loss due to respiration of the plants: 33 %; $\Rightarrow$ yield: 67 %
- The practical efficiency under field conditions is, however, lower due to different reasons. One major obstacle is the suboptimal CO2 concentration in the atmosphere:
- Maximal practical yield for short time (biomass production of 11 - 54 $g/m^2/d$): 1.4 - 4.3 %
- Yield over one year depending on plant and geographic location: 0.1 - 2.4 % (cereal typically 0.5 %, energy corn e.g. 1.3 %)

100 %
43 %
34 %
7,9 %
5,3 %

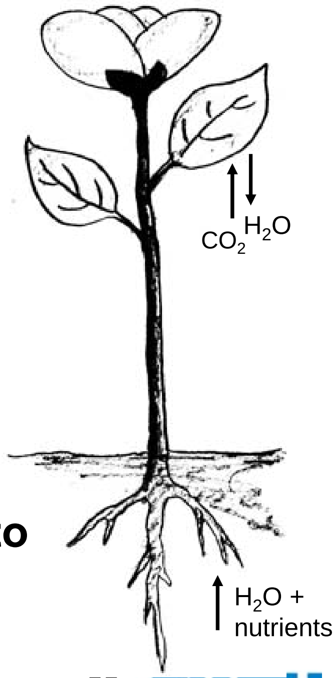


# Differences of $C_3$ and $C_4$ plants



# C3 and C4 plants (general information)

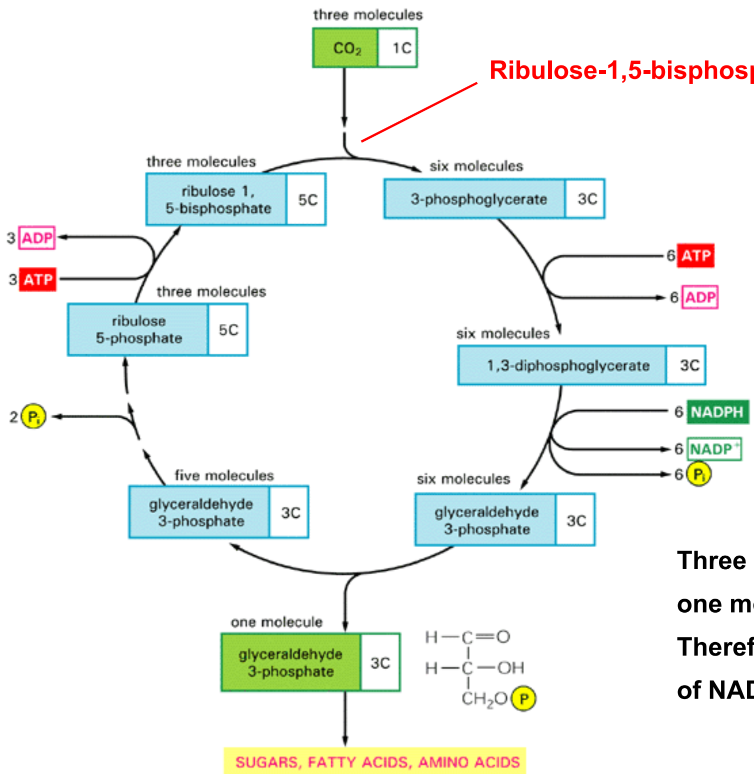
- plants absorb $CO_2$ through stomata at bottom side of leaves
- the $CO_2$ is used during photosynthesis
- through stomata the plants also release water
- undertow (Sog) from leaves to roots
- water and nutrient salts get from soil into all parts of the plant






# The Calvin cycle

3 $CO_2$ + 6 NADPH + 5 $H_2O$ + 9 ATP → glyceraldehyde 3-phosphate (G3P) + 2 $H^+$ + 6 $NADP^+$ + 9 ADP + 8 Pi




Ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCo)

At high $O_2$ and low $CO_2$ concentration RuBisCo oxidizes ribulose 1,5-bisphosphate and fixes no $CO_2$.

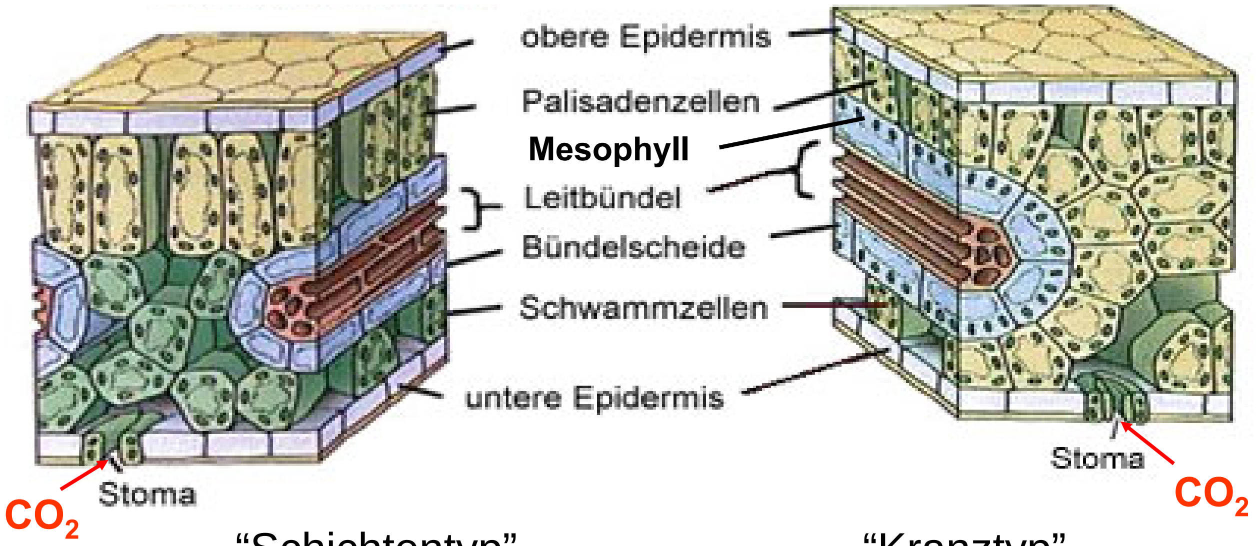
In C3 plants $CO_2$ is directly fixed by the RuBisCo.

Three molecules of $CO_2$ fixed give a net yield of one molecules of glyceraldehyde 3-phosphate. Therefore, 3 molecules of ATP and 2 molecules of NADPH are required to fix one $CO_2$ molecule.

# Leaf structure

**Plants absorb $CO_2$ through stomata ("Spaltöffnungen") at the bottom side of the leaves.**

**C3 plants** **C4 plants**

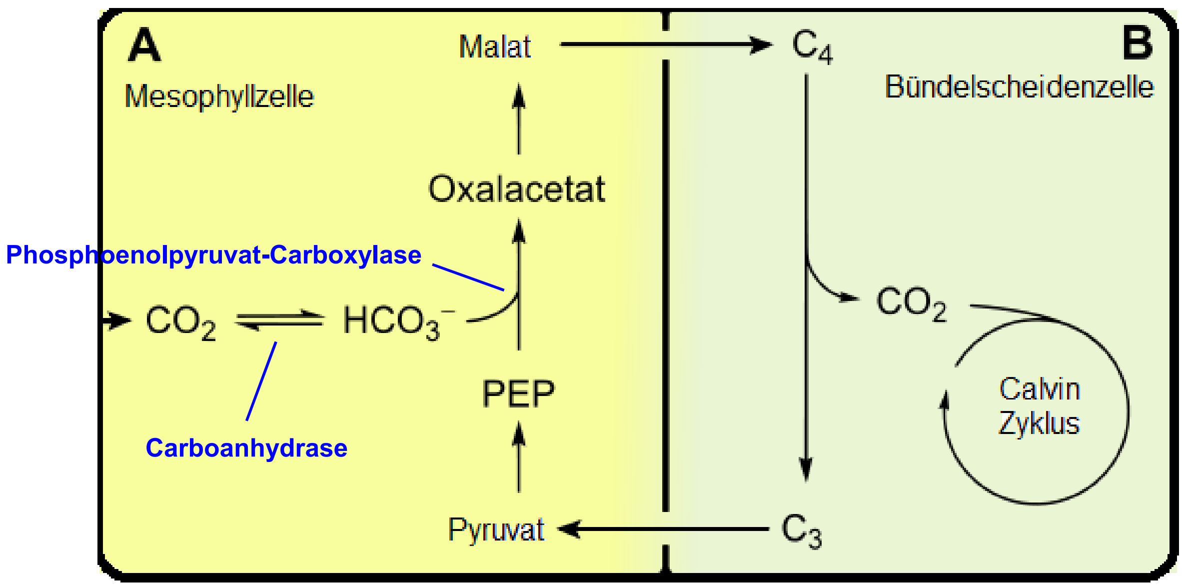



"Schichtentyp" "Kranztyp"



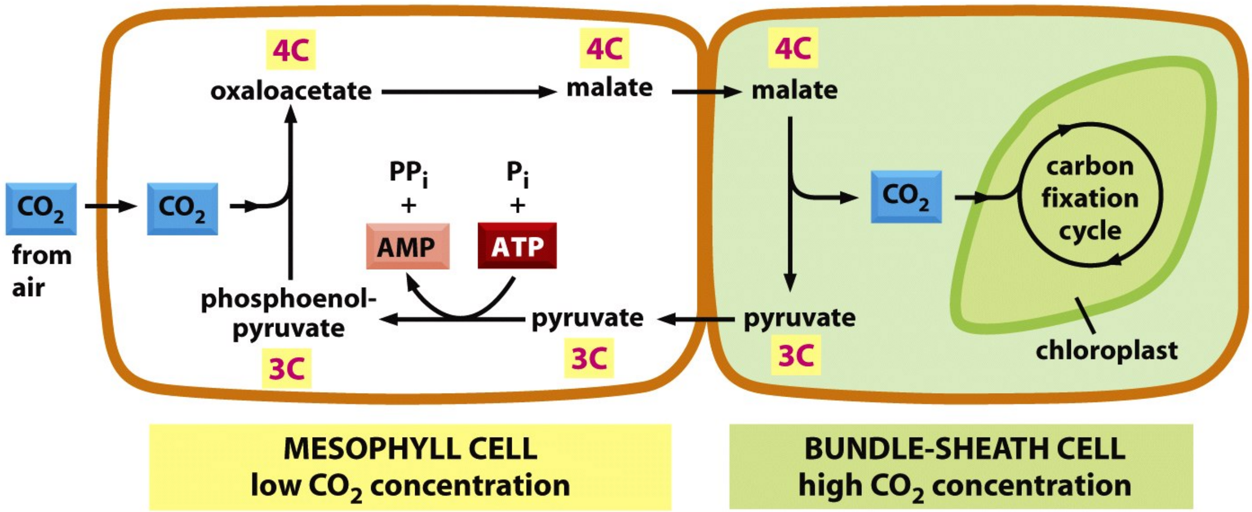
# C4 plants

**Locally separated fixation of $CO_2$ and Calvin cycle in C4 plants**
**⇒ photosynthesis more effective**




**This is a pumping mechanism resulting in an elevated $CO_2$ concentration at the RuBisCo.**

# C4 plants



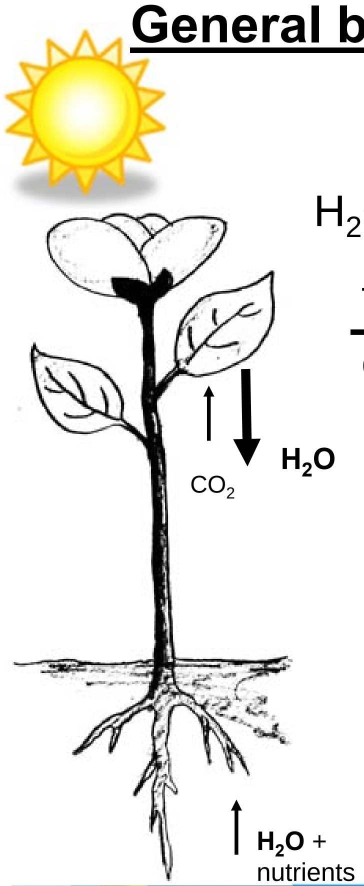

*Molecular Biology of the Cell* (© Garland Science 2008)



# Comparison of C3 and C4 plants

| | C3 plants | C4 plants |
|---|---|---|
| **enzyme to fix $CO_2$** | Ribulosediphosphat (RuDP) carboxylase | Phosphoenolpyruvat (PEP) carboxylase |
| **primary product of photosynthesis** | Phosphoglycerat (C3) | Oxalacetat (C4) |
| **examples** | Wheat, rice, soy | Corn, millet, amaranth, sugarcane, many grasses |

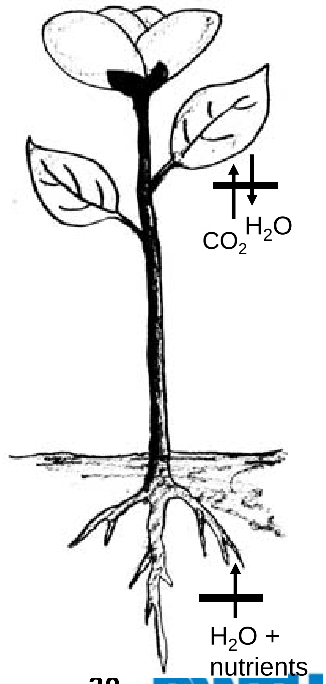
# General behavior of plants at hot weather




$H_2O$: evaporation > absorption

to prevent "drying-out":

closing of stomata




consequences:

- low water content
- reduced entry of $CO_2$
- no photosynthesis
- no cell growth



# Advantages of C4 plants

- The plants close their stoma at low external water supply. As a consequence $CO_2$ concentration in the leaves is reduced.
- However, photosynthesis and growth is still possible at low $CO_2$ concentration, because of the specific system which requires smaller $CO_2$ concentrations.
- Named for the 4-carbon compound formed in the first step of carbon fixation.
- Requirement of 230 – 250 mL water per gram dry cell weight (C3 plants: 500 mL – 750 mL)
- $C_4$ plants are suited for biomass production for energy generation. Miscanthus reaches yields of 15 – 25 t dry matter per ha and year.
- Tropical plants are getting increasing attention which are able to fix nitrogen and don't require nitrogen fertilizer.

# Comparison of C3 and C4 plants

- **The optimal growth temperature of C4 plants is 30 - 45°C, that of C3 plants is 15 - 30 °C.**
- **A leaf of a C4 plant contains at 30°C about 13 - 20 % of the amount of RuBisCo which is required by a C3 plant to achieve the same photosynthesis rate (at saturated light intensity).**
- **The nitrogen use efficiency in C4 plants is more than double as high as in C3 plants.**
- **The energy requirement of a C4 plant (NADP-ME and NAD-ME type) is 5 ATP and 2 NADPH molecules per fixed $CO_2$ molecule (PEPCK type C4 plants require 3.6 ATP and 2.3 NADPH molecules per fixed CO2 molecule.). The energy requirement is, therefore, higher ($CO_2$ pumping requires energy!) than for C3 plants. These require 3 ATP and 2 NADPH molecules per fixed $CO_2$ molecule. However, in this comparison the photorespiratory loss (which is higher for C3 plants) is not considered.**