Report

The atmosphere of our Earth, of planets of our solar system and of exoplanets

Author(s):
Brüesch, Peter

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6. Photosynthesis and Respiration of Plants
6.1 Photosynthesis

Photosynthesis is a process used by plants to convert light energy from the Sun into chemical energy that can be used to fuel the organisms’ activities. Carbohydrates, such as sugar (glucose), are synthesized from carbon dioxide and water. Oxygen is also released, mostly as a waste product, Photosynthesis maintains atmospheric oxygen levels and supplies most of the energy necessary for almost all live on Earth.
In Photosynthesis, substances which are rich in energy are produced from low-energy substances with the help of light energy $E = h\nu$ (\(\nu\) = frequency of light, \(h\) = Planck's constant). This conversion is carried out by plants, algae and some groups of bacteria. In this biochemical process, light energy absorbed by pigments, usually Chlorophylls, is converted in chemical energy. This chemical energy is then used to convert low-energy, inorganic compounds such as $\text{CO}_2$ and $\text{H}_2\text{O}$ to energy-rich compounds such as carbohydrates.

The Chloroplasts are organelles of cells of higher plants and green algae which are able to trigger photosynthesis.

In Chloroplasts, different pigments are incorporated, mainly the green Chlorophyll. [The pigment Chlorophyll only absorbs the red and blue light, but reflects the green light; for this reason, the leaves appear to be green s. p. 250]. The pigments are able to absorb light, which is converted in chemical energy.

**Photosynthesis: Chloroplasts - Chlorophylls**

![Plant cells with visible Chloroplasts (here in the leaf blade of mosses)](image)

**Struktur von Chlorophyll**


Chlorophyll a und b unterscheiden sich nur in einer der funktionellen Gruppen am Porphyrinring. Diese funktionellen Gruppen sind an der Stelle, die mit (für Rest) gekennzeichnet ist, mit dem Porphyrinring verknüpft.
Chlorophyll absorbs the light emitted by the Sun in the wavelength region between about 400 nm to 490 nm (Soret - range) and in the red region between 620 nm and 700 nm (1 nm = 10⁻⁹ m). The Soret – range is the most intensive band in the visible absorption region of Chlorophyll. This region has been discovered by J.L. Soret. Chlorophyll a absorbs light within the violet, blue and red wavelengths while mainly reflecting green. The addition of Chlorophyll b next to chlorophyll a extends the absorption spectrum. In low light conditions, plants produce a greater ratio of Chlorophyll b to chlorophyll a molecules, increasing photosynthetic yield.

The so-called «green gap» is the spectral range between 490 nm and 620 nm of Sun light which is outside the absorption spectrum of Chlorophyll a and b. In this spectral range, light is reflected by the leaves. This explains why most plants and trees appear green to the human eye.

The oxygenic Photosynthesis produces molecular oxygen (O₂). The oxygenic Photosynthesis is not only the most significant biochemical process of the Earth, but it is also the oldest one. By formation of glucose, \( \text{C}_6\text{H}_{12}\text{O}_6 \) (p. 252), together with Sun energy it directly or indirectly triggers almost all existing ecosystems. This is accomplished by providing energy-rich building materials and energy sources for other living beings. The green plants, algae and cyanobacteria are using the energy of light for storing energy in the form of Adenosine triphosphate (ATP) (s. pp 254, 258, 259):

Part of the generated oxygen acts as an oxidant for cellular respiration (aerobic respiration) (p. 254). As a consequence, the oxygenic Photosynthesis allowed the formation of more highly developed life forms. The remaining oxygen generated by Photosynthesis is released into the air (p. 254) and is used for breathing of living beings and for the formation of the protecting Ozon layer (pp 239 – 244).

The reaction equation for Photosynthesis includes a range of intermediate reactions which will not be discussed here. We rather restrict ourselves to the brutto reaction with 12 \( \text{H}_2\text{O} \)-molecules at the left- and 6 \( \text{O}_2 \)-molecules at the right-hand side of the equation.

\[
6 \text{CO}_2 + 12 \text{H}_2\text{O} \xrightarrow{\text{Light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{H}_2\text{O} + 6 \text{O}_2
\]

The colours of the atoms indicate, that the oxygen of the glucose originates from \( \text{CO}_2 \), but that the free oxygen is generated by the photodissociation (photolysis) of water. This fact could be established by radioactive tracer-experiments using isotopes \( ^{16}\text{O} \) and \( ^{18}\text{O} \) [s. Appendix 6-A-1-1]; (Net reaction: s. Ref. R.6.1.5).
The Glucose Molecule

The Glucose, \( \text{C}_6\text{H}_{12}\text{O}_6 \), (p. 251), produced in the brutto reaction of Photosynthesis, is a monosacharide (a single sugar) and belongs to the carbohydrates \([\text{C}_n(\text{H}_2\text{O})_m]\). In nature only the so-called D-Glucose occurs (see right-hand Figure). This sugar is also known as Dextrose. Normally, Glucose does not appear in a free form but rather in the form of Polymers, such as lactose, starch or cellulose. In plants, the Glucose polymers are acting both, as reserve materials as well as components of cell structure. All living beings are capable to produce Glucose from specific input products if the need arises.

D-Glucose exists in two forms: \( \alpha\)-D- Glucose and \( \beta\)-D-Glucose. The two forms differ only in the direction of the orientation of the -H and -OH groups of the carbon atom 1. If \( \alpha\)-D-Glucose molecules are chemically bound, a Starch polymer is formed. If \( \beta\)-D-Glucose molecules are bound, a Cellulose-Polymer is formed.

Photosynthesis in Rainforests

In a bell around the equator, the climate is usually warm and humid (right-hand Figure). Here, the Rainforest can thrive because in this region it encounters optimal conditions: Temperatures are between 20 and 28 °C, and it is coupled with high precipitation over the whole year.

a) Emergent Layer: small number of very large trees, called emergents growing above the general canopy, reaching heights of 45–55 m, occasionally even heights of 70–80 m.
b) Canopy Layer: contains the majority of the largest trees, typically 30–45 m tall. The densest areas of biodiversity are found in the forest canopy, a more or less continuous cover of foliage formed by adjacent treetops.
c) Understory Layer: lies between the canopy and the forest floor. It is the home to a number of birds, snakes, lizards and predators such as jaguars, leopards and boa constrictors.
d) Forest Floor: receives only 2 % of Sunlight. Only plants adapted to low light can grow in this region.

The foliage of the large trees makes a decisive contribution to the regeneration of the Earth’s Atmosphere. Together with Sun light, the leaves absorb the Carbon dioxide, \( \text{CO}_2 \), of the air and by means of Photosynthesis they transform the harmful \( \text{CO}_2 \) into oxygen (\( \text{O}_2 \)) and Glucose (s. pp 247 – 251; 254). One part of oxygen is used for cell respiration, the other part is released into the air for breathing of almost all living beings. As expected, photosynthetic capacity increases with canopy height.
Photosynthesis and respiration are reactions that complement each other in the environment. They are in reality the same reactions but occurring in reverse. While in Photosynthesis CO$_2$ and H$_2$O yield glucose and oxygen, through the respiration process glucose and oxygen yield CO$_2$ and H$_2$O.

Photosynthesis:

6 CO$_2$ + 12 H$_2$O $\rightarrow$ C$_6$H$_{12}$O$_6$ + 6 H$_2$O + 6 O$_2$

Respiration:

C$_6$H$_{12}$O$_6$ + 6 H$_2$O + 6 O$_2$ $\rightarrow$ 6 CO$_2$ + 12 H$_2$O

ATP: Contains energy for cells.

"Breathing out" of CO$_2$ during photosynthesis.

"Breathing in" of Oxygen during respiration.

Day and Night:

- Day: Photosynthesis occurs with sunlight.
- Night: Respiration occurs without sunlight.

Air and Sun-Light:

- Air: CO$_2$ and O$_2$.
- Sun-Light: Conversion of CO$_2$ and H$_2$O into glucose and O$_2$.
6.2 Cellular Respiration

Cellular Respiration and Photosynthesis - Facts

The Photosynthesis of plants not only produces free oxygen for the atmosphere but it also uses part of the oxygen in chemically bounded form for its cellular respiration for energy supply (p. 254). In contrast to animals and human beings, plants do not have a blood circulation which transports oxygen at the locations of need, but the oxygen is rather distributed by diffusion.

The undersite of the leaf of a plant growing at land contains a large density of stomata (s. P. Brüesch in «Water», Chapter 4, pp 217, 218). With these very small «mouths» they are «breathing in» oxygen during night (cellular respiration).

Plants are breathing during day and night. During day, Photosynthesis is dominating, i.e. more CO$_2$ is absorbed than emitted. Because of the missing sun light during night, Photosynthesis is stopped and the plant reduces its activity to cellular respiration. At the morning and at the evening there are specific times, at which Photosynthesis and respiration are balanced (compensation points).
Rates of Photosynthesis and Respiration of Plants in 24 hours

Since Photosynthesis produces carbohydrates, the rate at which the amount of carbohydrates change is positive (yellow area (a)). During the time of solar radiation it reaches a maximum (in the Figure at about 13:30 am). (The same is also true for the production of oxygen).

On the other hand, respiration consumes carbohydrates (green area (b)). Hence, the rate at which carbohydrates change is negative for respiration.

The area in yellow represents the total amount of carbohydrate produced in a 24 h period (due to Photosynthesis). The area in green (b) represents the total amount of carbohydrate consumed due to respiration.

For a green plant to survive, grow, and produce mature fruit, area (a) (yellow), must exceed area (b) (green).

Cellular Respiration of Plants – 1: Glucose → ATP

The respiration of plants as well as of animals consists of the inhalation of oxygen $O_2$ and in the release of carbon dioxide, $CO_2$. By the continuously occurring slow process of combustion in each plant cell, the operating power for the maintenance of vital activity is gained.

In case of particularly vivid cellular respiration occurring in freshly germinating seeds as well as in fresh blooming buts, an excess force is generated, which is noticable as a temperature increase.

If oxygen used for the maintenance of respiration is absent, all life activities such as growth, irritability, cellular respiration and photoplasmic movements are temporarily ceasing. After a prolonged time of oxygen deficiency, death by suffication occurs.

During respiration, the energy-rich glucose (sugar) is decomposed. The energy gained in this process is stored in cells as ATP (pp 6-A-2-1, 6-A-2-2), p. 254 and picture below). The cellular respiration can be represented by the following reaction:

$\text{Oxygen} + \text{Sugar} \rightarrow \text{Carbon Dioxide} + \text{Water} + \text{Energy}$  

Reaction illustrating the cellular respiration of plants
Cellular Respiration of Plants – 2: Mitochondria

A mitochondrion is a cell organelle (a cell organ) which is enclosed by a double layer cell membrane (i.e., a cell which contains a cell nucleus) and is used for power generation.

Mitochondria are large grain-shaped cell organelles. They frequently occur in cells, which have a high energy demand.

Mitochondria contain a double membrane. The outer membrane isolates the mitochondrion from the exterior and contains channels for the permeability of molecules.

The inner membrane contains numerous invaginations which are so-called cristae (from lat. crista «Kamm»). These cristae considerably increase the surface of the inner membrane, where chemical reactions can take place, thereby increasing the ability to produce ATP (pp 6-A-2-1, 6-A.2-2).

In the mitochondria the chemical processes of the respiratory chain take place. This makes it possible to use absorbed glucose (p. 252) for the synthesis of ATP with a high degree of efficiency. ATP is synthesized in the intermembrane space (between the two membranes of the double cell membrane) and can than be delivered to the cytosol (liquid component of the cell).

Mitochondria represent an intracellular storage for calcium and play an important role for the homeostasis (maintenance of a state of equilibrium) in the cell.

Compensation point for Light in Plants

We have discussed Photosynthesis and Respiration of plants at pp 251, 254, 256 – 258.

Photosynthesis: \[ 6 \text{CO}_2 + 12 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{H}_2\text{O} + 6 \text{O}_2. \]

The (light) compensation point is the amount of light intensity on the light curve where the rate of photosynthesis exactly matches the rate of respiration.

At this point, the uptake of CO\(_2\) through photosynthetic pathways is exactly matched to the respiratory release of CO\(_2\), and the uptake of O\(_2\) by respiration is exactly matched to the photosynthetic release of oxygen.

This point is reached during early mornings and late evenings. Respiration is relatively constant whereas photosynthesis depends on the amount of sunlight.

Let \([\text{O}_2]\) be the concentration of O\(_2\); then

\[ [\text{O}_2] = 0: \text{Cellular respiration.} \]
\[ [\text{O}_2] > 0: \text{Photosynthesis.} \]
\[ [\text{O}_2] = 0: \text{At the compensation point, the net concentration of oxygen, [O}_2], is exactly zero.} \]
Coloured Leaves of Deciduous Trees (Laubbäume) in Autumn

Trees which shed leaves in autumn are preventing their drying out in winter where the water from the soil is freezing and can no longer be absorbed by trees. Transpiration of the plants takes place over the stomata of the leaves (see P. Brüesch in «WATER», Chapter 4, Section 4.6, pp 202 – 223) which are not present anymore. After defoliation, no frost protection is necessary.

Before defoliation, many vital elements as for example Sodium (Na), Sulfur (S), Iron (Fe), Phosphorus (P), Potassium (K), and Manganese (Mn) as well as the mobilisable Carbohydrates are displaced into the storage tissue of the trunk and branches. Mobilisable Carbohydrates are present in a form, in which they can be transformed; this is the case for sucrose. In the following spring, these nutrients are delivered to the young developing leaves.

During winter, the trees fall into a «winter sleep» and are living from the nutrients which they have stored during summer. In this way, they are able to survive the winter time where no new leaves are growing. In this dormant state, the deciduous trees are living on the abundant Glucose which they have stored in the central vacuols of the tree.

Aquatic Plants: Photosynthesis and Respiration
Light Attenuation in a «clear» and in a turbic Lake

With increasing depth of water in a lake, the intensity of the incident sunlight decreases. The absorption and attenuation are major factors controlling temperature and Photosynthesis. Photosynthesis provides the food that supports much of the food web. It also provides much of the dissolved oxygen in the water.

The light intensity $I(0)$ at the lake surface varies seasonally and with cloud cover and strongly decreases with depth $d$ below the surface (see Figure). The deeper into the water column that light can penetrate, the deeper Photosynthesis can occur. For clear water, the intensity $I$ of the light decreases exponentially with $d$. If $k$ is the vertical extinction coefficient of clear water, the decay of light intensity for «clear» water ($k = 0.2$) is approximatively exponential, i.e.

$$I(d) = I(0) \cdot \exp(-k d) \quad \text{(Extinction - Law)}$$

The rate at which light decreases with depth depends upon the amount of light-absorbing dissolved substances and the amount of absorption and scattering caused by suspended materials. The Figure shows the light attenuation profiles for two lakes with attenuation coefficients $k = 0.2 \text{ m}^{-1}$ («clear» water) and $k = 0.9 \text{ m}^{-1}$ (turbid water).
In our lakes most of the higher plants belong to the pondweed and have nothing to do with „seaweed“ or algae.

In contrast to terrestrial plants, water plants do not possess a rigid supporting tissue. If they are removed from water they are flabby. In water, however, they are standing upright and are following the water movement flexibly without braking. Their stems are very tenacious and elastic. In contrast to land plants, water plants do not need an evaporation protection; their leaves are therefore very soft and tenuous. This allows for a direct uptake of nutrients from water through the leaves.

The roots function in the first place as ground anchors to the bottom of the pond.

According to the Figure at p. 223, the following species of water plants exist:

- a) Reed bed plants
- b) Floating leaf plants
- c) Pondweed plants
- d) Plants which are completely submerged under the surface of the water

**Respiration and Gas Exchange:** An influx and an outflux of air is established through the broken straws and is driven by the transpiration and the Venturi-effect (in the latter, wind generates a suction within the broken straws).

The numerous aerenchyma cells (*) of the Rhizomes are connected with the leaves through a continuous air chamber system. In this way, the photosynthetically produced atmospheric oxygen can quickly penetrate into the Rhizomes. Similar to nitrogen and CO₂, this produced oxygen can be stored in the aerenchyma cells.

At the beginning of the growth of new shoots (still within the water columns), respiration exceeds photosynthesis.

(*) Aerenchyma are large air-filled cavities that provide a low-resistance internal pathway for the exchange of gases (such as oxygen) between the plant organs above the water and the submersed tissues.)
b) Plants with floating leaves: Water lilies

Plants with floating leaves (e.g. water lilies and Lotus plants) represent a particularity: their roots are sticking to the underground while their leaves are floating at the water surface. By the presence of air chambers, the leaves are able to float on the surface, and on the other hand, these air chambers also transport the air through the hollow stem into the roots. Due to this air transport, the roots do not suffocate in the oxygen-deficient sludge. The water transport through the Xylem conduits is driven by the root pressure and not by transpiration pull as in tall terrestrial trees (s. Chapter 0, p. E; Ref. R.0.4).

The stomata of the leaves used for respiration are located at the upper surface of the leaves; this is in contrast to terrestrial plants where the stomata are at the lower surface of the leaves. These plants are thus breathing the oxygen of the air (not the oxygen dissolved in water). The leaves have wide-mashed air-filled cavities and the air is transported to the Rhizomes (see p. 266).

As mention above, Photosynthesis and Respiration takes place at the upper surface of the leaves.

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Lotus leaves are hydrophobic: The picture shows a water drop at the surface of the leaf. On the left side of the water drop an air bubble appears which is generated by the respiration of the leaf. (This picture has been obtained by a snapshot of a Video recording).
Pondweeds are plants which are used by fishes as spawning sites and for food. The pondweed zone has a depth of 2 - 5 m. The leaves of these plants are growing under water, only the blossoms extend over the water surface. Within the dense population of pondweeds, swarms of juvenile fishes, all possible invertebrates and lurking pikes can be observed during summer time.

Underwater plants (fully submerged plants) depend on the small CO₂ concentration in water for Photosynthesis. For this reason, submerged plants living in standing waters have narrow or cut-leaves. Diffusion of CO₂ contained in water into the plants is slow but the diffusion path is short. Due to the absence of transpiration, the plants can not gain mineral salts from the bottom of the lake. Their Xylem conduits are reduced.

Completely submerged water plants

These plants are blooming also under water. Normally, no part of the plant ever reaches the water surface.

Fragile stoneworts (Chara globularis)

Stoneworts are often covered with calcium carbonate, (CaCO₃). They are found at the bottom of the water body, where they are growing and thriving along the surface of the ground.

Most organisms denoted as algae are water plants. This implies that they have the same biological needs as pond plants. They have a cellular metabolism in which they respire sugar to water and carbon dioxide. For covering their energy need they are able to synthesize sugar from light, CO₂ and H₂O. The process of Photosynthesis is the same as that of higher plants.

Many stonewort plants are present at chalky habitats and are then covered with a rigid crust of salt. The reason for this crust formation lies in the fact that during intensive Photosynthesis they extract anorganic substances such as calcium carbonate (CaCO₃) from the water, resulting in a decalcification of water.

Biologically, algae are indispensable: they produce a large part of oxygen which is present today in our atmosphere.
Photosynthesis: Tracer-Experiments with $^{18}$O

Tracer- method for the determination of the free oxygen of Photosynthesis: The experiments are based on compounds which are marked with heavy oxygen $^{18}$O.

«Crossing» of two separate experiments:
- Isotope tracing of $H_2O$
- Isotope tracing of $CO_2$
  with heavy (non-radioactive) oxygen

**Experiment 1:**
$$6 \ CO_2 + 12 \ H_2^{16}O \rightarrow C_6H_{12}O_6 + 6 \^{18}O_2 + 6 \ H_2O$$

$\Rightarrow$ By using isotope tracing of water, the isotope appears in the generated oxygen!

**Experiment 2:**
$$6 \ C^{18}O_2 + 12 \ H_2O \rightarrow C_6H_{12}^{18}O_6 + 6 \ O_2 + 6 \ H_2^{16}O$$

$\Rightarrow$ By using isotope tracing of carbon dioxide, the isotope appears in the carbohydrate, ($C_6H_{12}O_6$), and in the water at the product side.

These experiments prove that the free oxygen originates from the photolysis of water:
$$H_2O \rightarrow 2 \ H^+ + 2 \ e^- + (1/2) \ O_2$$

The 6 water molecules at the right-hand side of the brutto reaction are evaporated through the stomata of the leaves into the Atmosphere (s. P. Brüesch, Ref. R.0.4: Chapter 4 about «Watter», pp 217, 218).
ATP
Adenosine triphosphate

ATP is the universal and immediately available energy carrier in each cell of plants and animals and at the same time it is an important regulator for energy supplying processes.

The ATP molecule supplies energy for chemical, osmotic or mechanical work. For this supply, the 3 phosphates \( \alpha, \beta, \text{ and } \gamma \) are of central importance: If the bond between \( \alpha \) and \( \beta \) is broken, the less energetic ADP is produced.

The energy released by the reaction of ATP to ADP is used by the cell for the regeneration of ATP (s. p. 6-A-2-2).

Phosphorylation of substrates by means of ATP produces a product and ADP which can be written in the following form:

\[ \text{ATP} + \text{substrate} \rightarrow \text{product} + \text{ADP} \]

In this reaction the bond between the \( \alpha \)- and \( \beta \)-phosphates is broken. The product is more energetic than the substrate. The less energetic ADP is again phosphorylated by energy producing reactions in the body to give the energy richer ATP (s. p. 6-A-2-2).

ADP
Adenosine diphosphate

ATP – ADP – Zyklus


6-A-2-2
Carnivorous plants have special leaves, called leaf pitchers, with which they are able to catch protozoons or arthropods, but larger species are also able to demolish frogs and mouses. They often are living at extreme habitats such as fenlands or blanc rocks and therefore they need and are able to improve their supply with mineral substances as well as nitrogen compounds.

In addition, an adequate supply of light and water must be ensured such that the pitched leaves are able to carry out sufficient Photosynthesis for energy conversion. The shape of a leaf is rolled up in order to be a better trap for prays, but at the same time, this shape decreases the efficiency for Photosynthesis.

Carnivors must also supply additional energy for glands, hair, adhesives and digestive enzymes of non-photosynthetic structures. To provide such structures, the plant needs ATP, (pp 254, 6-A-2-1, 6-A-2-2) and in addition, it is cell-breathing biomasses (decomposition of energy-rich glucose, see pp 251, 254, 256, 258). The energy gained is partly stored in cells such as ATP. For all these reasons, carnivorous plants have a reduced Photosynthesis, and an increased Respiration.
Saturation concentrations of O₂ and CO₂ in fresh water as a function of temperature (approximate values)

Over the ordinary temperature range (0 – 30 °C), the solubility of CO₂ is about 200 times larger than that of O₂.

Mean dissolved O₂- concentration and H₂O- temperature in Passaic River in N.J

The Figure shows that the concentration of dissolved oxygen in surface water is controlled by temperature and has both, a seasonal and a daily cycle. Cold water can hold more dissolved oxygen than warm water (see Figure in p. 6-A-3-1).

In winter and at the beginning of spring the O₂ – concentration is large; in summer and autumn it is small. (The concentration of dissolved oxygen is inversely related to water temperature (p. 6-A-3-1)).

Rules for practically important CO₂- concentrations

- A CO₂-concentration of 0.5–1 mg/L is not sufficient for a good plant growth
- Values between 5 - 15 mg/L provide an abundant plant growth
- A CO₂-concentration larger than 20 mg/L can be harmful for fishes
- In drinking water, CO₂ concentrations of 6 – 8 mg/L are favourable
- Limiting value: für a good plant growth but also for fishes, the CO₂- concentration should not be smaller than about 10 mg/L.

6 – 17
6.1 Photosynthesis

R.6.1.0 Advances in Photosynthesis – Fundamental Aspects
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R.6.2.0 Allgemeine Botanik - Kurzes Lehrbuch für Mediziner und Naturwissenschaftler

R.6.1.1 p. 247: Photosynthesis - Principle
a) Photosynthesis - https://en.wikipedia.org/wiki/Photosynthesis
b) Difference and Similarities Between Chemosynthesis and Photosynthesis
c) Getting started - What is Photosynthesis? Where does Photosynthesis happen? Plant Cells, Respiration, Starch, Why do plants need energy?
d) Was ist die Photosynthese ? - Growlight Solutions
   http://www.growlightsolutions.com/2011/11/was-ist-die-photosynthese

R.6.1.2 p. 248: Photosynthesis: Chloroplasts and Chlorophyll
a) For picture of Chloroplasts see Ref. R.6.1.1 a) of p. 247
b) Difference between Chlorophyll and Chloroplasts
c) Photosynthesis - http://de.wikipedia.org/wiki/Photosynthese - (contains also picture of Chloroplasts)

R.6.1.3 p. 249: Structures of Chlorophylls
c) Information about the Phytol -“tail” of Chlorophyll is found in:
R.6.1.3 p. 249: Structures of Chlorophylls - (cont.)

d) Information about Chlorophyll a and Chlorophyll b in: - «Light is part of the electromagnetic spectrum»
http://plantphys.info/plantphysiology/light.shtml

e) Strukturformel des Chlorophylls - (Structure with Porphyrin ring and Phyril tail)
http://www.uni-duesseldorf.de/MatHMat/Biologie/Didaktik/Fotosynthese/datei/chloroph.html

R.6.1.4 p. 250: Absorption of light by Chlorophyll a and b


c) Referenz R.6.1.2 c): Photosynthesis
d) Grünlücke - http://de.wikipedia.org/wiki/Gr%C3%BCnl%C3%BCcke


R.6.1.5 p. 251: Importance and brutto reaction of oxygenic Photosynthesis: from References R.6.1.1, R.6.1.2

Brutto reaction of Photosynthesis:: 6 CO₂ + 12 H₂O → C₆H₁₂O₆ + 6 O₂ + 6 H₂O

Net reaction of Photosynthesis:: 6 CO₂ + 6 H₂O → C₆H₁₂O₆ + 6 O₂

a) A Primer on Photosynthesis and the Functioning of Cells
http://www.globalchange.unich.edu/globalchange1/current/lectures/kling/energyflow/psn_primer.html


c) Tracer-Methode zur Aufklärung der Herkunft des freien O₂ bei der Photosynthese; Ursprünglich bewiesen durch Experimente von Samuel Rubens und Martin Kamen


R.6.1.6 p. 252: a-D-Glucose and b-D-Glucose


b) The Interactive Library: What is the difference between alpha and beta Glucose? http://www.edinformatics.com/interactive_molecules/a_b_gucose_differences.htm

Picture from Google under a-D-Glucose and b-D-Glucose
c) Glucose: http://de.wikipedia.org/wiki/Glucose


R-6-2

R.6.1.7 p. 253: Photosynthesis in Rainforests

http://en.wikipedia.org/wiki/Rainforest

b) Pictures of Rainforests: found under «Bilder of Tropical Rainforests»


d) Photosynthetic capacity in central Amazonian rain forests
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e) Troperischer Regenwald - http://wikipedia.org/wiki/Troperischer_Regenwald

f) AMAZONAS.de - Regenwald - http://www.amazonas.de/amazonas/wissen_regenwald1.html

g) Der tropische Regenwald - Die «grüne Lunge» der Erde

Die massive Zerstörung hat verheerende Folgen für Mensch und Natur

R.6.1.8 p. 254: Photosynthesis and cellular respiration - The closed Loop


b) How are Photosynthesis and Cellular Respiration coupled Reactions? http://answers.yahoo.com/question/index?qid=20100707235728AAab03h4p


d) Closed loop Diagram from P. Brüesch constructed from different literature sources

e) Sauertoff in Pflanzen – wie ein Lebenselixier gleichzeitig Stressfaktor und Signalstoff sein kann (Max – Planck - Gesellschaft)

f) Element: Luft - Photosynthese - Auch Pflanzen brauchen Luft
http://www.kindernetz.de/infonet/Themata/luft/fotosynthese/index=128294/nid=128294/did=128266/lnv2xt/

http://www.kindernetz.de/infonet/Themata/luft/fotosynthese/index=128294/nid=128294/did=128266/lnv2xt/

Wovon ernähren sich Pflanzen? Die Entdeckung der Photosynthese

[p. 3: Zeltatmung] - www.caau.ch/science_files/2.2_Fotosynthese.indd


s. p. 1 unter: «…und Abgabe (Ausatmung) des Kohlenstoffdioxids…»

s. p. 2: Kommentare über «Aerobe Atmung»
6.2 Cellular Respiration

R.6.2.1 p. 256: Cellular Respiration in Plants
a) s. Ref. R.6.1.8: References a), b), c), d)
b) Biology - Biology Rocks - Photosynthesis, Cellular Respiration, & Fermentation
   https://sites.google.com/site/mochebiologysite/online-textbook/photosynthesis
c) Cellular Respiration - http://biolypuoc.edu/boccurrdes/n100/2k4ch?respirationnotes.html
d) Photosynthesis abd Cellular Respiration - Study Guide
   Figure from: www.google - Images - (Figure – Text translated from German to English by P. Brüesch)

R.6.2.2 p. 257: Photosynthesis vs Respiration
   - Plants and Light – Energy Input into Ecosystems
     http://resources.yesican-science.ca/tomatophere/final/activity9a.html

R.6.2.3 p. 258: Respiration of Plants – 1
   (with Figure summarizing the cellular respiration)
b) Atmung der Pflanzen - Meyers grosser Konversationslexikon - Referenz von R.6.2.1
c) Proteolitic movement: produced by the inherent power of contraction and relaxation
   of protoplasm; such movements are of three kinds: muscular, streaming and villary,
   http://medical-dictionary.thefreedictionary.com/proteolitic+movement

R.6.2.4 p. 259: Respiration of Plants – 2: Mitochondria
b) Cellular Respiration - Mitochondria
   http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CellularRespiration.html
   (Aussenmembran – Innere Membran – Matrix - Cristae)

   (Ein Organell oder eine Organelle (Verkleinerungsform zu Organ) ist ein strukturell  abgrenzbarer Bereich
   einer Zelle mit einer besonderen Funktion).

R.6.2.5 p. 260: Compensation point for Light in Plants
   point/biology
b) What is the compensation point in Photosynthesis?
   http://in.answers.yahoo.com/question/index?qid=20090326025745AAwNeP2

c) Compensation point - http://en.wikipedia.org/wiki/Compensation_point


f) Lichtkompensationspunkt - http://wikipedia.org/wiki/Lichstkompensationpunkt
   [Der Lichtsättigungspunkt wird von Schattenpflanzen wesentlich schneller erreicht als von Lichtpflanzen]

g) Figure from google.ch/search - Figure text rewritten by P. Brüesch for better readability.

R.6.2.6 p. 261: Coloured leaves of deciduous trees in autumn
a) How Deciduous Trees Adapt to Winter
   (Deciduous means «falling out of maturity»)
c) What are Deciduous Trees and Shrubs: Types of Deciduous Trees and Shrubs
   http://www.gartenundknowhow.com/orchatales/genre/what-are-deciduousplants-hmt

d) How Deciduous Trees Adapt to Winter
e) Blattabwurf und Lautfärbung
   http://www.uni-duesseldorf.de/mednat/biologie/didaktik/winterprojekt/se2/botanik2/blattabw.htm
f) Laub (Botanik) - http://de.wikipedia.org/wiki/Laub_(Botanik)
3. Aquatic Plants

R.6.3.1 p. 262: Aquatic Plants: Photosynthesis and Respiration (Title)

- a) Aquatic Plants
  http://www.botgarf.ucla.edu/html/boranytextbooks/lifeforms/aquaticplants/fulltextonly.html
- b) Aquatic Plant - Wikipedia, the free encyclopedia - http://en.wikipedia.org/wiki/Aquatic_plants

R.6.3.2 p. 263: Lake Ecology - Light (see - Oekologie – Licht)

Light Attenuation in «clear» and in a turbid Lake
(Lichtabschwächung in «klaren» und turbiden Seen)
http://www.lakeaccess.org/oeckologie/lakeecologyprim3.html

R.6.3.3 pp. 264: Gewässerbiologie: Wasserpflanzen

Dr. Patrick Steinmann, Stein am Rhein
(Eine ausgezeichnete Einführung in das Gebiet der Wasserpflanzen)
Pflanzen mit zunehmender Wassertiefe: p. 1 in der Arbeit von Steinmann
http://www.psteinmann.net/bio_wasserpl.html

R.6.3.4 p. 265: General Properties and Species of Aquatic Plants

a) References listed under R.6.3.1
b) Reference R.6.3.3

R.6.3.5 p. 266: Reed bed Plants

a) Reed bed - http://en.wikipedia.org/wiki/Reed_bed
c) Kommentierte Literatur Recherche zum Thema «Röhricht»
  bearbeitet von Dipl.-Biol. Kathleen Goersch - Projektleiter: Dr. Michael Schirmer

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R.6.3.6 p. 267: Plants with floating leaves - Water lilies

- a) Some information is contained in Reference R.6.3.1
  - Picture of «White Water lily»: see Reference R.6.3.1 b)
  - Picture of «Air chambers in the stem»: see Reference R.6.3.1 c)
  - unteres Bild des Querschnitts des Stiels einer Seerose: Ref. R.6.3.1
  (translated to English by P. Brüesch)

R.6.3.7 p. 268: Plants with floating leaves Lotus flowers with leaves

Lotus leaves and water lily leaves

  [The Lotus effect refers to self-cleaning properties that are a result of very high water repellence
  (superhydrophobicity), as exhibited by the leaves of the Lotus flower.]
- b) Lotusblumen - Plant with floating leaves - Respiration of a Lotus leaf
  http://de.wikipedia.org/wiki/Lotusblumen
  left-hand upper picture: Lotus flower / left-hand lower picture: Lotus leaves and water lily leaves
  right-hand picture: Lotus leaf breathing / transpiring through a drop of rainwater
  www.youtube.com/watch?v=1-S1R1VLGE - By Vinod Eshwer - 24.04.2007

R.6.3.8 p. 269: Pondweeds

- a) COLUMN – Pondweeds play an important part in under water ecosystem
  www.peacecountrysun.com/.../column-pondweeds
- d) References R.6.3.1 to R.6.3.3
- e) Bild und Text zu Bild: Patrick Steinmann: Ref. R.6.3.3

R.6.3.9 p. 270: Fully submerged plants


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6 – 21
References to Appendix - Chapter 6

R.A.1.1  p. 6-A-1: Tracer Photosynthesis - Tracer experiments with 18O
b) Water is the Source of the Oxygen Produced by Photosynthesis
Life: The Science of Biology, Ninth Edition - @ 2011 Sinauer Associates
[PDF] Historische Experimente zur Erh\u00e4rmung der Pflan... www.totivista.com/..._Str%C3%A4te%20%20Teil%20VI.p-
c) Photosynthesis; Tracer-Experimente mit 18O (s. Ref. R.6.1.5, p. 251)

R.A.2.1  p. 6-A-2: Adenosine triphosphate (ATP) and Adenosine diphosphate (ADP)
f) Phosphors\u00e4ureester - Monoester - Diester - Triester
http://de.wikipedia.org/Pgosphores%C3%A4ureester

R.A.2.2  p. 6-A-2: ATP - ADP cycle
a) Bernie's Basics - Renewable energy: you're soaking in it
Renewable energy: you're soaking in it - The ATP - ADP cycle
http://www.abc.net.au/science/articles/2011/05/25/3226741.htm (Figure text rewritten for clarity)
b) Mystery behind ATP - ADP - http://alicsheart.blogspot.ch/2013/06/mystery-behind-atp-adp.html
c) Spaltung energiereicher Phosphate - http://www.sportunterricht.de/sportartikelp3.html

R.A.2.3  p. 6-A-2: Carnivorous Plants
b) Carnivorous plants can photosynthesise, so why eat flies ?
http://www.thenakedscientists.com/HTML/questions/question/2797/

6.A.2.3 (cont.)
c) How do carnivourous plant respire ?
http://answers.yahoo.com/question/index?qid=20110214052039AawFCW

R.A-3.1  p. 6-A-3: Saturation concentrations of O2 and CO2 of water as a function of temperature
Data collected from different sources by P. Br\u00e4sch
The absolut values of oxygen and carbon dioxide concentrations depend on the quality of water
a) O2 concentrations - Oxygen Solubility in Fresh and Sea Water
http://www.engineeringtoolbox.com/oxygen-solubility-water-d_841.html
b) Dissolved Oxygen and Carbon Dioxide - butane.chem.uiuc.edu/dissolvedplay/…/web-L23.pdf

c) Water Quality - Water Quality Assessment: Chemical: Dissolved Oxygen and Biochemical Demand
http://www.coef.edu/modules/waterq3/wassess3f.htm

d) CO2 Solubility in Water -
Diagrams found under Images of CO2 Saturation solubility of CO2 in water versus temperature
For direct comparison with the oxygen diagram, the concentrations given in g CO2 / 100 g H2O have been converted to mg CO2 / kg H2O

R.A.3.2  p. 6-A-3: Water properties: Dissolved oxygen
Mean daily dissolved oxygen concentration and water temperature
a) Water properties: Dissolved oxygen - Figure and Text from -Dissolved Oxygen, from USGS Water Science Figure and Text from -Dissolved Oxygen, from USGS Water Science for Scools: All about water - http://ga.water.usgs.gov/ndw/dissolvedoxygen.htm

b) Rules for practically important CO2 - concentrations in Waters and Lakes
- Carbon Dioxide in Water – About ScienceFairWater.com – sciencefairwater.com/…water_…dissolved_…carbon-d

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