Glossary - Botany *Plant Physiology*

Abscission: The dropping off of leaves, flowers, fruits, or other plant parts, usually following the formation of an abscission zone.

A. **Zone**: The area at the base of a leaf, flower, fruit or other plant part containing tissues that play a role in the separation of a plant part from the main plant body.

ATP (**a**denosine **t**riphos**p**hate): A nucleotide consisting of adenine, ribose sugar, and three phosphate groups; the major source of usable chemical energy in metabolism. On hydrolysis, ATP loses one phosphate to become **a**denosine **d**iphos**p**hate (ADP), releasing usable energy.

ATP **Synthase**: An enzyme complex that forms ATP from ADP and phosphate during oxidative phosphorylation in the inner mitochondrial membrane. During photosynthesis formed in the PS I photo-reaction: $ADP + P_i \rightarrow ATP$

Allelophathy: (Gk. allelon, of each + pathos, suffering) The inhibition of one species of plant by chemicals produced of another plant.

Bacterium: An auto- or hetero-trophic prokaryotic organism.

Cyanobacterium: Autotrophic organism capable of fixing nitrogen from air (heterocyst) and utilizing light energy to accomplish its energetical requirements.

- **Chloroplast**: The thylakoids within the chloroplasts of cyanobateria are not stacked together in grana, but randomly distributed (lack PS II, cyclic photo-phosphorylation).
  Oxygenic photosynthetic reaction: $CO_2 + 2H_2O \rightarrow (E_{light} = h \cdot f) \rightarrow CH_2O{\approx}P \rightarrow (CH_2O)_n + H_2O + O_2$
- **Heterocyst**: Site of N_2 fixation; a specially differentiated cells, working under anoxic onditions (H_2 would combine with O_2 to form water). Ferrodoxin taking part in the nitrogenase reaction, is reduced via a strongly exergonic reaction which is fueled by energy from photosynthesis of neighboring cells, probably maltose, which is broken down in the heterocyst (see also cycle N_2-fixation):
  $N_2 + 8e^- + 10H^+ \rightarrow$ (nitrogenase) $\rightarrow H_2 + 2NH_4^+$(strongly exergonic, ammonium, used in amino acids)

Halobacterium: A color-sensing chemo-autotrophic bacterium (contains rhodopsin) capable of phototaxis (move to/fro a light gradient with a H^+ powered flagellar motor); the purple pigment changes the absorptive spectrum under the influence of light 570 nm to 412 nm) yielding H^+ protons. The externally generated pH gradient drives phosphorylation of ADP to ATP via passive back diffusion. C-fixation is achieved by using H_2S; since this process results in a solid product, sulfur will be deposited in the soil. Anoxygic photosynthesis does not require two photosystems since the energy level to split H_2S is lower than that one of water (H_2O).
Anoxygic photosynthesic reaction: $CO_2 + 2H_2S \rightarrow (E_{light} = h \cdot f) \rightarrow (CH_2O) + H_2O + 2S$

Rhizobium: Flagellated, free-living heterotrophic soil bacteria. Approach chemotactically the rhizosphere of a susceptible root-hair, proliferating into it, causing curling growth. Rhizobia fuses with the plasma membrane of the root hair cell (without infecting them, separated by a peribacteroid membrane), tunnel through the cytosol of the cortex, force cortical- and pericycle cells to divide until in touch with the vascular tissues. Once there, bacterial colony stops dividing, enlarges, and differentiate into N_2-fixing endosymbiotic organelles (nodules). In exchange from fixed nitrogen (NH_4^+), the host provides C-compounds and a highly regulated watery O_2 environment. Since O_2 is a potent inhibitor of nitrogenase, “infected“ cells produce large quantities of the O_2 binding *leghemoglobin* to keep its partial pressure at 21% but that of N_2 below 78%; see cycle, nitrate fixation.

Calvin Cycle: see CO_2-pathway, or plant types.

CO_2 Pathways: The conversion of CO_2 to basic sugars during photo- or chemosynthesis can be fixed in plants in various ways based on their carbon-fixing metabolism; see plants, types of.

Carnivorous Plants: A semi-autotrophic plant, feeding upon animals; see motility.

Chemosynthesis: Chemosynthetic organisms derive their energy requirements from the oxidation of inorganic material; as performed by hydrogen bacteria etc.; see carbon cycle.
$6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 6H_2O + 12S$

Chlorophyll: see photosynthetic pigments.

Chloroplast: A two-membranous plastid containing pigments (chlorophyll and carotenoids); see photosynthesis.

Circadian Rhythm: The biological clock; see motility.

Coenzymes: An organic molecule, or nonprotein organic cofactor, that plays an accessory role in enzyme-catalyzed processes, often by acting as a donor or acceptor of electrons.

NAD$^+$ (**n**icotinamide **a**denine **d**inucleotide): A coenzyme that functions as an electron acceptor in many of theoxidation reactions of respiration.

NADP$^+$ (**n**icotinamide **a**denine **d**inucleotide **p**hosphate): A coenzyme that functions as an electron acceptor in many reduction reactions of biosynthesis; similar in structure to NAD$^+$ except that it contains an extra phosphate group. During photosynthesis in the PS II photoreaction, NADP$^+$ is converted to NADPH:
$4NADP^+ + 4H^+ \rightarrow (E_{light} = h \cdot f) \rightarrow 4NADPH$ (is 7 times more efficient as an energy carrier than ATP)

Cycle: Bio-geochemical cycles on a global and local scale.

Carbon C.: Is in equilibrium between the photo autotrophic plant kingdom, the heterotrophic animal kingdom and microorganisms. The final breakdown (mineralization) of organic matter bound in living systems is executed by bacteria and fungi by aerobic breakdown, and frequency by anaerobic degradation (fermentation). Besides the CO_2 which returns to the atmosphere, there is also carbon which is deposited in the form of carbonates in the oceans.

- **Photosynthesis**: Conversion of light energy to chemical energy; see there
  CO_2 Fixation: CO_2 can be fixed via a photosynthetic pathway or a chemosynthetic pathway:

	Light **dependent** reaction	Light **independent** reaction
Photosyn.: (algae, and plants)	$2H_2O \rightarrow (E_{light} = h \cdot f) \rightarrow O_2 + 4H^+ + 4e^-$	$CO_2 + H_2O \rightarrow CH_2O{\approx}P \rightarrow (CH_2O)_n$
	$ADP + P_i \rightarrow (E_{light} = h \cdot f) \rightarrow ATP$	$2NADPH \rightarrow 2CH_2O{\approx}P \rightarrow 2NADP^+ + 2H^+$
	$2NADP^+ + 2H^+ \rightarrow (E_{light} = h \cdot f) \rightarrow 2NADPH$	

- **Respiration**: Consumption of oxygen to obtain energy (light independent!)

Chemosyn.: (H-bacteria)	$2H_2 + O_2 \rightarrow 2H_2O$	$CO_2 + H_2O \rightarrow CH_2O{\approx}P \rightarrow (CH_2O)_n$
	$ADP + P_i \rightarrow ATP$	$2NADPH \rightarrow 2CH_2O{\approx}P \rightarrow 2NADP^+ + 2H^+$

- **Fermentation**: Catabolic reactions producing ATP; see microbiology.

Nitrogen C.: Organic (NH_3^-) and inorganic (NO_3^-) linked via denitrification and atmospheric N_2 fixation:

- **N_2 Fixation**.: The incorporation of atmospheric dinitrogen into nitrogen-compounds (usually ammonium NH_4^+); carried out by certain free-living and symbiotic bacteria; see also bacterium:
  $N_2 + 8e^- + 10H^+ \rightarrow (\text{nitrogenase}) \rightarrow H_2 + 2NH_4^+$(ammonium, used in amino acids); exergonic
  NH_4^+ is assimilated by beans and other nearby plants, which itself are consumed by herbivores; the released feces (nitrate) is converted back to ammonium ions in a process known as ammonification.
- **Ammonification**: Decomposition of amino acids and other nitrogen containing organic compounds, resulting in the production of ammonia (NH_3) and ammonium ions (NH_4^+) ready to be taken up again.
  Nitrate Fixation: The conversion of nitrate (NO_3^-) into amino nitrogen by heterotrophoc organs (roots) or by symbiotic organisms (*Nostoc sp.*) and takes place in leucoplasts. Although this process is light-independent, ATP used in these steps are generated during light-dependent carbon fixation:

$$NO_3^-(\text{cytoplasma}) + NADPH + H^+ \rightarrow (\text{nitrogen reductase}) \rightarrow NO_2^- + NADP + H_2O$$
$$NO_2^-(\text{chloroplast}) + 6\text{ferredoxin (e-donor)} + 8H^+ \rightarrow (\text{nitrite reductase}) \rightarrow NH_4^+ + 2H_2O$$
$$NH_4^+ + \text{2-oxoglutarate} + 2H^+ + ATP^{\ast} \rightarrow \text{glutamate} + H_2O + H^+ + ADP + P_i$$

  *) Conversion of the ammonium ion (NH_4^+) into organic compounds happens in chloroplasts (in tough competition with CO_2 reduction for ATP and free "e$^-$") predominately through a 2-step reaction in which glutamine serves as intermediary product. The successor glautamate is then used as an amino group donor for various 2-oxo acids, e.g. oxaloacetate, within and outside the chloroplast (transamination).
- **Denitrification**: Conversion of nitrate to gaseous nitrogen in which ammonia is oxidized, summarized in four enzymatic reactions yielding nitrogen; carried out by a few genera of free-living soil bacteria.

NO_3^-(*nitrate*) $\rightarrow$ NO_2^-(*nitrite*) $\rightarrow$ NO(*nitric oxide*) $\rightarrow$ N_2O(*dinitric oxide*) $\rightarrow$ N_2 (*dinitrogen*)

Oxygen C.: It is complementary to the carbon cycle; in contrast to CO_2 in photosynthesis, O_2 is due to its high concentration in the atmosphere, no longer a globally limiting factor. In water, however, it is often not possible to supply enough O_2 for the complete mineralization of dead organisms, leading to the deposition of organic materials; respiration and photosynthesis are elementary steps within the oxygen cycle.

Water C.: Evaporation from the oceans precipitates on land; runoffs (rivers and streams) close the loop.

Defense Mechanism of plants: Effective protection is often achieved by physical means (thorns,. Leaf hairs, sticky sap) but also chemically (cyanides, camphor, tannins, cocaine, caffeine, nicotine, morphine, salycilic acid, etc.). Injured areas are usually walled off (compartmentalization) with resins.

Growth of Plants: Growth proceeds in an irreversible sigmoidal increase in size (slow, fast, slow, adult plant). The roots are the first structure to emerge (rhizoid pole) anchoring the germinating seed. Light controls elongation of hypocothyl (HC), the thallus pole; see also photosynthetic pigments - phytochrome:

- Germinated, darkness promotes a huge increase in length of the HC, otherwise remain dormant.
- Blue light triggers germination, orientation toward light source, lateral branching and greening of HC.
- Red-light causes the HC to remain short (slow vertical cell elongation) but green (photosynthetic active);

Heat: Many plants, (e.g.: aroids) when inflorescence is ready for pollination, generate heat by oxidizing large amounts of stored food, manly fats (up to 1/4 of their total weight a day). The heat (up to 30°C above ambient temp.) causes bad smelling amines to emanate attracting pollinating insects (flies, etc.). A common fuel is known to be salicylic acid (similar to aspirin). Since many of these plants flower in late fall, trapped pollinating insects are kept warm during the night to be released, loaded with pollen, the morning after.

Hormones of Plants: (Gk. hormaein, to excite) Chemical-organic substances that regulate growth, flowering, etc. released by the action of light (phytochromes), water, temperature, or other influences. Some hormones act locally while others are transported to distant tissues, where they produce specific physiological responses; others act within the same tissue where they are produced.

- **ABA** (**ab**scisic **a**cid): (L. abscissus, to cut off) *Growth inhibitor*; brings about dormancy in buds, maintains dormancy in seeds (until washed out), and brings about <u>stomatal closure</u>, promotes yellowing of leaf; ABA levels increase during early seed development <u>preventing premature germination</u>; opposes growth hormones, among other effects. Travels short distances in leaves and fruits.
- **Cytokinins**: *Promote growth*; Stimulates cell division; kindle growth in lateral buds, and block leaf senescence. Chemically related to adenine. Transported from roots upward in vascular system.
- **IAA** (**i**ndole**a**cetic **a**cid) or **Auxin**: (Gk. auxein, to increase) *Promotes growth*; controls cell elongation (increases number of H^+-pump in tonoplast - extension of vacuole), inhibit growth of lateral buds (apical dominance), orient root/shoot growth, promotes cell division, root growth, at low concentration prevents abscission of leaves and fruits, among other effects. Excess auxin-dosage causes death due to growth beyond sustainability. Tryptophan is the precursor of IAA; IAA occurs in the tips of shoots, leaf premordia, young leafs and is transported down to the root tips of the vascular cylinder.
- **Ethylene**: *Promotes maturation*; a simple hydrocarbon involved in the ripening of fruit (transported via air-currents), leaf/flower abscission, and senescence (collapse of lytic compartment); ($H_2C = CH_2$). Plays a major role as a perhormone by communicating to neighboring plants attacks of herbivores, triggering the production of defensive chemicals.
- **Gibberellines**: *Promote growth*; stimulate both cell division and cell elongation, causes bolting (without the need to expose plant to cold or long days), new leaves, branches, flowering, larger and looser fruits, among other effects. Seeds need higher levels to germinate (conversion of starch to sugars); low levels in young plants cause dwarfism, high levels the opposite; is transported up-/downward in vascular system.

Auxin and gibberelline stimulate plant growth by increasing the extensibility of cell walls.

- **Jasmonate** or **jasmonic acid**: *Growth inhibitor*; a methylester occurring in the oil of jasmine. It inhibits growth of certain plants and promotes leaf senescence (deterioration and aging).

Law of the Minimum: The growth of a plant is dependent upon the amount of “foodstuff“ (trace elements) presented to it in minimum quantities (J. Liebig).

Light Compensation Point: CO_2 fixation balanced by mitochondrial respiration; see photosynthetic response.

Light Dependent Reaction: Photosynthetic reaction in the photosystems I & II that require light and cannot occur in dark; see photosynthetic proteins and photosynthesis.

Light Independent Reaction: The enzymatic reaction (calvin cycle) in photosynthetic cells concerned with the synthesis of glucose (more stable and compact than ATP and NADPH) from CO_2, ATP, and NADPH; see plants- types of and photosynthesis.

Light Shielding: Absorption (conversion into heat) of excessive light; see tropism (cytoplasmic streaming) and photosynthetic pigments (xanthophyllic carotenoids).

Malate (malic acid): A C_4 compound and the end-product of the C_4-pathway. Used as a counter ion for K^+ uptake, and to supply H^+ for the proton pump (intercellular pH regulation) and is the product of the C_4 pathway of the CO_2 fixation; see there. During stomatal opening, starch in the guard cells is broken down via glycolysis to phosphoenolpyruvate, which is used with CO_2 uptake to form malate, therefore the level of malate increases;

Mesophyll: The ground tissue (parenchyma) of a leaf, located between the layers of epidermis; it is structured into pallisade- and spongy parenchyma, housing chloroplasts which contain chlorophyll (site of photosynthesis).

Motility of Plants: Even though plants cannot move actively across a given area (except adventitious root development) it possesses various ways of motion, which requires ATP:

Insectivory: Feeding upon animals; plants that are able to utilize proteins obtained from trapped animals, chiefly insects; e.g. venus fly trap, in which inward-lying cells are elongated by virtue of the high vacuole-turgor-pressure; once an insect touches the trigger-hairs the flaps snap shut rapidly (deflation of stretched cells consumes ATP), pressing the insect against digestive glands on the inner surface of the trap. The trapping mechanism is so specialized that it can distinguish between living prey and inanimate objects.

Tropism: (Gk. tropes, turning) A growth response involving bending, curving of a plant part towards (positive) or away (negative) from an external stimulus that determines the direction of movements.

- **Gravitropism**: (L. gravis, heavy; also geotropism) Response of a shoot or root to the pull of the earth's gravity. Roots grow downwards, positive gravitropism (high levels of auxin inhibit growth in roots), whereas shoot grows upwards, negative gravitropism. Roots are more sensitive to the response of auxin than stems (high auxin concentration, inhibits root growth). Perception of gravity is correlated with sedimentation of amyloplasts (starch containing statolithic plastids) w/n specific cells of shoot and root.
- **Heliotropism**: (Gk. helios, the sun) Ability of the leaves and flowers of many plants to move diurnally, orienting themselves either perpendicular or parallel to the sun's direct rays; also called heliotropism.
  Diaheliotropism: the movement of the leaves is such that the broad surfaces of the blades remain perpendicular to the sun's direct rays, resulting in a higher **photosynthetic** rate.
  Paraheliotropism: Avoiding direct sunlight during periods of drought by orienting leaf blades parallel to the sun's rays. Minimizes absorption of solar radiation, lowers leaf temp., and transpirative water loss.
- **Phototropism**: (Gk. photos, light) Growth movement of cells or organs in which light plays a decisive role, and is related to the direction of light as the controlling external factor; e.g.: growth of a plant toward a light source by the influence of auxin; the cells of the shaded side of the tip migrates from the light-side to the dark-side, resulting in a turn or bend (compare photoperiodism).
  Cytoplasmic streaming: The plasma in the cell rotates and circulates actively under the influence of light. Particles in the protoplast such as nucleus, mitochondria, and plastids are often carried passively.
  Chloroplastic Orientation: Active repositioning of chloroplasts in the cytoplast of the mesophyll cells.
  i) **Diastrophic**: Dark-light position, with max. light absorption i.e.: perpendicular to incoming light.
  i) **Parastrophic**: Bright-light position; reduced light absorption; i.e.: almost parallel to incoming light.
- **Thigmotropism**: (Gk. thigma, to touch) Response to contact with a solid object as seen in tendrils. They wrap around any object with which they come in contact, and so enable the plant to cling and climb.

NADx: see coenzymes.

Oxaloacetate:): The C_4-molecule formed in C_4- plants, i.e.: the krebs cycle; the product when P_i is split off from PEP. Depending on the species, oxaloacetate is either reduced to malate or converted to asparate (additional amino group NH_2), both C_4 -compounds. Malate or asparate is a mediator transporting CO_2 used in the calvin cycle.

Pathogen: (Gk. pathos, suffering + genesis, beginning) An organism that causes disease.

PEP or **Phosohophenolpyruvate**: The compound to which CO_2 binds in C_4-plants. PEP converts under the influence of CO_2 to oxaloacetate, which is either reduced to malate (malic acid) or asparate (extra amino group NH_2).

Peroxisome: A microbody that plays an important role in glycolic acid metabolism associated with photorespiration.

PGA (3-phoshoglycocerate): The C_3-sugar formed in C_3- plants, i.e.: the calvin cycle.

Phosphoryltation: (Gk. phosphorous, bringing light) A reaction in which phosphate is added to a compound; e.g.: the formation of ATP from ADP (PSI), NADPH from $NADP^+$ (PSII) and inorganic phosphate; see photosystem.

Photo-P.: (Gk. photos, light) The formation of ATP in the chloroplast during photosynthesis.

Cyclic Photo-Phosphorylation: A photosystem lacking PSII, yielding only small amounts of ATP an no NADPH; a very ancient type of photosynthesis.

Noncyclic Photo-Phosphorylation: The modern type of plant having both PS I & II - the zigzag scheme providing both ATP, and the more efficient energy carrier NADPH.

Photoperiodism: Response to duration and timing of day and night; a mechanism evolved by organisms for measuring seasonal time. Plants that flower only under certain day-length conditions; and is a biological response to a change in the proportions of light and dark in a 24 hour daily cycle.

- **Short Day Plants**: Flower in early spring or fall when days are shorter with less intense light.
- **Long Day Plants**: Flower in the summer, when the light periods are longer than the critical length.
- **Day Neutral Plants**: Flower without respect to length of the day.

Photorespiration: see plants, types of - C_3-plant.

Photosynthesis: (Gk. photos, light + syn, together + tithenai, to place) Conversion of light energy to chemical energy;

PLANTS: Solar radiation is used by plants to oxidize water, reduce CO_2, and release of O_2. Plants use <5% of the radiant energy, the majority is reflected or lost as heat; see also cycle-carbon.

Chloroplast: A two-membranous plastid containing pigments (chlorophyll and carotenoids); most active photosynthetic tissue in higher plants is found in the pallisade parenchyma of leaves (mesophyll).

- **Granum**: Stacks of thylakoids seen with electron microscopes, and as green granules with light microscopes; grana contain chlorophylls and carotenoids; see also photosynthetic pigments.
- **Stroma**: (Gk. stroma, to spread out) Ground substance, aqueous region of plastids; the site of reactions by which photochemical energy is used to synthesize carbon containing compounds (site of dark reaction).
- **Thylakoid**: (Gk. thylakos, sac + oides, like) A saclike membranous structure in cyanobacteria and grana in eukaryotic autotrophic organisms (stacks of thylakoids form grana); chlorophyll pigments are found within the thylakoid membranes (site of light dependent reaction).

Intense photosynthesis, causes some of the photosynthate to be stored temporarily in chloroplast as starch-grains; sugars are transported via phloem to target cells (root) for nourishment and to produce cellulose.

Light dependent reaction: Light is required to generate ATP and NADPH.

PSII: $2H_2O \rightarrow (E_{light} = h\cdot f) \rightarrow O_2 + 4H^+ + 4e^-$

$ADP + P_i \rightarrow (E_{light} = h\cdot f) \rightarrow ATP$

PSI: $2NADP^+ + 2H^+ \rightarrow (E_{light} = h\cdot f) \rightarrow 2NADPH$

Light independent reaction (dark reaction in the stroma of photosynthetic cells), the enzymatic reactions resulting in the synthesis of glucose from CO_2, ATP; and NADPH;

$CO_2 + H_2O \rightarrow CH_2O{\approx}P \rightarrow (CH_2O)_n$

$2NADPH \rightarrow 2CH_2O{\approx}P \rightarrow 2NADP^+ + 2H^+$

Nitrate (NO_2^-) conversion to ammonium (NH_4^+) occurs in chloroplasts as well, hence, in stark competition for ATP and free electrons with the carbon fixing process!

Allover oxygenic photosynthesic reaction: $CO_2 + 12H_2O \rightarrow (E_{light} = h\cdot f) \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$

An/oxic autotrophic organisms use light energy to satisfy their energetical requirements; anoxic bacteria derive their H^+ protons from chemical compounds other than H_2O requiring less energy to be split); see bacterium.

Phototrophic anoxic reaction: $CO_2 + H_2S \rightarrow (E_{light} = h\cdot f) \rightarrow CH_2O + H_2O + S$

Photosynthetic Pigments: A substance that absorbs light, often selectively.

P. Spectrum: The spectrum of light waves absorbed by a particular pigment eliciting a certain reaction; gamma rays (short wavelength) are too energetic (destroy biological molecules), radio waves don't excite them at all.

Carotenoids: A class of fat-soluble pigments (yellow and orange pigments); found in chloro- and chromo-plasts of plants. Carotenoids act as accessory pigments in photosynthesis.

- **β-C**.: A yellow to red carotenoid with the empirical formula $C_{40}H_{56}$, found in fruits e.g.: pericarp of tomatoes.
- **Fucoxanthin**: (Gk. phykos, seaweed + xanthos, ye/br) Brownish pigment of brown algae and chrysophytes.
- **Xanthophyll**: (Gk. xanthos, yellowish-brown + phyllon, leaf) A yellow fat-soluble light shielding pigment. **Light Shielding**: Besides cytoplasmic streaming, xanthophyllic carotenoid absorb excessive light (**e**lectro**m**agnetic **r**adiation) to protect the photosynthetic complex from overexposure by converting EMR it into heat; light converts *violaxanthin* into *zeaxanthin* which deactivates the antenna complex of the photosystem, preventing photodistruction of chlorophyll by overexposition to pure O_2.

Chlorophyll: (Gk. chloros, green + phyllon, leaf) The green pigment of plant cells, which is the receptor of light energy in photosynthesis; a tetrapyrrole ring structure on top with 4 internally placed N-atom, itself facing towards the centrally located Mg-atom; the entire complex is attached to a hydrophobic $C_{20}H_{39}$ phytol tail, which anchors the molecule into the photosynthetic thylakoid membrane; see table and scan below.

- C. **a**: blue-green; with an extra CH_3 molecule attached at the opposite end of the tetrapyrrole.
- C. **b**: yellow-green; aldehyde (CHO) instead of CH_3 attached at the opposite end of the tetrapyrrole.

Phycobilins: A group of water-soluble accessory pigments, which occur in the red algae and cyanobacteria.

Phytochrome: A phycobilin-like pigment (photoreceptor for red and far-red light) found in the cytoplasm of plants and a few green algae; phytochromes <u>do not participate in photosynthetic</u> reactions.

Plants contain phytochrome in two different inter-convertible forms:

- $\mathbf{P_r}$ absorbs red light (660 nm), the biological inactive form of the protein (inhibits reactions, but allows plant to grow pale and spindly, changes to P_{fr} (**p**igment **f**ully **r**eactive) when exposed to (red) light. Phytochrome is continuously synthesized as P_r from its amino acid precursors.
- $\mathbf{P_{fr}}$ absorbs far-red light (730 nm), the biological active form triggering reactions, e.g.: induces germination flowering, dormancy, leaf formation, seed germination, <u>shade detection</u>, etc. by triggering the release of plant hormones via a ci<u>s-trans isomerisation</u> (cascade amplification). P_{fr} is converted back to P_r when exposed to far-red light (darkness, dark reversion) or lost through hydrolysis by proteases.

Photosynthetic Proteins: The protein complexes of PSI and PSII spatially separated within the thylakoid membrane indicating a one to one stoichiometric ratio between those two systems.

Antenna: Large numbers of light collecting pigment serve as antenna, where the excitation transfer process in the antenna is a purely physical phenomenon and does not involve an chemical change. Chemical reactions first take place in the reaction center of PSII and PSI; subsequent reactions stabilize the unstable products of the initial chemical reactions.

Cytochrome: (cyt b_6-f) Four different integral proteins, three of which contain iron that undergoes reduction to Fe^{2+} and then oxidation back to Fe^{3+} during electron flow. It mediates electrons generated by PSII towards the PSI reaction center.

Cyclic Electron Flow: In chloroplasts, the light induced flow of electrons originating from and returning to photosystem I.

Noncyclic Electron Flow: The light-induced flow of electrons from water to $NADP^+$ in oxygen-evolving photosynthesis; it involves both photosystem I and II.

Photosystem: A discrete unit of organization of chlorophyll and other pigment molecules embedded in the stroma thylakoids of chloroplasts and involved with the light-requiring reactions of photosynthesis. <u>Oxygenic photosynthesis requires two photosystems since the energy level to split H_2O is very high</u>. P_{680} and P_{700} refer to the wavelength of maximum absorption of the reactions center chlorophylls in PSII and PSI.

- **PS II**: A series of noncovalently bondend complex intrinsic polypeptides; associated with three peripheral (extrinsic) polypeptides, thought to aid in binding of Ca^{2+} and Cl^-, both of which are essential for <u>photolysis of water</u>. The P_{680} core complex (LIGHT HARVESTING COMPLEX-II) receives red light energy by inductive resonance from a total of about 250 *chlorophyll a* and *b* molecules (associated with few integral chlorophylls + xanthophylls proteins which act as an antenna system), producing a strong oxidant (oxidizes water) and a weak reductant: f, frequency [s^{-1}] [Hz]

  $2H_2O \rightarrow (E_{light} = h \cdot f) \rightarrow O_2 + 4H^+ + 4e^-$ h, plank's c. $6.63 \cdot 10^{-34}$ [J·s]

  more precise:

  $2H_2O$ + 4 photons + 2 oxidized plastoquinone (2PQ) $\rightarrow O_2 + 4H^+$ + 2 reduced plastoquinone ($2PQH_2$)

  $2PQH_2$ + 4 plastocyanin ($4PC\text{-}Cu^{2+}$) $\rightarrow 2PQ + 4PC(Cu^+) + 4H^+$ (lumen)

  The increasing H^+ concentration (low pH causes an electrochemical proton gradient) within the lumen of the thylakoid is used to synthesize ATP, when H^+ tunnels back out to the stroma through the integral coupling factors (CF's): $ADP + P_i \rightarrow (H^+) \rightarrow ATP$

  PS I: Even though it uses (far) red light independently, PSII recruits electrons originally released by the PSII H_2O-lysis mediated via the cytochrome complex. This reaction causes cytochrome to transport H^+ ions across the membrane from the stroma into the thylakoid membrane (further decrease of internal pH). Two large polypeptides bind the reaction center P_{700}, some *chlorophyll a* molecules and three electron carriers ($NADP^+$) called phylloquinone and a Fe-S group. The PSI core complex receives light by inductive resonance from about 100 *chlorophyll a* and *b* molecules formed to an other antenna system (LIGHT HARVESTING COMPLEX-I). The strong reductant produced by PSI reduces $NADP^+$, to NADPH, which is released into the stroma: f, frequency [s^{-1}] [Hz

  $2NADP^+ + 2H^+ \rightarrow (E_{light} = h \cdot f) \rightarrow 2NADPH]$ h, plank's c. $6.63 \cdot 10^{-34}$ [J·s]

  more precise:

  $4PC(Cu^+) + 4Fd(Fe^{3+}) \rightarrow (E_{light} = h \cdot f) \rightarrow 4PC(Cu^+) + 4Fe(Fd^{2+})$

  $4Fe(Fd^{2+}) + 2NADP^+ + 2H^+ \rightarrow 4Fd(Fe^{3+}) + 2NADPH$

Photosynthetic Products: Most of the fixed carbon is converted either to sucrose, the major transport sugar, or to starch, the major storage carbohydrate in amyloplasts and in the stroma (temporarily) of plants.

Sucrose (disaccharide) is favored over glucose (monosaccharide), to avoid digestion of monosaccharides during transportation down the phloem by those cells. Once arrived at target tissues, disaccarides are cleaved into glucose and fructose.

Photosynthetic Response: The dose-response of photosynthetic C-fixation as a function of photon flux. A C_4 (sun loving) plant has a higher light compensation point, a higher maximal photosynthetic rate, than a C_3 (shade) plant. Maximal saturation is determined by the slow-working carboxylase - see rubisco and plants, types of.

Light Compensation Point: At this point, the amount CO_2 evolved by mitochondrial respiration is balanced by the amount of CO_2 fixed by photosynthesis.

Phytochrom: see photosynthetic pigments.

Plants, Types of : According to the light-independent reaction, CO_2 fixation is achieved by the following:

C_3 P.: (Calvin cycle) Enzymatically mediated photosynthetic reactions of shade-plants during which CO_2 is attached to ribulose, a C_5-sugar (RuBP, a CO_2 acceptor), yielding a C_6-sugar which spontaneously breaks into 2 C_3-sugars (3-PGA). Rubisco is resynthesized out of $5C_3$-sugars giving $3C_5$-sugars. Sugar-compounds can temporarily be converted to starch, stored in amyloplasts, and reconverted into sugars via ATP and NADPH to ADP and $NADP^+$ (glucose is more stable and compact than ATP, NADPH) - see scan below:

$$6CO_2 + 12NADPH + 12H^+ + 18ATP \rightarrow 1glucose + 12NADP^+ + 18ADP + 18P_i + 6H_2O$$

- Photorespiration (PR): In C_3 plants only; photosynthesis in C_3 plants is always accompanied by PR, a process that consumes O_2 and releases CO_2 in the presence of light. Since no ATP is yielded by PR, it diverts some of the light-depending reactions from biosynthesis of glucose into reduction of O_2. Up to 50% of CO_2 fixed in C_3 plants may be again reoxidized to CO_2.

C_4 P.: Sun-loving plants; CO_2 is fixed to a compound known as PEP (by the enzyme PEP carboxylase in mesophyll cells) to oxaloacetate (a C_4 compound), which is rapidly converted to malic acid. This malate is then transported to bundle sheath cells (spatial separation), where the CO_2 is released (turbo charger) converting back to pyruvate. The CO_2 thus enters the calvin cycle, ultimately yielding sugars and starch. Pyruvate returns to the mesophyll cells for regeneration of phosphoenolpyruvate (PEP); requires more energy than in C_3 plants.

- Spatial separation: Photosynthesis in chloroplasts of mesophyll cells, synthesis of sugars and starch in the bundle sheath; due to spatial separation no competition between O_2 and CO_2, hence no photorespiration.

CAM P.: (Crassulacean Acid Metabolism) Variant of the C_4 pathway; phosphoenolpyruvate fixes CO_2 in C_4 compounds (PEP carboxylase) at night. The malic acid so formed is stored in the vacuole. During daytime, fixed CO_2 (malic acid) will be decarboxylated and transferred to the ribulose biphosphate (RuBP) of the calvin cycle within the same cell. Characteristic of most succulent, slow-growing, desert-plants; e.g.: cacti.

- Temporal separation: CO_2 fixation at night (dark reaction), photosynthesis at day (light reaction).

RuBP (ribulose 1.5-biphosphate): A C_5-sugar with two attached phosphate groups; the precursor of Rubisco and PGA (calvin cycle); rubisco is later regenerated by the synthesis of $5C_3$-sugars to yield $3C_5$-sugars.

Rubisco or **RuBP carboxylase**: A very abundant enzyme in chloroplasts that catalyzes initial reaction of the calvin cycle (C_3 plants), involving the fixation of CO_2 to ribulose 1.5-biphosphate (RuBP); plants need a large amount of this slow-working enzyme; up to 50% of leaf matter consists of carboxylase.

Senescence: Aging of a plant by dissolving cell walls; see hormones - ethylene.

Stomata: (Gk. stoma, mouth) Minute openings, bordered by guard cells in the epidermis of leaves and stems through which gases pass (CO_2, O_2, H_2O-vapor); the entire stomatal apparatus (guard cells plus pores).

Guard Cell: Pairs of specialized epidermal cells surrounding a pore, or stoma; changes in turgor pressure of a pair of guard cells cause opening and closing of the pore.

Stomatal Regulation: Stomatal movements results from changes in turgor pressure with in the guard cells. The major solute responsible for this gradient is potassium (K^+); higher K^+ and Cl^- concentration causes stomata to open (water rushes in due to osmosis), whereas closure when it drops. Opening occurs when solutes are actively accumulated in these cells. Stomatal closure is brought about by the reverse process (a declining guard cell solute); water moves out of the guard cells lowering turgor pressure. Guard cells chloroplasts fix CO_2 photosynthetically to form sugar, which contribute to the solute buildup required for stomatal opening. Environmental factors that effect stomatal movement:

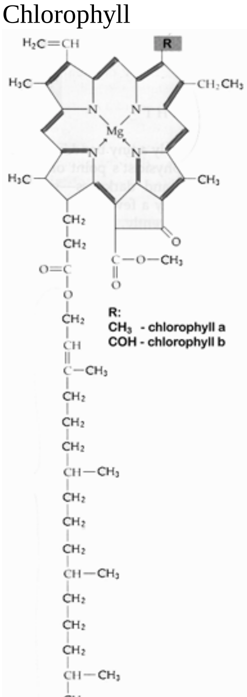
1. Increase in CO_2 concentration (sensors in guard cells, PEP & Rubisco) cause stomata to close.
2. Water shortage increases concentration of **ab**cidic **a**cid (ABA, originating from mesophyll) which causes K^+ to leave the guard cells resulting closed stomata.
3. Temperatures > 30 to 35°C causes stomatal closure.
4. Circadian rhythm (L. circa, approx. + dies, day) contribute to stomatal opening and closure. Stomata open with light (blue light stimulate stomatal opening, independent of CO_2 due to K^+ uptake by the guard cells) and close in darkness (red light stimulate stomatal closing).
5. Dryer air and wind accelerates dehydration of plant; water loss can be retarded by epidermal hairs or stomatal openings lowered into the mesophyll.
6. Glycolytic breakdown of starch (in guard cells of C_4-plants only) to PEP is used to form malate (along with CO_2), an increase level of malate, cause stomata to open.

Tropism: A growth response involving bending, curving of a plant; see motility of plants.

Distribution of chlorophylls and other photosynthetic pigments

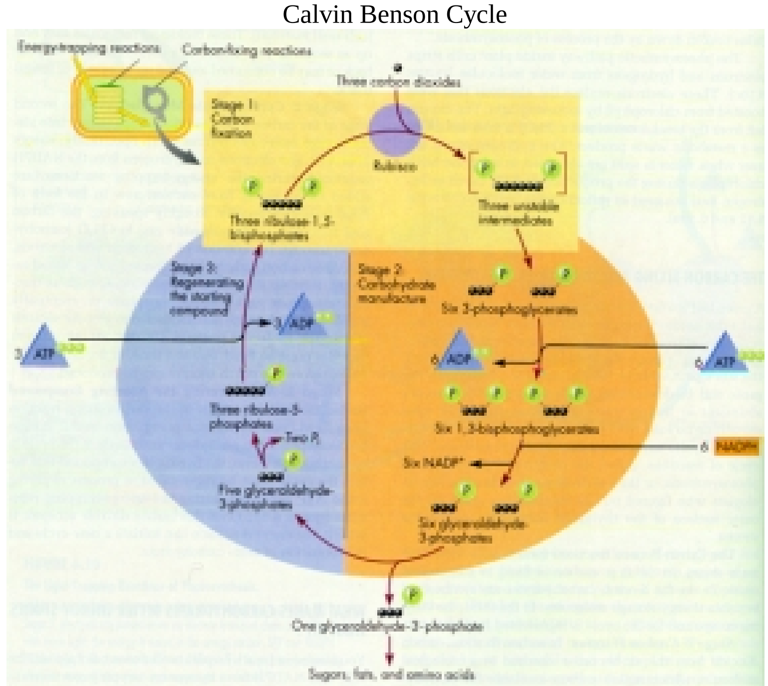
Organism	**Chlorophyll**				**Bacteriophyll**						**Carotenoids**	**Phycobilins**
Eukarotya	**a**	**b**	**c**	**d**	**a**	**b**	**c**	**d**	**e**	**f**		
mosses, ferns and seed plants	+	+	-	-							+	-
green algae	+	+	-	-							+	-
euglenoids	+	+	-	-							+	-
diatoms	+	-	+	-							+	-
dinoflagellates	+	-	+	-							+	-
brown algae	+	-	+	-							+	-
red algae	+	-	-	+							+	-
Prokaryota												
Cyanobacteria	+	-	-	-							+	+
Prochlorophytes	+	+	-	-							+	-
S-purple bacteria					+ **or**	+	-	-	-	-	+	-
non S-purple bact.					+ **or**	+	-	-	-	-	+	-
green bacteria					+	-	-	-	-	-	+	-
heliobacteria					-	-	-	-	-	+	+	-

Chlorophyll



This large molecule houses a Mg ion hold by a porphyrin ring; attached to this ring is a long insoluble CH-chain (phytol) which anchors the molecule to specific hydrophobic proteins.

Calvin Benson Cycle



These reactions take carbon molecules from the air and fix them into biological molecules. In stage 1, C is fixed. 3 CO_2 molecules from the atmosphere are added to 3 molecules of ribulose-biphosphate by the enzyme rubisco. This forms 3 molecules of an unstable 6-C compound, which breaks up rapidly to 2 molecules of a 3-C compound. In stage 2, carbohydrate is manufactured. Enzymes act on energy, electrons, and H from NADH and ATP made in the light-dependent reaction, altering the fixed C into 3 molecules of 3-C compounds (G-3-P, glyceral-dehyde-3-phosphate). One of these G-3-P molecules can be siphoned from the cycle and joined to others, generating sugars. After several turns, 5 G-3-P molecules are saved for the final stage 3. There, the cycle is completed. Energy from ATP modifies the 5 3-C (G-3-P) molecules into 3 5-C-ribulose-biphosphate molecules.