**Part 1 – Reproduction in angiosperms**

**Basic definitions**: **Spores** are haploid cells that are the starting point of reproduction. They undergo mitosis and form multicellular, haploid gametophytes. Male gametophyte is a pollen grain and female gametophyte is an embryonic sac.

The female gametophyte consists of 7 haploid cells: 2 synergid cells at the entrance and one egg cell, further inside is a central cell with two nuclei (2n) and at the back are 3 antipodal cells. The entrance is also called mykropyle. It’s where the pollen tube connects to. The synergid cells release a chemoattractant, such that the pollen tube can grow to the right direction and through the entrance too, so that the pollen grains (male genetic carriers) meet the egg and central cell.

An **ovule** is an embryonic sac (this is the 7-celled structure) and its surrounding sporophytic cells (all 2n). They are called **integuments**.

**Genesis of spores**

**Megasporogenesis**: The starting point of female gametophytes. The integuments contain megaspore mother cells (=: MMCs), which perform meiosis and produce 4 haploid megaspores. Three of them will degenerate and the surviving one performs mitosis 3 times (8 cells in the end). The central cell has two nuclei.

**Microsporogenesis**: A pollen grain has an outer, extine cell wall which is secreted by sporophytic cells and its structure is therefore of sporophytic origin. An internal, intine cell wall is created by the vegetative cell and contains cellulose and callose. In a pollen grain, there are two sperm cells for **double fertilization**.  
In Staubbeutel, the pollen mother cell (=: PMC) performs meiosis and creates a tetrade. Enzymes from surrounding sporophytic cells open the tetrade and release the haploid cells. Then, asymmetric mitosis occurs twice: First, a small and a big cell are made (big cell is the vegetative cell). Small cell performs mitosis a second time and we have the sperm cells.

**Self-incompatibility**

Inhibit inbreeding depression by recognizing own pollen. In sporophytic SI, the extine cell wall of the pollen is recognized. It contains SCR which are recognised by S-receptor kinases on the carpel. Autophosphorylation of the receptors 🡪 pollen tube growth never happens. In gametophytic SI, the haploid cells of the pollen are recognized. The carpel expresses S-RNase from the S-locus (female determinant). When a pollen lands on the stamen, pollen tube growth is initiated and the S-RNase can get into the cells of the pollen tube. If it is a self-pollen the S-RNase is recognized by a SI-protein in the pollen tube and RNAs are degraded which end pollen tube growth.

Genetically, pollen and stamen have a S-locus encoded which is polymorphic and is always inherited as a haplotype. If a pollen with the same S-locus as the stamen lands on it, there will be no pollen tube growth and SI occurs.

**Kor.**: Female determinants are always diploid (2n, sporophytic, style and stigma), because their haploid cells are far deep in the ovarium.

**Pollen tube growth**

After a pollen lands on the stigma, its extine wall is lost through hydration. Its intine wall extends into the style and forms the pollen tube. There are short- and long-range factors during pollen tube growth. Long range signals come from the style, so that the pollen finds its way through the whole style. Synergid cells secrete short range signals, such that the growing tube finds it way through the micropyle correctly. These signals induce Ca2+ dependent signal transduction pathways such that elongation occurs at the front side of the growing pollen tube (Ca2+ is ten times higher in the front than in the back).

**Embryogenesis**

**Def. double fertilization**: In a pollen, there are two sperm cells. One fertilizes the egg cell, while the other fertilizes the central cell (2n already) such that an endosperm forms (3n).

**Steps in embryogenesis**: zygote and asymmetric division 🡪 cell which is apical and basal, **auxin creates this polarity** 🡪 8-cell stage also known as globular stage (4 cells called hypophysis, like a rod, 4 cells like a ball on top of it known as the quiescent center with quiescent cells (origin of RAM)), auxin at the apical side 🡪 heart stage, auxin at the basal side 🡪 mature embryo in seed with two cotyledons (SAM in between cotyledons at the roof).

Auxin induces the differentiation of many organs.

**Def. RAM**: Root apical stem cells, create the whole root tissue.

**Def. SAM**: Shoot stem cells, create the whole shoot such as stem, all flower organs and leaves. At the globular stage, the TF WUSCHEL is expressed 🡪 STM (shoot meristemless) 🡪 other SAM-specific genes.

**Endosperm and seed dormancy**

The initial endosperm divides many times and encloses the zygote for protection and metabolic support. The endosperm is enveloped by an aleurone layer. The transient endosperm is degenerated and provides the embryo with nutrients (e.g. in arabipodsis, peas, nuts). The persistent endosperm accumulates starch and provides the embryo with it during germination (e.g. in crops).

Seed = embryo, endosperm, perisperm (sporophytic cells from parents), seed coat/tesla, sometimes also a fruit coat.

**Seed dormancy** = dessication, low metabolic activity, accumulation of reserve nutrients.

**Part 2 – Plant cells and vascular tissue**

The **primary cell wall** is made of hemicellulose, cellulose and pectin. Pectin is a heterogenous polymer containing **rhamnogalacturonan 1 and homogalacturonan**. Cellulose is a glucose polymer with beta-1,4-glycosidic bonds. They are not produced in the ER. Cellulose is made in the cytoplasm. There are CESA proteins that form trimeric or hexameric subunits. These subunits combine with 5 further subunits to form rosettes. Rosettes are on the PM. They create the special bond with UDP-glucose, thus they grow along MT. Rosettes produce 18 or 36 long chains. The chains form H-bonds.

**Enzymes for cellulose production**: sucrose synthase (suc + UTP <-> fruc + UDP-gluc), invertase (sucrose to fructose and glucose) and then pyrophosphorylase (gluc-1-P + UTP -> gluc-UDP and PP\_i).

The secondary cell wall has lignin instead of pectin. Lignin is an irregular polymer consisting of the phenol monolignins. Monolignins are produced in the ER and then transported into the cytoplasm where they undergo further modifications by enzymes and form polymers.

Having a second cell wall increases protection against bacteria, make the cell water proof and more stable, but the cell cannot expand anymore and divide.

**Cell division and expansion in plants**

The pre-prophase band already determines where the future cell plate will be located. It is an actin and MT network which accumulates around equatorially at the cortex of the cell. After mitosis, the actin is gone. Other actin and MT filaments accumulate in the center of the cell, so called **phragmoplasts**. Vesicles from the ER with cell wall material are directed to the phragmoplasts (in the middle) and extend towards the PM. Thus, the cell is separated into two cells.

Cells remain connected via plasmodesmata. When the ER extends into the cell plate during its formation, there will be no closure. Thus, we have an opening (tubule-like, since the ER is tubule-like when passing through the cell plate. It is called a desmotubule). Cells exchange hormones, minerals, proteins, RNAs, miRNAs, metabolites etc. via the plasmodesmata.

Plant **vacuoles** regulate turgor pressure, contain toxins against bacteria, pigments in flowers and reserve energy. Its membrane is called **tonoplast**.

During cell expansion, it is important to regulate pressure, perform cell wall loosening and increase the volume of vacuole. **Cell wall loosening** occurs when expansins are active in low pH environments. Auxin signals proton pumping into the cell, thus lowering the pH value. Thus, expansins are activated. They break the H-bonds of cellulose to some extent, which makes the cell wall looser. The turgor pressure falls and water flows in, thus increasing the volume of vacuoles.

When microfibrils of primary cell wall is parallel ⬄ longitudinal expansion. When microfibrils of primary cell wall is criss-cross ⬄ spherical expansion.

**Macrostructures in plants: xylem and phloem**

Xylem transports water and minerals. Phloem transports sugars and other metabolites, nutrients and hormones. During early spring, the xylem can also transport sugars with water.

Xylem cells are dead and hollow. There are two types: tracheen and tracheids.  
Tracheen: smaller, wider, only in angiosperms, have perforation plates where two cells meet for fast transport.  
Tracheids: longer, in all vascular plants, have pits (secondary cell wall present) for slower transport.  
Both are highly lignified.

In their close proximity, there are parenchymal cells, whose main function is the support of xylem cells with monolignols and enzymes for further lignification of the secondary cell wall. Since water travels antiparallel of the gravitation vector, there is a high underpressure requiring strong cell walls (high amounts of lignin).

The phloem has two types of cells: sieve cells and companion cells.  
Sieve cells: no cell nucleus, alive, contact with **sieve plates with pores** => create sieve tubes for mass flow.  
Companion cells: have cell nucleus, alive, contact with sieve plates via plasmodesmata for metabolic support.

Wood is highly lignified tissue. It is separated into heartwood (Kernholz) and sapwood (Splintholz). Both types have year rings (early and late). Heartwood is in the center of the tree and sapwood is around it. Both are dead (made of xylem cells), but heartwood makes no transport anymore – only stability.

**Tree inside-out**: heartwood, sapwood, cambium (stem cells for xylem and phloem), phloem, periderm (Kork).

**Part 3 & 4 – Shoot and Root development**

**Shoot development**

During germination, the seed induces skotomorphogenesis when there is no light. Else, it induces photomorphogenesis. COP1 inhibits HY5 activity in the nucleus, by binding to it and subsequently ubiquinating it (COP1 is an E3 ligase). In presence of light, COP1 is transported into the cytoplasm such that HY5 is active in the nucleus. Thus, photomorphogenesis is induced.

**Skotomorphogenesis**: leaves yellow, no photosynthesis, heterotroph (energy from endosperm), wide apical hook (to penetrate earth layers), wide organs, wide cotyledons (known as **triple response**).

**Photomorphogenesis**: loss of apical hook, green leaves, photosynthesis, short hypocotyledone, new leaves growing.

Gibberillic acid and abscisic acid both control germination. Gibberillic acid promotes germination while abscisic acid inhibits it. The plant perceives light via photoreceptors called phytochrome, cryptochrome and phototropins (both blue light + UV). Phytochrome is inactivated by far red light (730nm) and activated by near red light (670nm).

Germination is further controlled by auxin and ethylene. Ethylene synthesized from methionine via ACC synthase and ACC oxidase.

WUS and CLV are genes that control stem cell abundance. SAM stem cells are found at the tip of the shoot, the zone below is called the **rib zone**. The tip in the central zone produces CLV which inhibits WUS. WUS leads to cell division of stem cells when activated. **Leaf primordia** are the future leaves of the plant, that originate from SAM cells. Auxin intiates their development.

**Spiral phyllotaxy**: An angle of 137° is between two leaves (of different heights) in order to minimize area overlap, such that maximal sunlight falls on the leaves.

**Root development**

The whole root tissue originates from **RAM cells**. Specifically, there are 4 quiescent centers which from the stem cell center.

**A root inside-out**: central cylinder (phloem+xylem), ground tissue (cortex+endoderm), epidermis (location of root tissue), root hood (Wurzelhaube). The stem cells are in the tip of the root below the central cylinder.

**Important genes during root development**: PLT (activated by auxin during heart stage), SCR (expressed in endodermis and regulates cell division) and SHR (epistatic to SCR, expressed in central cylinder and diffuses to QC where it regulates cell division and differentiation).

Root hairs originate in the endodermis from trichoblasts. There are cells in the endodermis, which do not produce root hairs and they are called atrichoblasts. If a cell is between two cortex cells, it will become a trichoblast from a difficult signalling process and produce roots, while it will remain a non-hair cell when it is next to one cortex cell.

**Lateral roots**: There are pericycle cells in the outer segment of the central cylinder. There, PLT, SCR and SHR are also expressed which induces a lateral root. Auxin controls this process. It flows through the central cylinder and then back through the ground tissue and epidermis (2 ways).

**Casparian strips**

Those are strips that are in between the space of cells in the endodermis. They inhibit the apoplastic way. Thus, nutrients and minerals that flow in between the cells will eventually take a symplastic route and go into the cells. Casparian strips are made of lignin and suberin (a lipid). Thus, it is hydrophobic and a water-proof diffusion barrier. The endodermis cells have Casparian domains on their PM. There, they recruit specific proteins (CASP) and attract enzymes like NADPH oxidases and peroxidases that polymerize lignin via oxidation and suberin in order to create a Casparian strip.

**Part 5 – Flowering**

The process of flowering is regulated by the circadian cycle in principle. There are different activating moleclues such as GA, Constans, FT and other factors such as daylight length, temperature and winter.

A plant receives light as input which changes its intrinsic clock to express different genes. Phytochrome and cryptochrome both register light. Constans (=: Co) is a gene only stable during light conditions which activates the flowering locus T (=: FT) gene. FT is produced in the leaves and it travels to the tip of SAM. There, it activates apetala1, which induces changes which creates the **floral meristem** out of SAM. The floral meristem is the origin of sepals, petals, stamen and carpel. CAL, LEAFY and AP1 are necessary for flowering and are known as the floral meristem identity genes.

Therefore, FT is a **florigen** (a gene/protein that induces flowering). FT encodes SOC1 which interacts with FD to activate AP1 and others. SOC1 is inhibited by FLC.

The differentiation of the floral meristem organs is described by the ABC model, which consists of the three genes AP1, AP3 and AG (Agamous), which are MADS box genes. The following relationship holds true: AP1 => sepals; AP1+AP3 => petals; AG => carpel; AG+AP3 => stamen. (**define:** AP1 = A, AP3 = B, AG = C).

**Vernalisation** is the process of immediate flowering in spring after winter. During winter, FLC is expressed, which inhibits FT and other flowering mechanisms. Epigenetic changes in FLC allow vernalisation to take place. These plants are called winter annuals. Summer annuals flower in summer (without long, cold winter exposure).

**Grafting experiment**: …

**Part 6 – Photosynthesis (macrostructure)**

**Photosynthesis reaction (simplified)**: 6 CO2 + 6 H2O 🡪 glucose + 6 O2

The photosystems contain macromolecules that are capable of capturing photons and transmitting light energy in a chain of steps. Thus, the sun is the primary energy source of all photosynthetic active lifeforms.

**Light compensation point**: Light intensity where CO2 assimilation is balanced (no net loss/win).

There is oxygenic (electron donor: H2O) and anoxygenic (electron donor: anorganic, like H2S) photosynthesis. Plants only do oxygenic photosynthesis. 15% of the total CO2 is assimilated by plants and cyanobacteria (each assimilates about 50%), of which 5.4% is finally converted into glucose. Plants absorb around 0.05% of the light that hits its surface. Age of photosynthesis was approximated through stromatoliths to be 3.5 Mia years.

**Thylakoids** are the main organelle for photosynthesis found in chloroplasts. They also produce ATP and recover NADPH. Beta-carotene, Chlorophyll a and b are both located in the intermembrane space. They contain delocalized electron centers allowing them to harvest photons. These three molecules form a LHPC (:= light harvesting protein complex) with a defined configuration. Several LHPCs make up the **antenna** (photosystem). Chlorophyll b is occurs predominantly at the periphery, due to an additional =O bond allowing it to absorb higher energetic photons. This energy is transmitted into the inner parts of the complex, where mainly chlorophyll a is found. The transmitted energy will be less than the initially absorbed energy due to energy loss (process also known as FRET). This energy transfer process is said to be very efficient. The **central core** consists of two chlorophyll a (called P680) which transfer electrons from the harvested energy. Before the photon energy reaches the central core, it passes the water splitting complex. It contains **4 Mn+** that are reduced ⬄ electrons are passed one by one to the central core, when all Mn+ are reduced.

This subsequent transfer of 4 electrons is necessary since: 2 H2O 🡪 O2 + 4e- + 4H+. Otherwise, radicals would be produced, which are highly toxic for the cell (cell death due to ROS).

**Further path (thylakoid membrane)**: PSII transports the electrons to PQ (=: plastoquinone) 🡪 Cyt 🡪 PC (=: plastocyanin) 🡪 PSI. ATP synthase is present near PSII. It produces ATP in the stroma using 4 protons (two are pumped in through PQ, the other two come from the PSII of the water splitting complex). NADP+ is reduced to NADPH at the stromal side of PSI.

**Regulation of NADPH and ATP ratio**: ATP is produced mainly at the stacked side of the thylakoid membrane (since protons are generated from PSII). Phosphorylation of LHPCs induces **state transition**. That site becomes unstacked and LHPCs leave the photosystem. PSI is always found in unstacked membrane to have better contact to the stroma (NADP+).

**Part 7 – Photosynthesis & photorespiration (pathways)**

**Calvin cycle**

3 phases: carboxylation, reduction, regeneration. It takes place in the stroma of chloroplasts.

**Carboxylation**: Ribulose-1,5-phosphate and CO2 are the substrates of RubisCO (has 8 katalytic sites) which produces two 3-PG.

**Reduction**: 3-PG is reduced to GAP using ATP and NADPH. One out of six GAPs leave the cycle and is transported into the cytoplasm of the cell where it is used for sugar production (final sugar: sucrose).

**Regeneration**: The 5 remaining GAPs are transformed back into 3 ribulose-1,5-phosphates. 8 enzymes are involved which catalyse 10 steps (7 reversible, 3 irreversible).

**Summary of Calvin cycle**: 3 ribulose (5C) + 3 CO2 + 6 NADPH + 6 ATP 🡪 6 GAP (3C), 5 GAP + 3 ATP 🡪 3 ribulose.

**Photorespiration**

RubisCO is capable of binding both CO2 and O2. A reason might be that during anoxic times, RubisCO only used CO2 carboxylation, since O2 was not present back then (no oxygenation possible). Selective pressure made CO2 a preference, but O2 is a possible substrate nonetheless. In photorespiration, O2 is used and CO2 is a product downstream. Also, chloroplasts, peroxisomes and mitochondria are involved in this process and their membranes are close to one another for easier transport.

The binding of O2 does not yield 2 3-phosphoglycerates, but a 3-PG and a 2-phosphoglyconate. The 3-PG follows the default pathway (Calvin cycle or sugar production). 2-phosphoglyconate is transported to a peroxisome where it undergoes two important reactions: oxygenation and transamination. Oxygenation yields glyoxylate (enzyme: glycolate oxidase) and transamination yields glycine (enzyme: glutamate glyoxylate aminotransferase). In the mitochondria, two glycine yield CO2, NH3 and serine via glycine decarboxylase. The NH3 is transported into the cytoplasm of a chloroplast where it is used for the production glutamine via glutamine synthetase.

**Uses of photorespiration**

Photorespiration acts against photoinhibition, that is, NADPH production without CO2 (too much NADPH present). Photorespiration also produces CO2. It yields less energy, less sugar (fewer GAPs) and accumulation of phosphoglyconate poses a problem.

**Def. carbon compensation point**: Point in a graph, where there is no net gain/loss of extracellular CO2.

CAM and C4 plants can omit photorespiration.

**Working mechanism of C4 plants**

C4 plants have a spatial barrier to inhibit photorespiration. There are mesophyll and bundle sheath cells. Bundle sheath cells are surrounded by mesophyll cells which are closer to the stomata (therefore, closer to CO2 and O2). This anatomy is called **Kranz anatomy**. **PEP carboxylase** uses PEP and CO2 as its substrate and yields oxaloacetate (C4). Oxaloacetate is transported from mesophyll cells to bundle sheath cells, where it decarboxylates (releases CO2) and loads RubisCO with it. The normal Calvin cycle takes place. Bundle sheath cells are free from O2 due to their spatial situation.

**Working mechanism of CAM plants**

CAM plants have a temporal barrier to inhibit photorespiration. During the night, they produce oxaloacetate via PEP carboxylase and PEP. Then, oxaloacetate is transformed into malate and stored as such during the night. After sunrise, malate is carboxylated and CO2 is released, ready to be loaded on RubisCO. The normal Calvin cycle takes place.

C4 plants evolved 30M years ago, CAM plants evolved 250-500M years ago. These mechanisms are an example of convergent evolution.

**Advantages of CAM/C4 plants**: Omit photorespiration, stomata are closed during the day => less H2O loss => survival in dry and low CO2 areas.

**Part 8 – Plant carbohydrates and respiration**

After a GAP exists the Calvin cycle via the triose phosphate antiporter (GAP out, phosphate in), two of them are transformed into fructose-1,6-biphosphate. This molecule goes into the hexose-phosphate pool, where it is transformed to either G1P or F6P. Sucrose phosphate synthase makes both of them to sucrose. Mostly, leaves produce sucrose due to their big surface and high numbers of chloroplasts.

Sucrose production is regulated by a demand after sucrose (feedback-loop) or by the availability of CO2 (feedforward-loop). 3 important key points of control: fructose-1,6-biphosphatase, sucrose phosphatase synthase, ADP-glucose pyrophosphorylase.

Plants store energy (sugar) as either starch, fructans or as raffinose sugars. Starch is created in starch granules in the plastids of chloroplasts. Starch consists of alpha-1,4-glycosidic bonds between glucose for linear elongation and alpha-1,6-glycosidic bonds for branching. Fructans are made of a glucose followed by many fructose molecules in vacuoles in the cytoplasm. Raffinose is sucrose+galactose.

**Enzymes for starch production**: ADP-glucose pyrophosphorylase (glucose-P to ADP-glucose (very active)), branching enzyme, debranching enzyme, starch synthase.

Transitory starch is only stored during the day, such that it can be used during the night or it is transported into non-photosynthetic organs such as roots.

There are two types of starch: amylopectin (organized branches create semi-crystalline zones) and amylose (unorganized, has amorphous zones).

**Respiration in plants**

Breakdown of glucose/fructose into pyruvate, which is fed into the CAC such that ATP and NADH can be regenerated.

**Simplified pathway**: sucrose decays via sucrose synthase 🡪 fructose and glucose into hexose-phosphate pool 🡪 F1,6BP via phosphofructokinase 🡪 GAP 🡪🡪 PEP 🡪 pyruvate via pyruvate kinase. Pyruvate is fed into the CAC in mitochondria via pyruvate transporter where it is oxidated. 1 pyruvate generates 4 NADH and 1 FADH2. In respiratory electron transport chain, 1 NADH pumps 10 H+ and 1 FADH2 pumps 6 H+.

The respiratory electron transport chain is made of NAD(P)H dehydrogenase (complex 1), succinate dehydrogenase (complex 2), complex 4 (reduction), electron carriers such as UQ and Cyt c and ATP synthase.

**Oxidative pentose phosphate pathway**

Happens parallel to glycolysis. Oxidation of pentoses transfers electrons to NADP+ and it produces F6P for the hexose-phosphate pool as well as GAP.

**Def. thermogenesis**: A process in which a plant cell pumps in H+ via the transmembrane protein “uncoupling protein” without producing ATP. This process generates heat such that certain chemicals can evaporate quicker.

**Part 9 – Lipid metabolism**

Plants produce lipids because they can use it as a good energy source (more reduced C-atom than in glucose, it costs many ATPs and NADHs though) and for cell wall synthesis. 1g of lipid mass contains 9 cal (1g of starch contains only 3.5 cal). Lipids are stored in pollen, seeds and in fruit bodies.

**Oil bodies** are made in the ER out of many TAGs. Their inside has no water and the outside contains amphilic phospholipids and oleosin proteins.

**Production of TAGs**: In plastids, pyruvate 🡪 acetyl-CoA (one C-atom is lost here) 🡪 malonyl-CoA 🡪 acyl-CoA (C16-18). Enzyme: acetyl-CoA carboxylase, FA synthase.  
Then, in ER: acyl-CoA + glycerol-P 🡪 TAG, enzyme: acyltransferase.

Some plants have RubisCO present during the loss of a C-atom: 3-phosphoglycerate + RubisCO with C 🡪 pyruvate, this pyruvate goes back into FA synthesis (not in Calvin Cycle).

**Remobilisation of lipids**: lipolysis:cytosol, gluconeogenesis:cytosol, glyoxylate cycle:glyoxysome, beta-oxidation:glyoxysome/peroxisome.

Lipolysis: TAG 🡪 fatty acids + glycerol, enzyme: lipase on surface of oil bodies.  
Beta-oxidation: fatty acids 🡪 acetyl-CoA + NADHs, enzyme: LACS, dehydratase, acetyl-CoA oxidase.

Glyoxylate cycle: acetyl-CoA 🡪 NADHs + FADH2.  
Gluconeogenesis: oxaloacetate 🡪 sugars, enzyme: PEP carboxykinase.

**Part 10 – Transport and minerals**

The leaves have their stomata open which leads to water evaporation. Thus, water in the roots flows upwards in the xylem (xylem has strong lignified cell walls to withstand the underpressure). This process is called **transpiration** and it is a passive transport since water flows along its gradient.

Sucrose transport takes place in the phloem, where the leaves are the source and the roots are the sink. The transport is opposite of the gradient and there are two types of transport: Type 1: Sucrose binds galactose resulting into raffinose. Symplastic transport delivers raffinose into the roots through plasmodesmata (since raffinose is bigger, there is no back flow). Type 2: Two membrane proteins (sucrose/H+ symporter, passive and H+/ATPase pump, active) transport sucrose to the roots. It is a secondary-active transport and does not involve any plasmodesmata between mesophyll cells and phloem.

Macronutrient ⬄ dry weight > 0.1g, else it is called a micronutrient.  
Macronutrients: N, P, S, Mg, Ca, K. Micronutrients: Cl, Fe, Zn, Mn, B, Mo, Cu, Ni.

**How the plant obtains NH3**

NO3- is taken up in the roots via nitrate transporter. Then in root cells in their cytoplasm and plastids: NO3- + nitrate reductase 🡪 NO2- + nitrite reductase 🡪 NH3. NH3 is added to glutamic acid via glutamine synthase to produce glutamate. The NH2 of glutamine is transferred to oxoglutarate via GOGAT to close the cycle and regenerate glutamic acid.

**Rhizobia**

Plants signal flavonoids. Bacteria in response secrete nod factor, such that the root hairs curl. Bacteria infect the root hairs and multiply there to produce a nodule. In this symbiosis, bacteria fixate N2 via nitrogenase complex to make NH3 for the plant: N2 + 8H+ + 16ATP + 8e- 🡪 2 NH3 + H2. The plant provides the bacteria with sugars and amino acids.

Ectomycorrhiza: optional symbiosis, fungal sheath on root surface, does not enter the cell itself, especially in lignified plants.  
Endomycorrhiza: intracellular hypha enter the cells (more intimate contact), obligatory symbiosis, especially in herbaceous plants.

**Part 11 – Phytohormones**

**Important plant hormones**

Isoprenoid-derived: GA, ABA, Zeatin (cytokine), Brassinosteroids (=: BR).  
Monoamine-derived: Auxin (=: IAA) from tryptophan, Ethylene from methionine, Salicylic acid (=: SA) from phenylalanine.  
Lipid-derived: Jasmonic acid (=: JA).

**Induction of processes by different phytohormones**

GA: induces cell expansion, internodium growth, germination and development of flower and fruit. Important enzymes for GA production: cyclases (proplastids), P450 monooxygenase (ER), dioxygenase (cytoplasm).

ABA: seed dormancy, bud dormancy, reduction of shoot growth, abscission of leaves and flowers, stomata closure. Antagonistic to GA. Important enzymes for ABA production: indirect: beta-carotene (from chloroplast), violaxanthin, xanthonine. Direct: from farnesyl diphosphate.

BR: cell expansion and cell elongation.

Auxin: cell elongation (synergy with BR), photo- and gravitropism, SAM differentiation, maintenance of RAM stem cells, root branching.

Cytokines: Shoot branching, RAM differentiation, cell division, germination, prevent ageing. Antagonistic to auxin in some aspects.

Ethylene: fruit body ripening, promotes ageing (= senescence). Important enzymes: ACC synthase and ACC oxidase with methionine as precursor molecule.

SA: immune response against biotrophs (bacteria, fungi, viruses). In humans: aspirin.

JA: defense response against herbivores and necrotrophs.

**Part 12 – Biotic and abiotic stress**

**Biotic stress**

Necrotrophs such as fungi secrete HC-toxins. These toxins inhibit histone deacetylase which is needed to active the plant immune response. It weakens the host, takes it over and kills it. **TTSS**, type-III secretion system, are enemy transport proteins that are added into the plant membrane such that enemy effectors (**virulence factors**) can be taken up. These molecules inhibit SA. (**PAMP triggered immunity** – immunity against bacterial flagellates). Effector-triggered immunity is the plant response against effectors (evolution of **R genes**). This response leads to a **hypersensitive response** (=: HR) that leads to apoptosis of the infected cell. This suppresses the spread of the pathogens very effectively.

Plants produce ROS such as H2O2 or superoxide to fight viruses and other pathogens. In turn, catalases and superoxide dismutase neutralize ROS. It also induces apoptosis for HR.

**Abiotic stress**

Adaption: inherited traits to a specific environmental stress passed on from generations. Acclimatisation: Reduced effect of a stress on an organism if it has been exposed to it before already.

**Def. resurrection plants**: Plants that survive in very hot areas. After drying out, they only need water to recover fully again. (Ex.: Craterostigma plantagineum).

**Def. wetland plants**: Plants that survive in very humid, low-oxygen areas. They have several specializations: **aerenchym** for bigger vessels which transport oxygen to the roots, **lenticels** for openings in the periderm at the stem, **pneumatophore** (roots grow out of the water).

**O3, ozone**: Dangerous for plants since it reacts with the membrane phospholipids of the PM 🡪 leads to holes and O3 can diffuse into the cell and react with DNA and proteins and cause damage.

**Heat-shock proteins** (=: HSPs) are only present during elevated temperature levels. Normal proteins denature and expose their hydrophobic core to the outside. This has the potential to form aggregates which is toxic for cells as they are non-functional. HSPs bind to the exposed hydrophobic parts to inhibit the formation of aggregates. **Heat-shock factors** (=: HSFs) as monomers bind to HSP70. When temperature is high, they dissociate and form trimeric HSFs which bind to the HSP promoter regions to activate HSP transcription. Phosphorylation of trimeric HSF unbinds it again. Trimeric HSF and HSP70 leads to monomeric HSFs again and HSP transcription is stopped.