

## LECTURE 1

- plant body is dynamic, plants exhibit indeterminate growth
- **plants are**
  - multicellular → single celled organisms that photosynthesize are not considered plants
  - eukaryotic → all plants have compartmentalized organelles
  - photosynthetic autotrophs → plants feed themselves using E from light, E from sun turns into sugars which are used to build their bodies
    - cellulosic cell walls
- plants gather their nutrients from extremely dilute sources
  - soil → water is present in films around soil particles
    - nutrients are present in 1mM or less conc. in the soil solution but the conc is higher in the plant body
  - air → oxygen and nitrogen
    - CO<sub>2</sub> is at 400 ppm
  - light → sunlight is more than sufficiently bright for photosynthesis, under shade light is less available
  - plant cells and bodies are built to maximize surface to volume ratio
- **Plant body organization** (plant structure → morphology)
  - level of organization
    - organ → tissue → cells
  - monocots: a major group of angiosperms
  - eudicots/dicots: a major group of angiosperms
  - angiosperms: a plant that has flowers and produces seeds enclosed within a carpel
  - gymnosperms: a plant that has seeds unprotected by an ovary or fruit
- **Plant organ system** → both systems are dynamic
  - shoot system: aboveground, takes CO<sub>2</sub> and light from the atmosphere
  - root system: below ground, gets water and nutrients dissolved from the soil
- organ system
  - tissue: group of cells consisting of one or more cell types that together perform a specialized function
  - organ: consists of several types of tissues that all together carry out a specific function, for example a leaf
    - 3 basic organs → roots, stems, and leaves
      - basic morphology of vascular plants demonstrates their evolution as organisms that draw nutrients from below and above the ground
      - root and shoot
        - roots rely on sugars that are produced by photosynthesis in the shoot system (which rely on water and minerals absorbed from the root system)
        - root and shoot system are connected by vascular tissue which facilitates transport between them
        - root is an organ that has important functions
          - anchors the plant
          - absorbing minerals and water
          - storing carbs
        - roots in monocots and eudicots (2 major groups of angiosperms)
          - most eudicots and gymnosperms have a taproot system
            - taproot: main vertical root
            - lateral roots/branch roots: arise from the taproot

- roots
  - root systems observed in dif species are diverse
  - diversity can be analyzed on 3 levels for shoots and roots
    - morphological
    - phenotypic plasticity
    - modified roots
  - to explain the diversity of root systems among systems that grow in the same habitat, biologists suggests that natural selection has favoured structures that minimize competition for water and nutrients
  - roots can be modified and can have specialized functions
- modified roots
  - adventitious roots—> roots that develop from the shoot system instead of the root system
  - prop roots —> corn plants have adventitious roots prop roots that help brace individuals in windy weather
  - pneumatophores —> from mangrove trees allow gas exchange to occur between root tissues and the atmosphere
- stems
  - nodes —> the points at which leaves are attached
  - internodes —> segments between nodes
  - axillary bud —> a structure that lies at the junction of the stem and petiole of a plant and has the potential to form a lateral shoot or branch
  - apical bud —> terminal bud, located near the shoot tip and causes elongation of a young shoot
  - apical domination —> helps to maintain dormancy in most axillary buds
- modified stems
  - not all stems grow vertically and they don't all need CO2 and photons
  - examples:
    - stems of cacti —> store h2o
    - stolons —> stems that run over the soil surface
    - rhizomes —> grown underground horizontally
    - tubers —> rhizomes modified to store carbs
    - thorns —> stems that protect the plant from herbivores (plant-eaters)
- Leaves
  - in most plant species the vast majority of photosynthesis occurs in leaves, the large surface area of leaves is good for the absorbance of photons
  - external anatomy of a typical leaf consists of the expanded portion called the blade and the petiole/stalk
  - monocots and eudicots differ in the arrangement of veins (the vascular tissue of leaves)
    - monocots —> parallel veins
    - eudicots —> branching veins
  - simple leaves: have a petiole and a single blade
  - compound leaves: bladed divided into leaflets
  - modified leaves: don't all function primarily in photosynthesis some perform other roles
    - onion leaves store food
    - aloe vera store water
    - pea tendrils ain in climbing

- poinsettia leaves attract pollinators
- pitcher plant leaves trap insects
- phenotypic plasticity → leaves do not grow continuously
  - example: oak tree leaves vary depending on the amount of sun to which they are exposed to
  - sun leaves → small surface area
  - shade leaves → large and broad
- **Tissue**
  - primary growth lengthens roots and shoots produced by apical meristems
  - meristems → popn of undifferentiated cells that are able to continuously divide and produce new cells, plants grow continuously bcs of meristems
  - apical meristems → located at the tip of each root and shoot
    - as the cells in the apical meristems divide, enlarge, and differentiate, root and shoot tips extend the plant body outward, allowing it to explore new space
    - this is primary growth → cells that are derived from apical meristems form the primary plant body
  - **apical meristems** in both the root and shoot give rise to 3 distinct pop of cells called the protoderm, ground meristem and procambium → give rise to 3 major tissue systems
    - protoderm → **dermal tissue (epidermis)**, single layer of cells that covers the plant body and protects it
      - dermal tissue system → first line of defence against pathogens
        - interface between the individual and the external environment
        - protect the plant body
      - made up of several different cell types, each of which has a distinct structure and function → epidermal cells, stomata, trichomes
        - epidermal cells → protects the surface, periderm
          - secrete the cuticle, waxy layer that covers the shoot system (protects and reduces water loss)
          - cuticle forms a barrier to protect the plant from viruses, bacteria, and the spores or growing filaments of parasitic fungi
        - stomata → regulates gas exchange and water loss, cuticle
          - allow CO<sub>2</sub> to enter photosynthetically active tissue
          - consists of 2 guard cells → change shape to open or close an opening called a pore
        - Trichomes → have an array of functions
          - protective hairlike appendages made up of specialized epidermal cells
          - found in shoot system, come in a wide variety of shapes, sized and abundance
          - depending on species → keep leaf surface cool by reflecting sunlight, reduce water loss by forming a dense mat that limits transpiration, provide barbs or store toxic compounds that thwart herbivores, trap and digest insects
        - \*\*woody plants protective tissue is called periderm, replace epidermis, trichomes are outgrowths of the shoot epidermis and can help with insect defense\*\*
    - ground meristem → **ground tissue system**, makes up most of the plant body and is responsible for photosynthesis and storage
      - internal to the vascular tissue is pith
      - external to the vascular tissue is cortex
      - includes cells specialized for storage, photosynthesis and support
      - photosynthesis and carbs storage takes place here
      - made up of 3 distinct cell types

- parenchyma
  - parenchyma cells
  - have thin and flexible primary walls
  - store starch, proteins and fats
  - lack secondary walls
  - fleshy tissue of many fruits
  - perform the most metabolic functions
  - retain the ability to divide and differentiate (totipotency)
    - allows gardeners to clone plants by making cuttings
    - if you cut a coleus stem and place it in water, parenchyma cells will divide to produce a callus, a mass of undifferentiated cells
- collenchyma
  - collenchyma cells
  - grouped strands and help support young parts of the plant shoot
  - have thicker and uneven primary cell walls
  - lack secondary walls
  - provide flexible support without restraining growth
  - abundant in elongating stems and in the petioles of leaves
- sclerenchyma
  - supporting elements in plants
  - rigid bcs of thick secondary walls strengthened with lignin
  - are dead at functional maturity (can not elongate)
  - 2 types
    - fibers cells → long slender and arranged in threads
    - sclereids cells → short and irregular in shape and have thick lignified secondary walls
- procambium → **vascular tissue system**, provides support and transports water, nutrients, and photosynthetic products between the root and shoot systems
- two types of vascular tissues
  - xylem (root to shoot): conveys water and dissolved minerals upward from roots into the shoots
    - two types of water conducting cells → have thick, lignin-containing secondary walls and dead at maturity
      - tracheids: found in the xylem of all vascular plants
        - narrow and elongated cells
        - thin with tapered ends
        - water flows between adjacent cells through pits
        - found in gymnosperms
      - vessel elements
        - shorter and wider cells
        - vessel elements align end to end to form long micro pipes called vessels
        - perforations and pits
        - found in angiosperms
  - phloem (shoot to root, up and down and side to side): transports organic nutrients from where they are made to where they are needed
    - sugar conducting cells of the phloem
    - two types of specialized parenchyma cells
      - sieve-tube elements: cells that transport sugar in angiosperms and;
      - companion cell: connected to sieve-tube element

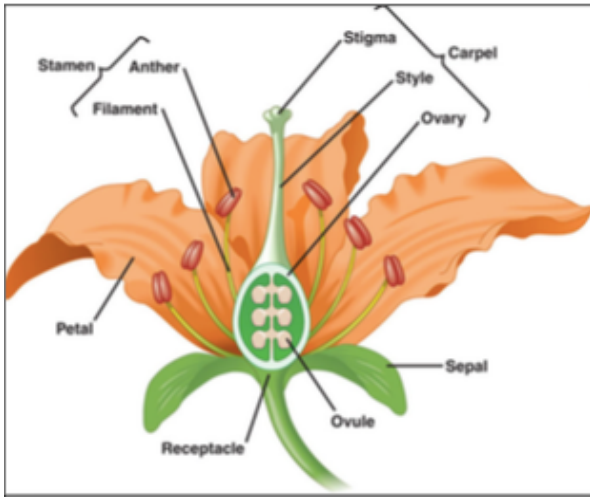
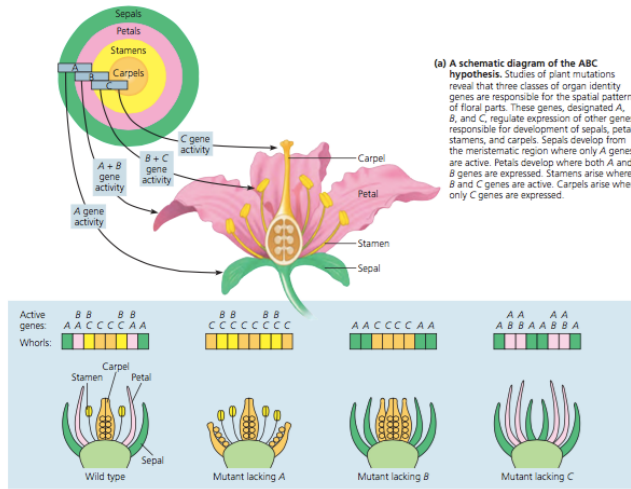
- long thin cells that have perforated ends called sieve plates
- responsible for transporting sugars and other nutrients
- alive at maturity but lack nuclei, chloroplasts, and other organelles
- vascular tissue of a stem or root is called the stele
- angiosperm → stele of the root is a solid central vascular cylinder where as the stele of stems and leaves is divided into strands of xylem and phloem
- Primary root system organization
  - root tip is covered by a root cap → protects the apical meristem as the root pushes through soil
  - growth occurs behind the root tip, in 3 zones of cells
    - zone of cell division
      - contains the apical meristem, cells are actively dividing and protoderm, ground meristem, and procambium
    - zone of elongation
      - comprised of cells that are actively increasing in length
    - zone of differentiation/maturation
      - older cells complete their differentiation into dermal, vascular and ground tissue
  - in angiosperm roots the stele is a vascular cylinder
    - eudicots → xylem is star-like in appearance with phloem between the “arms”
    - monocots → core of parenchyma cells is surrounded by rings of xylem then phloem
  - vascular tissues are grouped into vascular bundles which form strands running the length of the stem
  - ground tissue inside the vascular bundles is pith
  - ground tissue outside the vascular bundles is cortex
  - eudicots → vascular bundles are arranged in a ring around the stem’s perimeter
  - monocots → scattered throughout the ground tissue
- Secondary growth → widens shoots and roots
  - increases the amount of conducting tissue and structural support for primary growth to continue
  - secondary plant body consists of the tissues produced by the vascular cambium and cork cambium
  - cambium = secondary meristem
    - **differs from an apical meristem in 2 ways**
      - it is made up of single layers of meristematic cells that form cylinders running the length of a root or stem **vs** apical meristems form a dome shaped cell clusters localized at root and shoot tips
      - cells divide in a way that increases the width of roots and shoots **vs** apical meristem cells divide and extend root and shoot tip
  - vascular cambium
    - produces both phloem and xylem
    - new cells produced to the outside of the meristem differentiate into secondary phloem
      - functions in sugar transport, in combination with cork cambium tissues it forms bark
    - new cells produced to the inside differentiate into secondary xylem
      - functions in water transport and structural support, forming the structural material called wood
  - cork cambium
    - cork cells to the outside and a smaller layer of cells called the phelloderm to the inside
      - cork cells are impermeable to water and gases

- cork cambium, cork cells and phelloderm make up the **periderm** ( **\*\*woody plants protective tissue is called periderm, replace epidermis, trichomes are outgrowths of the shoot epidermis and can help with insect defense\*\***)
  - periderm protects the woody stem as it increases in girth and is part of the bark
- bark
  - protects the woody stem as it increases in girth
  - replaces the epidermal tissue as the woody stem or root matures
  - takes over the role of preventing water loss and protecting stem and toot from pathogens and herbivores
  - gas exchange occurs through small, spongy segments of the bark called lenticels
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- **Plant cells —> unique feature**
  - plant cells are surrounded by a cell wall —> supports/protects and defines its shape
  - cytoplasm of adjacent plant cells is connected via cytoplasm and segment of smooth ER that run through gaps in the cell wall
  - contain organelles, chloroplasts and vacuoles
  - plant cells do not change position once they form

## **Chapter 35.5: Growth, Morphogenesis, and cell differentiation produce the plant body**

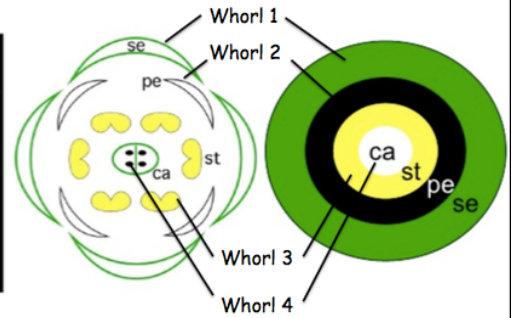
- development: specific series of changes by which cells form tissues, organs, and organisms
- developmental plasticity: the ability to alter form in response to local environmental conditions
- 3 overlapping processes in development
  - growth: irreversible increase in size
  - morphogenesis: process that gives a tissue, organ or organism its shape and determines the positions of cell types
  - differentiation: process by which cells with the same genes become different from one another
- Model Organisms: revolutionizing the study of plants
  - arabidopsis thaliana have catalyzed a research explosion in the last two decades
  - arabidopsis: a tiny weed in the mustard family, has no inherent agricultural value but is favoured model organism of plant geneticists and molecular biologists
  - easy cultivated in restricted space
  - amenable to selection under lab conditions
  - very small
  - short generation time → 6 weeks for a seed to grow into a mature plant that produces more seeds
  - arabidopsis genome → includes about 27,400 protein encoding genes, among the smallest known plants
    - only has 5 pairs of chromosomes
    - first plant to have its entire genome sequenced
  - plant cells are easy to transform with foreign DNA
  - transformation of arabidopsis cells is useful for studying how genes function and interact with other genes
  - biologists usually transform plant cells by infecting them with genetically altered varieties of the bacterium → agrobacterium tumefaciens
    - **agrobacterium tumefaciens has tumor inducing(Ti) plasmid**
    - **plasmid: circular molecule of DNA**
    - **agro injects T-DNA into plant cell**
    - **T-DNA integrates into the genome Opine synthesis enzyme in plant but opine catabolism enzyme in Agro**
- Growth: plane and symmetry of cell division
  - preprophase band: microtubules in the cytoplasm become concentrated into a ring
  - abnormal cell division does not affect leaf shape
  - mutant leaves grow more slowly than wild-type leaves, but their overall shape remain normal → leaf shape does not depend solely on precise spatial control of cell division
  - the plane of cell division does not determine the shape of plant organs, the symmetry of cell division (the distribution of cytoplasm between daughter cells) is important in determining cell fate
  - chromosomes may divide asymmetrically, plant cells don't always divide into two equal halves during mitosis
  - asymmetrical cell division: one daughter cell receives more cytoplasm than the other during mitosis, usually signals a key event in development
    - ex. guard cells from epidermal asymmetrical division
  - asymmetrical cell division give polarity → condition of having structural or chemical differences at opposite ends of an organism (root and shoot end)
    - polarity is most obvious in morphological differences

- Growth: orientation of cell expansion
  - water uptake typically accounts for about 90% of expansion → most of water is packaged in the large central vacuole
  - plant cells don't expand in all directions, they mostly grow on their main axis
  - innermost layer of cell wall = cellulose microfibrils → do not stretch and they are oriented horizontally
  - with the plane of cell division microtubules play a key role in regulating the plane of cell expansion
- Morphogenesis and Pattern Formation
  - during morphogenesis cells acquire different identities in an ordered spatial arrangement
    - ex. dermal tissue forms on the exterior and the vascular tissue in the interior, not the other way around
  - pattern formation: development of specific structures in specific locations
  - 2 hypothesis how cell fate is determined
    - 1. lineage-based mechanisms
      - cell fate is determined early in development and that cells pass on this identity to their progeny
    - 2. position-based mechanisms
      - cells final position in an emerging organ determines what kind of cells with lasers have demonstrated that a plant cell's fate is established late in development
  - gene expression and control of cell differentiation
    - cells of a developing organism can synthesize different proteins and diverge in structure and function even though they share a common genome
  - Shifts in Development: Phase Changes
    - phase changes: A shift from one developmental phase to another
      - morphological changes that arise from these transitions in shoot apical meristem activity
      - plant developmental stages occur within a single region, the shoot apical meristem (SAM)
        - establishment of SAM takes place in the embryo, continuous development from SAM, SAM form different organs at dif. stages of development
  - Genetic Control of Flowering
    - transition from vegetative growth to flowering is associated with the switching on of floral meristem identity genes
    - the protein products of these genes are transcription factors that regulate the genes requires for the conversion of the indeterminate vegetative meristems to determinate floral meristems
    - organ identity genes: a plant homeotic gene that uses positional information to determine which emerging leaves develop into which types of floral organs
    - ABC hypothesis: a model of flower formation identifying 3 classes of organ identity genes that direct formation of the 4 types of floral organs
      - A genes: switched on in the 2 outer whorls (sepals and petals)
      - B genes: switched on in the 2 middle whorls (petals and stamens)
      - C genes: switched on in 2 inner whorls (stamens and carpels)

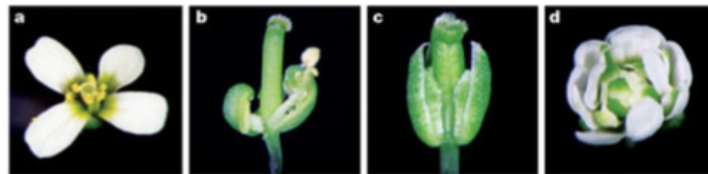
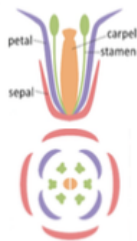


## Arabidopsis Flower

In Arabidopsis:  
 Whorl1 - 4 Sepals  
 Whorl2 - 4 Petals  
 Whorl3 - 6 Stamens  
 Whorl4 - 2 Carpels



## Arabidopsis homeotic mutants led to the identification of floral organ identity genes



	Whorl1	Whorl2	Whorl3	Whorl4	
WT	Sepal	Petal	Stamen	Carpel	
<i>ap1/ap2</i>	Carpel	Stamen	Stamen	Carpel	Class A activity
<i>pi</i>	Sepal	Sepal	Carpel	Carpel	Class B activity
<i>ap3</i>	Sepal	Sepal	Carpel	Carpel	
<i>ag</i>	Sepal	Petal	Petal	Sepal	Class C activity

## **Chapter 36**

### 36.1: Adaptations for acquiring resources were key steps in the evolution of vascular plants

- Evolution of Vascular Plants
  - algal ancestors of land plants absorbed water, minerals, and CO<sub>2</sub> directly from the water in which they lived
  - earliest land plants were nonvascular plants that grew photosynthetic shoots above the shallow fresh water in which they lived
    - the leafless shoots typically had waxy cuticles and few stomata → allowed them to avoid excessive water loss while still permitting some exchange of CO<sub>2</sub> and O<sub>2</sub> for photosynthesis
  - evolution of vascular tissue consisting of xylem and phloem made possible the development of extensive root and shoot systems that carry out long-distance transport
  - evolution has resulted in many structural adaptations for efficiently acquiring light from the sun
    - photosynthetic shoots
    - waxy cuticle
    - xylem, phloem
    - roots
- Shoot Architecture and Light Capture
  - stems are supporting structures for leaves and as conduits for the transport of water and nutrients
  - leaf size and structure account for much of the outward diversity in plant form
    - largest leaves = found in tropical rain forests
    - smallest leaves = found in species from dry or very cold environments (liquid water is scarce and evaporative loss from leaves is potentially more problematic)
  - phyllotaxy: arrangement of leaves on a stem (specific to each species)
    - determined by shoot apical meristem
    - most angiosperms have alternate phyllotaxy with leaves arranged in a spiral (137.5 degree)
  - leaf area index: ratio of total upper leaf surface of a single plant or an entire crop divided by the surface area of the land on which the plant or crop grows

- too many leaves at the top = too much shade below
  - leaves can't do photosynthesis + self-prune (apoptosis)
- leaf orientation
  - horizontally oriented leaves
    - low light conditions → capture sunlight much more effectively than vertical leaves
    - sunny regions → may expose upper leaves to overly intense light therefore injuring leaves and reducing photosynthesis
  - vertical plant leaves
    - essentially parallel to the leaf surfaces, so no leaf receives too much light and light penetrates more deeply to the lower leaves

## Chapter 37

- Nutritional requirements of plants
  - plants can't live on sugar alone
  - they need to synthesize their own macromolecules
  - plants need other elements other than the ones from CO<sub>2</sub> and water
  - soil provides most of these nutrients
- Plants require essential elements to complete their life cycle
  - soil → 4% of a plant's dry mass is inorganic substances
  - water → 80-90% of a plant's fresh mass
  - air → 96% of a plant's dry mass is from CO<sub>2</sub> assimilated during photosynthesis
  - 17 essential elements
    - macronutrients: plants require them in relatively large amounts → building blocks for nucleic acids, proteins, carbs, phospholipids, ...
      - carbon, oxygen, hydrogen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium
    - micronutrients: plants need them in very small amounts, they function as enzyme cofactors
      - chlorine, iron, manganese, boron, zinc, copper, nickel, molybdenum
- Symptoms of mineral deficiency
  - this depends on the nutrients
  - deficiency of mobile nutrients (magnesium) affects older organs more than young ones
  - deficiency of immobile nutrients (iron) affects younger organs more than older ones
  - most common deficiencies are those of nitrogen, potassium and phosphorus
- Soil contains a living, complex ecosystem
  - plants obtain most of their water and minerals from the upper layers of soil
  - living organisms play an important role in these soil layers
- Physical Properties of soil
  - Texture
    - soil particles are classified by size: largest to smallest
      - sand → silt → clay
    - soil is stratified into layers called soil horizons
    - topsoil consists of mineral particles, living organisms, humus, decaying organic material

- humus: complex organic substance formed by the remains of dead organisms
- soil solution consists of water and dissolved minerals in the pores between soil particles
- after a heavy rainfall, water drains from the larger spaces in the soil, but smaller spaces retain water bcs of its attraction to clay and other particles
- loams: most fertile topsoils and contain equal amounts of sand, silt, and clay
- Composition: inorganic (mineral) and organic components
  - inorganic
    - nutrients required for plant growth occur in the soil as ions
    - anions are negatively charged particles
      - stay in solution in soil water
      - readily available to plants but may wash away easily
    - cations are positively charged → K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>
      - adhere to negatively charged soil particles; this prevents them from leaching out of the soil through percolating groundwater
      - cation exchange, cations are displaced from soil particles by other cations
      - displaced cations enter the soil solution and can be taken up by plant roots
  - organic: plant nutrition often involves relationships with other organisms
    - plant and soil microbes have mutualistic relationship
    - dead plants provide E needed by soil-dwelling microorganisms
    - secretions from living roots support a wide variety of microbes in the near-root environment
- nutrient uptake
  - occurs just above the growing root tip, in the region called the **zone of maturation**
  - root hairs increase the surface area available for nutrient and water absorption
  - root hairs create a zone of nutrient depletion in the soil immediately surrounding them, which is why continued root growth is vital to a plant's health
- Additional ways of taking up nutrients
  - 1. mycorrhizae
    - most of these and plants are mutualistic
    - ectomyxorrhizal fungi (EMF): wrap around the exterior of the roots and radiate into the soil
    - Arbuscular mycorrhizal fungi (AMF): penetrate into root cells
  - 2. Nitrogen fixation
    - even though it comprises 80 percent of the atmosphere, plants and other eukaryotes cannot use atmospheric nitrogen gas
    - some bacteria are able to absorb N<sub>2</sub> from the atmosphere and convert it to ammonia, nitrates and nitrites = nitrogen fixation
  - Bacteria in the Nitrogen cycle
    - nitrogen can be an important limiting nutrient for plant growth
    - plants can absorb nitrogen as either NO<sub>3</sub><sup>-</sup> or NH<sub>4</sub>
    - most soil nitrogen comes from actions of soil bacteria

- Getting more nutrients
  - nitrogen bacteria take up residence inside plant root cells
    - ex. Rhizobium associate with plants in the pea family (legumes), nodules is where they are found
- Nutritional Adaptations of plants
  - most plants use proton pumps as a mechanism for importing nutrients from the soil and/or acquire nutrients from symbiotes
  - 99% of plants make their own sugars
- Unusual Nutritional Adaptations in plants
  - some plants have nutritional adaptations that use other organisms in non-mutualistic ways
  - epiphytes: grow on other plants and obtain water and minerals from rain
  - parasitic plants: absorb sugars and minerals from their living host plants
  - carnivorous plants: photosynthetic but obtain nitrogen by killing and digesting mostly insects

## **Chapter 10**

- What is photosynthesis
  - photosynthesis is the process that converts solar E into chemical energy
  - directly or indirectly, photosynthesis nourishes almost the entire living world
  - process that feeds the biosphere
- Autotrophs
  - defn: sustain themselves without eating anything derived from other organisms
  - producers of the biosphere, producing organic molecules from CO<sub>2</sub> and the other inorganic molecules
  - almost all plants are **photoautotrophs**, using the E of sunlight to make organic molecules
  - photosynthesis occurs in plants, algae, certain other protists and some prokaryotes
  - these organisms feed not only themselves but also most of the living world
- Heterotrophs
  - defn: obtain their organic material from other organisms
  - heterotrophs are the consumers of the biosphere
  - almost all heterotrophs, including humans, depend on photoautotrophs for food and O<sub>2</sub>
- Chloroplast

- chloroplast are structurally similar to and likely evolved from photosynthetic bacteria
- leaves are the major locations of photosynthesis
- their green color is from chlorophyll
- chloroplasts are found mainly in cells of the mesophyll (inner tissue of a leaf), the ground tissue of the leaf
- each mesophyll cell contains 30-40 chloroplasts
- chlorophyll is on the membranes of thylakoids, thylakoids can be stacked in columns called grana, granum is a stack of thylakoids
- chloroplasts also contain stroma, a dense interior fluid
- Photosynthesis
  - process of using light energy to produce carbs
  - $6\text{CO}_2 + 12\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
- Stages of photosynthesis
  - 1. Light reaction (in the thylakoid): convert solar E to the chemical E of ATP and NADPH
    - split H<sub>2</sub>O
    - release O<sub>2</sub>
    - reduce NADP<sup>+</sup> to NADPH
    - generate ATP from ADP by photophosphorylation
  - 2. Calvin cycle → in the stroma
    - begin with carbon fixation — absorb CO<sub>2</sub> into organic molecules
    - form sugar from CO<sub>2</sub>, using ATP and NADPH
- Photosynthesis Pigments
  - pigments: substances that absorb visible light
  - chlorophyll a: main pigment
  - chlorophyll b: accessory pigment, they broaden the spectrum used for photosynthesis, it absorb blue and red light and transmit green light
  - carotenoids: absorb excessive light that would damage chlorophyll, absorb blue and green light and transmit yellow, orange, or red light
  - pigments that absorb blue and red photons are the most effective at triggering photosynthesis
- Excitation of Chlorophyll by light
  - when a pigment absorbs light it goes from a ground state to an excited state which is unstable
  - when electrons fall back to the ground state photons are given off and its called fluorescence
- Photosystems
  - PSII: functions first and is best at absorbing a wavelength of 680 nm, the reaction-center chlorophyll a of PSII is called P680

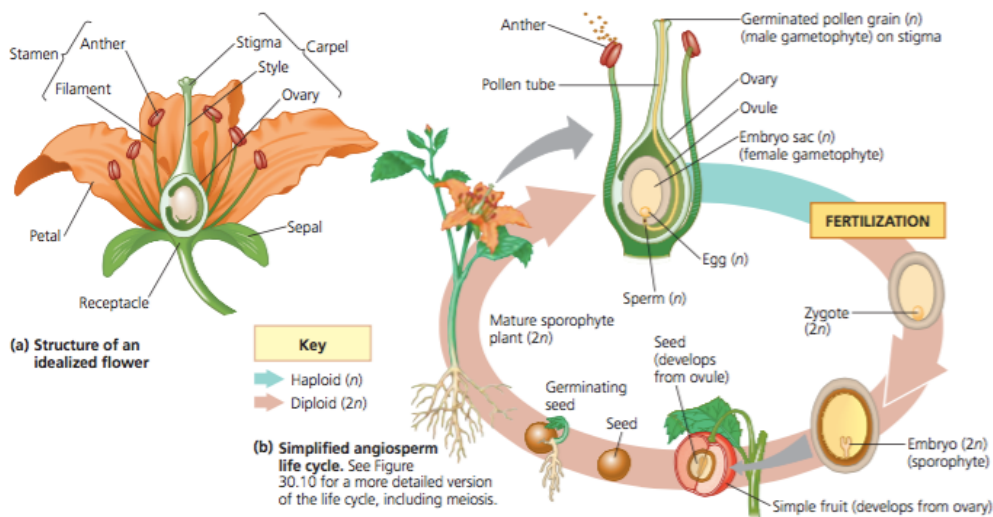
- split water, producing oxygen
- only operates non-cyclically
- PSI: best at absorbing a wavelength of 700nm, the reaction-centre chlorophyll a of PSI is called P700
  - can form NADPH when non-cyclic
  - can operate cyclically producing ATP
- Electron Flow
  - linear: primary pathway, involves both photosystems and produces ATP and NADPH using light E
  - cyclic: involves only photosystem 1 and produces ATP but not NADPH
    - no O<sub>2</sub> is released
    - cyclic electron flow generates surplus ATP, satisfying the higher demand in dif energy consuming processes
- Calvin Cycle and Carbon Fixation
  - E transformation of the light-dependent reactions and the carbon dioxide reduction of the calvin cycle are two separate but linked processes in photosynthesis
  - carbon enters the cycle as CO<sub>2</sub> and leaves as sugar named G3P
  - for the net synthesis of 1 G3P the cycle must take place 3 times fixing 3 molecules of CO<sub>2</sub>
  - calvin cycle has 3 phases
    - carbon fixation
      - $3\text{RuBP} + 3\text{CO}_2 \rightarrow 6 \text{ 3-phosphoglycerate}$
    - reduction
      - $6 \text{ 3-phosphoglycerate} + 6\text{ATP} + 6\text{NADPH}$
      - 5 G3P to step 3
      - 1 G3P yield to glucose/fructose
    - regeneration of CO<sub>2</sub> acceptor (RuBP)
      - $5 \text{ G3P} + 3\text{ATP} \rightarrow 3 \text{ RuBP}$
- Importance of Rubisco
  - rubisco is found in all photosynthetic organisms that use the calvin cycle to fix carbon and is thought to be the most abundant enzyme on earth
  - rubisco is inefficient because although it does catalyze the addition of CO<sub>2</sub> to RuBP it also catalyzed the addition of O<sub>2</sub> to RuBP
- Photorespiration
  - when O<sub>2</sub> and RuBP react in rubisco's active site, one of the products undergoes a process called photorespiration

- photorespiration undoes photosynthesis because it consumes E and releases fixed CO<sub>2</sub>
- Rubisco acts as both carboxylase and an oxygenase
  - reaction with CO<sub>2</sub> during photosynthesis
    - RuBP + CO<sub>2</sub> → two 3-phosphoglycerate → used in calvin cycle
  - reaction with oxygen during photorespiration
    - RuBP + O<sub>2</sub> → one 3-phosphoglycerate (used in calvin) + one 2-phosphoglycolate → when processed, CO<sub>2</sub> is released and ATP is used
- Plants have evolved a CO<sub>2</sub> concentration mechanism, utilizing a second enzyme, PEP carboxylase
  - C<sub>3</sub> PLANTS
    - RuBP + CO<sub>2</sub> —(rubisco)—→ two 3-phosphoglycerate (3 C sugar)
  - C<sub>4</sub> PLANTS (sugarcane, corn etc.)
    - 3 C compound + CO<sub>2</sub> —(PEP carboxylase)—→ 4-C organic acids
- Mechanisms for increasing CO<sub>2</sub> concentration (C<sub>4</sub> and CAM → function as CO<sub>2</sub> pumps)
  - C<sub>4</sub> photosynthesis
    - C<sub>4</sub> plants minimize the cost of photorespiration by incorporating CO<sub>2</sub> into four-carbon compounds in mesophyll cells, this step requires PEP carboxylase
    - PEP carboxylase has a higher affinity for CO<sub>2</sub> than rubisco does; it can fix CO<sub>2</sub> even when CO<sub>2</sub> concentrations are low
    - these four carbon compounds are exported to bundle-sheath cells, where they release CO<sub>2</sub> that is then used in the calvin cycle
  - Crassulacean acid metabolism (CAM)
    - some plants including succulents use CAM to fix carbon
    - CAM plants open their stomata at night absorbing CO<sub>2</sub> into organic acids
    - stomata close during the day, and CO<sub>2</sub> is released from organic acids and used in the calvin cycle thus minimizing the effects of photorespiration
- Fate of sugar produced by photosynthesis
  - G3P molecules produced by the calvin cycle are often used to make glucose and fructose → makes sucrose
  - rapidly photosynthesizing cells where sucrose is abundant, glucose is temporarily stored in the chloroplast as starch
  - because starch is not water soluble it is broken down at night and used to make more sucrose for transport throughout the plant

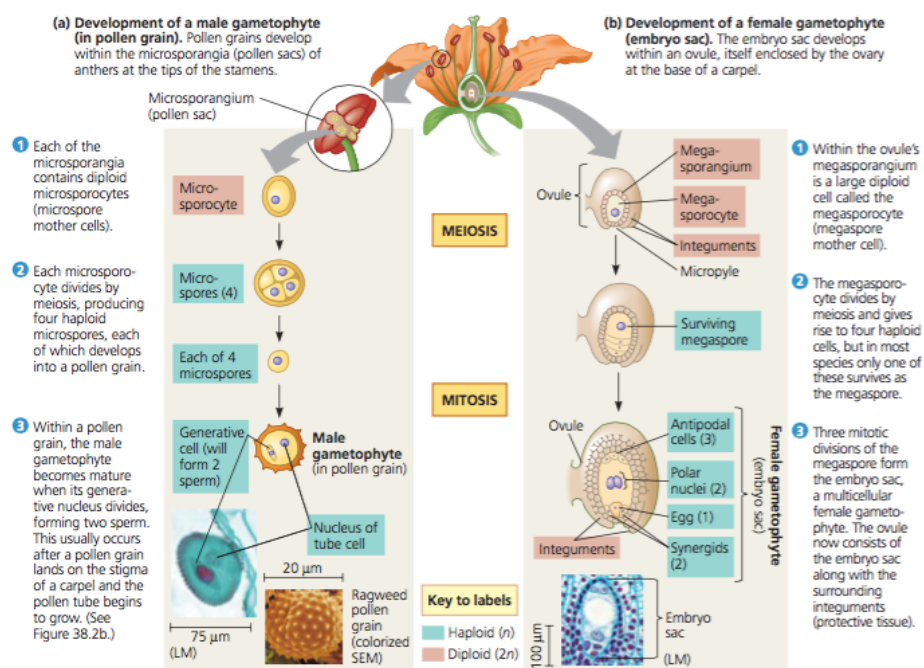
## Chapter 38

38.1: flowers, double fertilization and fruits are unique features of the angiosperm life cycle

- diploid plant = sporophyte → produces haploid spores by meiosis
- spores divide by mitosis = multicellular gametophytes
- fertilization = fusion of gametes → diploid zygotes
- in angiosperms the sporophyte is the dominant generation
- angiosperms and gymnosperms are seed plants
- flower structure and function
  - flowers = reproductive shoots of angiosperm sporophytes, composed of 4 whorls of modified leaves called floral organs → sepals, petals, stamens and carpels
  - stamens and carpels → reproductive organs
    - stamen: consists of a stalk called the filament and a terminal called the anther and inside the anther there are chambers called microsporangia (pollen sacs, produce pollen)
    - carpel: has an ovary, at its base and a long slender neck called the style, and the top has a sticky end called the stigma (captures pollen)
      - the ovary has one or more ovules, the number of ovules depends on the species
      - pistil is sometimes referred to as a single carpel or two or more fused carpels
  - sepals and petals → sterile
    - sepals: enclose and protect unopened floral buds (leafy)
- complete flowers have all four basic floral organs
- incomplete flowers → lack sepals, petals, stamens, or carpels (ex. grass flowers lack petals)
  - lacking functional stamens or carpels, they are sterile and unisexual



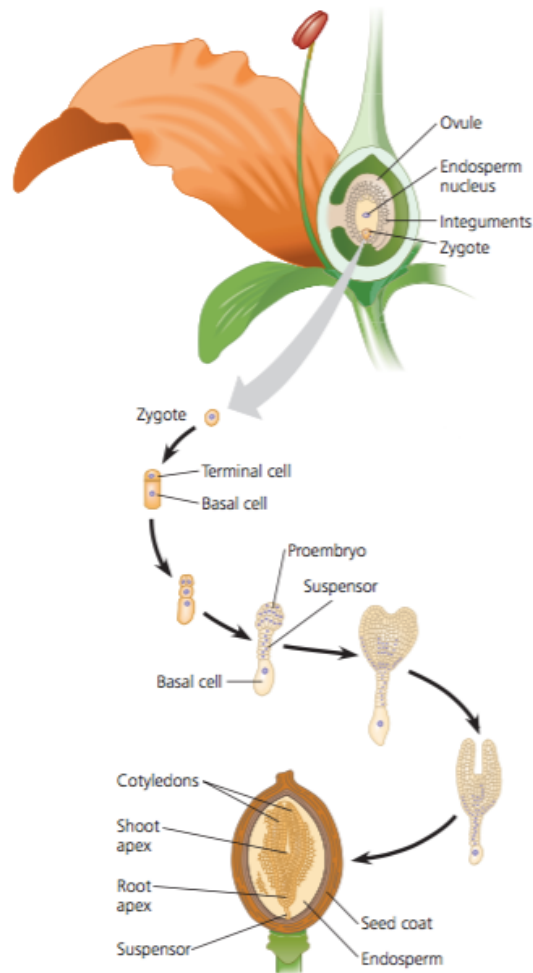
- development of male gametophytes in pollen grains
  - each anther contains 4 microsporangia (pollen sacs)
  - each microsporangia contains many diploid cells called microsporocytes
  - each microsporocyte undergoes meiosis → forms 4 haploid microspores → each give rise to a haploid male gametophyte consisting of only two cells: generative cell and the tube cell (generative cell and tube cell = pollen grain)
  - after the microsporangium breaks open and releases the pollen, a pollen grain may be transferred to a receptive surface of a stigma, which is where the tube cell will produce a pollen tube (long cellular protuberance that delivers sperm to the female gametophyte)
    - as a pollen tube elongates through the style the generative cell usually divides and produces two sperm cells, which remain inside the tube cell
    - the pollen tube grown through the style into the ovary where it release the sperm cells in the vicinity of the female gametophyte
- development of female gametophyte
  - there are over 15 variations in the development of the female gametophyte (embryo sac)
  - entire process occurs in a tissue within each ovule called the megasporangium
  - 2 integuments (layers of sporophytic tissue that will develop into the seed coat) surround each megasporangium except at a gap called the micropyle
  - female gametophyte development begins when one cell in the magasporangium of each ovule (megaspore) enlarges and undergoes meiosis, producing four haploid megaspore



- pollination
  - pollination: transfer of pollen from an anther to a stigma, accomplished by wind, water or animals
- coevolution of flower and pollinator
  - coevolution: joint evolution of two interacting species, each in response to selection imposed
  - natural selection favours individual plants or insects having slight deviations of structure that enhance the flower-pollinator mutualism
- double fertilization: joining of a female gametophyte with 2 male sperm
  - at the the time of pollination the pollen grain typically consists of only the tube cell and the generative cell
  - after a pollen grain lands on a suitable stigma, it absorbs water and germinates by producing a pollen tube
  - the nucleus of the generative cell divides by mitosis and forms two sperm
  - „It begins when a **pollen grain** adheres to the stigma of the **carpel**, the female reproductive structure of a flower. The pollen grain then takes in moisture and begins to **germinate**, forming a **pollen tube** that extends down toward the **ovary** through the style. The tip of the pollen tube then enters the ovary and penetrates through the **micropyle** opening in the ovule. The pollen tube proceeds to release the two sperm in the megagametophyte.”
  - upon reaching the female gametophyte one sperm fertilizes the egg, forming the zygote
  - the other sperm combines with the 2 polar nuclei, forming a triploid (3n) nucleus in the center of the large central cell of the female gametophyte → give rise to the endosperm (food storing tissue of the seed)
  - double fertilization ensures that endosperms develops only in ovules where the egg has been fertilized
- seed development, form, and function
  - after double fertilization, each ovule develops into a seed and the ovary develops into a fruit enclosing the seed(s)
- endosperm development
  - endosperm usually develops before the embryo does
  - endosperm stores nutrients that can be used by the seedling after germination
- embryo development
  - first mitotic division of the zygote splits the fertilized egg into a basal cell and a terminal cell
  - terminal cell gives rise to most of the embryo
  - basal cell continues to divide producing a thread of cells called the suspensor → anchors the embryo from the parent plant
    - suspensor helps carry in transferring nutrients to the embryo from the parent plant and in some species of plants from the endosperm
  - terminal cell divides several times and forms a spherical pro embryo attached to the suspensor
    - cotyledons begin to form as bumps on the pro embryo
      - eudicots → form two cotyledons
      - monocots → one cotyledon

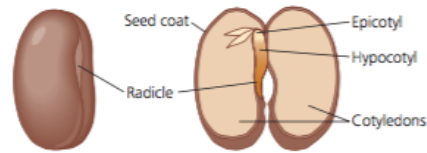
- in between the two cotyledons is the embryonic shoot apex

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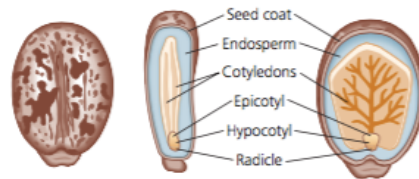


**▲ Figure 38.7 The development of a eudicot plant embryo.** By the time the ovule becomes a mature seed and the integuments harden and thicken into the seed coat, the zygote has given rise to an embryonic plant with rudimentary organs.

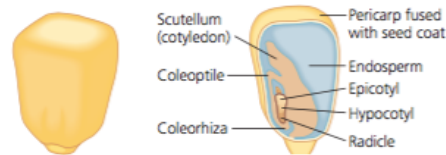
- structure of the mature seed
  - during last stage of maturation the seed dehydrates until its water content is only about 5-15% of its weight
  - embryo enters dormancy → stops growing and its metabolism nearly ceases
  - embryo and food supply (cotyledons, endosperm) are enclosed by a hard protective seed coat



(a) **Common garden bean, a eudicot with thick cotyledons.** The fleshy cotyledons store food absorbed from the endosperm before the seed germinates.



(b) **Castor bean, a eudicot with thin cotyledons.** The narrow, membranous cotyledons (shown in edge and flat views) absorb food from the endosperm when the seed germinates.



(c) **Maize, a monocot.** Like all monocots, maize has only one cotyledon. Maize and other grasses have a large cotyledon called a scutellum. The rudimentary shoot is sheathed in a structure called the coleoptile, and the coleorhiza covers the young root.