Dermal

Periderms and epidermis

Ground

Bulk of plant body, tissues that are not dermal or vascular

- Photosynthesis, storage and support
- **cortex**: between dermal and vscular tissues
- **pith**: in vascular cylinder

1. **Parenchyma**: general purpose cells of the plant, alive at maturity
    - most common and least specialized
    - **Where**: majority of ground tissue in leaves, stems, roots, flowers and fruits
    - **Appearance**: Polyhedral, large, thin and primary walls, highly vacuolated(bubbles)
    - **Funtion**: photosynthesis, storage, structure and transportation
    - Also vascular tissue
2. **Collenchyma**: Provide flexible support, alive at maturity
    - **Where**: leaves, petioles and stems but rarely in roots
    - **Apperance**:
        - unevenly (irregular) thick primary walls (lack secondary walls)
        - Usually located directly beneath eprdermis in discrete bundles or a ring
        - Usually elongated and various shapes
    - **Function**: flexible mechanical support
        - more collenchy in response to mechanical stressors
        - **Turgor pressure**: parenchyma and collenchyma provide support by water content in vacuole
            - **turgid** or swollen when full of water (high turgor pressure)
            - **Wilting** is a physical symptom of loss of water in vacuole
3. **Sclerenchyma**: rigid support with lignin reinforced secondary walls, dead at maturity
    - Abundance of sclerenchyma <=> increased plant size
    - in regions where growth has stopped and flexibility not required
    1. **Fiber**:
        - **Where**: associate with vascular tissue, found in stems, tree trunks.
        - **Appearance**:
            - elongated with thick cell walls (secondary wals fortified with lignin)
            - can be 0.05mm wide and 70mm long
            - clustered in groups
        - **Function**: Provide mechanical support and protection for surrounding cells
    2. **Sclereids**:
        - **Where**: Associated with vascular tissue. In leaves and hard shells and nuts (fruit pits)
        - **Appearance**:
            - NOT elongated

        - various shape determined by adjacent air spaces, often cubical or spherical. (Astrosclereids star shaped)
        - lignin fortified secondary walls
    - **Function**: mechanical support and protection for surrouding cells

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Stem Function and Anatomy

- **shoot**: A stem and its leaves
- **Functions**:
    - conducting water, minerals, and organic molecules between roots and leaves
    - supporting the weight of leaves
    - moving leaves towards light and away from shade
    - withstanding wind and other mechanical stressors
    - storage and reproduction in specialized stems
- seed:
    - seed coats, cotyledon(子叶, embryonic leaf), endosper(store food), Hypocotyl(embryo stem?)
    - Plumule(embryonic shoot) in monocot, but only future location of that in dicot seed.
- **Meristem**: small populations of rapidly proliferating(dividing) cells => produce all matrure organs of a vasular plants
    - often protected by **bud scales** and leaf primordia (embryonic leaves)
    - **SAM**: shoot apical meristem
        - Grow in length (cells dividing below growing point)
        - Located at **primary stem tip (terminal end)**
        - dormant before growing season
    - **Axillary buds**:
        - contain bud primordia (meristems)
        - Grow outwards, forming leaves/flowers/branches from meristems in it.
        - located along **internodes**: space between leaf attachment points
        - leaves are attached to stems at **nodes**
        - Dormant axillary buds located between the stem and the leaf petiole become branches, leaves or flowers
        - **stupules**: paired, leaf-like appendages at base of leaf.
- Specialized stems:
    - **tendrils**: fastening to surfaces (cucumber, Boston ivy)
    - **Stolons(runners)**: horizontal stems that grow above ground and have long internodes (strawberry). Vegetative reproduction
    - **Bulb**: large buds with fleshy leaves attached to short stem (onion, tulips)
    - **Corms**: resemble bulbs, almost entirely made up of stem tissue, with paperly leaves (crocus, gladiolus)
    - **Cladophylls**: flattened, leaf-like stems (orchids, prickly pear cactus)
- Vascular tissue Patterns:

- **protostele**:
  - solid xylem core, phloem surrounds xylem, cortex, epidermis => earliest plants and some SVP
  - **siphonosteles**: Pith, phloem, xylem, phloem, cortex, epidermis. Commin in ferns.
  - **Eusteles**: Epidermis, cortex, vascular bundle (phloem, xylem), pith
    - some dicots and some gymnosperms: tight ring
    - most dicots and some gymnosperms: loose ring
    - **Vascular bundles**:
      - Collateral (sunflower): fiber, phloem, xylem
      - Bicollateral (cucumber) phloem, xylem, phloem
    - **Atactostele**: vascular bundles scattered, variation of eustele
      - **most monocots**
      - two large vessels with several smaller ones, an air space, sieve tubes and companion cells
      - surrounded by schlerenchyma sheath

Monocots and Dicots

	Dicot Angiosperms	**Monocot Angiosperms**
seed	Two cotyledons	One cotyledon
flower	mostly primitive	mostly advanced
Flower parts	multiples of 4 or 5	multiples of 3
leaves	reticulate veins, petiole	parallel primary veins, sessile, leaf sheath
root	tap root, pith	fibrous root
vascular bundle	eustele loose ring	atactostele, scattered
cambium	vasc & cork present (primary and secondary growth)	vasc absent (predominantly primary growth)

- Seed:
  - 2 cotyledons in dicot
  - 1 cotyledon in monocot
- Shoots: (**MANY EXAMPLES ON SLIDES**)
  - Dicot:
    - broad leaves, **reticulate veins**, **petiole**
    - **Deciduous trees and shrubs**: oak, maple..
  - Monocot:
    - narrow leaves, **parallel primary veins**, sessile (direct) attachment. **Leaf sheath** wrapped around stem
    - **Warm climate trees**: palms

- Flower:
  - Dicot: most primitive flowers, multiples of 4 or 5
  - Monocot: most advanced flowers, multiples of 3
- Vascular seed plant stems:
  - **Gymnosperm**: Eustele with tight rings
  - Dicot: Eustele
  - Monocot: Atactostele
- roots:
  - **Gymno**/dicot: Epidermis, exodermis, cortex, endodermis, pericycle, primary phloem, primary xylem, **Fibrous root systems**
  - Monocot: Epi, exo, cortex, endo, pericycle, px, pp, **pith**, **tap root system**

Primary growth in shoots and roots

- increase of **length** by cellular division of the apical meristem
- meristems present in ALL plants (mosses to seed plants)
- **SAM/RAM**: length. Stem outwards in **axillary buds**, roots branch with **lateral roots** (pericycle).
- **initials**: cells of meristem. totipotent. mitosis to daughter cells, differentiation to derivative cells (or go back to initial?)
- **SAM**:
  - stem, leaves and flowers.
  - dividing cells are small, dense with sytoplasm. Mature, differentiated cells are larger and highly vacuolated.
- **LAB5: overwintering**:
  - *Bundle scars* mar the vascular (conduction) tissue with leaf scars
  - *Deciduous* trees and shrubs lose all leaves annually. After leaves fall, have dormant axillary buds with leaf scars below.
- **RAM**:
  - resides in quiescent center of root tip
  - each lateral root has their own RAM

Secondary Growth (Vascular cambium) in shoots

- An increaset in **girth** generated by cell divisions of **lateral meristems**
- observed in **stems** and **roots** of woody plants
- All gymnosperms, some perennial tree and shrub angiosperms (20% of dicots and 5% of monocots)
- **Lateral meristems** form in regions of maturation in stems and roots that have completed growing in length
- Cylindrical and **radial expansion**
- Why needed?
  - Most angiosperms do not have or need secondary growth.

    - Annual plants -> NO
    - increase conduciton and support
    - replace old tissues so do not have to maintain over hundreds of years
- Secondary xylem and phloem
    - **Xylem**: water conducting tissue 'root to shoot.
    - **Phloem**: metabolite conducting tissue 'shoot to root'
    - function the same as primary
    - secondary xylem tends to have **thicker walls** due to increase in **lignin** content
    - lignin 2nd most common organic compound on Earth
- Wood = secondary xylem
    - largely of dead cells, tracheids or vessel members
    - highly lignified
    - only the more recently formed layers of secondary xylem conduct water and minerals.
    - primary and older secondary xylem become inactive
        - Dicots form **hardwood**: xylem are made of fibers and vessels (hard, more lgnin)
        - Conifer form **softwood**: xylem consists primarily of tracheids (softer, less lignin)
- Secondary phloem
    - only more recent layers of living secondary phloem conduct photosynthetic products
    - promary and older secondary phloem become stretched and broken as vascular cambium push them outward (bark)
- Growth patterns (ring)/dendrochronology
    - size of cells varies with season: small in later summer (**summerwood**/late wood), large in the spring (**spring wood**/early wood)
    - stress = less growth
    - **Heartwood**: older, non-conducting rings of xylem in the center of the trunk or root. Usually darker
    - **Sapwood**: outer xylem rings that still conduct water and minerals.
    - **Antibacterial** and **antimicrobial** compounds are produced by parenchyma
        - Antimicrobials: Resin
            - **Pine** and **nonflowering** plants.
            - Flow through **resin canals** in secondary xylem and phloem, periderm and leaves.
        - Latex
            - **10 % of flowering** plants produce **latex**(乳胶)
            - blocks entry of pathogens, contains compounds with growth inhibitory properties
            - deter insect and animal predators
            - produced in vessel or special cells called **laticifers**, network not as visible as resin canals
            - close to surface, released upon injury
- Lateral Meristems (**Cambium**)

- Vascular cambium
  - secondary xylem (wood) & secondary phloem (bark)
  - Forms from dedifferentiated cortex and procambium
  - produces secondary xylem and secondary phloem in between primary xylem and primary phloem
  - **Auxin hormone** signals the formation of vascular cambium from (in dicot and conifer stems):
    - **Fusiform initials**: cells derived from residual procambium cells located between primary xylem and phloem
    - **Ray Initials**: arise from parenchyma cells or cortex (ground tissue) between vascular bundles
- Cork cambium (Phellogen)
  - Two types of dermal tissu: **epidermis** and **periderm**
  - During secondary growth, **cork cambium** (phellogen) replaces epidermis and cortex with **periderm** (cork, cork cambium, phelloderm)
  - **cork(phellem)**: forms to the outside of the cork cambium. Consists of dead cells when mature
  - **phelloderm**: forms to inside and consists of thin layer of living parenchyma cells
  - Expansion of cortex causes cortex to break apart and fall off stem.
  - Subsequent cork cambia arise from secondary phloem to the inside
- Bark = **Periderm**
  - consists of all tissues external to the vascular cambium
    - **Inner bark**
      - living secondary phloem, vascular cambium, inner most cork cambium and any remaining cortex
      - **carries sugar** and other organic molecules
    - **Outer bark**
      - dead tissue (includes dead secondary phloem, all layers of periderm outside of most recent cork cambium)
      - provides protection from abiotic and biotic stress
  - Bark is typically thinner than the woody portion of stem. Essential for tree viability
  - Pattern variable but characteristic for different species
  - Bark = protection
    - preventing water loss and infection by pathogenic organisms and predation
    - cork cambium cannot grow in diameter, must reform inside the old one (toward a source of water and nutrients)
    - cork cells enlarge and become impregnated with **suberin**
  - **Suberin**
    - a complex polyester bioplymer that is lipophilic
    - in stems and roots, barrier of water and solutes.
    - make cork cells water proof

        - nothing gets in, nothing gets out
    - Gas Exchange
        - **lenticels** are small openings in outer bark of stems and roots that allow gas exchange in tissue blocked by suberin coated cork cells
  - Antimicrobials
    - **Resin**
  - **Dedifferentiate**
    - From derivative cell
    - can be observed in vegetative propagation (asexual reproduction)
  - More secondary xylem is produced than phloem. Phloem produced before xylem.
- Monocot: no vascular cambium, no true secondary growth. Only thicking of ground tissue, no annaul growth rings.

Leaves and Epidermis

- Most dicot mature leaves have:
  - petiole
  - flattened blade (lamina)
  - network of vascular bundles
  - stipules at base of petiole
- Pattern
  - parallel veins in monocots and gymnosperms
  - Netted or reticulate veins in dicots and ferns
- phyllotaxy
  - Alternate: one leaf per node
    - Distichous for non spiral?
  - Opposite: Two leaves per node (Decussate?)
  - Whorled: Three or more leaves at a node (Verticillate?)
  - Leaf primordia form from meristem in pattern that determines phyllotaxy of mature organs.
- Abscission (落叶？)
  - Deciduous plants drop(abscise) leaves seasonally
  - abscission zone near base of petiole
  1. Protective layer of cells coated and impregnated with suberin to seal off leaf scar
  2. Separation layer of pectins in the middle lamella are broken down by enzymes, at petiole and stem border
- Internal structures
  - **Epidermal tissue**: protection and gas exchange
    - Devoid of chloroplasts
    - Coated with **Cuticle** and **Surface waxes** provide protection from water loss, light irradiation and pathogen attack
    - The surface waxes also serve as a semi-permeable barrier and regulate gas exchange and evaporation of water
    - **Trichome hairs** control moisture loss and predation

        - uni- or multi cellular outgrowths of the epidermis
        - primary function is **plant defence**, particularly against insects
        - can be simple physical barriers and deterrents to insect movement OR can be glands secreting essential oils
            - **Essential oils**: prevent predation (taste) and act as insect repellant and antimicrobials. -- scent
    - Waste materials may accumulate in peridermal cells
    - **Stomata** for gas exchange:
        - lower epidermis cutin perforated by
        - regualte **gas exchange** between leaf interior and atmosphere
        - more sophisticated than lenticels, can open and close with turgor pressure of **guard cells**
- **Mesophyll**: photosynthesis
    - **Palisade mesophyll**
        - elongated cells, below upper epidermis, tightly packed
    - **Spongy mesophyll**
        - below, loosely pack, air spaces to allow CO2 diffusion
    - Both involved in photosynthesis, contain chloroplasts
    - Monocot do not have differentiated palisade and spongy layers.
        - often have **bulliform** cells flanking the central vein, partly collapse under dry conditions, causing leaf to fold and reducing transpiration.
    - **Vascular tissue**: form veins to transport organic molecules, water and minerals between leaves and the rest of the plant.

- Specialized leaves
    - **Succulent**: (water) storage
        - parenchyma cells with large vacuoles for water storage
        - often found in desert(arid) plants
        - leaves appear swollen and have shiny appearance due to thick waxy cuticle
    - **Spines**: Defence
        - reduce leaf surface and water loss, protect from herbivory
        - **NOT** spelized leaves
            - **Throns**: modified stems arising from leaf axils
            - **Prickles**: outgrowths from epidermis or cortex
    - **Floral leaves**: Bracts
        - bases of flowers or flower stalks, **Poinsettia** and **Clary's sage**
    - Nutrients and Reproduction: **Flower-pot leaves**
    - Insect trapping: **Venus fly traps**, **Sundews**, and **Pitcher plants**
        - Grow in nitrogen and mineral deficient soils such as swampy areas and bogs. Obtain nutrients from digesting insects.

Roots

Structure and functions

Functions

- **vascular transport**: Conduit of vascular cylinder (stele): xylem and phloem
  - Xylem: water conducting tissue (root to shoot)
  - Phloem: food conducting tissue (shoot to root)
- **Absorption** of water and nutrient minerals (N, P, K)
- **Anchor** (stablize) plants into soil
- **storage** of water or food
- Aide in **Asexual Reproduction**
- **Produce hormones** and **Secondary metabolits** that regulate plant development and communication

Systems

- **Embryo radicle** emerges immediately upon germination, from this radicle a **primary root** forms, then secondary root.
- **Firous**: found in **monocots** and some dicots
  - large number of fine roots of similar diameter
  - **Adventitious roots** form from stem or leaf
  - **Lateral roots** form from adventitious roots
  - typically shallow
  - imcreased number of roots lead to improved water acquisition; not drought tolerant
  - stabilize soil, decrease erosion
  - core of parenchyma cells (**pith**) is surrounded by **rings of xylem and phloem** in monocot root. pith cells arise from procambium and not ground meristem. in Monocot
- **Tap root**: in **dicots** and **gymnosperms**
  - thick **tap root**, and thinner **secondary roots** form from that.
  - deep into soil
  - not as effective at water absorption as fibrous root systems, but allow survive under extreme conditions.
  - **water or food storage** in dicots
  - "arms" of xylem with phloem patches in between, **no pith**
- Root specialization: **water storage**: pumpkin family
- Root specialization: **Food storage**:
  - **starch (carbonhydrate)**: sweet potatoes, cassava, hemlock and dandelions
  - storage cells are increased number of **parenchyma**, formed by **anomalous secondary** (thickening) growth

external structure

- General structures
  - **Lateral Roots**: from pericycle
  - **Root hairs**: epidermal cell extensions, absorption of water and nutrients
    - Adhere tightly to soil particles in order to compete for water and nutrients
    - Increase total surface area of absorption
    - In growing roots, new root hairs are continuously formed with older root hairs dying off; root hairs always in zone of maturation near root cap.
  - **Root cap**: mass of parenchyma cells that cover teach root tip
    - protect tissues from damage as root grows, first cell layer has **waxy cuticle**

        - Secretes mucilage that aides in growth through soil and provides medium for beneficial bacteria
        - Amyloplasts in tip act as gravity sensors
- **12 Essential nutrient elements**:
    - root compete with negatively charged soil silicates for minerals and water
    - Macronutrients:
        - primary: Nitrogen, phosphor, potassium
        - intermediate: sulpher, calcium, magnesium
    - Micronutrients: Iron, zinc, manganese, molybdenum, copper, boron
- Root Protection Permeability
    - prevent microorganism in soil from getting into root vascular cylinder
    - **Chemical Protection**
        - woody gymnosperm roots have resin canals and dicot taproots produce latex
        - Polyphenol **flavonoids** with anti-funggal, anti-viral and anti-microbial properties accumulate in root cell vacuoles (eg. **Glabridin flavonoid** of licorice (Glycyrrhiza sp.) root has great pharmaceutical significance as an anti-bac, anti-inflammatory and anti-cancer agent)
    - Root Hair
        - epidermal root hairs **do not have a cuticle** to aide in absorption
        - **cell walls are permeable** to water, solutes and potentially invasive microorganisms without cuticle
        - impregnate key cell layers of cortex with **suberin** and **lignin** to restrict water and solute movement
        - **casparian strips**: deposits of lignin and suberin in the radial primary cell wall and middle lamella of endodermis and exodermis
    - **Endodermis** (all vascular plants) and **Exodermis** (majority)
        - both are part of root cortex and have **Casparian strips**
        - Exo: **outermost** cell layer of cortex
        - Endo: **innermost**, above pericycle and vascular cylinder
        - **Passage cells**: lack casparian strips, allow fast passive transport, not always present
- Mycorrhizae mutualistic Relationships
    - >70%, mycorrhizae essential for development
    - **Mutualistic relationship**: both benefit and dependent
        - Fungi: facilitate absorption, particularly P
        - plants provides protection, sugars and amino acids
    - **Ectomycorrhizae**:
        - Fungi on surface, forming **mantle** around root
        - accumulate minerales in mantle coated root hairs (plant)
        - solid substrate to grow on (fungi)
    - **Endomycorrhizae**:
        - **Fungi penerate root cortex**(parenchyma cells)
        - **Arbuscules**: fungi branching structures

        - plant increase absorption of nutrients (Phosphorous)
        - fungi provided with food (carbohydrates) and protection
    - Bacteria root nodules:
        - Rhizobia (bacteria) with **Legumes** (Fabaceae)
        - Rhizobia: enzymes to convert (fix) **Nitrogen** from atomosphere into plant usable forms (nitrates and ammonia)
        - **Root Nodules** contain large numbers of nitrogen-fixing bacteria

Primary and Secondary Growth

Root primary growth

- **Region of Cell Division(Root Apical Meristem, RAM)**: in the center of root tip
    - **Protoderm**: give rise to epidermis
    - **Ground meristem**: give rise to cortex (parenchyma, exodermis, endodermis)
    - **Procambium**: give rise to primary xylem, primary phloem and pericycle (vascular cylinder)
- **Regions**:
    - **Maturation**: differentiated(mature) cells into distinctive cell types
    - **Elongation**: cells become several times original length, not differentiated
    - matures in retrograde
- **Pericycle**
    - single cell later, directly below **endodermis**
    - give rise to lateral roots and part of the vascular cambium
    - displaces cortex and epidermis as lateral root grows outwards, from vascular cylinder to epidermis
    - eventually **break through epidermis**
    - vascular cylinder stays connected

Secondary Root Growth

- NO in fibrous
- occurs where primary growth has been compelted
- **Dicots and conifer tap roots** have secondary growth to:
    1. Increase conductivity
    2. Replace old vascular tissue
    3. provide protection (periderm = bark)
    4. Form specialized storage roots by anomalous secondary growth (thickening)
    5. Provide support in specialized roots
- **Vascular cambium**
    - forms from de-differentiated **parenchyma** between primary xylem and phloem and pericyle, Initiated by hormone **auxin**
    - forms **continuous ring** of meristemic cells
    - primary xy/ph: stars; then secondary: rings
    - as in stems: secondary xylem = wood, and less secondary phloem produced
    - Xylem rays: living parenchyma, transfer water horizontally across secondary xylem.
- **Cork cambium**:

    - Cork (phellem), cork cambium, Phelloderm
    - forms from dedifferentiated parenchyma cortex, then secondary phloem.
- **Annual Growth Rings**
    - hard to distinguish as secondary xylem size does not vary by growing season as in stems
- Anomalous secondary thickening: **Food storage**:
    - xylem, phloem and parenchyma
    - Beets have growth rings: repeating secondary xylem, secondary phloem and storage parenchyma
- Root periderm scars
    - **NOT for gas exchange**
    - **wound response** to lateral root break

Specialized root function

- water and food storage from previous sections
- **Asexual Reproduction**: form **adventitious buds** from these **aerial stems (suckers)** form; suckers develop their own roots and can survive independently. (shurbs and fruit trees)
- **Gas Exchange**: **pheumatophores** extend above surface ans use **lenticels** to obtain oxygen for respiration (near water or swamps)
- **Aerial Roots**: **Epiphytes** such as orchids grow on other plants for support but nourish them selves (not parasite)
    - **Velamen layer**: epidermis several cel layers thick to reduce water loss
    - Epiphyte roots absorb water and nutrients from rain water
    - Aerial roots can also aide in climbing (English Ivy)
- **Aerial (Prop) Roots**: Tropical trees (figs, banyan) have stilt-like **prop roots** that grow down from branches. continue secondary growth to expand radius and stability once they reached ground.
- **Additional support**: **Buttress roots** extend from the base of tree trunk to help stabilize tree in shallow soil; common in tropical trees.
- **Parasitism**: **Parasitic roots (dobbers)**
    - have no chlorophyll and dependent on chlorophyll-bearing plants for nutrition.
    - Use peg-like projections (**haustoria**) to tap into vascular system of host plant.
    - Parasitic as NOT beneficial to host

Water Transport

Transport Pathways and Cohesion Tension theory

Pathways

- **Apoplastic** transport (dead space):
    - outside of the plasma membrane: through permeable cellulose **cell wall** and **middle lamellae**
    - movement through **permeable** cell walls
- **Symplastic** transport (living space):

    - "cytoplasmic continuum" between cells, does not cross plasma membrane: through **cytoplasm** and **plasmodesmata**
    - Plasmodesmata （胞间连丝）
        - water and dissolved substances can pass through
        - **Size exclusion** limits
        - Do not have to pass through semi-permeable plasma membrane
    - must pass through **semi-permeable** barrier
- **Transmembrane** Transport (living space):
    - Movement through semi-permeable plasma membranes: through **cytoplasm**, **plasma membrane** and **cell wall**
    - plasma membranes are semi-permeable barriers
        - Diffusion
        - Facilitated diffusion: transport proteins
        - Acitve transport: transport proteins and ATP
        - Endocytosis and exosytosis
        - Osmosis（渗透）: solute concentraton
    - must pass **size-exclusion** limit
- **Casparian strips** (cell wall and midlle lamella reinforced with **suberin** and **lignin**):
    - block apoplastic pathway.
    - in exo- and endodermis
    - plasmodesmata on front and back of endermal cells facilitate transport into pericycle
    - water and solutes enter xylem from pericycle via apoplastic pathway; tracheids and/or vessel members are dead at maturity thus no membrane
    - additional **lignified, secondary walls** to further restrict apoplastic transport
    - **passage cells**: not secondary wall thickening or casparian strips, allow unrestricted transport at the front and back of cell

Transport in vascular cylinder

- **Sap**
    - the fluid transported in xylem (tracheids and vessel members) or phloem (sieve tube elements)
    - made up water, nutrients and sugars
    - maple syrup: xylem samp, moving up from storage roots in the spring

Tracheids	Vessel Members
vascular plants	angiosperms
narrow (2-10 um) and tapered	Wide (100); short units but can be meters long when stacked into column. transport 100x more water than tracheids
staggered stacking	stacked on top of on another to form "pipes"
closed off and tapered at ends	Perforation plates or open ended at top and bottom, continuous water flow

Tracheids	Vessel Members
>	Dead at maturity, thick lignified secondary walls. Provide structural support. Pits on side of vessels allow lateral water and solute flow

- **Tracheids**: vascular plants
  - movement is restricted between pits since closed on the end
  - pits:
    - **simple pits**: pore formed from absence of secondary wall, primary wall only barrier
    - **Bodered pits**: have secondary wall extending over opening and a torus that functions like a hydraulic valve
    - **torus** helps block movement of gases and pathogenic microorganism

Cohesion-Tension theory

- explain water transport in they xylem
- **Adhesion**: attraction between different kinds of molecules (most important): water adher to cellulose walls of xylem tracheids and vessels, forming water column
- **Cohesion**: attraction between molecules of the same kind: water are ploar and bind to each other (hydrogen bonds), further supports water column
- **Tension**: negative pression on water or solutions which draws water upward, crated by transpiration（蒸腾作用）
- Cavitation （空化）:
  - Tracheids and vessel elements have thick, lignified secondary wall to withstand tension generated from negative pressire
  - greater tension increases the risk of breakage of water column; trunks of trees can contract from tension like a straw
  - Formation of air bublles or ice crystals known as **embolism** can break the water column
  - Breakage occurs less in tracheids than vessle elements because of their anatomical difference
    - water less supported by vessle member walls: wider, air bubble easier
    - Embolisms form separately in each tracheid; have to move through pits, lateral flow
    - In vessel members, entire column fills with air or ice when cavitation occurs
  - Embolisms block water flow: from when flower stems are cut => remove by cutting of the lower 3cm of the stem, underwater

Osmosis and Water potential

- Principles of water movement: controlled by three processes

Bulk flow

- molecules of water move in mass from one place to another in response to differences in potential energy

diffusion

- the spontaneous movement of water down a concentration gradient

Osmosis

- movement of water or any solvent across a selectively permeable membrane
- across plasma membrane facilitated by **aquaporins**
- spontaneously from lower solute concentration (higher water concentration) to high (low)
- **Hypotonic solutions**: the solution surrouding the cells has a lower concentration of solutes
    - water into cell, cell wall prevents cell rupture, ideal condition for plant
- **Isotonic solutions**: same concentration: (dynamic) euquilibrium but the cell is NOT turgid
- **Hypertonic solutions**: higher
    - water out, plasma membrane shrinks (**plasmolysis**), symplastic transport impaired. Unusual to see in nature, typically in laboratory settings
- **Water potential**
    - measure ment that predicts which way water will flow between a plant cell and its surroundings or between different parts of the plant (root/shoot)
    - $$\Psi_w = \Psi_\pi + \Psi_p$$
        - $\Psi_\pi = \text{osmotic potential}$
            - always -ve
        - $\Psi_p = \text{pressure potential (turgor pressure)}$
            - based on mechanical pressure
            - as water enters vacuole, pressure against wall (it) increases
            - always +ve
        - most living cells: 0 or -ve (hypotonic)
    - Relative water potential
        - determining direction of flow
        - more and more -ve as water moves up from soil to leaves

Transpiration

- release of water vapour into the air from aerial organs
- functions:
    - cools leaves heated by sunlight
    - pulls water and water-soluble minerlas up from teh roots
- tree: 700-3500 liters of water/day, corn: 2L/day
- **Stomata**:
    - 90% transpiration occurs through
    - occurs at highest density on the underside of leaves
    - > 1% of the leaf surface area
    - can be found on all aerial (above ground) organs
    - controlled through turgor pressure of guard cells
        - Open: turgid guard cells, K+ enter and water follows
        - Close: Flaccid guard cells: K+ exit and water follows
    - Signal varies: water status, CO2 levels, light intensity, humidity, temperature and hormones
- **Lenticels**
    - pores, cannot open/close

    - aren't as high up in water column (stems/trunks) as leaves, only account for 0.1% of overall transpiration in a plant
    - In fruits (apple, mango, pear and avocado), lenticels form from stomata => can account for 20$ of overall transpiration in plant
    - allows very little water loss (5%)
    - reduce water loss (in arid env) by:
        - Thicker cuticles
        - Mesophyll packed closer together, no air soaces
        - sunken stomates to reduce evaporation
        - increased layers of epidermis
        - only open stomata at night

Vascular

- Xylem: transports water and nutrients from the roots to stems and leaves. Complex tissue that can be made of the following:
    - **Parenchyma** (ALIVE at maturity)
    - **Sclerenchyma** (DEAD)
    - **Vessel members** (angiosperm): DEAD, short and have perforation plates and pits
    - **Tracheids** (ferns, gymnosperms and angiosperm): DEAD, have pits but not perforation plates
- Phloem: Distributes products of photosynthesis to rest of plant
    - **Parenchyma**
    - **Sieve Tube Members and Companion Cells**: Tube are ALIVE but lack nucleus and are assoiciated with companion cells to form **Sieve Tube Element**. Sieve tube memebrs have **sieve plates** on either end.
- Cambium
    - Layer of dividing cells between xylem and phloem responsible for the secondary growth of stems and roots.