F 6 Biology - Ch 22: Uptake & Transport in Plants

Name: ____________________________

Plants are advantageous in being large, e.g. they can compete more readily for light. Some trees may as tall as 10 meters. Water has then to be transported upwards to supply minerals & raw materials for photosynthesis in the leaves. On the other hand, sugars manufactured from photosynthesis have to be sent downwards to sustain respiration of the root cells. Plants depend to a large extent on passive rather than active means of transport.

22.1 The Water Molecule

Water is the most abundant liquid on earth and is essential to all living organisms. Its hydrogen bonds react readily with many molecules and make it an ideal constituent of living things.

22.1.1 Structure of the water molecule

- normal water molecule: \( ^1\text{H}_2^{16}\text{O} \)
- isotopes: heavy water - \( ^2\text{H}_2^{16}\text{O} \) may be harmful to living organisms

22.1.2 Polarity & hydrogen bonding

- H bonds provide weak attractions among water molecules to hold them together and form water a stable compound

22.1.3 Thermal properties

- high specific heat: maintain a constant temperature for lives in water
- ice has a lower density with denser water beneath; lives below ice

22.1.4 Dissociation, pH & buffers

- \( \text{H}_2\text{O} \) dissociates into \( \text{H}^+ + \text{OH}^- \) with a pH of 7
- water is an excellent buffer within cells with pH 6 to pH 8
- water causes dissociation of other substances, i.e. an excellent solvent

22.1.5 Colloids

Cytoplasm is a colloid, made up largely of protein molecules dispersed in water. It is hydrophilic, i.e. attracts water molecules around them and prevent them to aggregate into large particles and settle out. Imbibition is the process by which water is absorbed by hydrophilic colloids inside seeds at the beginning of germination.

22.1.6 Cohesion & surface tension

Cohesion is the tendency of molecules of a substance to attract one another.

Cohesive force of water molecules pulling them inwards towards each other to create a skin-like layer at the surface \( \rightarrow \) the SURFACE TENSION

The cohesive forces between water molecules accounts for the upward pull of water in xylem when evaporation occurs at the leaves and insects to stand on water surface.

22.1.7 Adhesion & capillarity

Adhesion is the tendency of molecules to be attracted to ones of a different type.

Capillarity is the result of intermolecular forces between various molecules. Xylem vessels with diameters around 0.02 mm, have considerable capillarity forces which contribute to the movement of water up a plant.
22.1.8 The importance of water to living organisms

Metabolic role of water:
1. Hydrolysis
2. Medium for chemical reactions
3. Diffusion and osmosis
4. Photosynthetic substrate/raw material

Water as a solvent: It readily dissolves many substances & therefore is used for
1. Transport
2. Removal of wastes
3. Secretions

Water as a lubricant:
1. Mucus
2. Synovial fluid
3. Pleural fluid
4. Pericardial fluid
5. Perivesical fluid

Supporting role of water: because of its incompressiveness, support is possible
1. Hydrostatic skeleton
2. Turgor pressure
3. Humours of the eye
4. Amniotic fluid
5. Erection of the penis
6. Medium in which to live

Miscellaneous functions of water:
1. Temperature control
2. Medium for dispersal
3. Hearing and balance

22.2 Simple Plant Tissues
1. Parenchyma
2. Collenchyma
3. Sclerenchyma

22.3 Water Relations of A Plant Cell
Water potential of a system is the difference in chemical potential of water in a system and that of pure water at the same temperature and pressure. The water potential of pure water at standard temperature and pressure is “0”.

Osmotic potential is the component of water potential that is due to the presence of ______________.

Pressure potential is the component of water potential that is due to the ______________.

Incipient plasmolysis is the point at which the protoplast of the cell just lost contact with the cell wall.

Plasmolysis is a condition of the cell when the protoplast shrinks away from the cell wall due to osmosis.
22.4 Transpiration

Transpiration is

This takes place in 3 sites:
1) __________
2) __________
3) __________

22.4.1 Stomatal mechanism

1. Stoma and Guard Cells
   - found mainly in the lower epidermis of dicotyledonous leaves & stems
   - possess chloroplasts;
     outer cell wall __________; inner cell wall __________;
     differential expansion/contraction

2. The Mechanism of Opening and Closing of Stomata
   - Size of stomatal opening is controlled by changes in the shape of the guard cells:
     water potential of guard cells ↑
     → water flows in → cell turgid
     → stoma opens (outer wall expands more than inner wall)
     water potential of guard cells ↓
     → water flows out → cell flaccid
     → stoma closes (outer wall contracts more than inner wall)
22.4.2 Movement of water across the leaf
Usually the humidity of the atmosphere is less than that in the sub-stomatal air space. With some air movement, water vapour is swept away once it leaves the stomata. Water lost is replaced from spongy mesophyll cells surrounding the space, then from xylem in 3 ways:

1. The apoplast pathway -
   Most water travels from cell to cell via the cell wall by a tension due to evaporation from the sub-stomatal space.

2. The symplast pathway -
   Some water travels through cytoplasm of cells via plasmodesmata through a concentration gradient.

3. The vacuolar pathway -
   A little water passes from vacuole to vacuole of cells through a concentration gradient.

22.4.3 Structure of Xylem: vessels & tracheids
- They are dead when mature and serve for support and water transport.
- Vessels: cross walls degenerated for carrying water protolaxylum with lignin deposited in rings or spirals and the cell is still capable of expansion metaxytem with extensive lignification (reticulate, scalariform or pitted).
- Tracheids: spindle-shaped with end-walls overlapping; highly lignified with no cell contents; support and water transport (not so efficient).
22.4.4 Movement of water up the stem
Water moves up the stem and into the leaves through xylem vessels and tracheids.
Evidences that xylem carries water up the stem:
1. Experiment using a dye, e.g. eosin
2. Removal of xylem causes leaf wilting
3. Metabolic poison has no effect on the uptake of water by xylem
4. Wilting of plants by drawing up fatty substances + microscopic examination

**Cohesion-Tension Theory:**
The transpiration of water from the leaves draws water across the leaf. This water is replaced by that entering the mesophyll cells from the xylem by osmosis. As water molecules leave xylem cells in the leaf, they pull up other water molecules. This pulling effect (*Transpiration Pull*) is possible because of the large cohesive forces between water molecules. The pull creates a tension in the xylem cells which, if cut, exude water. *Adhesive forces* between the water molecules and the walls of xylem vessels help water to rise upwards in xylem - capillarity. *Root pressure* also contributes to the uprise of water.

22.4.5 Xylem structure related to its role of water transport
1. Both vessels and tracheids consist of long cells joined end to end to allow water to flow in a continuous column.
2. End walls of xylem vessels broken to give uninterrupted flow of water.
   Tracheids have large bordered pits to reduce the resistance to flow.
3. Lateral flow of water by pits in the lignified walls.
4. Lignin enables xylem walls very rigid to prevent them collapsing under the large tension forces set up by transpiration pull.
5. Cellulose in lignin increases the adhesion of water molecules & creates capillarity.
6. Very narrow lumen of vessels & tracheids increases the capillarity forces.

22.4.6 Measurement of transpiration
- By a potometer,

22.5 Factors Affecting Transpiration
22.5.1 External factors affecting transpiration
External factors include all aspects of the environment which alter the diffusion gradient between the transpiring surface and the atmosphere. Among these are:
1. Humidity - transpiration rate ↓ with higher humidity
2. Temperature - ↑ kinetic energy of water molecules thus ↑ rate of evaporation
   - ↓ relative humidity of air, thus ↑ transpiration
3. Wind speed - ↑ transpiration
4. Light - ↑ transpiration rate in light because stomata usually open in light to get more CO₂ for photosynthesis; ↑ temperature by light
5. Water availability - if plant lacks water, stomata close to decrease transpiration rate

22.5.2 Internal factors affecting transpiration
1. Leaf area
2. Cuticle
3. Density of stomata
4. Distribution of stomata, e.g. in dicot leaves with stomata on the lower surface only in order to reduce the heating effect of direct sunlight
22.5.3 Xerophytic adaptations

Xerophytes are ____________________________

Mesophytes are ____________________________

Halophytes are ____________________________

Plants with xeromorphic adaptations are not confined to plants in hot, dry deserts but also others:
1. many species in cold regions due to frozen water
2. plants in windy, exposed areas
3. halophytes.

<table>
<thead>
<tr>
<th>General form</th>
<th>Specific adaptation</th>
<th>Example</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of the transpiration rate</td>
<td>thick cuticle</td>
<td>Pinus</td>
<td>waxy cuticle, water loss</td>
</tr>
<tr>
<td></td>
<td>rolling of leaves</td>
<td>marram grass</td>
<td>moist air trapped within inner surface</td>
</tr>
<tr>
<td></td>
<td>hairs</td>
<td>marram grass</td>
<td>moist air trapped in hair layer</td>
</tr>
<tr>
<td></td>
<td>sunken stomata</td>
<td>Pinus</td>
<td>lengthen diffusion path</td>
</tr>
<tr>
<td></td>
<td>surface area/volume ratio</td>
<td>Pinus</td>
<td>needle-shaped leaves; also gives rigidity</td>
</tr>
<tr>
<td></td>
<td>absence of leaves</td>
<td>cacti</td>
<td>water loss with flattened stem for photosynthesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>compass plant</td>
<td>change positions of leaves to reduce temperature thus transpiration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>halophytes</td>
<td>high water potential than outside to avoid water loss</td>
</tr>
<tr>
<td>Succulence</td>
<td></td>
<td>Bryophyllum</td>
<td>stores water</td>
</tr>
<tr>
<td></td>
<td>cacti</td>
<td>stores water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cacti and C₄ plants</td>
<td>keep stomata closed during the day so as to reduce transpiration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>most succulents</td>
<td>absorb water readily after a rain over a large area</td>
<td></td>
</tr>
<tr>
<td>Resistant to desiccation</td>
<td>cacti</td>
<td>spines to protect from grazing; flattened stem for photosynthesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>butcher's broom</td>
<td>no leaves but flattened stem for photosynthesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acacia</td>
<td>lamina lost with petiole flattened for photosynthesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hakea</td>
<td>supports leaves during drought for continuous photosynthesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>xerophytes</td>
<td>more cell wall material thus extra support to prevent wilting</td>
<td></td>
</tr>
</tbody>
</table>
F 6 Biology - Ch 22: Uptake & Transport in Plants

Name: 

Hydrophytic adaptations

Hydrophytes:

There are 3 types with respect to their habitats:
1. March plants
2. Swamp plants
3. Aquatic plants

Adaptations:
1. Anaerobic because 

2. Aeration tissue in lacunae to store O₂ manufactured by photosynthesis and to give 

3. Little/no mechanical tissue because of buoyancy from water and less rigidity to give resistance to water current

4. No or non-functional stomata or stomata on surface only for water floating plants

22.6 Uptake of Water by Roots

22.6.1 Root structure

- Endodermis (angled cell layer with a Casparian strip)
- Pericycle (layer of parenchyma cells which produces lateral roots)
- Cortex (parenchyma cells storing starch)
- Root hair (epidermal cell outgrown)

- Pith (parenchyma cells)
- Xylem (transports water and mineral salts)
- Phloem (transports organic material)
- Cambium (in some plants)
- Exodermis (transports organic material)

- Pith (parenchyma cells)
- Xylem (transports water and mineral salts)

TS through a typical dicotyledonous root, as seen under a microscope (100 x)

TS through a typical monocotyledonous root, as seen under a microscope (100 x)

root cap - protects the root when it grows up soil
epidermis - protection
growing point - cell carry out cell division
region of elongation - cells become elongated with large vacuoles
vascular tissues - with phloem and xylem
region of root hairs - thin walled extension of epidermis;

- increases the surface area for uptake of water & minerals

22.6.2 Mechanisms of uptake

The same pathways which are responsible for movement of water across the leaf also bring about its movement in the root:

1. **The apoplast pathway** - movement through __________ is prevented by the suberin of the Casparian strip in the endodermis; water forced into living protoplast of endodermis;

 salts actively secreted into vascular tissue to create a water potential gradient to drawn water continuous inwards
22.6.3 Root pressure
The water potential gradient from root hair cells across the cortical cells creates a force called the root pressure. The process probably involves the pumping of salts into the xylem. *guttation*: liquid being forced out of pores on the leaves called *hydathodes*. Root pressure may be important in herbaceous plants, but its contribution is far less than that in transpiration.
Water enters the root hairs through the cell walls & the selectively permeable membrane by **osmosis**. Mineral salts in the soil water enter the root by **diffusion** or **active transport**, **not by osmosis**.

**Transverse Transport Of Water To The Xylem**

1) Water enters root hair by osmosis
2) Water passes across the cortex from cell to cell
3) Water travels in or between the cell walls
4) Water is drawn up the xylem by transpiration pull

---

**22.7 Uptake & Translocation of Minerals**

**22.7.1 Mechanisms of mineral uptake**: passive or active

**Passive absorption**

**Active absorption**

Once absorbed, mineral ions move along cell walls by diffusion or mass flow. When these ions reach the endodermis, they enter the cytoplasm of the cell from where they diffuse or are actively transported into the xylem. Alternatively, minerals go through the symplast pathway to the xylem into which where they diffuse or are actively pumped.
22.7.2 Transport of minerals in the xylem
Analysis of the contents of xylem vessels: mineral salts, water, may be some sugars & amino acids

**Evidences:**
1. Mineral ions present in xylem sap
2. Similarity between rate of mineral transport & rate of transpiration
3. Use of dyes, e.g., eosin dye
4. Experiments using radio-active tracers:
   Interpretation - Lateral transfer of minerals can take place from xylem to phloem;
   When it is prevented, minerals transport takes place almost exclusively in xylem

22.8 Translocation of Organic Molecules
22.8.1 Evidence for transport of organic material in the phloem
1. When phloem is cut, the sap which exudes contains carbohydrates with pressure
2. The sugar contents of phloem varies with that of sucrose content in leaves. Ringing experiment
3. Use of radio-active tracers $^{14}$CO$_2$: when xylem & phloem separated by wax paper, $^{14}$C found entirely in phloem
4. Aphids with their needle-like mouth parts penetrate into phloem to obtain sugars. A feeding aphid is anaesthetized & its mouth parts cut for analysis for its contents: sugars & amino acids + diurnal variation in concentrations

22.8.2 Structure of phloem sieve tubes
Phloem tissue: sieve tubes, companion cells, phloem parenchyma & phloem fibres

**sieve tube cells:** adapted for longitudinal flow material:
- elongated with perforated end walls (sieve plates) + callose;
- well defined cell membrane, numerous plastids & mitochondria;
- lumen with transcellular longitudinal protein strands;
- mature sieve tube cells (sieve tube elements) lack a nucleus

**The companion cells:** have thin cellulosic cell wall & dense cytoplasm, large nucleus,
- numerous mitochondria, plastids, small vacuoles, an extensive rough endoplasmic reticulum;
- metabolically active, communicates with sieve tube element through plasmodesmata
22.8.3 Mechanisms of translocation in phloem

**Mass Flow (pressure flow) Hypothesis** - widely accepted

At the source (leaves):
Photosynthesizing cells in leaves make sucrose → water potential increases

At the sink (root):
sucrose either respired or stored as starch → water potential decreases

A gradient of pressure potential exists between the source & the sink with phloem linking them and as result liquid flows from the leaves to other tissues along the sieve tube elements.

**Evidences supporting the mass flow theory:**
1. There is a flow of solution from phloem when it is cut or punctured by the stylet of an aphid
2. Evidences of concentration gradients: high concentration of sucrose in leaves but low concentration in root
3. Some researchers have observed mass flow in microscopic sections of living sieve elements
4. Viruses or growth chemicals applied to leaves are only translocated downwards to the roots when the leaf to which they are applied is well illuminated & therefore photosynthesizing. When applied to shaded leaves, no downward translocation occurred.

**It is likely that energy is needed for the sucrose transport into the sieve elements**

**Criticism:**
Sieve plates could be a series of barriers impeding flow since the process is passive after the initial process. Suggested reason for sieve plate function:
seal off damaged sieve tube elements with callose deposits across the pores.

**Other hypothesis:**
1. Electro-osmosis hypothesis - K⁺ ions actively transported across the sieve plates draw the polar water molecules across the plate, thus mass flow
2. Transcellular strand hypothesis - strands through pores in sieve plates carry out a form of cytoplasmic streaming to aid the movement of the solutes through the sieve tube elements