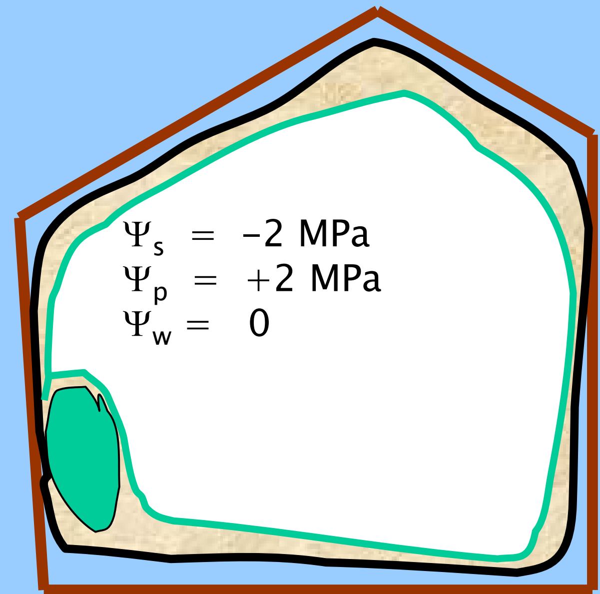
salty water

$\Psi_s = -2$

$\Psi_p = 0$

$\Psi_w = \Psi_s + \Psi_p = -2$



$-2 + 0 = -2$

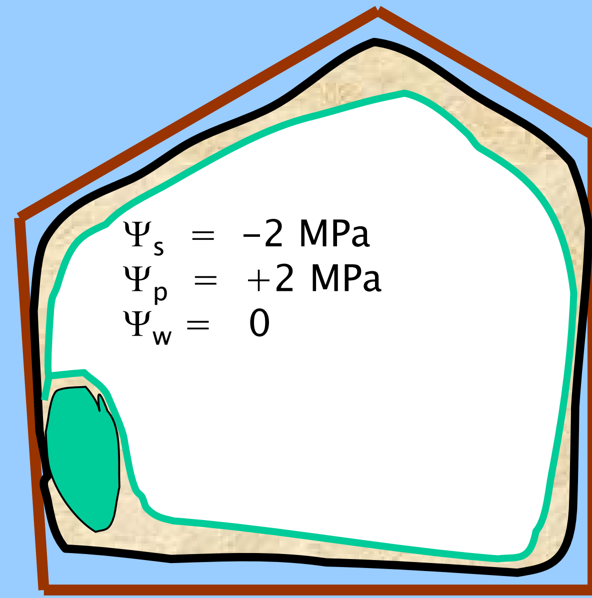
When turgor falls to zero, the cell "plasmolyzes". Ψ_p in a living cell cannot fall below zero!! If the solute potential of the solution is lower than the solute potential of the cell, the membrane ruptures and the cell contents spill salty water

$\Psi_s = -3$

$\Psi_p = 0$

$\Psi_w = \Psi_s + \Psi_p = -3$

-3 + 0 = -3



When turgor falls to zero, the cell “plasmolyzes”. Ψ_p in a living cell cannot fall below zero!! If the solute potential of the solution is lower than the solute potential of the cell, the membrane ruptures and the cell contents spill

Absorption by roots

Water in the soil

The water content and the rate of water movement in soils depend to a large extent on soil type and soil structure.

Like the water potential of the plant cells, the water potential of soils may be dissected into three components: the osmotic potential, the hydrostatic pressure (Ψp) and the gravitational potential (Ψg).

The osmotic potential (Ψs) of soil water is generally negligible.

For wet soils, Ψp is very close to zero. As soil dries out Ψp decreases and can become quite negative.

Gravity plays an important role in drainage

Chemical potential of water

$$\Psi_w = \Psi_s + \Psi_p + \Psi_m + \Psi_g$$

Gravity (0.01 MPa m^{-1}) -- *usually referenced to be zero at the soil surface and increases in the "up" direction*

Matric potential (very important in soils; often ignored in plants, although it is very important in cell walls)

Pressure potential

solutes (osmotic potential)

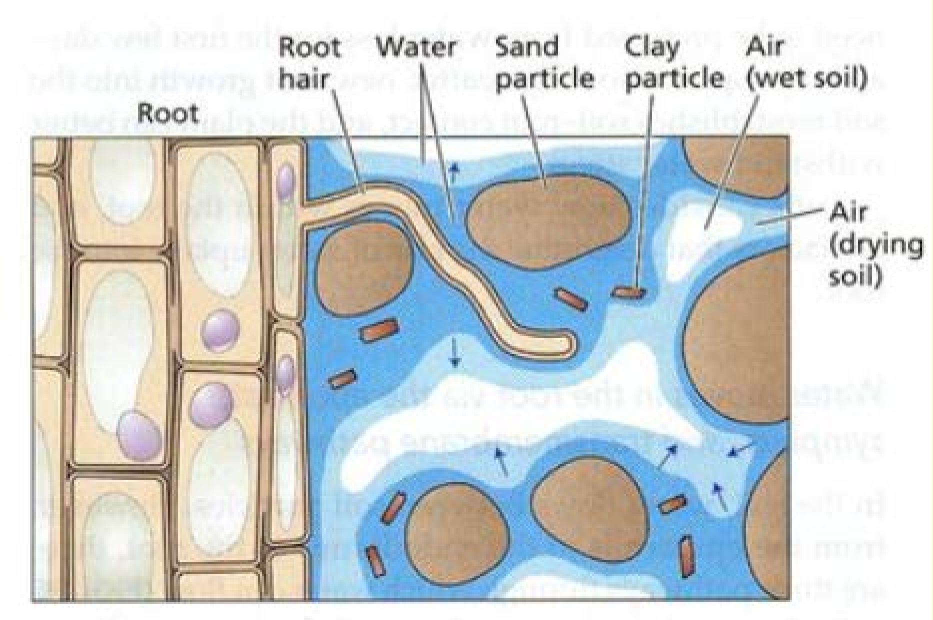
Water absorption by roots

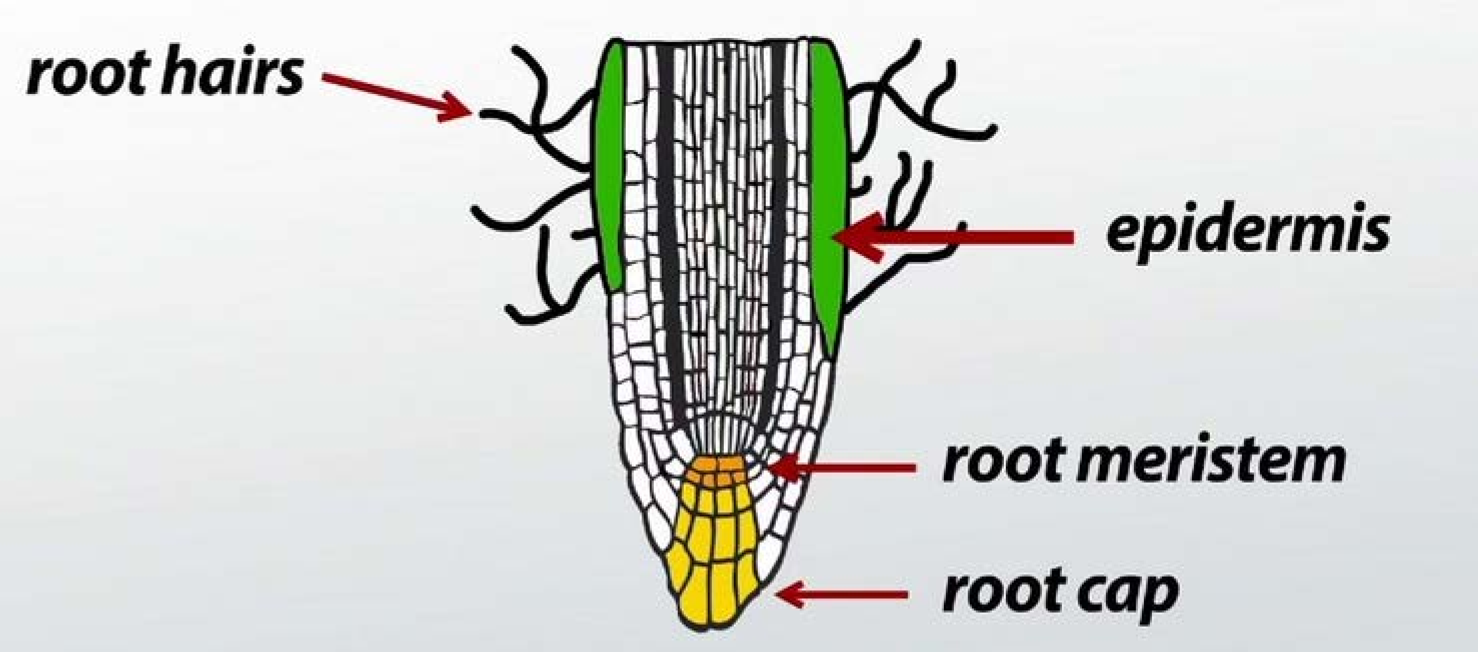
Intimate contact between the surface of root and the soil is essential for effective water absorption.

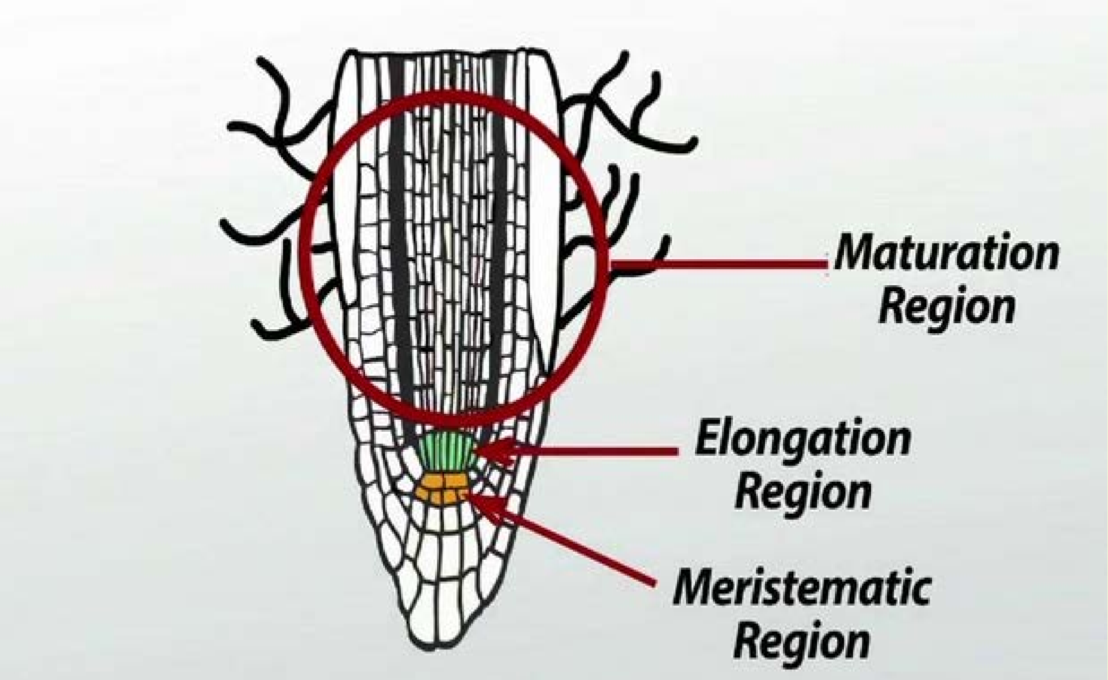
Root hairs of root epidermal cells greatly increase the surface area of the root, thus providing greater capacity for absorption of ions and water from the soil (**Figure**).

Water enters the root most readily near the root tip.

The intimate contact between the soil and the root surface is easily ruptured when the soil is disturbed. It is for this reason that newly transplanted seedlings and plants need to be protected from water loss for the first few days after transplantation.




root hairs
epidermis
root meristem
root cap


Maturation Region
Elongation Region
Meristematic Region

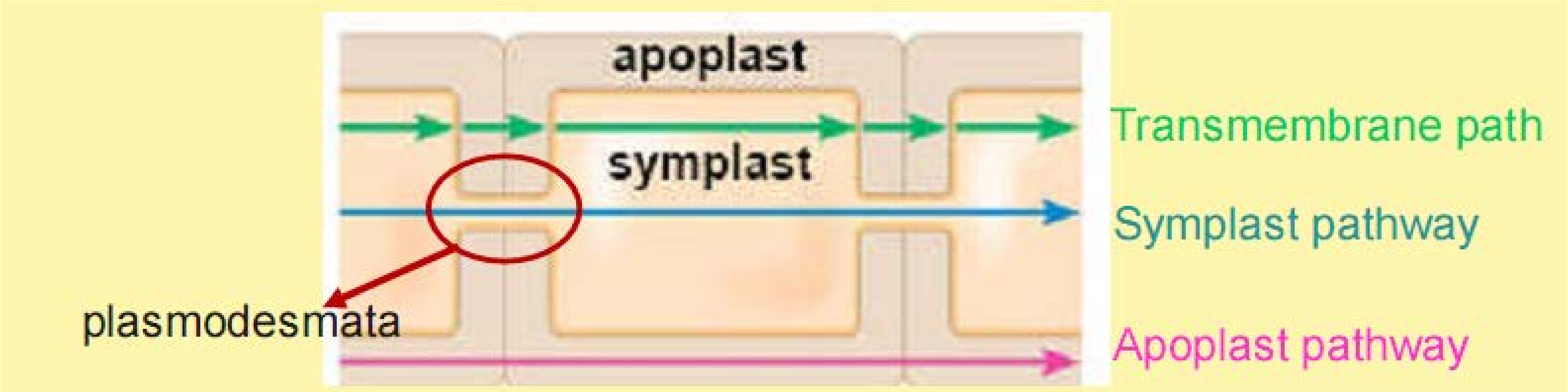
From the epidermis to the endodermis of the root, there are three pathways through which water can flow: the **apoplast**, the **symplast** and the **transmembrane** pathway (**Figure**).

1. The apoplast is the continuous system of cell walls and intercellular air spaces. In this pathway water moves without crossing any membranes as it travels across the root cortex.

2. The symplast consists of the entire network of cell cytoplasm interconnected by plasmodesmata. In this pathway, water travels across the root cortex via the plasmodesmata.

3. The transmembrane pathway is the route by which water enters a cell on one side, exits the cell on the other side, enters the next in the series, and so on. In this pathway, water crosses the plasma membrane of each cell in its path twice.

- Pathways of water transport
  - Apoplast
  - Symplast
  - Transcellular



Though there are three pathways, water moves not according to a single chosen path, but wherever the gradients and resistances direct it. At the endodermis the Casparian strip breaks the continuity of the apoplast pathway, forcing water and solutes to pass through the plasma membrane in order to cross the endodermis. The requirement that water move symplastically across the endodermis helps explain why the permeability of roots to water depends strongly on the presence of **aquaporins**.

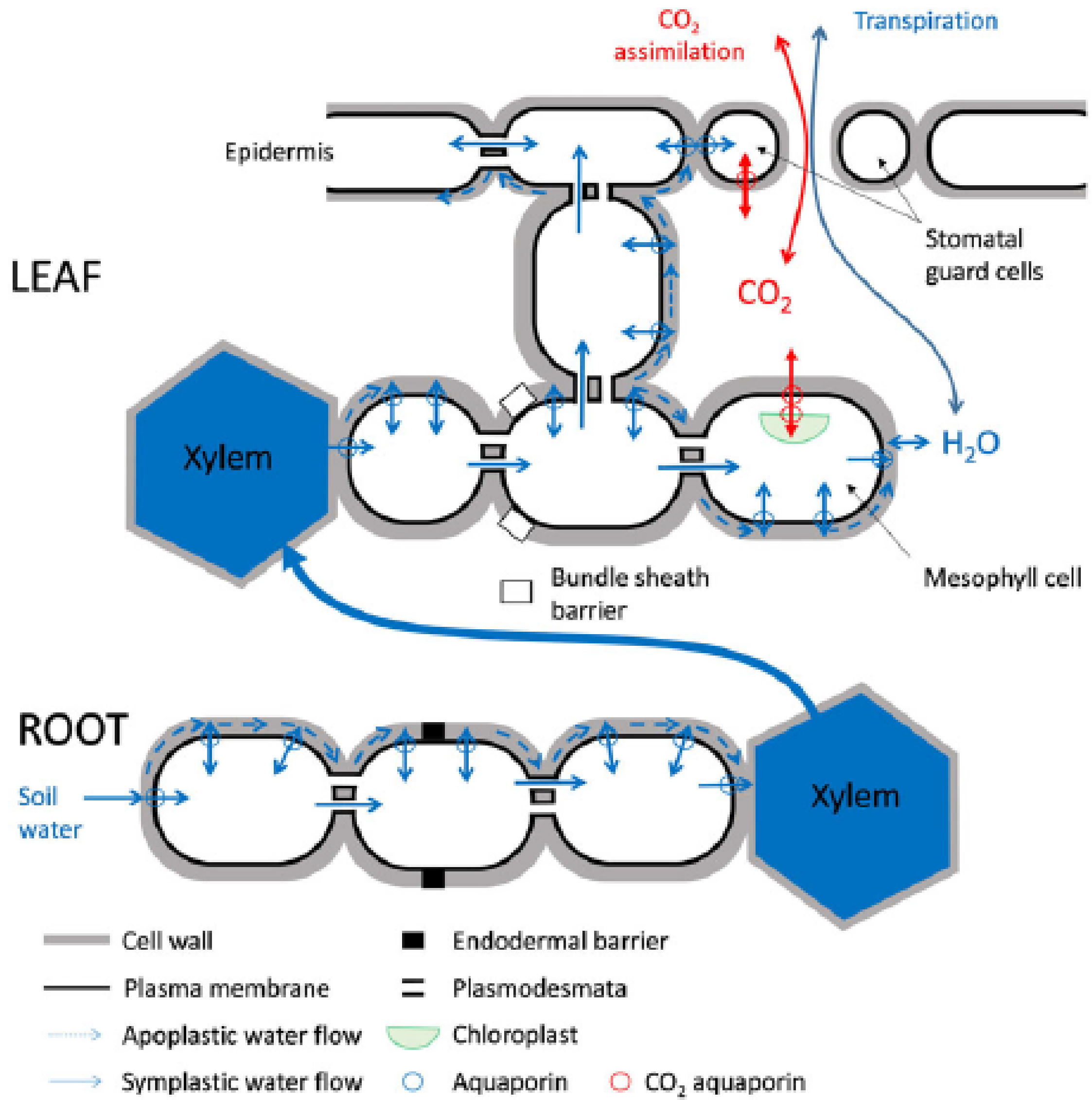
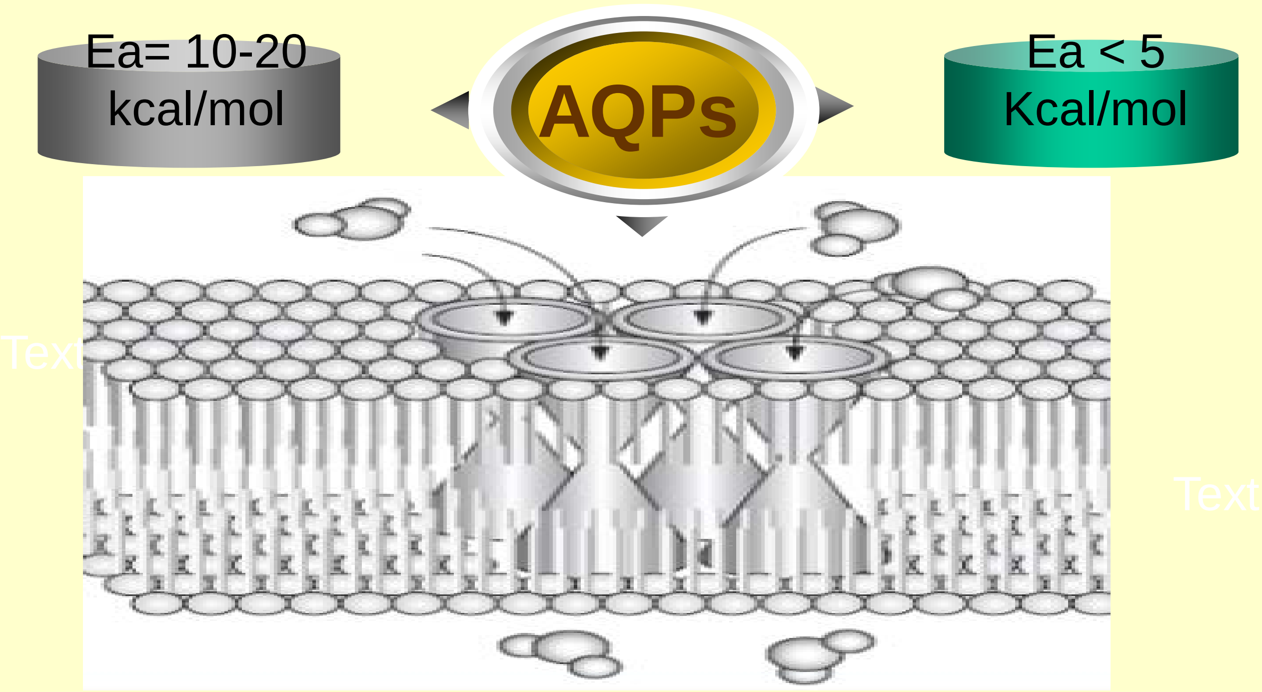


Figure 2. Diagrammatic illustration of water flow from the soil through the plant to the atmosphere and CO_2 diffusion between the leaf and atmosphere. Water can flow either along cell walls via the apoplast or through cells via plasmodesmata in the symplast. Water needs to cross plasma membranes at several points along the way through aquaporins, which allow bidirectional flow. The combination of apoplastic and symplastic flow enabled by entry and exit via aquaporins is termed transcellular flow. Water entry and exit from the vascular system are isolated from apoplastic flow by the endodermis in roots and the bundle sheath in leaves. Mature guard cells have no symplastic connection to adjacent epidermal cells. Not shown is the cuticle that lines the external surface of the epidermis making it impermeable to water and CO_2. Leaf mesophyll and stomatal guard cells have aquaporins that enhance the permeability of the plasma membrane and chloroplast envelope to CO_2

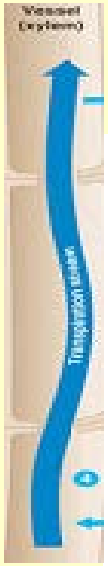
Aquaporins (AQPs)

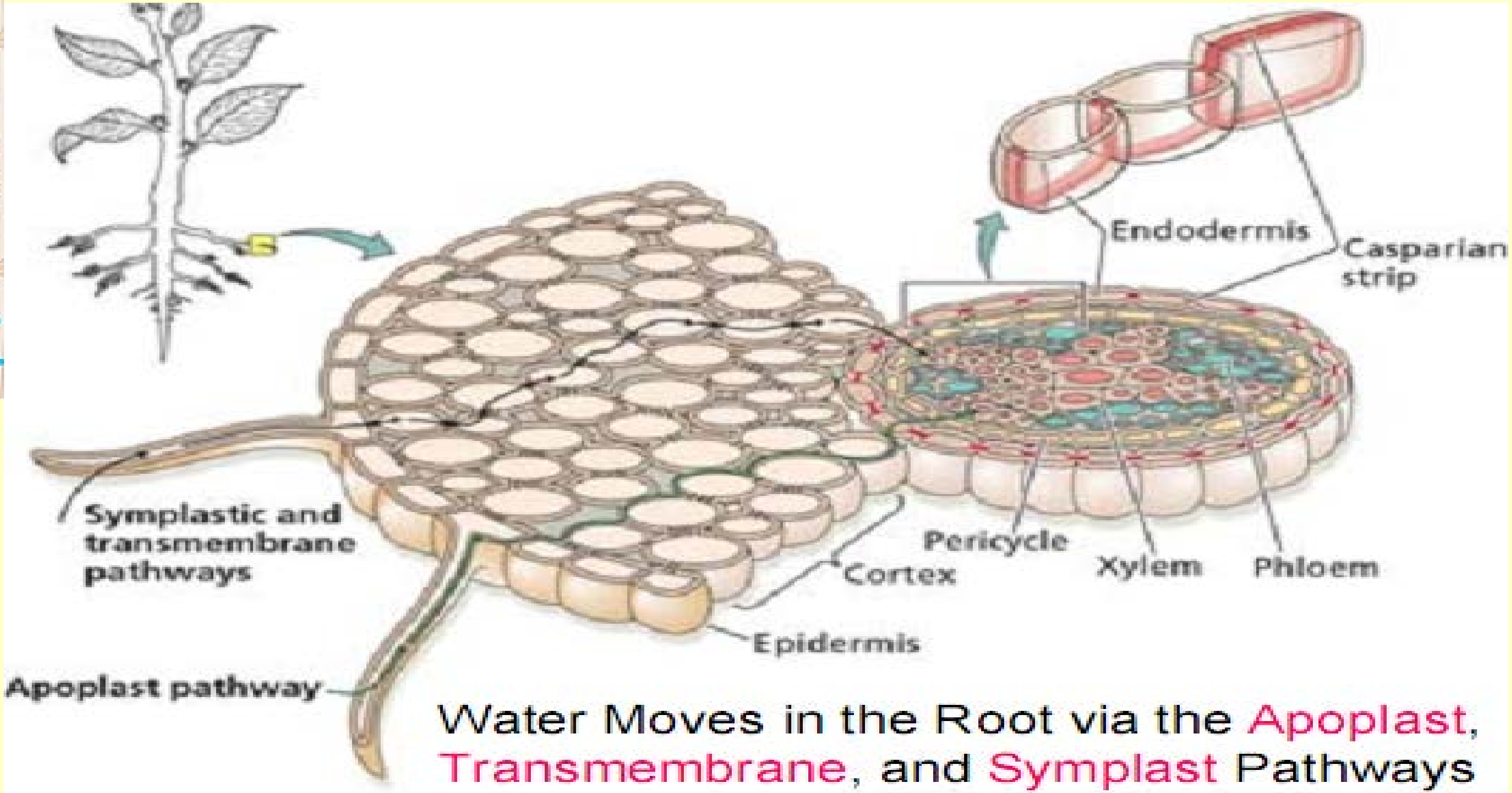


Two main topics were of special interest

◇The high water transport rate (10^9 molecules per second)

◇The high selectivity for water





Water uptake decreases when roots are subjected to low temperature or anaerobic conditions. Decreased rate of respiration, in response to low temperature or anaerobic conditions, can lead to increases in intracellular pH. This increase in cytoplasmic pH alters the conductance of aquaporins in root cells, resulting in roots that are markedly less permeable to water.

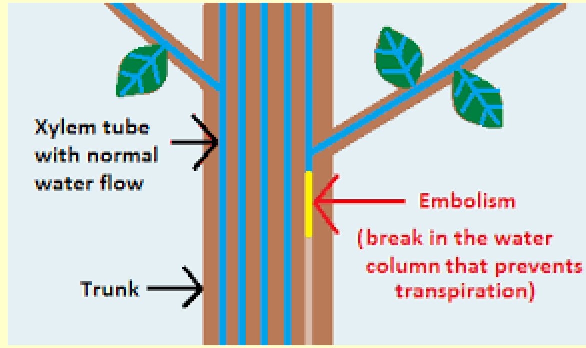
Transport through the xylem

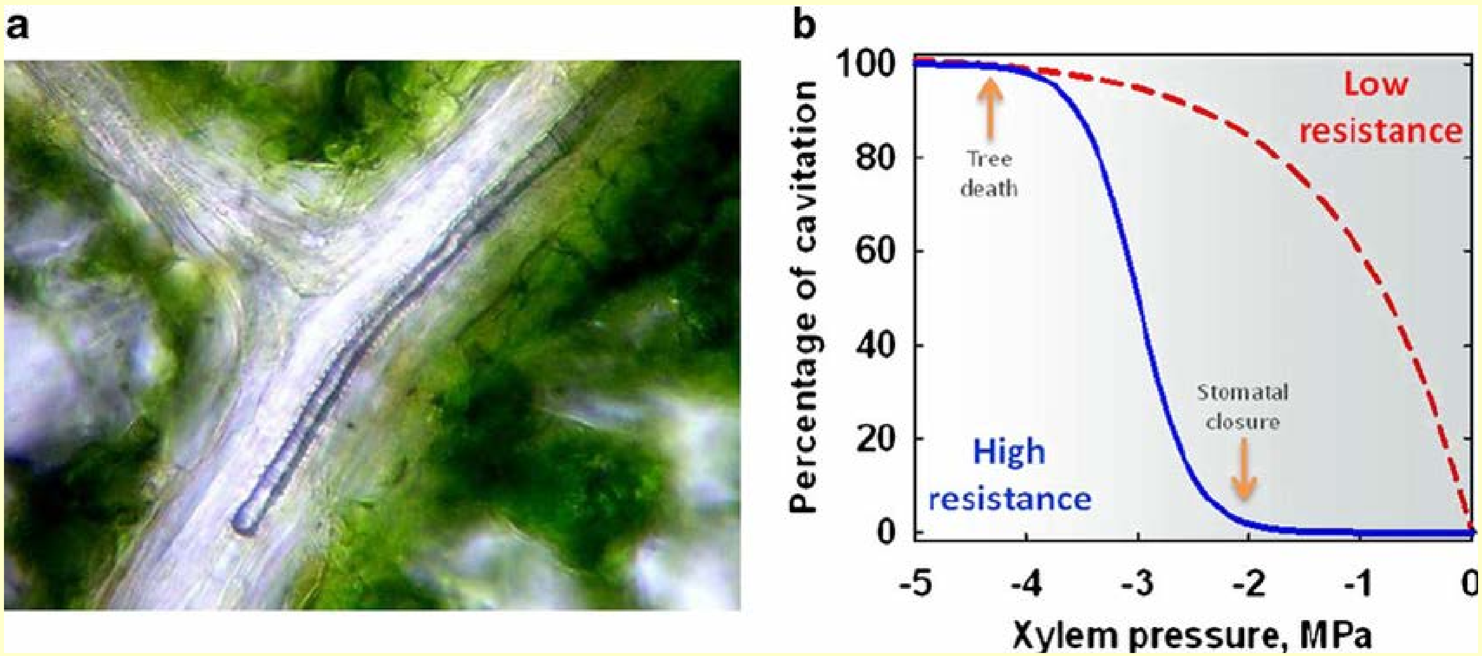
- Xylem tissue is responsible for the transport of water and dissolved minerals from the root to the stem to aerial organs.
- Phloem, on the other hand, is responsible primarily for the translocation of organic materials from sites of synthesis to storage sites or sites of metabolic demand.
- There are two main types of tracheary elements in the xylem:
  tracheids and **vessel elements**.
- Both tracheids and vessel elements dead cells with thick, lignified cell walls, which form hollow tubes through which water can flow with relatively little resistance.
- **Tracheids** are elongated, spindle-shaped cells that are arranged in overlapping vertical files. **Vessel elements** tend to be shorter and wider than tracheids and have perforated end walls that form a perforation plate at each end of the cell.

Water moves through the xylem by pressure-driven bulk flow

- Pressure-driven bulk flow of water is responsible for long-distance transport of water in the xylem.
- It is independent of solute concentration gradient, as long as viscosity changes are negligible.
- It is extremely sensitive to the radius of the tube. If the radius is doubled, the volume of flow rate increases by a factor of 16.
- Vessel elements up to 500 µm in diameter are, nearly an order of magnitude greater than the largest tracheids (the average diameter: 30-50 micrometers).

Cavitation





Cavitation in plants. a Light micrograph showing an air bubble formed by cavitation in the vein of a walnut leaf. b Vulnerability curves showing the increase in cavitation with decreasing xylem pressure during drought. Cavitation was initially thought to occur only in conditions of intense drought stress after stomatal closure

The problem is concerned with the diffusion of water vapour rather than liquid water

when a gas phase is saturated with water vapour, the system will have achieved its **saturation vapour pressure.**

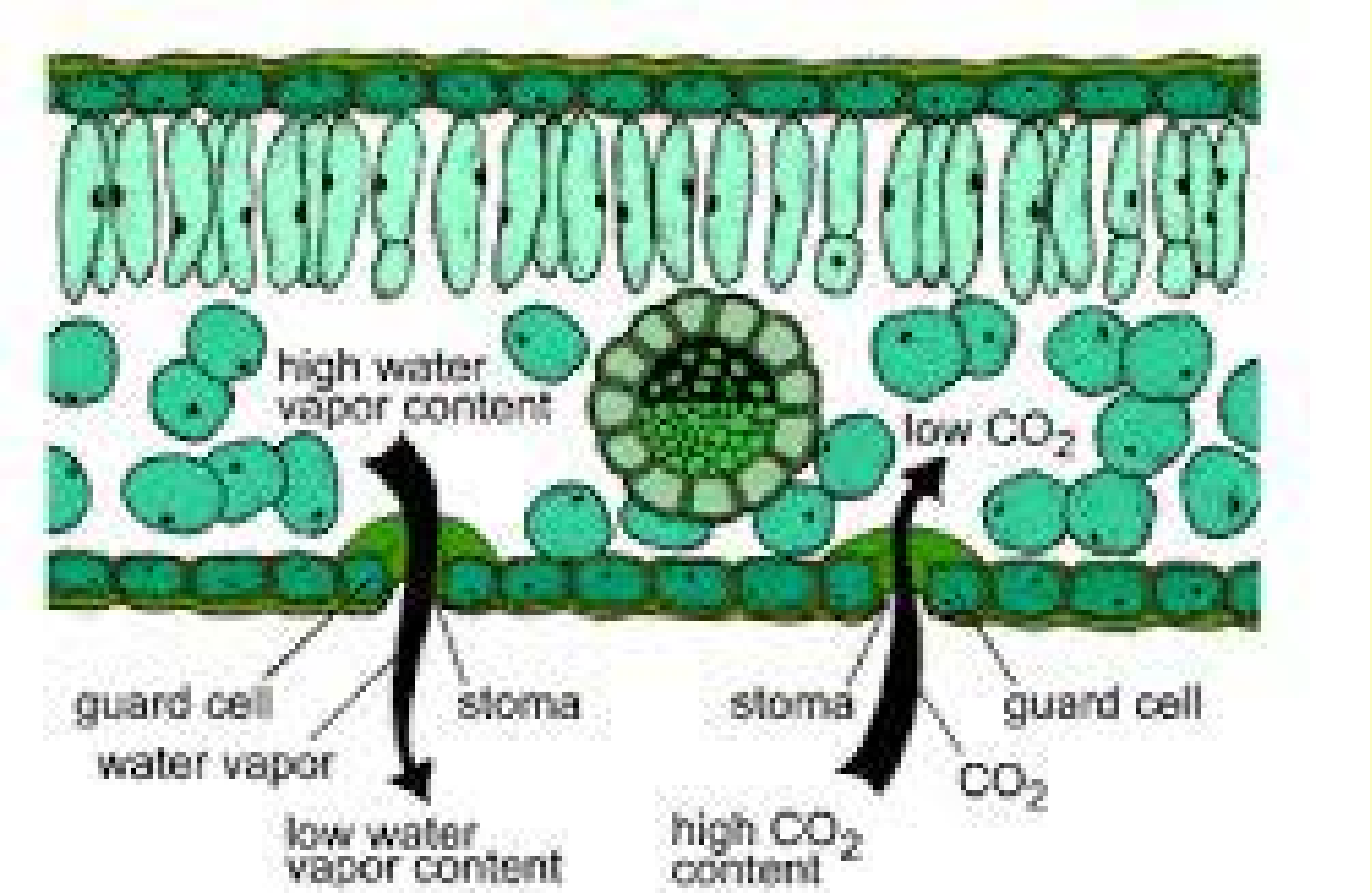
The vapour pressure over a solution is influenced by solute concentration and mainly by temperature.

In principle we can assume that the substomatal air space of leaf is normally saturated or very nearly saturated with water vapour.

On the other hand, the atmosphere that surrounds the leaf is usually unsaturated and may often have a very low water content.

This difference in water vapour pressure between the internal air spaces of the leaf and the surrounding air is the driving force of loss of water from a plant (transpiration).

The movement of liquid water through the living tissues of the leaf is controlled by gradients in water potential. However, transport in the vapor phase is by diffusion, so is controlled by the concentration gradient of water vapor. Almost all of the water lost from leaves is lost by diffusion of water vapour through the tiny stomatal pores.



Transpiration

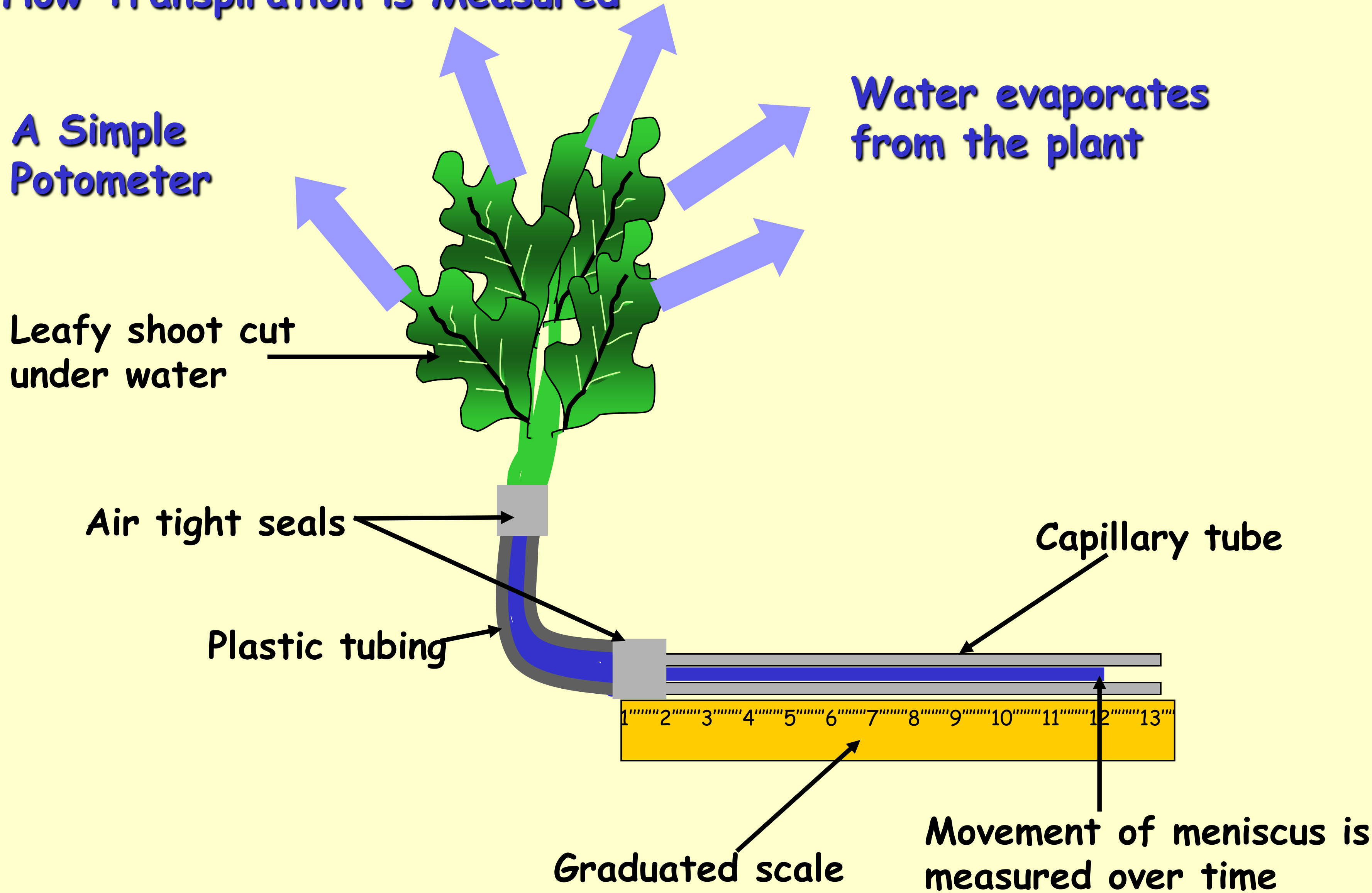
- Transpiration is the loss of water from a plant by **evaporation**
- Water can only evaporate from the plant if the **water potential** is **lower** in the **air** surrounding the plant
- Most transpiration occurs via the leaves
- **Most** of this transpiration is **via the stomata**.

(The stomatal transpiration accounts for 90 to 95% of water loss from leaves. The remaining 5 to 10% is accounted for by cuticular transpiration)

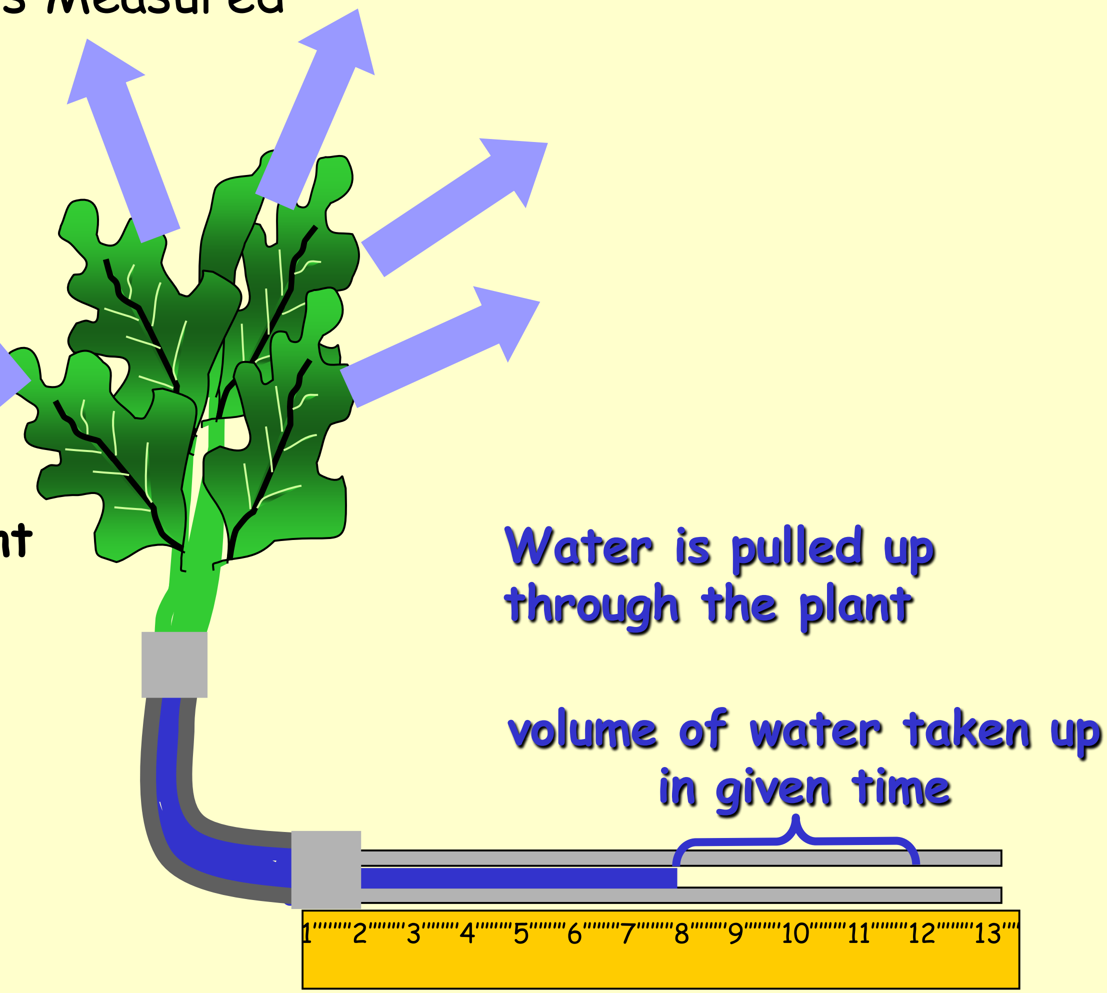
- In most herbaceous species, stomata are present in both the **upper and lower surfaces of the leaf**, usually more abundant on the **lower surface**. In many tree species, stomata are located only on the lower surface of the leaf.

How Transpiration is Measured

A Simple Potometer



How Transpiration is Measured



The rate of water loss from the shoot can be measured under different environmental conditions

Limitations

•measures water uptake

•cutting plant shoot may damage plant

•plant has no roots so no resistance to water being pulled up

6 Environmental Factors Affecting Transpiration

1. **Relative humidity**:- air inside leaf is saturated (RH=100%). The lower the relative humidity outside the leaf the faster the rate of transpiration as the Ψ gradient is steeper

2. **Air Movement**:- increase air movement increases the rate of transpiration as it moves the saturated air from around the leaf so the Ψ gradient is steeper.

3. **Temperature**:- increase in temperature increases the rate of transpiration as higher temperature
   - Provides the latent heat of vaporisation
   - Increases the kinetic energy so faster diffusion
   - Warms the air so lowers the Ψ of the air, so Ψ gradient is steeper

4. **Atmospheric pressure**:- decrease in atmospheric pressure increases the rate of transpiration.

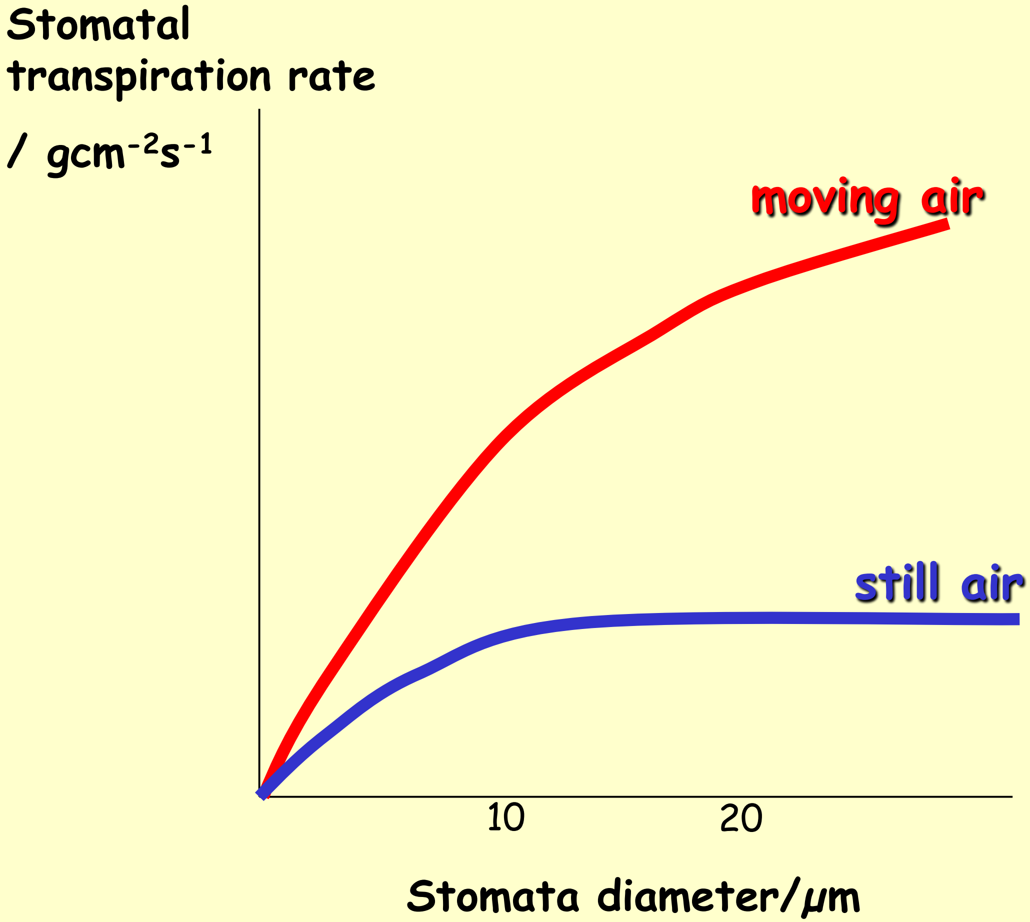
5. **Water supply**:- transpiration rate is lower if there is little water available as transpiration depends on the mesophyll cell walls being wet (dry cell walls have a lower Ψ). When cells are flaccid the stomata close.

6. **Light intensity** :- greater light intensity increases the rate of transpiration because it causes the stomata to open, so increasing evaporation through the stomata.

Intrinsic Factors Affecting the Rate of Transpiration.

1. Leaf surface area
2. Thickness of epidermis and cuticle
3. Stomatal frequency
4. Stomatal size
5. Stomatal position

The Effect of Wind Speed on the Rate of Transpiration



In still air closing the stomata is less effective in controlling the transpiration rate

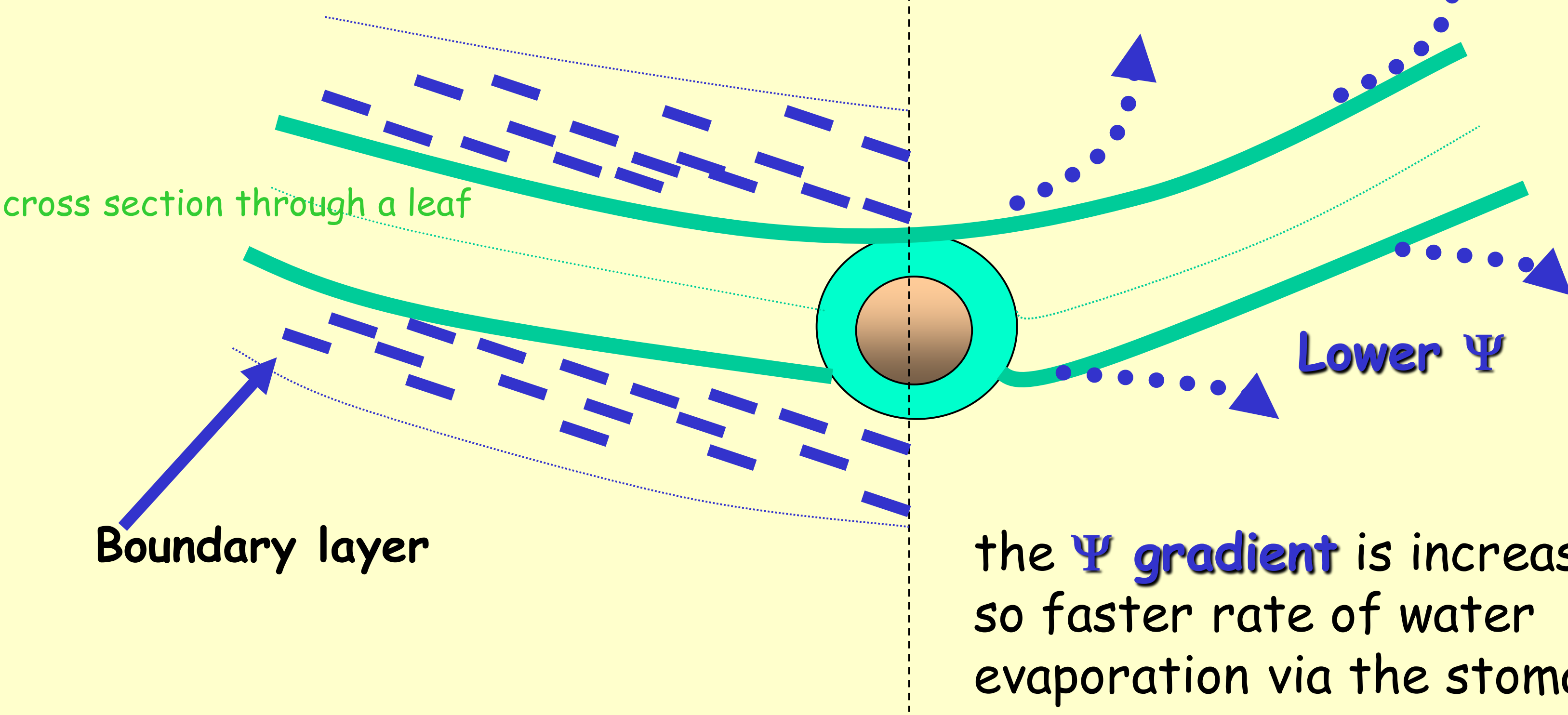
Moving Air Removes the Boundary Layer of Water Vapour From the Leaf

Still air

Moving air

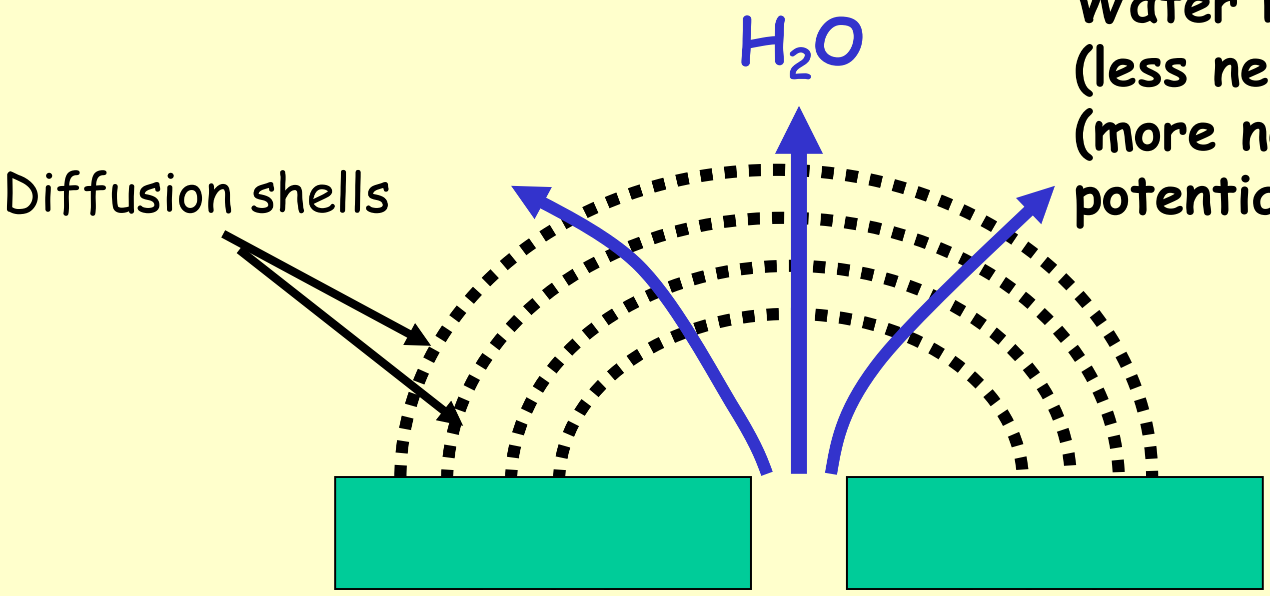
Saturated air accumulates around leaf

Water vapour is removed from the leaf surface



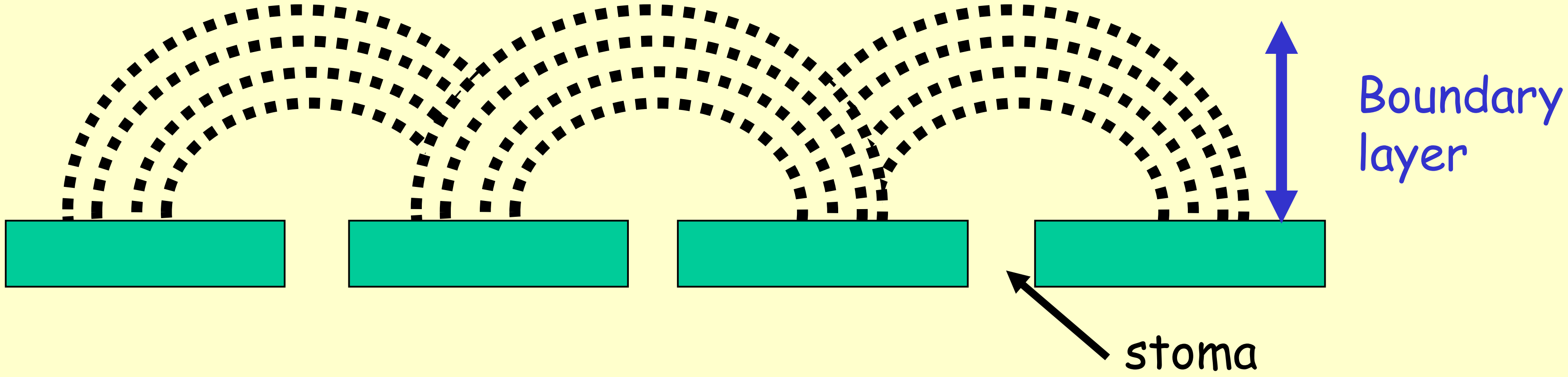
the Ψ **gradient** is increased, so faster rate of water evaporation via the stomata

Movement of Water Through the Stomata



Water moves from a higher (less negative) to a lower (more negative) water potential

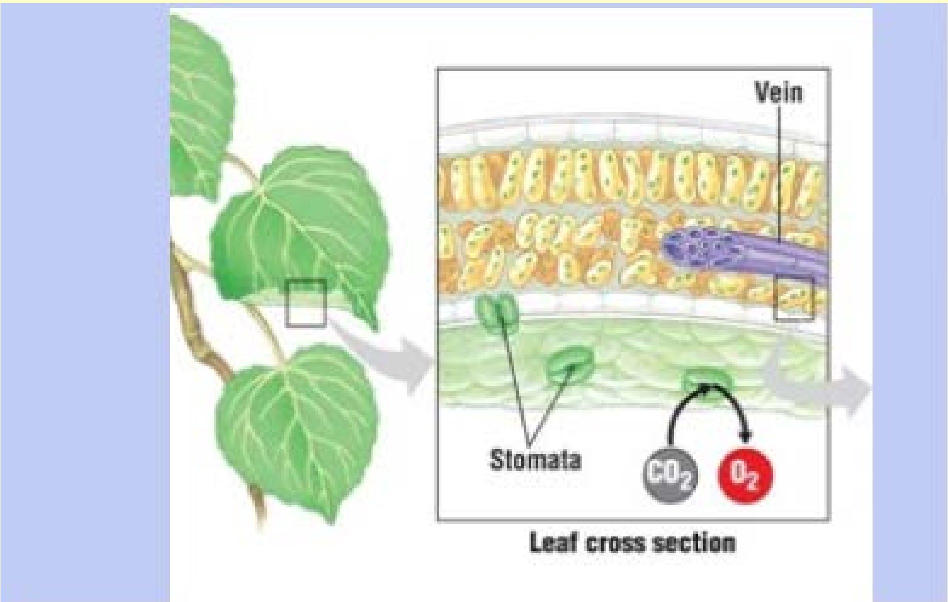
Increase in stomatal frequency increases the rate of transpiration

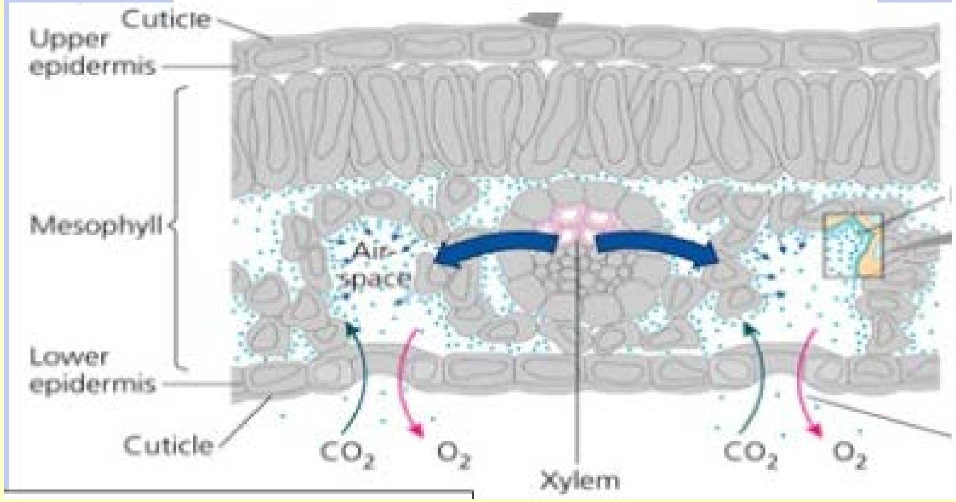


If the distance between the stomata is less than 10 X the pore diameter the diffusion shells overlap

So increasing the number of stomata per unit area will have no further effect on transpiration

Leaf section





The upper epidermis has no stomata

The lower epidermis has stomata.

The *guard cells* control the opening and closing of the stomata

Wilting

If water lost by transpiration is greater than water uptake via the roots the **plant cells** become **flaccid** and the plant wilts.

When the guard cells are flaccid the stomata close