Water

Relation to Plants

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Properties of Water	Associated Uses of Water
Polar Solvent	Dissolves soil minerals, sugar, amino acids, widest range of any liquid!
Hydraulic Fluid	Does not compress, so turgor pressure supports plant tissue, permits flow of material in xylem (transpiration) and phloem (translocation)
Reactive	Reactant: $CO_2 + H_2O \text{ -> } O_2 + CH_2O$ Product: $CH_2O + O_2 \text{ -> } H_2O + CO_2$
High Specific Heat	Heat Buffer: 1 Calorie = 1 Liter 1°C

Water in plant life

- It is the most abundant constituents of most organisms (70 percent by weight of non-woody plant parts)

- The constant flow of water through plants is a matter of considerable significance to their growth and survival

- The thermal properties of water contribute to temperature regulation, helping to ensure that plants do not cool down or heat up too rapidly.

- The uptake of water by cells generates a pressure known as turgor

- Photosynthesis requires that plants draw carbon dioxide from the atmosphere, and at the same time exposes them to water loss. To prevent leaf desiccation, water must be absorbed by the roots

- Water has excellent solvent properties . Many of the biochemical reactions occur in water and water is itself either a reactant or a product in a large number of those reactions.

Sources of Water

Precipitation: Fog, Mist, Rain, Snow, Sleet, Hail

Runoff: Brook, Creek, Stream, River

Water Table: Puddle, Pond, Lake (Ocean not freshwater)

Soil Water: Most useful for plants

Aquifers: porous rock, wells, artesian wells, springs

The practice of crop irrigation reflects the fact that water is a key resource limiting agricultural productivity. Plants use water in huge amounts, but only small part of that remains in the plant to supply growth. About 97% of water taken up by plants is lost to the atmosphere, 2% is used for volume increase or cell expansion, and 1% for metabolic processes, predominantly photosynthesis. Water loss to the atmosphere appears to be an inevitable consequence of carrying out photosynthesis. The uptake of CO2 is coupled to the loss of water (**Figure**). Because the driving gradient for water loss from leaves is much larger than that for CO2 uptake, as many as 400 water molecules are lost for every CO2 molecule gained.

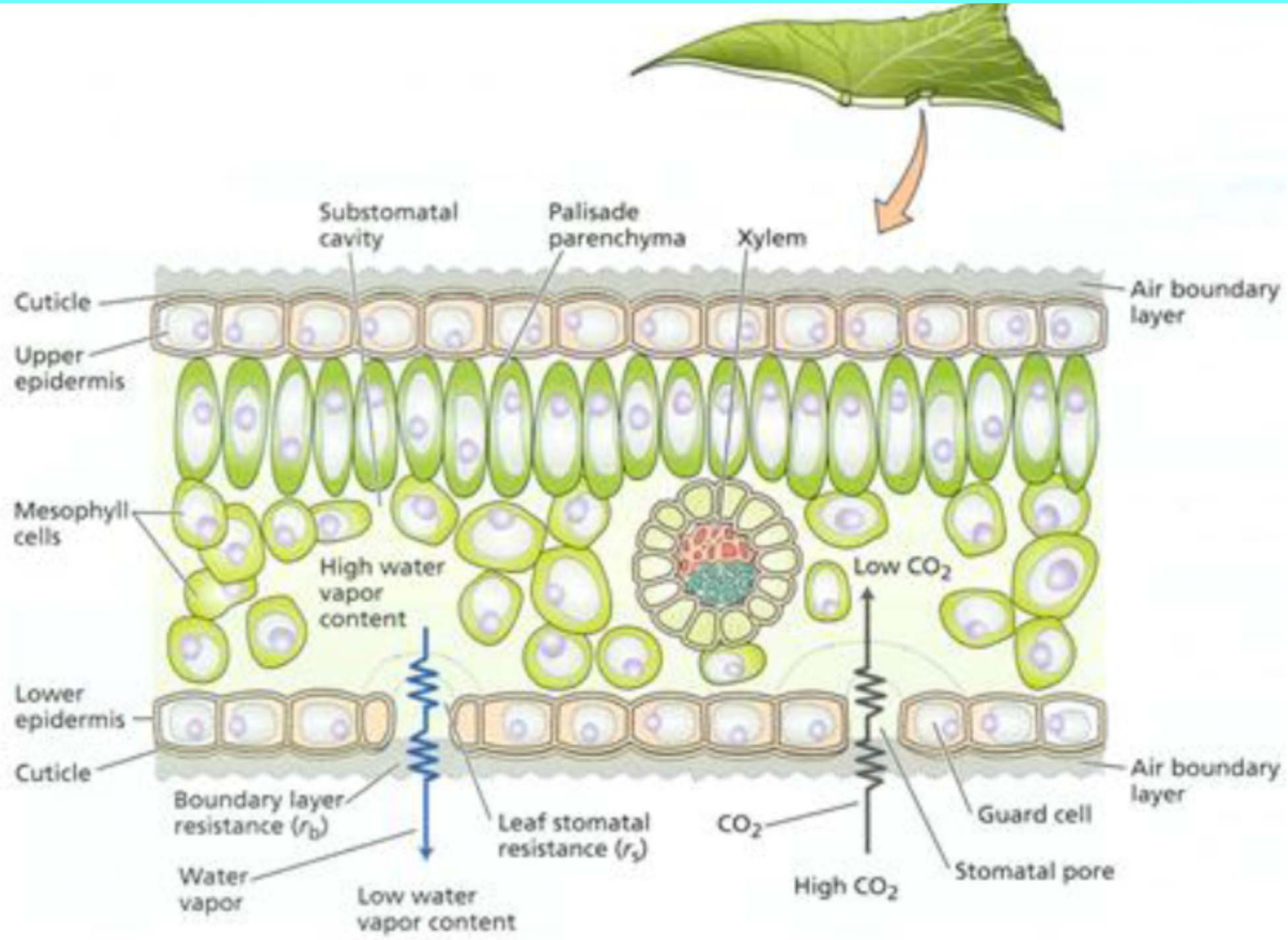


Figure 1.2 Water pathway through the leaf (*source: Taiz L., Zeiger E., 2010*)

The structure and properties of water

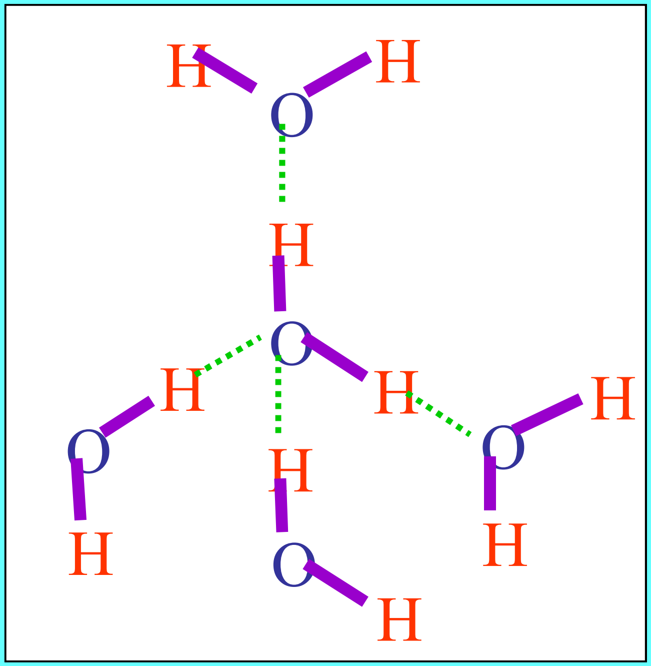
Water consists of an oxygen atom covalently bonded to two hydrogen atoms

Water molecules have a weak negative charge at the oxygen atom and weak positive charge at the hydrogen atoms

The positive and negative regions are attracted to the oppositely-charged regions of nearby molecules. The force of attraction, dotted line, is called a hydrogen bond.

Each water molecule is hydrogen bonded to four others.

The hydrogen bond has ~ 5% of the strength of a covalent bond. However, when many hydrogen bonds form, the resulting union can be sufficiently strong as to be quite stable.

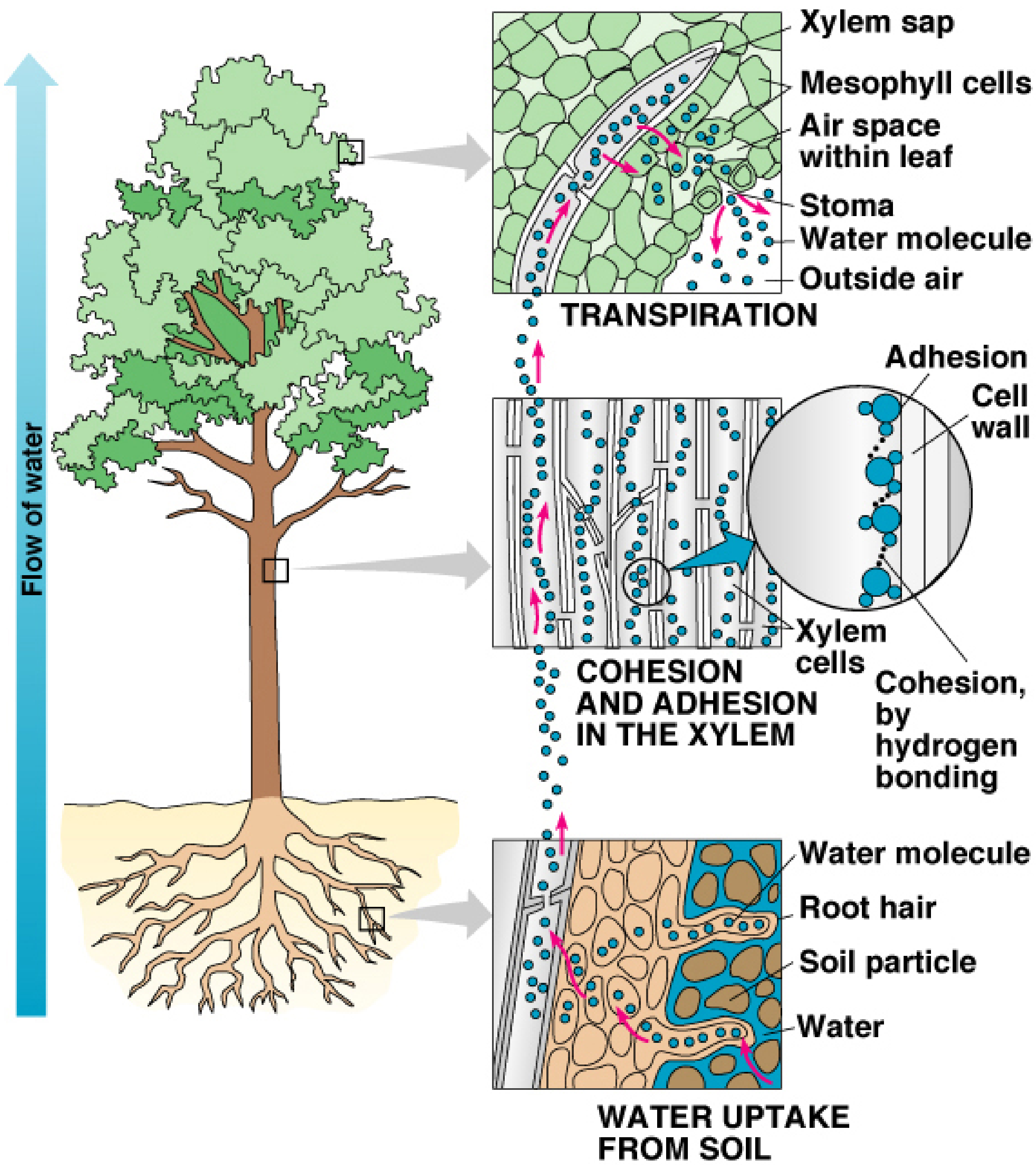


The hydrogen bonding ability of water and its polar structure make it a particularly good solvent for ionic substances and for molecules such as sugars and proteins. The hydration shells that form around biologically important macromolecules are often referred to as bound water. Bound water prevents protein molecules from approaching close enough to form aggregates large enough to precipitate.

The extensive hydrogen bonding between water molecules results in water having both a high **specific heat capacity** and a high **latent heat of vaporization**. Because of its highly ordered structure, liquid water also has a high **thermal conductivity**. This means that it rapidly conducts heat away from the point of application. The combination of high specific heat and thermal conductivity enables water to <u>absorb</u> and <u>redistribute</u> large amounts of heat energy without correspondingly large increases in temperature. The heat of biochemical reactions may be quickly dissipated throughout the cell. Compared with other liquids, water requires a relatively large heat input to raise its temperature. This is important for plants, because it helps buffer temperature fluctuations.

The extensive hydrogen bonding in water gives a new property known as **cohesion**, the mutual attraction between molecules. A related property, called **adhesion**, is the attraction of water to a solid phase, such as cell wall. The water molecules are highly cohesive. One consequence of cohesion is that water has exceptionally high **surface tension**, which is the energy required to increase the surface area of a gas-liquid interface. Surface tension and adhesion at the evaporative surfaces in leaves generate the physical forces that pull water through the plant’s vascular system. Cohesion, adhesion and surface tension give rise to a phenomenon known as **capillarity**. These combined properties of water help to explain why water rises in capillary tubes and are exceptionally important in maintaining the continuity of water columns in plants. (collum of 10 µm in diameter ad 3000 m in height)

Cohesion and adhesion in the transpiration stream



Mechanisms for translocation may be classified as:
either active or passive.

It is sometimes difficult to distinguish between active and passive transport, but the **translocation of water is clearly a passive process**.

Passive movement of most substances can be accounted for by **bulk flow** or **diffusion**.

Bulk flow accounts for some water movement in plants through the **xylem tissues** of plants.

Movement of materials by **bulk flow** (or **mass flow**) is **pressure driven**.

Bulk flow occurs when an **external force**, such as gravity or pressure, is applied. As a result, all of the molecules of the substance move in mass.

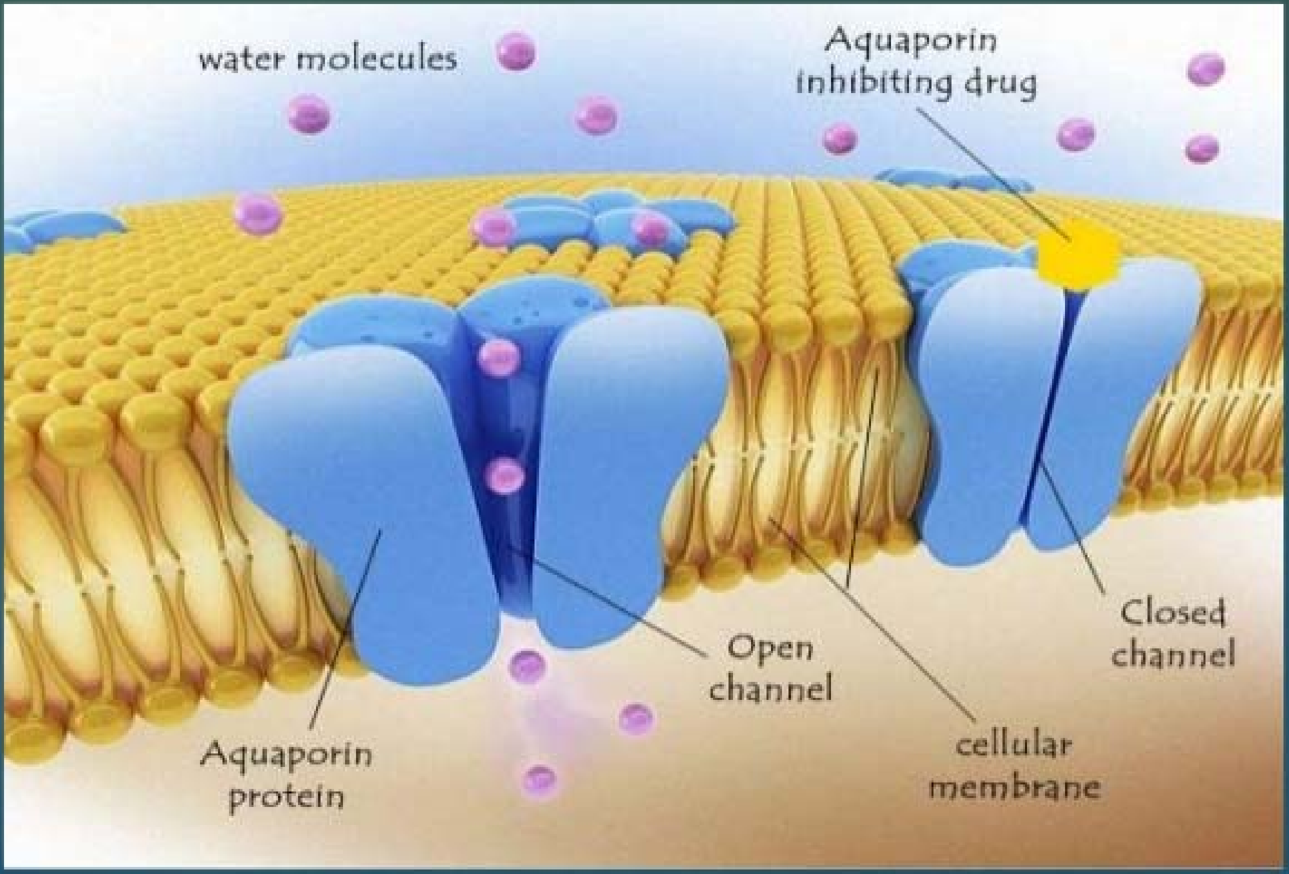
Bulk flow is pressure-driven, **diffusion** is driven principally by **concentration differences**.

Diffusion results in the net movement of molecules from regions of high concentration to regions of low concentration.

Diffusion in solutions can be effective **within cellular dimensions** but is far too slow to be effective over long distances.
(The average time required for a glucose molecule to diffuse across a cell with a diameter of 50 µm is 2.5 s. However, the average time needed for the same glucose molecule to diffuse a distance of 1 m in water is approximately 32 years).

The net movement of water across a selectively permeable barrier is referred to as **osmosis**.

Membranes of plant cells are selectively permeable. The diffusion of water directly across the lipid bilayer is facilitated by **aquaporins**, which are integral membrane proteins that form water-selective channels across membrane.


water molecules
Aquaporin inhibiting drug
Closed channel
Open channel
cellular membrane
Aquaporin protein

There are three ways that water (and other materials) move in plants

1. Diffusion

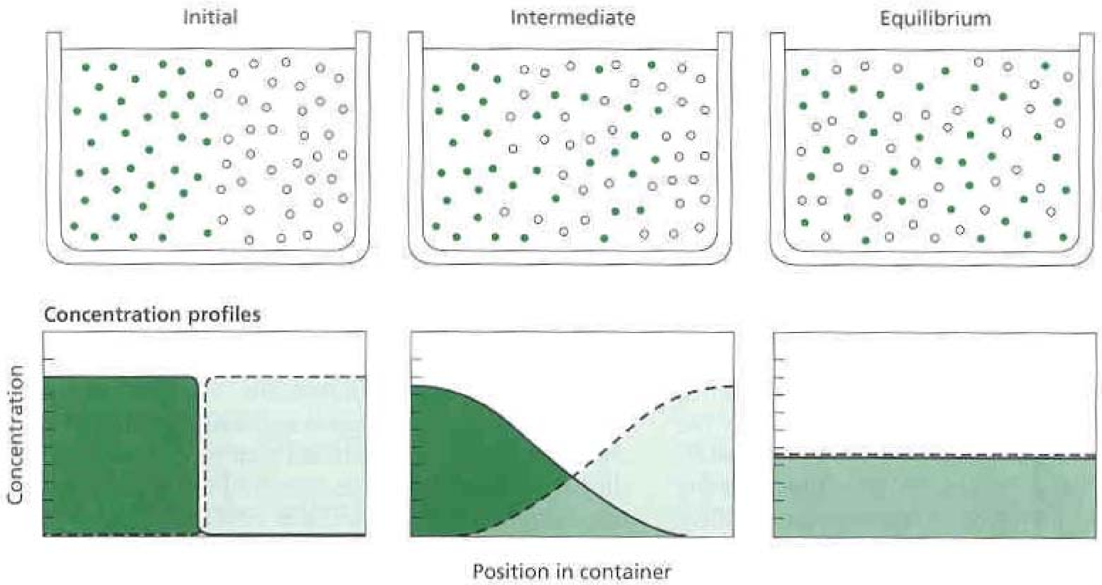


Figure 3.6 Thermal motion of molecules leads to diffusion—the gradual mixing of molecules and eventual dissipation of concentration differences. Initially, two materials containing different molecules are brought into contact. The materials may be gas, liquid, or solid. Diffusion is fastest in gases, intermediate in liquids, and slowest in solids. The initial separation of the molecules is depicted graphically in the upper panels, and the corresponding concentration profiles are shown in the lower panels as a function of position. With time, the mixing and randomization of the molecules diminishes net movement. At equilibrium the two types of molecules are randomly (evenly) distributed.

Diffusion is driven by a *concentration gradient*

(usually we think of this as a difference in concentration of the solute, not water molecules, which make up the solvent, although you can consider it from either perspective) technically, $\Delta\Psi_s$, where Ψ_s = solute potential = $-RTc_s$; R is the gas constant, T is Kelvin temperature and c_s is solute concentration)

Diffusion is extremely slow over large distances.

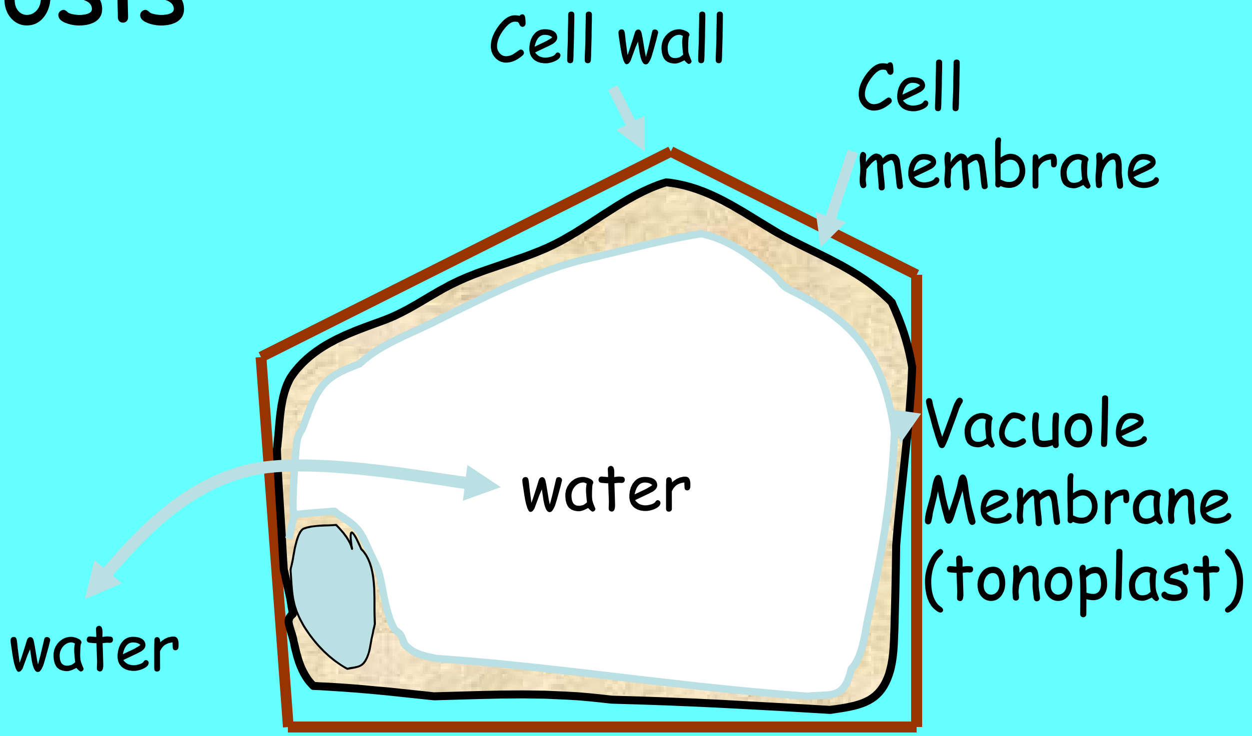
It would take about 32 years for a sugar molecule to diffuse through a stem 1 meter long!

2. Mass Flow

Transport over large distances occurs by mass flow.

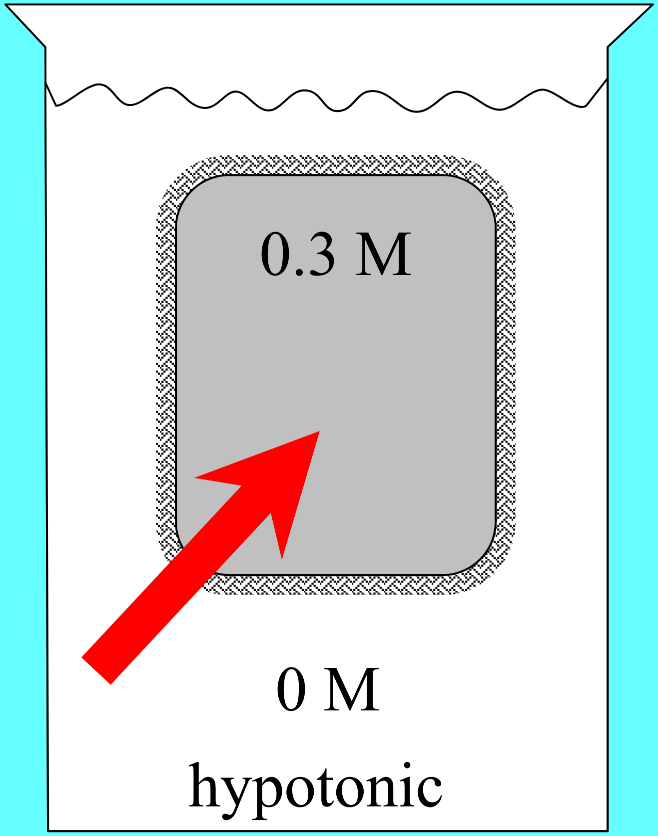
Mass flow is driven by a *pressure gradient*

3. Osmosis



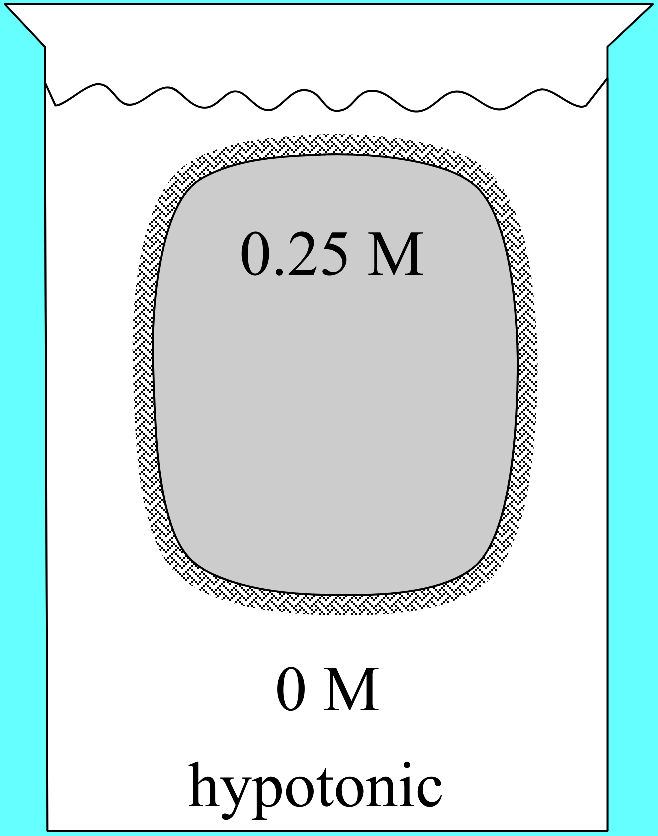
Osmosis is driven by a *water potential difference* across a membrane – in other words, both pressure and concentration are important

Osmosis: the passive movement of water from a place that is purer water to a place that is more polluted

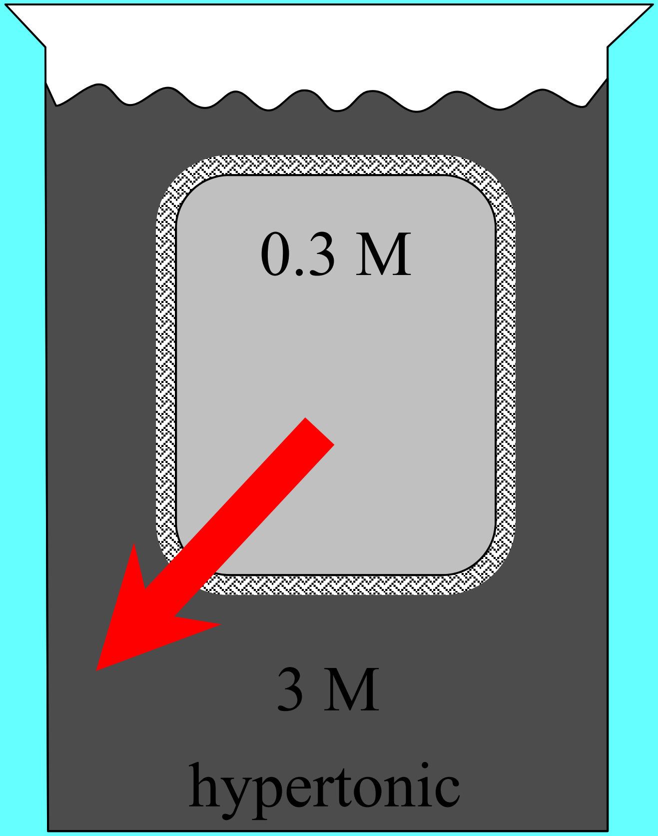


Water moves into the cell

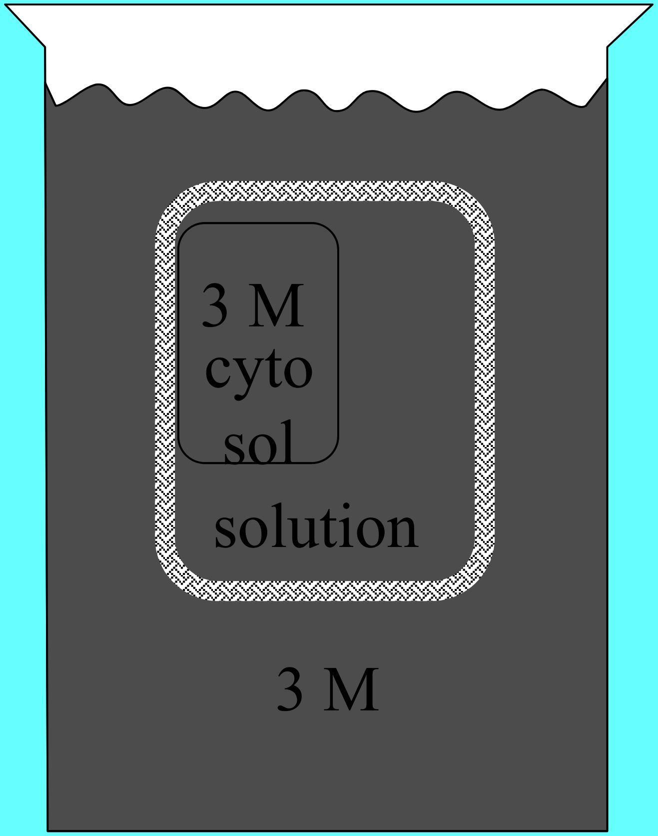
- weight increase
- size increase
- turgor pressure increase



Osmosis: the passive movement of water from a place that is purer water to a place that is more polluted

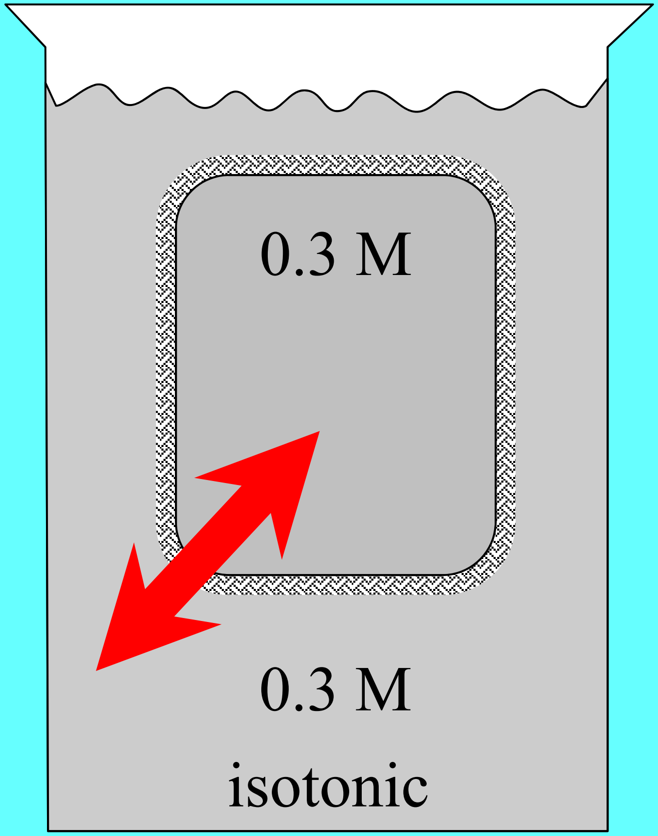


- weight decrease
- size decrease
- turgor pressure to 0
- plasmolysis: membrane pulls away from cell wall



Water moves out of the cell

Osmosis: the passive movement of water from a place that is purer water to a place that is more polluted



Water moves into and out of the cell at same rate!

- no weight change
- no size change
- no turgor pressure change

The concept of water potential

The status of water in plants is described by:

water potential, Ψ_w

Chemical potential is a quantitative expression of the free energy associated with a substance.

Technically, the units of the chemical potential of water are Joules/mole.

But in plant physiology it is much more common to describe water potential in units of *pressure* (derived from the chemical potential divided by the volume of a mole of water)

Water potential indicates how strongly water is held in a substance. It is measured by the amount of energy required to force water out of it. Think of squeezing a sponge or cloth.

Water potential , is measured in megapascals, MPa, (SI) units.

Typically ψ_{leaf} = -1 to – 4 MPa

Ψsoil = 0.01 to - 0.1 MPa

- Water potential is a measure of the free energy content of water.

- The potential of a particular sample of water is defined relative to energy status of **pure free water (which by definition has zero potential)**.

- Water potential is the work that would be required to move water from where it is to the pure free state.

The major factors influencing the water potential in plants are: *concentration*, *pressure and gravity*.

$$\Psi w = \Psi s + \Psi p + \Psi g$$

The terms Ψs and Ψp and Ψg denote the effects of solutes, pressure, and gravity, respectively, on the **free energy** of water.

The reference state (Zero) most often used to define water potential is pure water at ambient temperature and standard atmospheric pressure.

Ψ_w always a negative number (pure water at standard temperature is a reference, with “zero” water potential.

Ψ_s (solute potential) – zero for pure water, negative number when there are solutes ($\Psi_s = -RTc_s$)

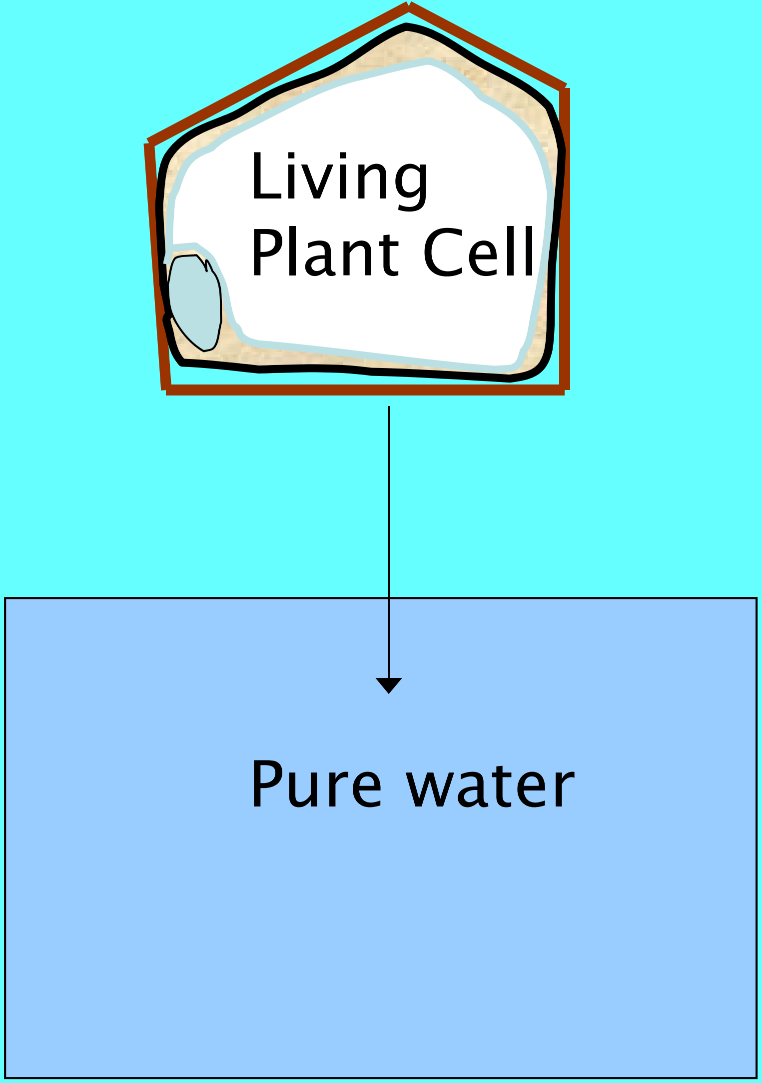
Ψ_p (pressure potential) – positive in healthy, living cells
negative in xylem

Ψ_g (gravitational potential) – zero at ground level,
increases with height
0.01 MPa per meter

Examples

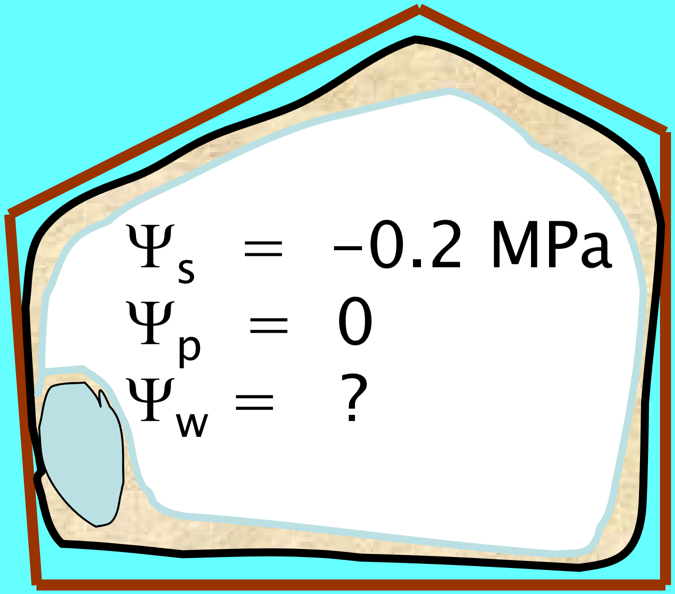
Here are some examples of cell-level water relations with **no change** in gravitational potential. On Wednesday, we'll look at water relations on a whole plant level, where the gravitational component can be important, especially in large trees.

EXAMPLE 1: lets suppose we drop a plant cell into pure water



Water can move by osmosis across the cell wall and cell membrane but most solutes cannot

Plant Cell: before equilibrating with water



$\Psi_s = -0.2$ MPa

$\Psi_p = 0$

$\Psi_w = ?$

Pure water

$\Psi_s = 0$

$\Psi_p = 0$

$\Psi_w = \Psi_s + \Psi_p = 0$

What is the total water potential of the plant cell?

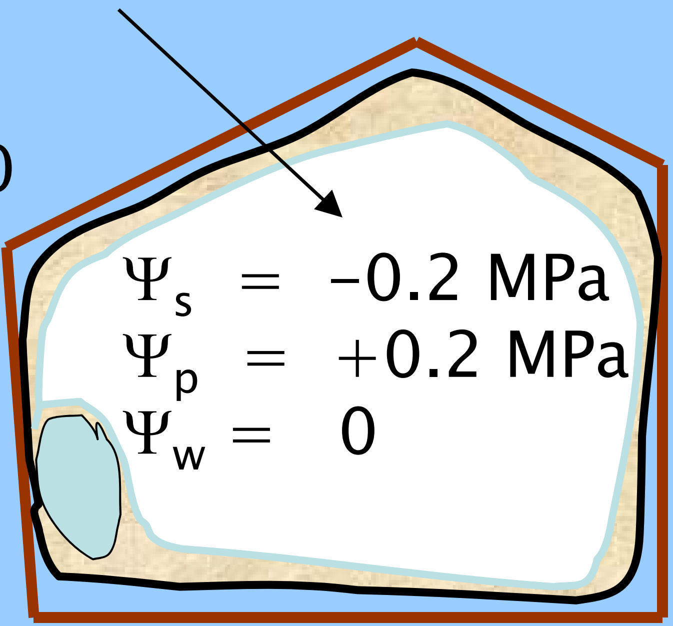
What will happen to the total water potential of the plant cell when it is dropped in water?

Pure water

$\Psi_s = 0$

$\Psi_p = 0$

$\Psi_w = \Psi_s + \Psi_p = 0$



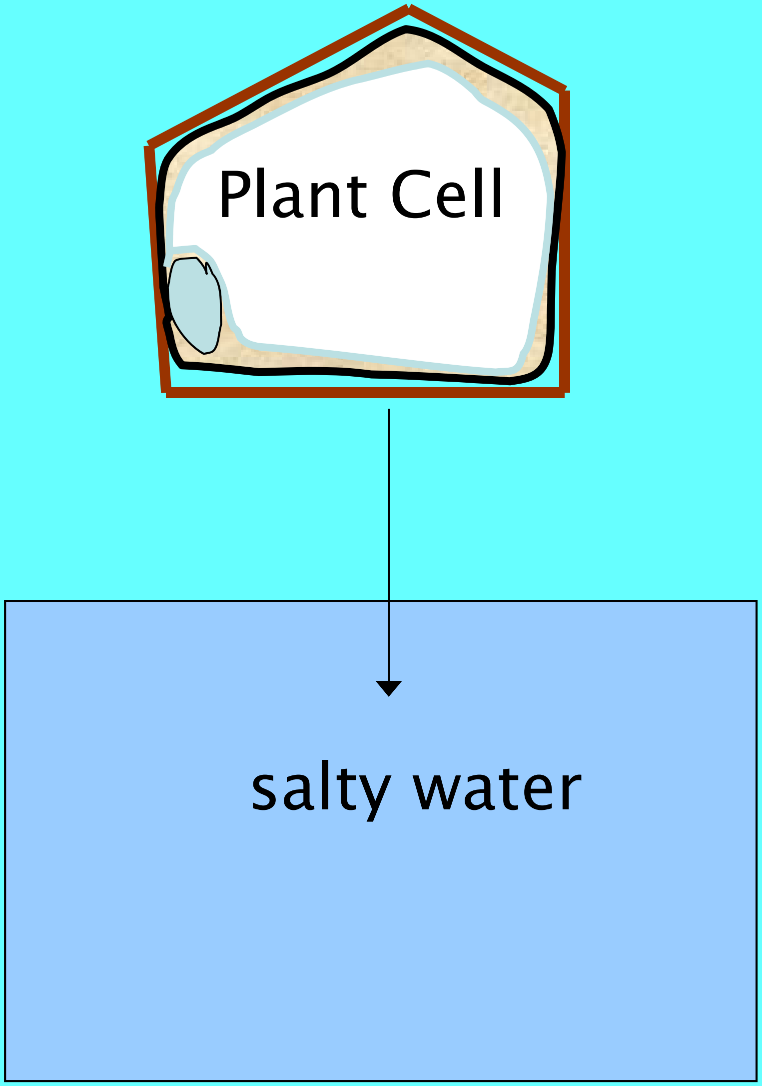
$\Psi_s = -0.2\ \text{MPa}$

$\Psi_p = +0.2\ \text{MPa}$

$\Psi_w = 0$

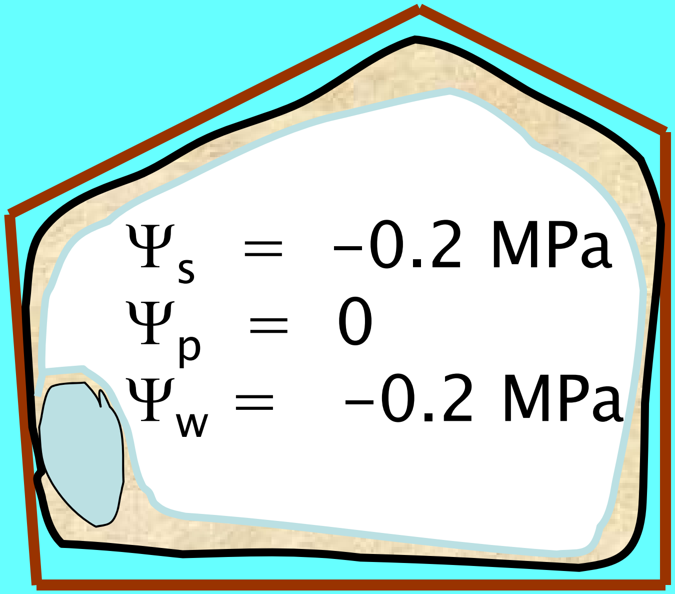
This is what produces turgor, or positive pressure, in plant cells

EXAMPLE 2: Putting a plant cell into salty water



Water can move by osmosis across the cell wall and cell membrane but most solutes cannot

Plant Cell: before equilibrating with salty water



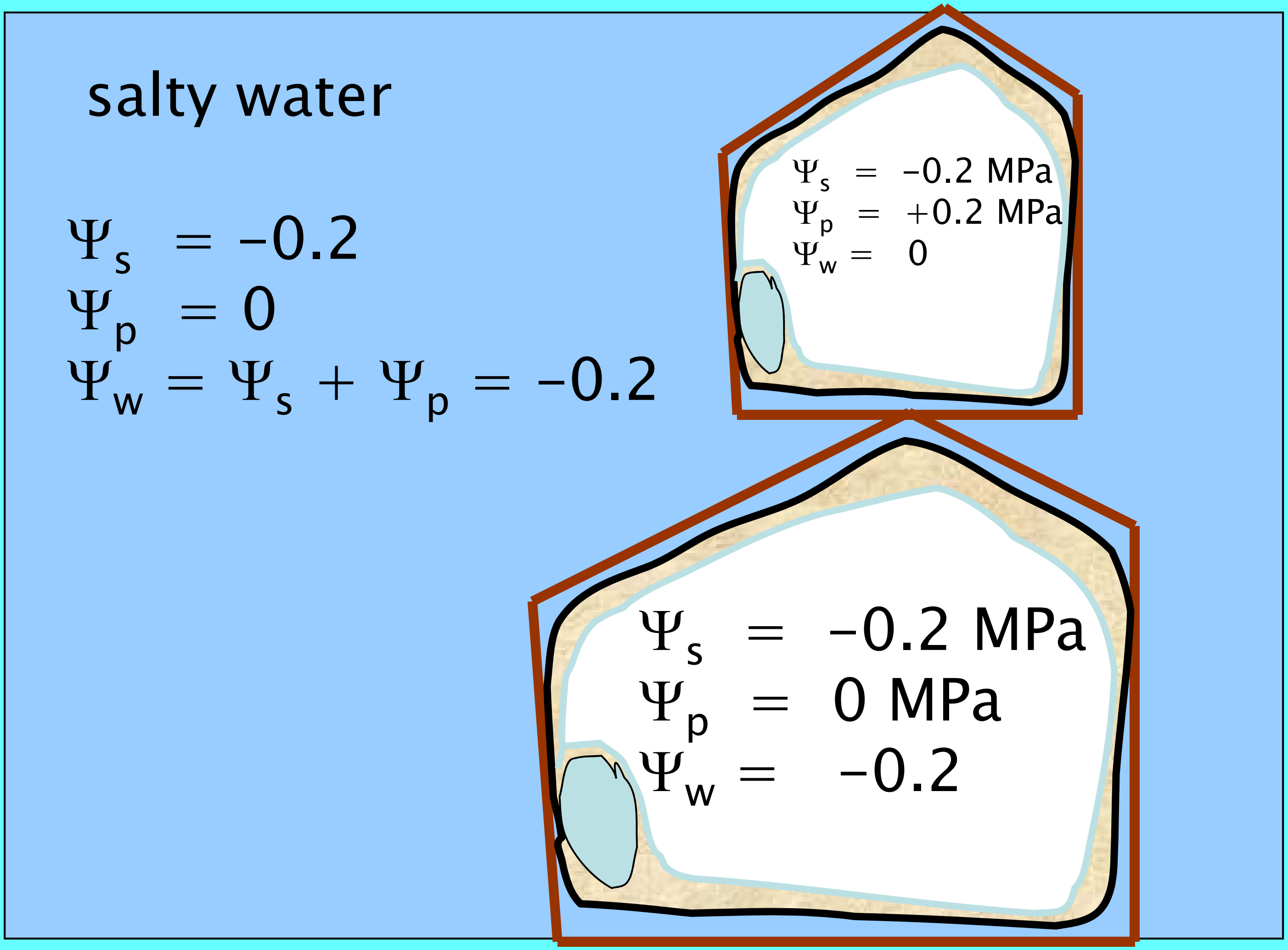
Ψ_s = –0.2 MPa
Ψ_p = 0
Ψ_w = –0.2 MPa

Salty water

Ψ_s = –0.2 MPa
Ψ_p = 0
$\Psi_w = \Psi_s + \Psi_p$ = –0.2 MPa

What is the total water potential of the salty water?

What will happen to the total water potential of the plant cell when it is dropped in water?



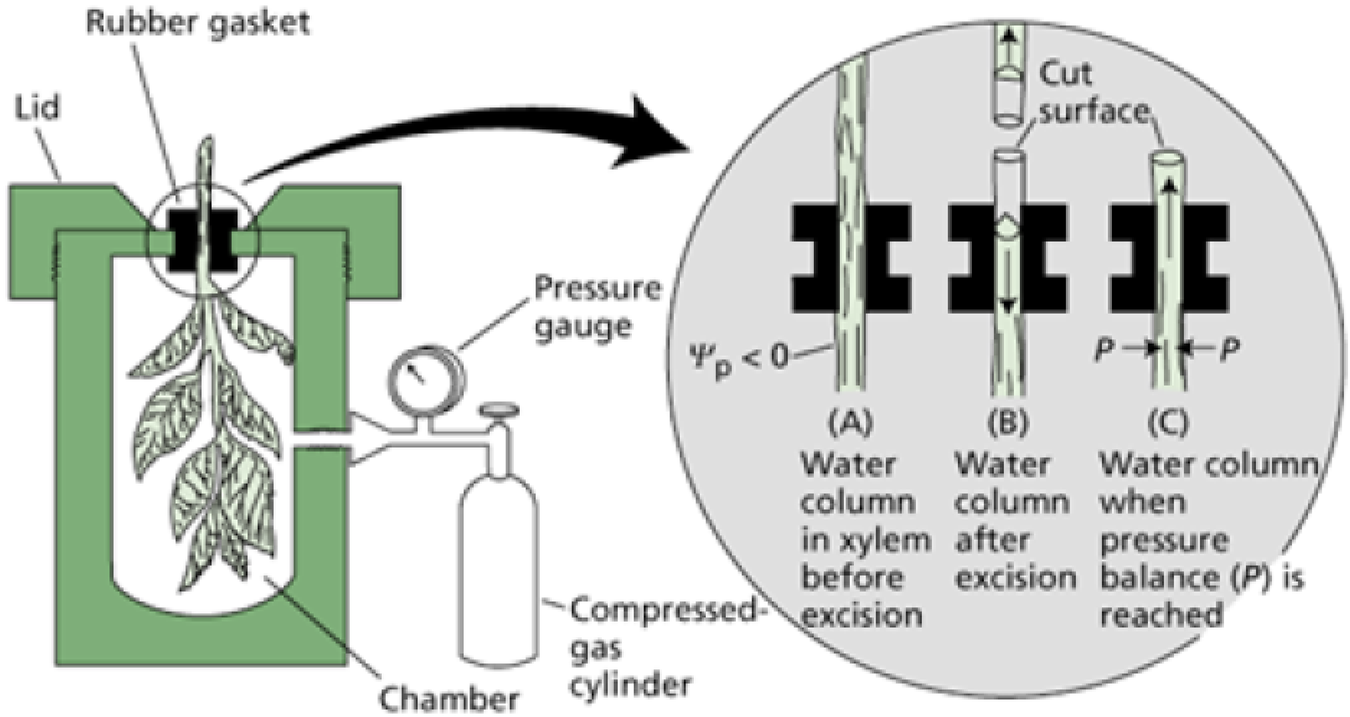
salty water

$$\Psi_s = -0.2$$
$$\Psi_p = 0$$
$$\Psi_w = \Psi_s + \Psi_p = -0.2$$

Ψ_s = −0.2 MPa
Ψ_p = +0.2 MPa
Ψ_w = 0

Ψ_s = −0.2 MPa
Ψ_p = 0 MPa
Ψ_w = −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


Rubber gasket
Lid
Pressure gauge
Compressed-gas cylinder
Chamber
Cut surface
$\Psi_p < 0$
P
P
(A)
Water column in xylem before excision
(B)
Water column after excision
(C)
Water column when pressure balance (P) is reached