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

1. Diffusion

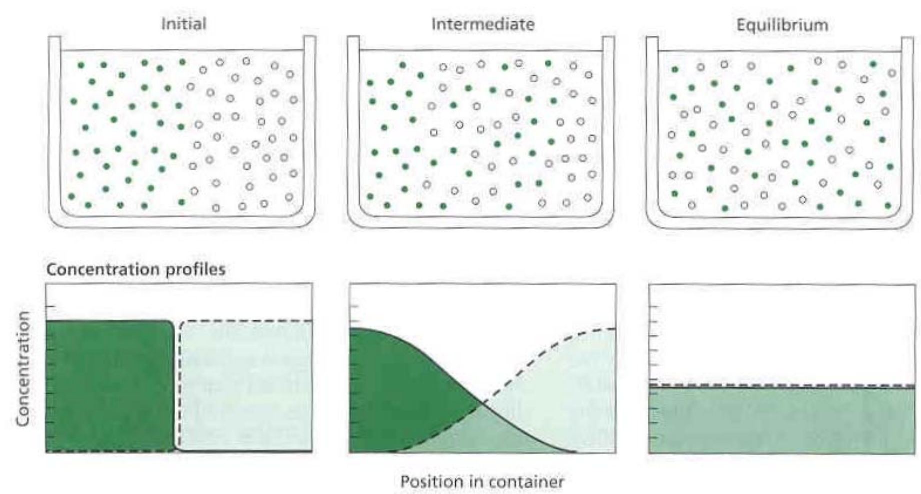


Figure 3.6 Thermal motion of molecules leads to diffusion—the gradual mixing of molecules and eventual dissipation of concentration differences. Initially, two materials containing different molecules are brought into contact. The materials may be gas, liquid, or solid. Diffusion is fastest in gases, 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.

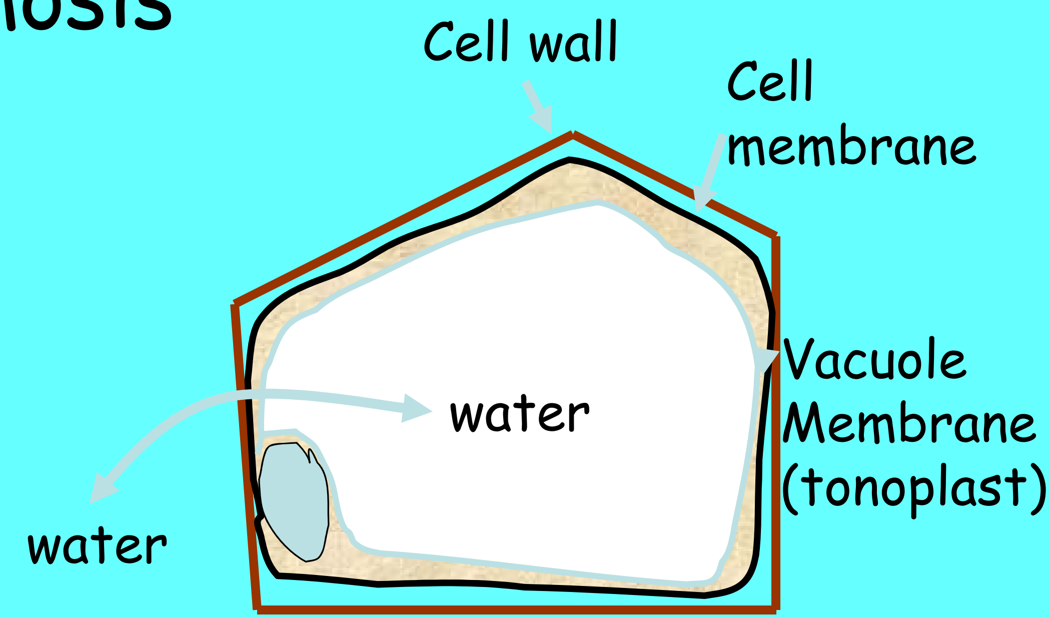
It would take about 32 years for a sugar molecule to diffuse through a stem 1 meter long!

2. Mass Flow

Transport over large distances occurs by mass flow.

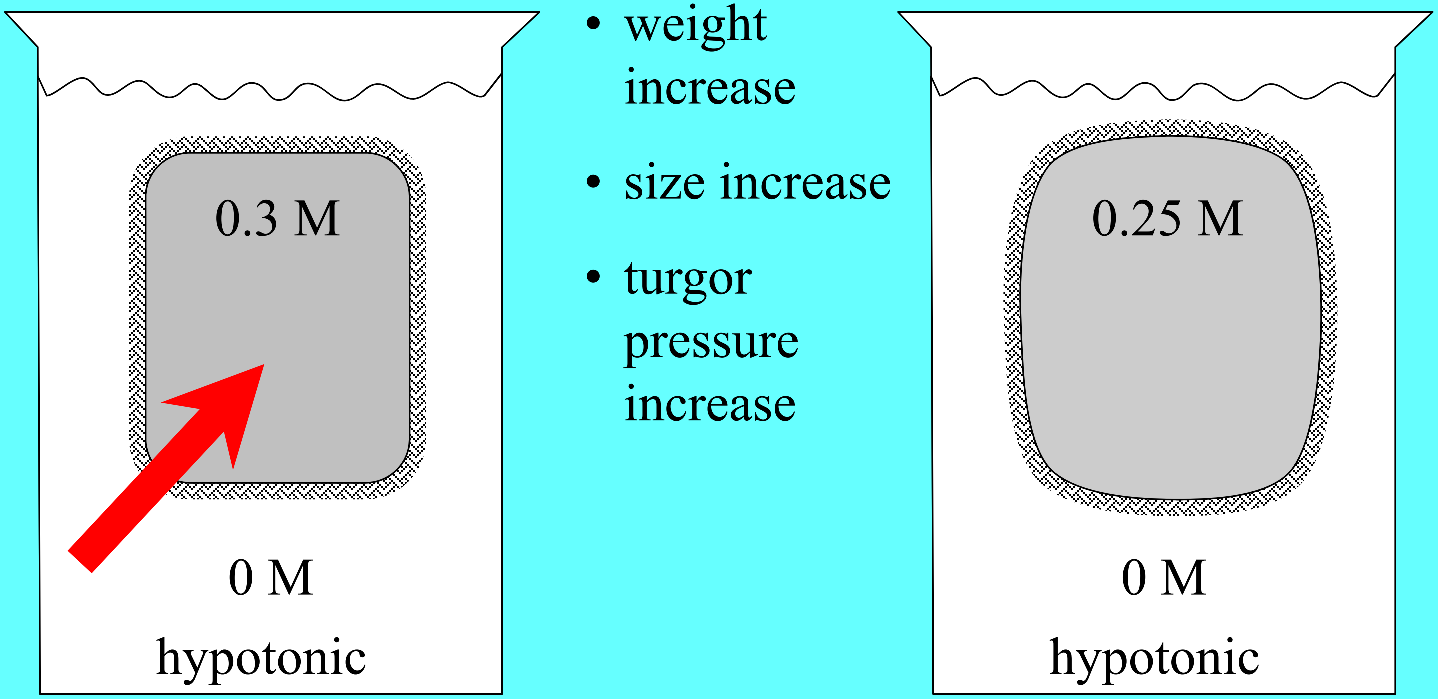
Mass flow is driven by a *pressure gradient*

3. Osmosis



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

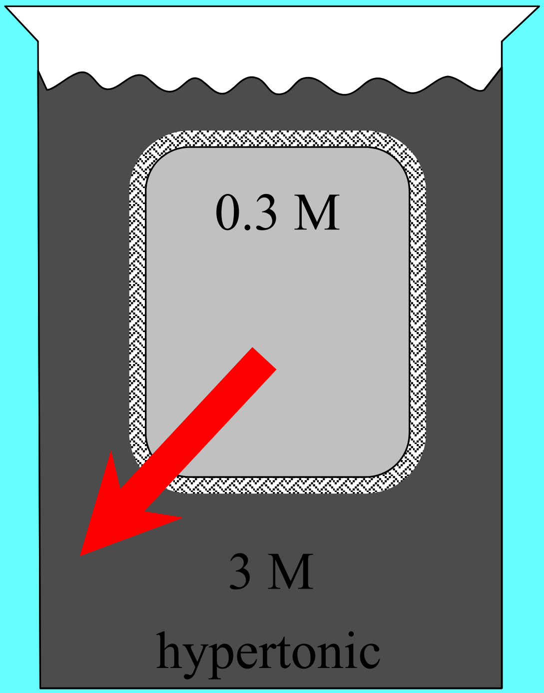
Osmosis: the passive movement of water from a place that is purer water to a place that is more polluted



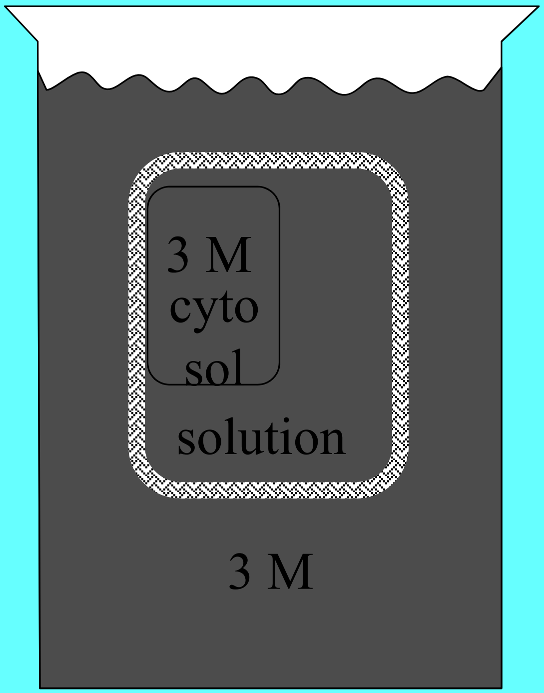
- weight increase
- size increase
- turgor pressure increase

Water moves into the cell

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

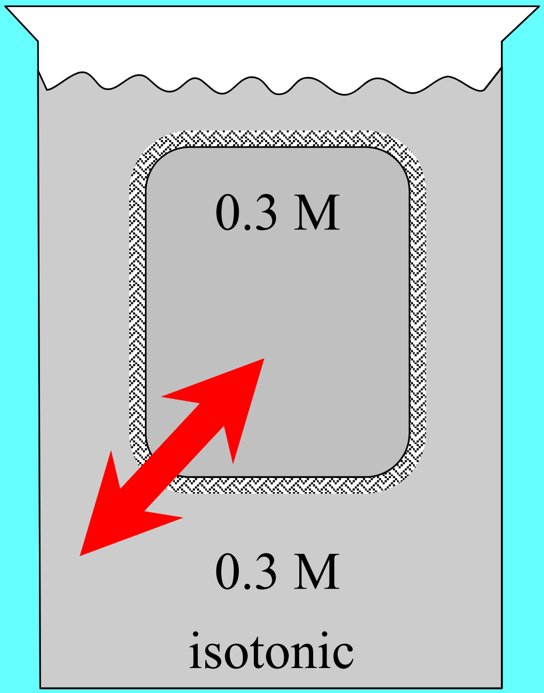


- weight decrease
- size decrease
- turgor pressure to 0
- plasmolysis: membrane pulls away from cell wall



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

($\Psi_s = -RTc_s$)

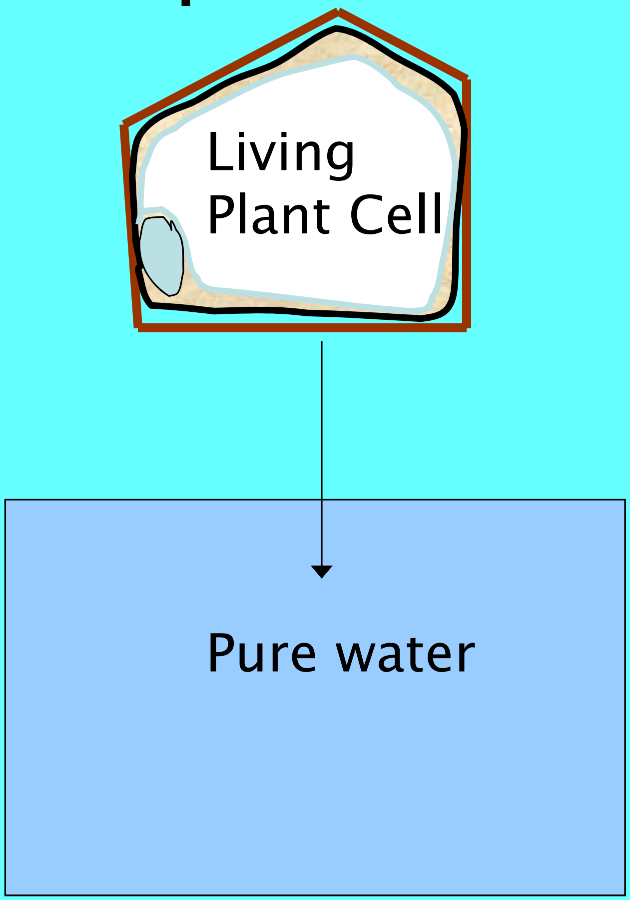
Ψ_p (pressure potential) – positive in healthy, living cells
negative in xylem

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

Examples

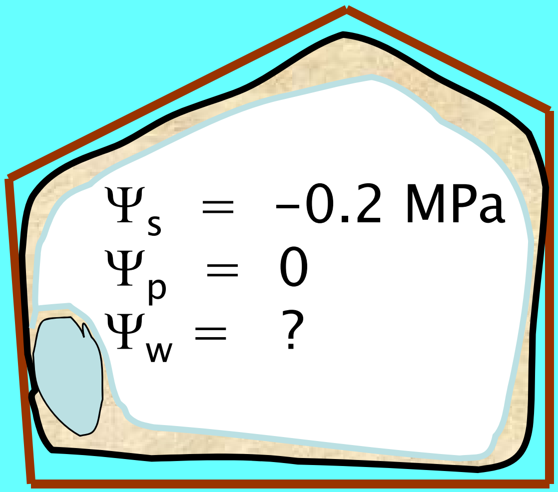
Here are some examples of cell-level water relations with **no change** in gravitational potential. On Wednesday, we'll look at water relations on a whole plant level, where the gravitational component can be important, especially in large trees.

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

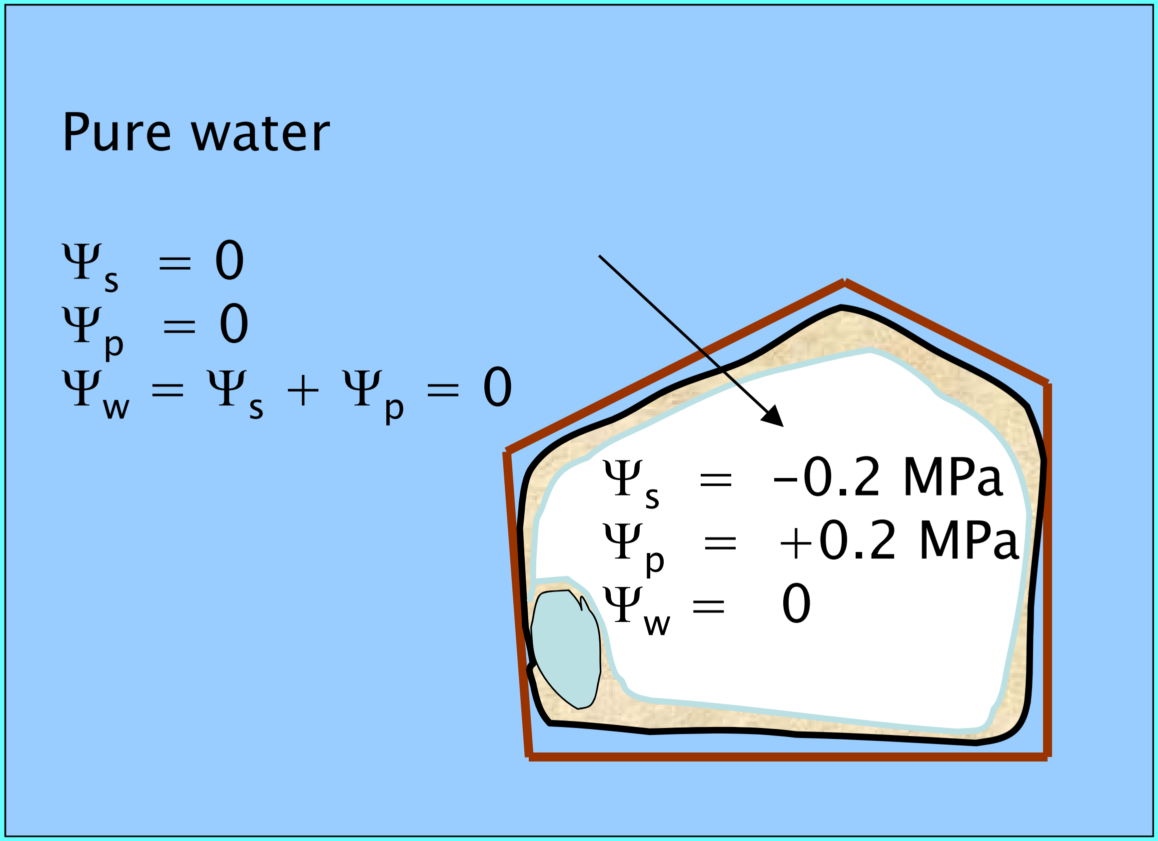


Pure water

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

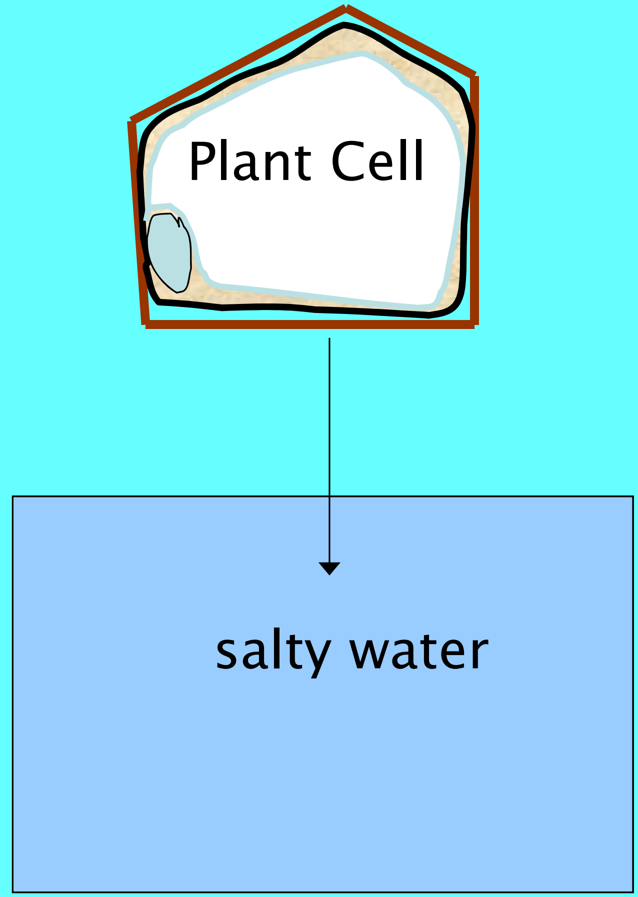
What is the total water potential of the plant cell?

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

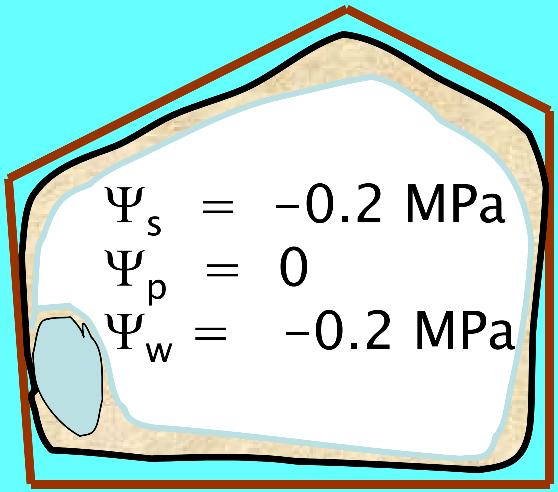


This is what produces turgor, or positive pressure, in plant cells

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

Salty water

$\Psi_s = -0.2$ MPa

$\Psi_p = 0$

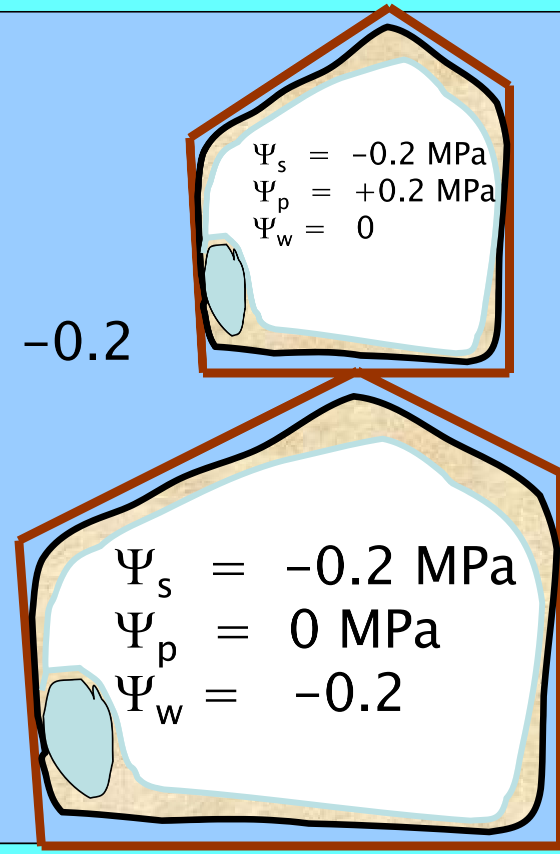
$\Psi_w = \Psi_s + \Psi_p = -0.2$ MPa

What is the total water potential of the salty water?

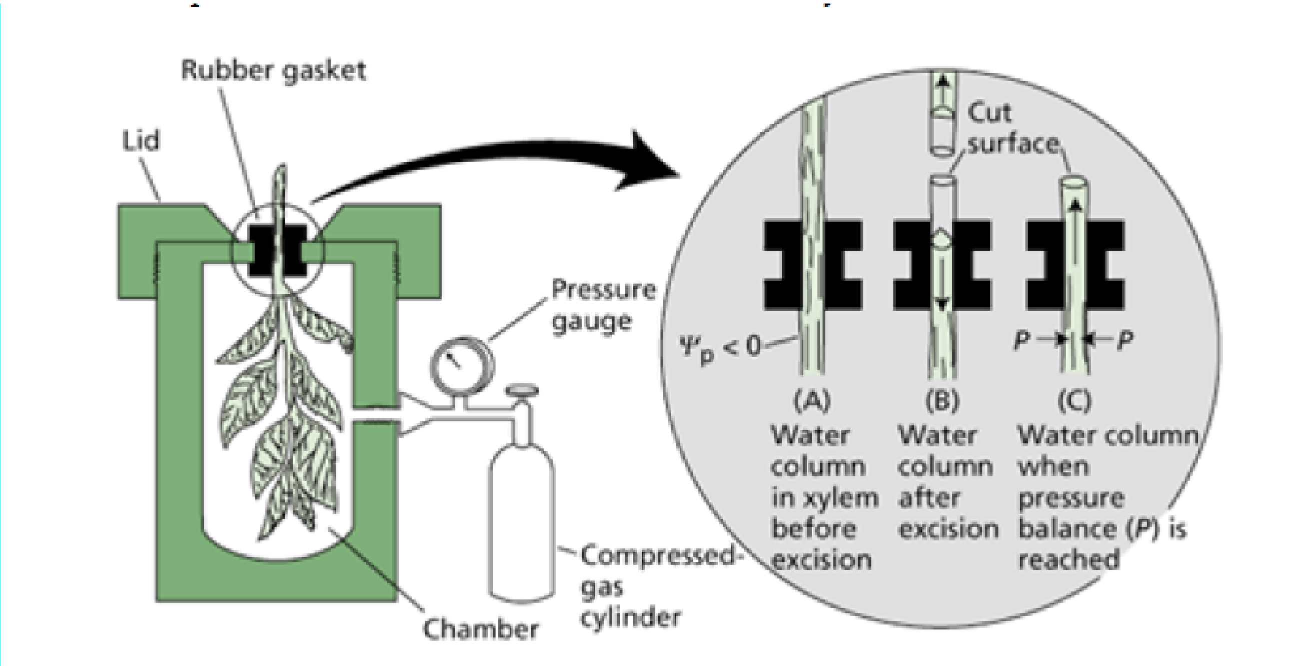
What will happen to the total water potential of the plant cell when it is dropped in water?

salty water

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



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

Plants are seldom fully hydrated.

During periods of drought, they suffer from water deficits that lead to inhibition of plant growth and photosynthesis.

Several physiological changes occur as plants experience increasingly drier conditions (**Figure**).

Cell expansion is most affected by water deficit.

In many plants reductions in water supply inhibit shoot growth and leaf expansion but stimulate root elongation.

Drought does impose some absolute limitations on physiological processes, although the actual water potentials at which such limitations occur vary with species.

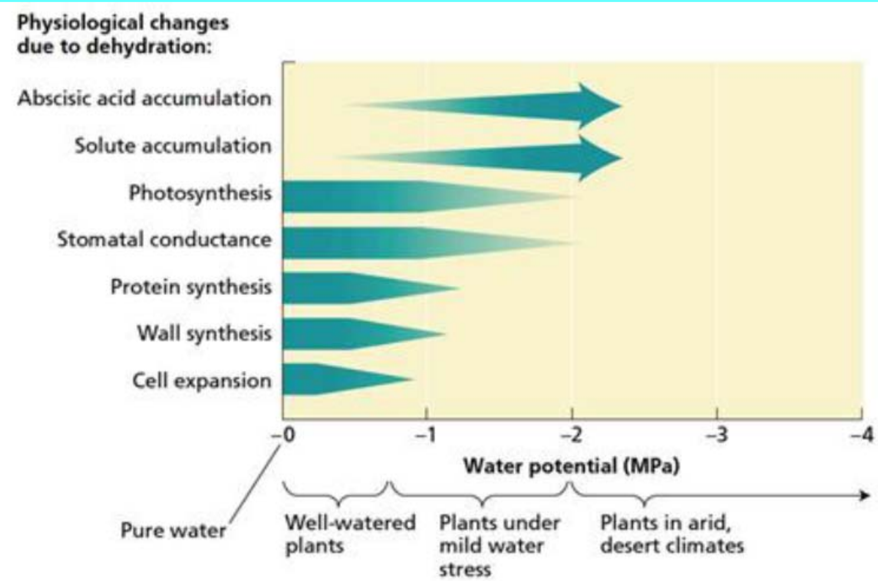


Figure 1.10 Sensitivity of various physiological processes to changes in water potential under various growing conditions (*source: Taiz L., Zeiger E., 2010*)