Cellular Processes:
Energy and Communication

INVeStIGatIoN 4
DIFFUSIoN aND oSMoSIS

What causes my plants to wilt if I forget to
water them?

■ BACkground

Cells must move materials through membranes and throughout cytoplasm in order
to maintain homeostasis. The movement is regulated because cellular membranes,
including the plasma and organelle membranes, are selectively permeable. Membranes
are phospholipid bilayers containing embedded proteins; the phospholipid fatty acids limit
the movement of water because of their hydrophobic characteristics.

The cellular environment is aqueous, meaning that the solvent in which the solutes,
such as salts and organic molecules, dissolve is water. Water may pass slowly through the
membrane by osmosis or through specialized protein channels called aquaporins.
Aquaporins allow the water to move more quickly than it would through osmosis. Most
other substances, such as ions, move through protein channels, while larger molecules,
including carbohydrates, move through transport proteins.

The simplest form of movement is diffusion, in which solutes move from an area
of high concentration to an area of low concentration; diffusion is directly related to
molecular kinetic energy. Diffusion does not require energy input by cells. The
movement of a solute from an area of low concentration to an area of high concentration
requires energy input in the form of ATP and protein carriers called pumps.

Water moves through membranes by diffusion; the movement of water through
membranes is called osmosis. Like solutes, water moves down its concentration
gradient. Water moves from areas of high potential (high free water concentration)
and low solute concentration to areas of low potential (low free water concentration) and
high solute concentration. Solutes decrease the concentration of free water, since water
molecules surround the solute molecules. The terms *hypertonic, hypotonic,* and *isotonic* are
used to describe solutions separated by selectively permeable membranes.
A hypertonic solution has a higher solute concentration and a lower water potential
as compared to the other solution; therefore, water will move into the hypertonic
solution through the membrane by osmosis. A hypotonic solution has a lower solute
concentration and a higher water potential than the solution on the other side of the
membrane; water will move down its concentration gradient into the other solution.
Isotonic solutions have equal water potentials.

In nonwalled cells, such as animal cells, the movement of water into and out of a cell is affected by the relative solute concentration on either side of the plasma membrane. As water moves out of the cell, the cell shrinks; if water moves into the cell, it swells and may eventually burst. In walled cells, including fungal and plant cells, osmosis is affected not only by the solute concentration, but also by the resistance to water movement in the cell by the cell wall. This resistance is called turgor pressure. The presence of a cell wall prevents the cells from bursting as water enters; however, pressure builds up inside the cell and affects the rate of osmosis.

Water movement in plants is important in water transport from the roots into the shoots and leaves. You likely will explore this specialized movement called transpiration in another lab investigation.

■ Understanding water Potential

Water potential predicts which way water diffuses through plant tissues and is abbreviated by the Greek letter psi (ψ). Water potential is the free energy per mole of water and is calculated from two major components: (1) the solute potential (ψ_S), which is dependent on solute concentration, and (2) the pressure potential (ψ_P), which results from the exertion of pressure—either positive or negative (tension) — on a solution. The solute potential is also called the osmotic potential.

$$\psi = \psi_P + \psi_S$$

Water Potential = Pressure Potential + Solute Potential

Water moves from an area of higher water potential or higher free energy to an area of lower water potential or lower free energy. Water potential measures the tendency of water to diffuse from one compartment to another compartment.

The water potential of pure water in an open beaker is zero ($\psi = 0$) because both the solute and pressure potentials are zero ($\psi_S = 0$; $\psi_P = 0$). An increase in positive pressure raises the pressure potential and the water potential. The addition of solute to the water lowers the solute potential and therefore decreases the water potential. This means that a solution at atmospheric pressure has a negative water potential due to the solute.

The solute potential (ψ_S) = - iCRT, where i is the ionization constant, C is the molar concentration, R is the pressure constant (R = 0.0831 liter bars/mole-K), and T is the temperature in K (273 + °C).

A 0.15 M solution of sucrose at atmospheric pressure ($\psi_P = 0$) and 25°C has an osmotic potential of -3.7 bars and a water potential of -3.7 bars. A bar is a metric measure of pressure and is the same as 1 atmosphere at sea level. A 0.15 M NaCl solution contains 2 ions, Na_+ and Cl_-; therefore i = 2 and the water potential = -7.4 bars.

When a cell's cytoplasm is separated from pure water by a selectively permeable membrane, water moves from the surrounding area, where the water potential is higher ($\psi = 0$), into the cell, where water potential is lower because of solutes in the cytoplasm

(ψ is negative). It is assumed that the solute is not diffusing (Figure 1a). The movement of water into the cell causes the cell to swell, and the cell membrane pushes against the cell wall to produce an increase in pressure. This pressure, which counteracts the diffusion of water into the cell, is called turgor pressure.

Over time, enough positive turgor pressure builds up to oppose the more negative solute potential of the cell. Eventually, the water potential of the cell equals the water potential of the pure water outside the cell (ψ of cell = ψ of pure water = 0). At this point, a dynamic equilibrium is reached and net water movement ceases (Figure 1b).

Figures 1a-b. Plant cell in pure water. The water potential was calculated at the beginning of the experiment (a) and after water movement reached dynamic equilibrium and the net water movement was zero (b).

If solute is added to the water surrounding the plant cell, the water potential of the solution surrounding the cell decreases. If enough solute is added, the water potential outside the cell is equal to the water potential inside the cell, and there will be no net movement of water. However, the solute concentrations inside and outside the cell are not equal, because the water potential inside the cell results from the combination of both the turgor pressure (ψ_p) and the solute pressure (ψ_s). (See Figure 2.)
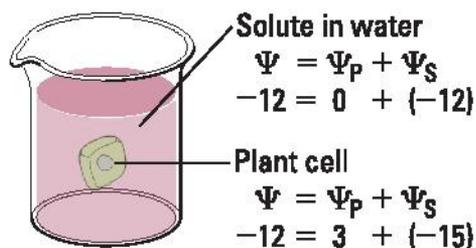

Figure 2. Plant cell in an aqueous solution. The water potential of the cell equals that of surrounding solution at dynamic equilibrium. The cell's water potential equals the sum of the turgor pressure potential plus the solute potential. The solute potentials of the solution and of the cell are not equal.

If more solute is added to the water surrounding the cell, water will leave the cell, moving from an area of higher water potential to an area of lower water potential. The continued loss of water will cause the cell to lose turgor. A loss causes the membrane to shrink away from the cell wall, and the cell will plasmolyze.

PROTOCOL:
The solutions got mixed up!!

 "Oh no! I forgot to write down which solutions were which Molarity!!" Not what you want to hear from your lab assistant on the morning of the lab.

We know that the solutions mixed up for the lab are **0.0M, 0.2M, 0.4M, 0.6M and 0.8M.**

Using the protocol below collect your data and record in the data table.

You will be using the % change in mass to determine the Molarity of the solutions.

You can test for molarity using the following procedure:
DAY ONE

1. Pick up one of the dialysis membranes from the 1000ml beaker and place it into a 250ml beaker.
2. With a PENCIL write the color that you are assigned in the group on the white bubble on the beaker.
3. Tie off one end of each of the dialysis membranes (these are selectively permeable membrane, analogous to a cell membrane) as close to the end as possible.
4. With a funnel, place 5 ml of your solution into the membrane.
5. Tie off the other end of the membrane, again as close to the end as possible.
6. Place it into the 250ml beakers.
7. Mass the dialysis tubing: Place the beaker on the balance, take out the dialysis membrane, tare the balance, place the membrane back in the beaker. **Make sure that your beaker is clean so that you DO NOT get the sucrose solution on the balance.
8. Record the mass for your color in the data table below and on the board.
9. Cover with 100ml of distilled water.

DAY TWO

1. Pour off the water from the beaker and gently blot dialysis tubing with paper towel.
2. Repeat procedure for determining the mass.
3. Record the mass in the data table and on the board.
4. Determine % change in mass and record in your data table.
5. Determine the Molarity of the different colored solutions and record in the data table.
6. Graph your results using the **colors** as your independent variable. Place the colors so that you have an increasing line of best fit.