Osmosis and tonicity

Osmosis and tonicity. Hypertonic, isotonic, and hypotonic solutions and their effect on cells.

Introduction

Have you ever forgotten to water a plant for a few days, then come back to find your once-perky arugula a wilted mess? If so, you already know that water balance is very important for plants. When a plant wilts, it does so because water moves out of its cells, causing them to lose the internal pressure—called turgor pressure—that normally supports the plant.

Why does water leave the cells? The amount of water outside the cells drops as the plant loses water, but the same quantity of ions and other particles remains in the space outside the cells. This increase in **solute**, or dissolved particle, concentration pulls the water out of the cells and into the extracellular spaces in a process known as osmosis.

Formally, **osmosis** is the net movement of water across a semipermeable membrane from an area of lower solute concentration to an area of higher solute concentration. This may sound odd at first, since we usually talk about the diffusion of solutes that are dissolved in water, not about the movement of water itself. However, osmosis is important in many biological processes, and it often takes place at the same time that solutes diffuse or are transported. Here, we'll look in more detail at how osmosis works, as well as the role it plays in the water balance of cells.

How it works

Why does water move from areas where solutes are less concentrated to areas where they are more concentrated?

This is actually a complicated question. To answer it, let's take a step back and refresh our memory on why diffusion happens. In diffusion, molecules move from a region of higher concentration to one of lower concentration—not because they're aware of their surroundings, but simply as a result of probabilities. When a substance is in gas or liquid form, its molecules will be in constant, random motion, bouncing or sliding around one another. If there are lots of molecules of a substance in compartment A and no molecules of that substance in compartment B, it's very unlikely—impossible, actually—that a molecule will randomly move from B to A. On the other hand, it's extremely likely that a molecule will move from A to B. You can picture all of those molecules bouncing around in compartment A and some of them making the leap over to compartment B. So, the net movement of molecules will be from A to B, and this will be the case until the concentrations become equal.

In the case of osmosis, you can once again think of molecules—this time, water molecules—in two compartments separated by a membrane. If neither compartment contains any solute, the water molecules will be equally likely to move in either direction between the compartments. But if we add solute to one compartment, it will affect the likelihood of water molecules moving out of that compartment and into the other—specifically, it will reduce this likelihood.

Why should that be? There are some different explanations out there. The one that seems to have the best scientific support involves the solute molecules actually bouncing off the membrane and physically knocking the water molecules backwards and away from it, making them less likely to cross[1,2].

Regardless of the exact mechanisms involved, the key point is that the more solute water contains, the less apt it will be to move across a membrane into an adjacent compartment. This results in the net flow of water from regions of lower solute concentration to regions of higher solute concentration.

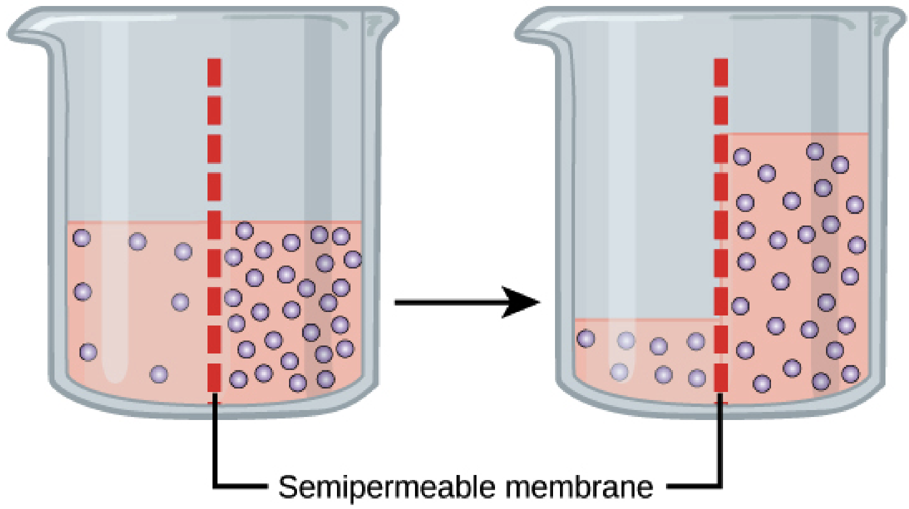

Image credit: OpenStax Biology

This process is illustrated in the beaker example above, where there will be a net flow of water from the compartment on the left to the compartment on the right until the solute concentrations are nearly balanced. Note that they will not become perfectly equal in this case because the hydrostatic pressure exerted by the rising water column on the right will oppose the osmotic driving force, creating an equilibrium that stops short of equal concentrations.

Tonicity

The ability of an extracellular solution to make water move into or out of a cell by osmosis is know as its **tonicity**. A solution's tonicity is related to its **osmolarity**, which is the total concentration of all solutes in the solution. A solution with low osmolarity has fewer solute particles per liter of solution, while a solution with high osmolarity has more solute particles per liter of solution. When solutions of different osmolarities are separated by a membrane permeable to water, but not to solute, water will move from the side with lower osmolarity to the side with higher osmolarity.

Three terms—hypotonic, isotonic, and hypertonic—are used to compare the osmolarity of a cell to the osmolarity of the extracellular fluid around it.

Note: When we use these terms, we are considering only solutes that cannot cross the membrane.

- If the extracellular fluid has lower osmolarity than the fluid inside the cell, it's said to be **hypotonic**—*hypo* means less than—to the cell, and the net flow of water will be into the cell.

- In the reverse case, if the extracellular fluid has a higher osmolarity than the cell's cytoplasm, it's said to be **hypertonic**—*hyper* means greater than—to the cell, and water will move out of the cell to the region of higher solute concentration.

- In an **isotonic** solution—*iso* means the same—the extracellular fluid has the same osmolarity as the cell, and there will be no net movement of water into or out of the cell.

Hypotonic, hypertonic, and isotonic are relative terms. That is, they describe how one solution compares to another in terms of osmolarity. For instance, if the fluid inside a cell has a higher osmolarity, concentration of solute, than the surrounding fluid, the cell interior is *hypertonic* to the surrounding fluid, and the surrounding fluid is *hypotonic* to the cell interior.

Tonicity in living systems

If a cell is placed in a hypertonic solution, water will leave the cell, and the cell will shrink. In an isotonic environment, the relative concentrations of solute and water are equal on both sides of the membrane. There is no net water movement, so there is no change in the size of the cell. When a cell is placed in a hypotonic environment, water will enter the cell, and the cell will swell.

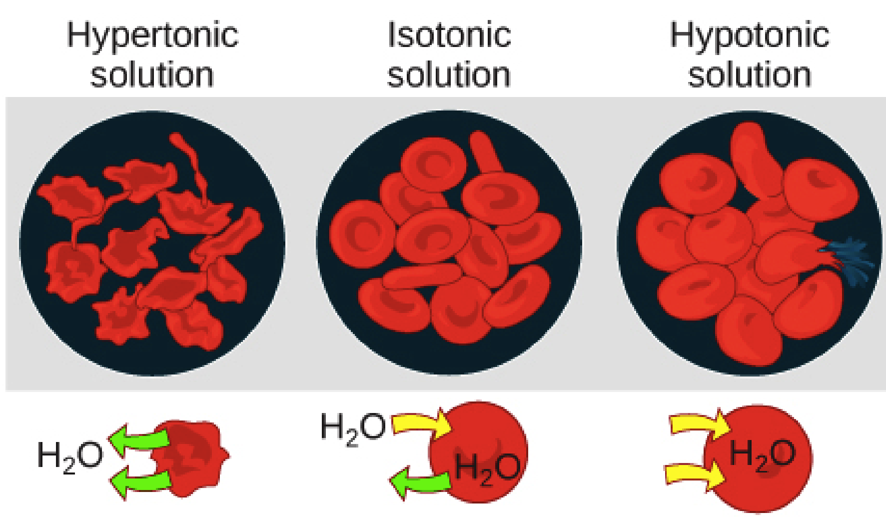

Image credit: Mariana Ruiz Villareal

In the case of a red blood cell, isotonic conditions are ideal, and your body has homeostatic (stability-maintaining) systems to ensure these conditions stay constant. If placed in a hypotonic solution, a red blood cell will bloat up and may explode, while in a hypertonic solution, it will shrivel—making the cytoplasm dense and its contents concentrated—and may die.

In the case of a plant cell, however, a hypotonic extracellular solution is actually ideal. The plasma membrane can only expand to the limit of the rigid cell wall, so the cell won't burst, or lyse. In fact, the cytoplasm in plants is generally a bit hypertonic to the cellular environment, and water will enter a cell until its internal pressure—**turgor pressure**—prevents further influx.

Maintaining this balance of water and solutes is very important to the health of the plant. If a plant is not watered, the extracellular fluid will become isotonic or hypertonic, causing water to leave the plant's cells. This results in a loss of turgor pressure, which you have likely seen as wilting. Under hypertonic conditions, the cell membrane may actually detach from the wall and constrict the cytoplasm, a state called **plasmolysis** (left panel below).

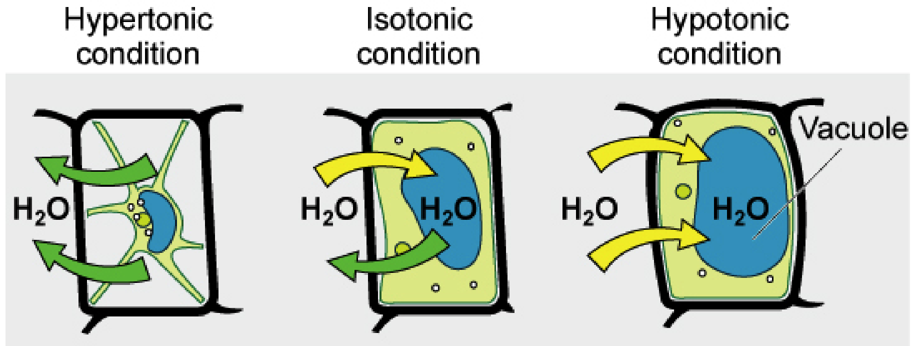

Image credit: OpenStax Biology, modification of work by Mariana Ruiz Villareal

Tonicity is a concern for all living things, particularly those that lack rigid cell walls and live in hyper- or hypotonic environments. For example, paramecia—pictured below—and amoebas, which are protists that lack cell walls, may have specialized structures called contractile vacuoles. A contractile vacuole collects excess water from the cell and pumps it out, keeping the cell from lysing as it takes on water from its hypotonic environment.

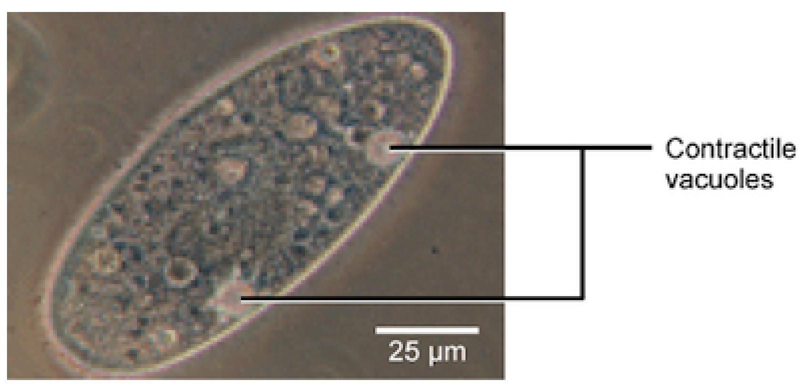

Image credit: OpenStax Biology, modification of work by the National Institutes of Health (NIH), scale-bar data from Matt Russell

[Attribution and references]

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Why doesn't the pressure of the cell (even a red blood cell that isn't rigid), balance out the net inflow in a hypotonic solution? The net inflow doesn't work with energy, but because their is room to slide around!?

• 14 votes • Comment • Flag
2 years ago by Dovid Shaw

I think this is the case with a plant cell that has a rigid cell wall thus in a fixed volume hydrostatic pressure will increase until osmotic pressure is opposed. But with an RBC the volume is not fixed (due to lack of cell wall) so osmotic pressure increases unopposed until the cell lyses.

• 12 votes • Comment • Flag
2 years ago by jschwime

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It seems odd to me that the sole factor driving osmosis is the relative concentration of the solute (osmolarity), and that other characteristics of the solute (size of molecules, polarity, etc..) don't play a role as well. Is this really true and, if so, can someone explain why?

7 votes • Comment • Flag 2 years ago by Paul Norris

When we talk about hypertonic, hypotonic, isotonic... we are only talking about solutes that cannot diffuse through the membrane. Because of this the solvent (water) attempts to make the concentration of these solutes even on both the inside and the outside of the membrane. This is all an attempt to maintain homeostasis. If the solutes are small, non charged... they will diffuse through the membrane.

6 votes • 1 comment • Flag
2 years ago by nichole.owens

I'm confused how can water diffuse through a Phospholipid bi-layer without well, scaring the hydrophobic Lipids.

4 votes • Comment • Flag 2 years ago by Jawad

Actually, there are channels in the cell membrane that create opening for water molecules to pass. They are formed by proteins called aquaporins. Without these channels, the rate of osmosis across a phospholipid bilayer would be MUCH less, for the reason you point out.

6 votes • Comment • Flag
2 years ago by saenz.melissa

What could be an example of solute in a plant cell?

4 votes • Comment • Flag
3 years ago by Valeria Ventosa

Glucose? Sodium, Potassium and Chloride Ions.

4 votes • Comment • Flag 3 years ago by Laurent

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what is ion and molecule? and how do elements become positive / negative charged?

1 vote • Comment • Flag 3 years ago by Nomunaa

An Ion is basically a charged atom. The atom can be either positively charged (by losing one electron) or negatively charged (by gaining one electron).
Molecules are groups of electrically neutral atom/s which are chemically bonded.
Charge is due to loss or gain of an electron in an atom.

9 votes • 1 comment • Flag
3 years ago by Prajjwal Rathore

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What is reverse osmosis?

3 votes • Comment • Flag
2 years ago by Tarek Seif El Nasr

When water move in the opposite direction predicted by osmosis and it does this because of higher pressure on the side with the greater concentration of solutes.

4 votes • 1 comment • Flag
2 years ago by John Morgenthaler

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Why does the cells of stomata becomes flaccid instead of shrinking when they loss water from them?

2 votes • Comment • Flag
2 years ago by shreypatel0101

First cells become flaccid. If enough water is lost they will plasmolyse, which is where they shrink away.

5 votes • 2 comments • Flag
2 years ago by Yasmeen.Mufti

What is the meaning of Osmole, Equivalent simply?

3 votes • Comment • Flag 2 years ago by souada464

Osmole a nun SI Measurement. Equivalent simply is path connected

2 votes • Comment • Flag
about a year ago by keirsten-harper

My group and I are making lab project by estimating the osmolarity in tissues by bathing the blood samples from the 3 members of my group with hypotonic and hypertonic solutions and observing it by using our microscope. Since we are done with observations, we are assigned to do a group lab report, and my individual task is to basically do the data analysis. However, I do not know which type of graph should I create regarding the observation and its results of the osmolarity of the blood samples… (more)

2 votes • Comment • Flag 8 months ago by timar.pink

I might recommend using a line graph because it will clearly show the difference between the three blood samples.

3 votes • Comment • Flag
5 months ago by Shredder

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what effect does concentration have on osmosis? does a higher concentration create faster or slower rates of osmosis?

2 votes • Comment • Flag about a month ago by Natalie

If osmosis depends on the presence of a concentration gradient (in other words, if there is no concentration gradient, no osmosis will occur), what do you think would happen if you had one solution with a much higher solute concentration than another solution?

1 vote • Comment • Flag 18 days ago by Jen

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