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.

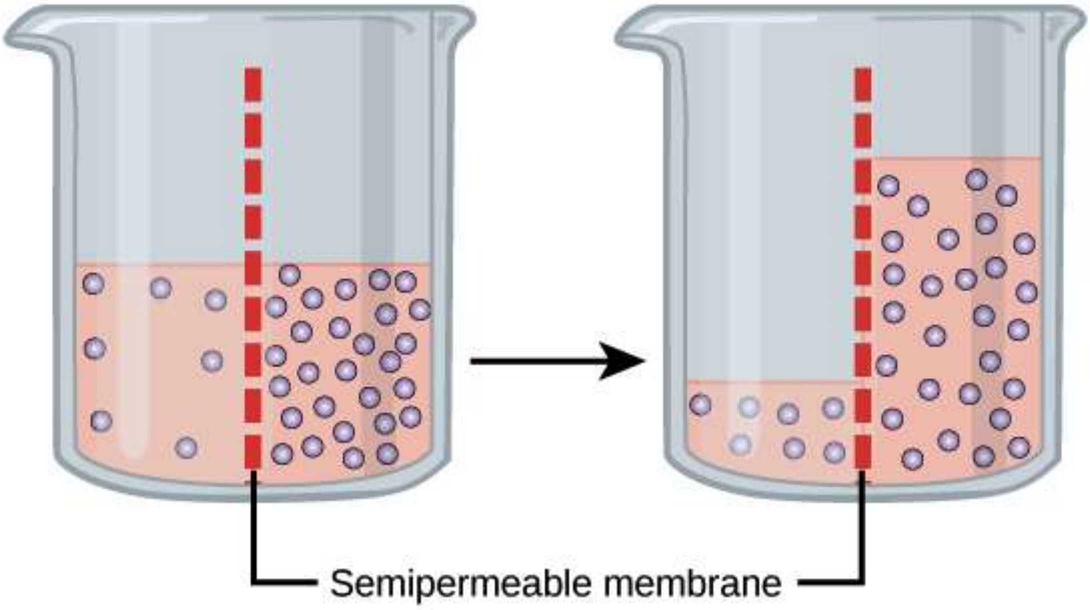


Illustration of osmosis. A beaker is divided in half by a semi-permeable membrane. In the left—initial—image, the water level is equal on both sides, but there are fewer particles of solute on the left than on the right. In the right—final—image, there has been a net movement of water from the area of lower to the area of higher solute concentration. The water level on the left is now lower than the water level on the right, and the solute concentrations in the two compartments are more equal.

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 **osmolality**, which is the total concentration of all solutes in the solution. A solution with low osmolality has fewer solute particles per litre of solution, while a solution with high osmolality has more solute particles per litre of solution. When solutions of different osmolality’s are separated by a membrane permeable to water, but not to solute, water will move from the side with lower osmolality to the side with higher osmolality.

Three terms—hypotonic, isotonic, and hypertonic—are used to compare the osmolality of a cell to the osmolality 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 osmolality 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 osmolality 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 osmolality 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 osmolality. For instance, if the fluid inside a cell has a higher osmolality, 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.

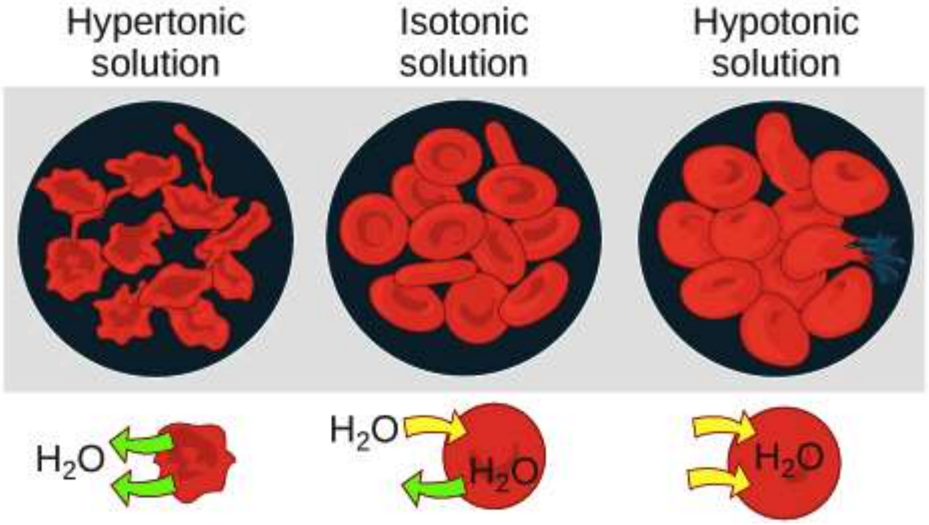


Diagram of red blood cells in hypertonic solution (shrivelled), isotonic solution (normal), and hypotonic solution (puffed up and bursting).

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).

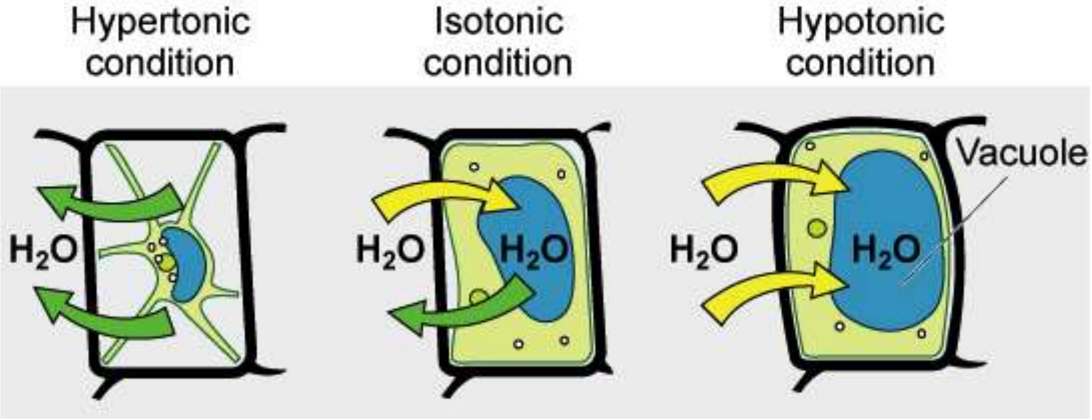
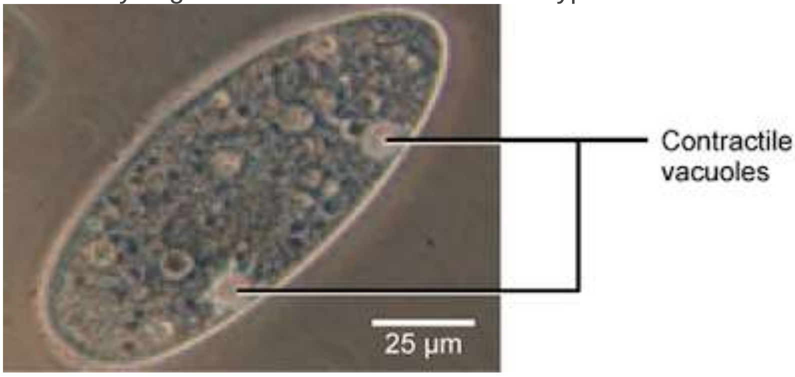


Image of a plant cell under hypertonic conditions (plasmolyzed / shrivelled), isotonic conditions (slightly deflated, not fully pressed up against the cell wall), and hypotonic conditions (pressed firmly against the cell wall, normal state).

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.



Microscope image of a paramecium, showing its contractile vacuoles.

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