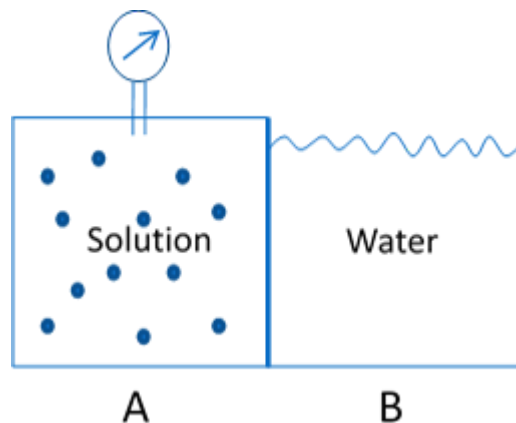


## 5.2.4

# Osmosis

A special type of passive transport is the movement of water across a membrane, or **osmosis**. By definition, osmosis is the diffusion of water through a **selectively permeable** membrane from an area of high water potential (low solute concentration) to an area of low water potential (high solute concentration). Therefore, for osmosis to occur, the membrane must be permeable to water and the concentration of the solute must be different on the two sides of the membrane. Water will move from the side with lower solute concentration to the side with higher solute concentration until the concentrations are equal or until some external force prevents further movement of water. This is a passive facilitated process, in that no energy is required for the movement of water through specialized channel proteins known as **aquaporins**. All cells of the body express aquaporin proteins which enable osmosis to occur across cellular membranes.

Let's start to apply this information. In an artificial system such as the one depicted in the figure below, water will attempt to move from chamber B to chamber A across the water-permeable membrane separating the two chambers. This will occur because chamber A has more solute dissolved in it than in chamber B (no solute). Since chamber A is a rigid chamber, pressure will develop. The pressure that is just sufficient to prevent water from moving across the membrane is referred to as **osmotic pressure**. Osmotic pressure can also be defined as the force exerted by the process of osmosis (diffusion of water).



**Osmotic Pressure. Minimum pressure needed to be applied to a solution to prevent the inward flow of water across a semipermeable membrane from chamber B to chamber A.** Image by BYU-Idaho student, Hannah Crowder, 2013.

Similar to this system, water will move into or out of cells depending on the solute concentration of the extracellular fluids and the intracellular fluids. If the solute concentration in the extracellular fluid is lower than the solute concentration inside the cell, water moves into the cell and the cell will swell and potentially burst! If the opposite is true (extracellular solute concentration is greater than intracellular), then water will leave the cell causing it to shrivel, or crenate. This phenomenon is due to osmosis and it is critical that you understand how to predict this activity since the cell shape directly affects its functionality.

Earlier this semester, we discussed how total solute concentration, or the total number of moles of particles dissolved per liter of solution is expressed as **osmolarity**. This is different than molarity. Molarity represents the number of moles of a specific compound per liter of solution. Why do we have these different ways of expressing concentration? In the cellular environment, the extracellular and intracellular fluid are complex mixtures of numerous dissolved solutes, all of which contribute to the osmotic pressure driving osmosis. To understand osmosis, we need to consider the osmolarity of the extra- and intracellular compartments.

For example, when 1 mole of NaCl is dissolved in 1 liter of water, it is a 1 molar (M) NaCl solution. However, NaCl is an ionic compound that dissociates (breaks apart) into 1 mole of  $\text{Na}^+$  and 1 mole of  $\text{Cl}^-$  ions when dissolved in water. Thus, there are now twice as many particles ( $\text{Na}^+$  and  $\text{Cl}^-$  ions) prior to dissolving it and we call it a 2 osmolar (OsM) solution (simply add the number of moles of dissolved ions). Glucose is different. Glucose doesn't dissociate in water because the atoms are covalently bonded. Therefore, a 1 M solution of glucose (1 mole of glucose in 1 liter of water) will be a 1 OsM solution. What if you had a 1 liter solution that contained 1 mole of NaCl and 1 mole of glucose? The molar concentration would be 1 M NaCl and 1 M glucose, but what would the osmolarity be? Simply add the moles of dissolved particles: 1 mole  $\text{Na}^+$  + 1 mole  $\text{Cl}^-$  + 1 mole glucose = 3 moles of particles per 1 liter. This solution would be a 3 OsM solution.

In physiological solutions like the intracellular or extracellular fluid, there are many solutes dissolved including ions, proteins, nutrients, and waste products. All of these dissolved components contribute to the osmolarity of the fluid. The normal osmolarity of body fluids is 285–295 mOsM (for simplicity we often round this number to 300 mOsM...you need to remember this number). We place the small m, which stands for milli or one-thousandth, in front of OsM because we are dealing with very small amounts, 1000 times less than 1 osmole/liter. Osmolarity is often used to compare two solutions using the following terms: *isosmotic*, meaning two solutions have the same osmolarity; *hyperosmotic*, meaning one solution is more concentrated than the other; and *hypoosmotic*, meaning one solution is less concentrated than the other. In the previous figure illustrating osmotic pressure, you could say, "Solution A is hyperosmotic to solution B" because solution A has greater osmolarity than solution B. Always use the term osmolarity to describe solutions that have not been administered to cells (no cells are present).

In more complex physiological environments, the osmolarity of the extracellular environment and the process of osmosis (water diffusion) across cellular membranes play a significant role on the function of cells. When water moves out of a cell, the cell shrinks; likewise, when water moves into a cell, the cell swells. These changes in cell shape affect membrane and cell function and can even cause the cell to die. The term **tonicity** is used to describe these osmotic effects on cells based on the solution or extracellular environment the cells are in. Remember that water diffuses to areas of greater solute and like osmolarity, the prefixes iso-, hypo-, and hyper- are used to describe tonicity. If red blood cells (RBCs) are placed into a 300 mOsM solution containing  $\text{Na}^+$  and  $\text{Cl}^-$  ions which cannot diffuse into the cells, then there will be no net movement of water into or out of the RBCs because the intracellular osmolarity is also 300 mOsM. We would classify this solution as 'isotonic' (note that it is not isosmotic because cells are present). In the healthcare setting, this isotonic solution is called physiologic saline, or 0.9% NaCl, or 0.9% saline. The 0.9% NaCl solution is about 300 mOsM. If RBCs were placed into a different NaCl solution (no diffusion of ions into the cell) with a 600 mOsM osmolarity (or 1.8% NaCl solution), water would diffuse out of the RBCs to the area of higher solute, causing them the cells crenate. This solution would be considered 'hypertonic.' If RBCs are placed into distilled water (i.e. no solute), then water will diffuse into the RBCs (following solute) causing them to swell and potentially burst (called 'hemolysis'). This type of environment is considered 'hypotonic.' This may seem simple, but it can get quite complex especially if the membrane is permeable to the solute in the extracellular fluid.

Understanding membrane permeability, osmolarity, and osmosis will enable you to properly predict the resulting tonicity of various solutions when administered to a person intravenously and the resulting effects on the tissue. Always use the term tonicity to describe the effects of a solution in the presence of cells. Let's consider some examples involving RBCs to better understand tonicity:

A patient comes to the clinic having overdosed on insulin and is severely hypoglycemic (really low blood glucose). A 5% glucose (sometimes called dextrose) solution (~300mOsM) is prepared and administered to the patient. The patient's

blood glucose increases but then the patients RBCs begin to swell and lyse (burst). What is happening?

If the cells are swelling, that means water is diffusing into the cells, so the RBCs must be in a hypotonic environment. How can this be if the solution of glucose administered (5%) was isosmotic with the inside of the cell (both ~300mOsM)? Unlike NaCl, RBCs express GLUT proteins that allow glucose to diffuse into the cells. Once in the cell, the cell metabolizes the glucose for energy. Then more glucose enters the cell and is further metabolized. Eventually, all of the 5% glucose solution is metabolized by the cell and nothing is left but the water. That is why the cells, upon reaching equilibrium began to swell. As the glucose was diffusing into the cells, the extracellular environment was becoming less concentrated and more hypotonic, causing water to diffuse into the cell. This is why glucose is typically administered in a 0.9% NaCl solution. The glucose-saline solution is hyperosmotic to the intracellular environment (>300 mOsM), but after administration to the patient, the glucose diffuses into the cell, gets metabolized, and the remaining NaCl solution maintains an isotonic environment for the cells.

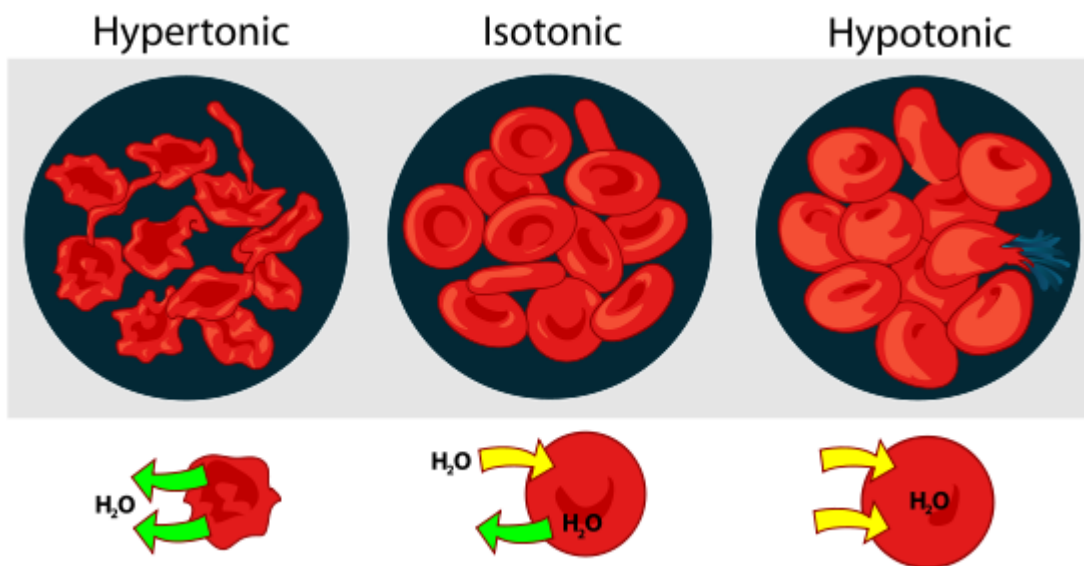
Here are three rules to help you better understand tonicity:

1. In order for ions or polar (hydrophilic) molecules to cross the cell membrane, there needs to be channel or carrier proteins expressed on the cell membrane. Then, solute will diffuse across the membrane until equal concentrations are reached on both sides of the membrane (equilibrium).
2. If solute cannot diffuse across the membrane, then water will diffuse into, or out of the cell in attempt to balance the difference in osmolarities between the intra- and extracellular environments.
3. Based on the direction of osmosis (into or out of cell) we can classify the extracellular environment as iso-, hypo-, or hypertonic.

Consider what might happen with a membrane-permeable solute that moves into the cell but does not disappear (e.g. urea). If we start with an isosmotic solution of urea (~300 mOsM) and then place a cell into this solution, the urea, a membrane-permeable solute, will move down its gradient into the cell. We say down the gradient because initially, the concentration of urea outside the cell is much greater than the concentration inside the cell. Urea will move into the cell until the urea concentration inside the cell equals the urea concentrations outside the cell. In other words, 150 milliosmoles of urea will eventually diffuse into the cells, leaving 150 milliosmoles in the extracellular solution. As this diffusion of urea is taking place, what is happening to the intracellular osmolarity? Theoretically, the intracellular osmolarity should reach 450 mOsM (300 mOsM + 150 mOsM urea) while the extracellular solution should approach only 150 mOsM urea. What is water going to do in this situation? It will diffuse into the cell in attempt to balance out the unequal osmolarities between the intra- and extracellular fluids to reach equilibrium. The cells will swell, and this solution will be classified as hypotonic. A good rule to remember is that any isosmotic solution of a penetrating or permeable solute will act as a hypotonic solution to the cell.

Here is another way to think of osmolarity and tonicity. Osmolarity can be used to compare the concentration of solutes in two solutions. It can also be used to compare the osmolarity of a solution with that of the cell before equilibrium is achieved, or before the solution is administered to cells. Tonicity is used to describe what effect the solution has on the cell. Osmolarity doesn't take into account the permeability of the solutes, while tonicity is dependent upon the concentration of the *nonpermeable* solutes.

The figure below shows what happens to red blood cells when they are placed into hypertonic, isotonic, or hypotonic solutions.



**Osmotic Pressure on Blood Cells Diagram.** Title: File: Osmotic pressure on blood cells diagram.svg; Author: LadyofHats;

Site:

[https://commons.wikimedia.org/wiki/File:Osmotic\\_pressure\\_on\\_blood\\_cells\\_diagram.svg](https://commons.wikimedia.org/wiki/File:Osmotic_pressure_on_blood_cells_diagram.svg)

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The link below shows what happens to a wilted plant when it is placed into a hypotonic solution.

<https://books.byui.edu/-vip>

To check understanding, complete the table below by filling in the missing column items with regard to osmolarity and tonicity. Use the terms *iso*, *hypo*, and *hyper* to complete the table.

SOLUTION	OSMOLARITY (No cells, but compared to normal intracellular osmolarity 300mOsM)	TONICITY (Solution is administered to cells and equilibrium is being reached)
0.9 % saline		
5% dextrose		
5% dextrose + 0.9% saline		
0.45% saline		
5% dextrose + 0.45% saline		

Here are the answers for the table above. Be sure you understand why the answers are what they are.

SOLUTION	OSMOLOARITY	TONICITY
0.9% saline	Isosmotic	Isotonic
5% dextrose	Isosmotic	Hypotonic
5% dextrose + 0.9% saline	Hyperosmotic	Isotonic
0.45% saline	Hypoosmotic	Hypotonic
5% dextrose + 0.45% saline	Hyperosmotic	Hypotonic

**\*\*Note:** Other texts, even hospitals on occasion, tend to use less rigorous definitions of tonicity. For example, definitions are loosely given to define all hyperosmolar solutions as hypertonic. This is based on the observation that water can cross the membrane faster than the permeable solute can cross. It may also be based on the incorrect assumption that tonicity and osmolarity are the same thing. Having a more accurate understanding of osmolarity and tonicity will not only benefit you in this course, but it will also enable you to better understand the relationship between chemistry and cell biology.



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