# Osmosis Demystified — How It Works

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"Osmosis" is the process by which small molecules automatically cross a semi-permeable membrane, compensating for a difference in the concentration of those molecules on either side of the membrane. But how do the molecules know to do that? What makes it happen? I have found the standard explanation to be a bit **fuzzy and mystical;** hence this tutorial.

First, the standard explanation of osmosis:

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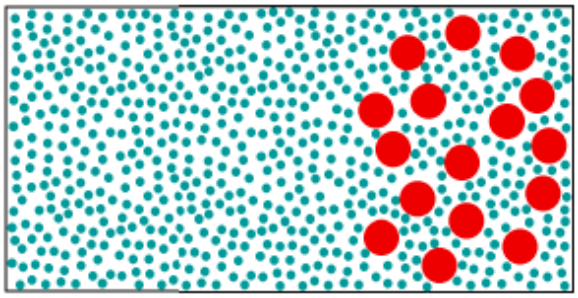
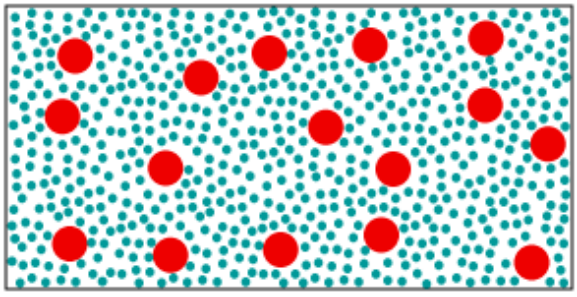
|  | A tank contains water. A quantity of sugar-water is introduced at the right end of the tank. |
|  | Moving about randomly, the sugar molecules scatter throughout the tank until they are fairly evenly distributed. This can be interpreted as the water moving from an area of high water concentration (the left side of the tank) to an area of lower water concentration (the right side of the tank). Water naturally moved "across the concentration gradient," from high to low. (Notice that the sugar did the same — it moved from an area of high sugar concentration to an area of low sugar concentration.) |

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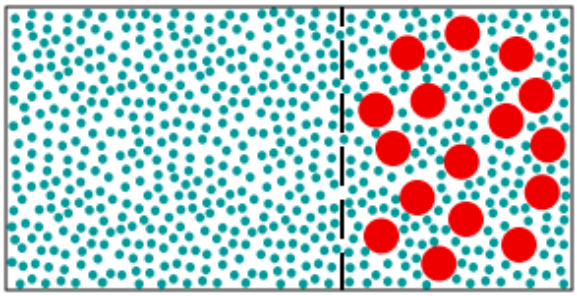
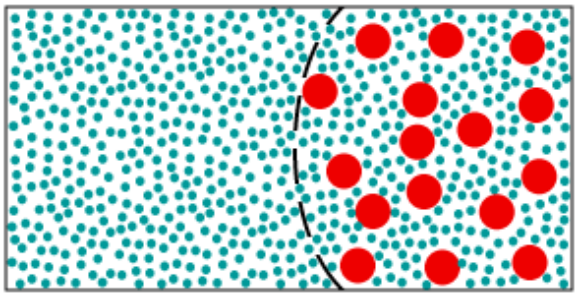
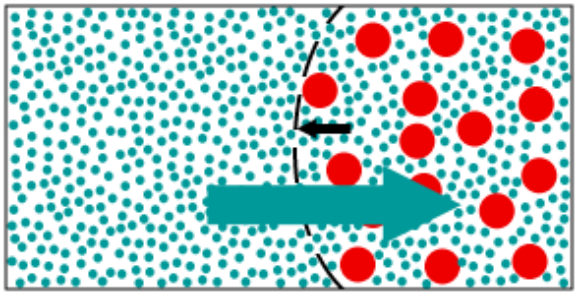


Now we perform the experiment again, but this time with a semi-permeable membrane separating the sugar-water from the pure water. The membrane has tiny pores in it which are large enough for water molecules to pass through, but too small for sugar molecules. What happens this time?



The water flows through the membrane into the right side of the tank — this flow is called "osmosis". The membrane swells under the pressure of the invading water — this is known as "osmotic pressure".



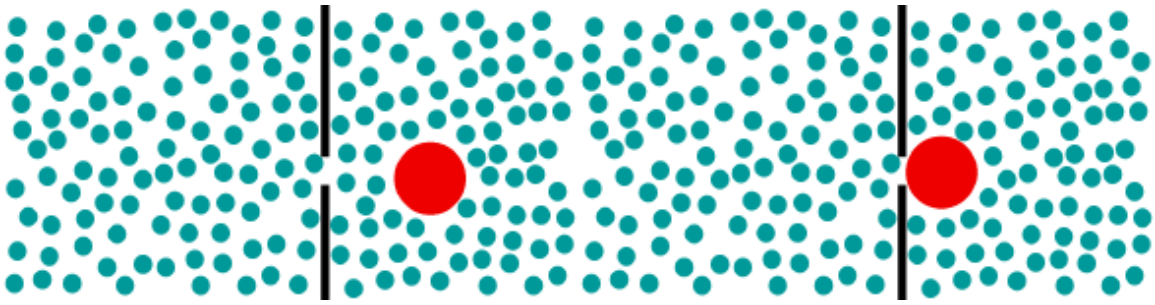
What made the water do that? The standard explanations are:
A. Water wants to move across its concentration gradient, from high to low, and this requires it to cross the membrane. or B. Molecules on both sides are bumping into the membrane. Because there is a higher concentration of water molecules on the left side of the membrane, water molecules will attempt to pass through a pore more often from left-to-right than right-to-left, resulting in a net flow of water from left-to-right.

Sounds good, doesn't it? But something's wrong.

First, A. Water does not "want" to cross a concentration gradient. In the non-membraned tank, it did so simply because all the molecules were free to move around any which way, and their random movements scattered them randomly. But with the membrane, the sugar molecules are trapped on the right side, so why wouldn't the water just flow

randomly through the membrane's pores in either direction, causing no osmotic pressure?

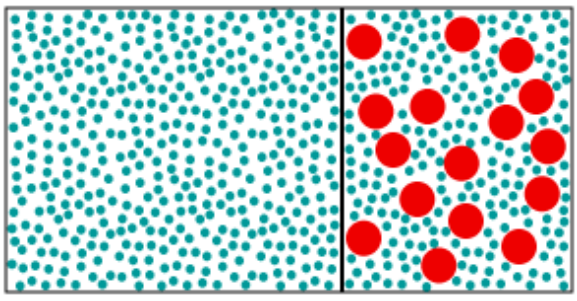
And, B. Yes, the concentration of water is lower on the right side, but what does that mean to any individual pore? If a sugar molecule is not nearby the pore, the water concentration is the same on both sides of the pore, and if a sugar molecule is close enough to the pore to prevent water molecules from escaping right-to-left, it is also blocking water molecules from *entering* left-to-right. When a sugar molecule blocks a pore, it blocks water flow in both directions, indiscriminately.



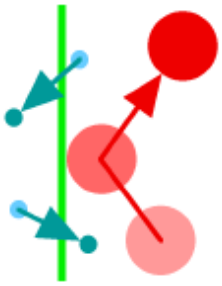
When the sugar molecule is not blocking the pore, the water concentration is the same on both sides of the pore.

When a sugar molecule is blocking the pore, water cannot pass through in either direction. Water molecules trying to get through the pore from the left may beat against the sugar molecule, but water molecules are also beating against the sugar molecule from the right.

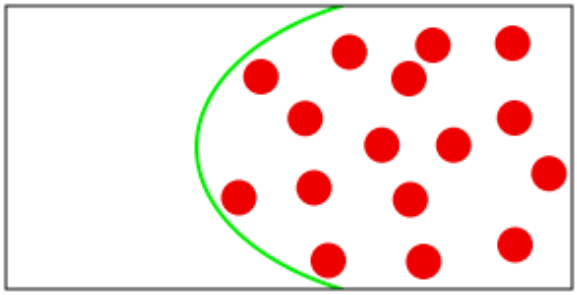
Obviously, another explanation is required. This is it:



Let's put in a *non-permeable* membrane. It has no pores, and nothing passes through it. Although the membrane is elastic, it is not swelling in either direction, so we know that the force of the water molecules beating from the left is exactly counterbalanced by the force of (fewer) water molecules and some sugar molecules beating on the membrane from the right. In other words, there is no absolute pressure differential between the two sides.



Now we snap our fingers and the membrane changes to a magical material that is impervious to sugar, but does not interfere with water molecules at all! Water molecules pass right through it, and it through them, as if they weren't even in the same universe.



What happens? The water pressure on both sides disappears completely, because water cannot affect the magic membrane, *but the force of sugar molecules beating from the right is still there.* This unbalanced pressure causes the membrane to swell to the left! And as it swells, the membrane passes magically through water molecules, encompassing more water on the right side of the membrane. The water did not "move in" and swell the membrane — the sugar molecules pushed the membrane to the left, causing it to encompass more water. When the membrane resists stretching further, and stays in its swollen state, it is the sugar molecules that are holding it there by beating against it from the right — the water molecules can do nothing to the membrane, because they pass right through it with no effect.

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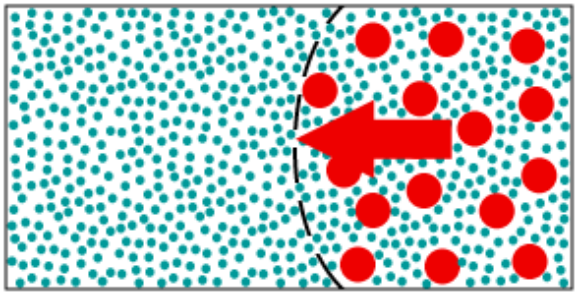
|  | Of course, no such magical material exists. But a good approximation is a membrane with small holes that allow water to pass through. In that case, the solid parts of the membrane experience a balanced impact of water molecules from the left, and water and sugar molecules from the right. The pores experience no water pressure in either direction, but do receive sugar pressure from sugar molecules bouncing off the pore's opening (unable to fit through). The effect is the same as with the magical material described above, although it is weaker since only the pores have the "magical property". |

Mystery solved — osmosis explained entirely by random movements of molecules, without reference to mysterious "tendencies" to cross gradients! Water's tendency to cross its concentration gradient is properly interpreted as an *effect* of osmosis, not as its cause. Osmosis is caused by the *large molecules bouncing against pores through which they cannot fit.*

***Reverse Osmosis:*** What is "reverse osmosis?" It's just fancy term for pushing water through a very fine filter to purify it. That's all.

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