Osmosis PhL 3.17.08

This is always a tricky subject. Although I have lots of physics, chemistry and biology books, none really gives a good explanation of what is going on here. On the web are some discussions discounting the explanation I will give here, but I am happy with it and, if nothing else, it tells me which way the force works.

Every source draws the right picture: water on one side (the right), and water + sugar on the other side (the left), and the membrane does not let the sugar through.

1. My naive explanation is as follows: the rule at the membrane for any component which can pass through it is this: the "partial pressure" must be the same on both sides when you reach equilibrium. Presumably such molecules can go either way through the membrane.

The reason for this rule arises from entropy and statistical mechanics: the number of states for the system is maximized when the component partial pressures are equal, and the free energy is minimized.

For a liquid, I guess you would say that the *densities* [concentrations] for each component have to be the same on both sides, the number of molecules/cm^3. When these densities are the same, the transport rate to the left through 1 cm^2 of membrane is the same as the transport rate to the right and we are in equilibrium. If you add sugar to water to make a solution on the left side, you decrease the density of water (in particular, of "free water" which is not hydrating the sugar). If you increase hydrostatic pressure on the right side, you increase the density of water on the right.

So, when things are in equilibrium in the above situation, we have total pressure balance [this is where we are using Dalton's Law of Partial Pressures which says the total pressure is the sum of the partials in an ideal gas situation] , so

$$P_{water_left} + P_{sugar_left} = P_{water_right} + P_{osmotic}$$

where $P_{osmotic}$ is the difference required in the hydrostatic pressure on the two sides of the membrane caused by the fact that the water rises on the right side. But we have

$$P_{water_left} = P_{water_right}$$

and therefore

$$P_{osmotic} = P_{sugar_left} = n_{Sugar}\, RT$$

Usually one writes the osmotic pressure with the letter π, so we have

$$\pi = n_{Sugar}\, RT$$

as the result for the osmotic pressure. You would then set this equal to $mg\Delta h$ to find the height difference.

2. The following web page http://alienryderflex.com/osmosis/ [which I have preserved in my osmosis folder] varies the above argument a bit. It imagines the you suddenly make the membrane holes appear,

and that this neutralizes the water pressure on both sides, since the water is now free to go back and forth. the membrane is then like an imaginary surface inside a glass of water. I guess I would say that the water pressure was the same acting on the two sides of an imaginary surface. What you are left with is that there is extra pressure on the sugar side because sugars are swatting the membrane on one side only. The membrane thus bends out, encompassing more water, and $P_{osmotic} = P_{sugar}$, same as my result above.

3. The original derivation was done by **van 't Hoff** in an 1887 paper which you can read here:

http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/vantHoff.1887.html

Jacobus Henricus van 't Hoff (August 30, 1852 – March 1, 1911) was a Dutch physical and organic chemist and the winner of the inaugural Nobel Prize in chemistry. His research on chemical kinetics, chemical equilibrium, osmotic pressure and crystallography is credited to be his major work. Van 't Hoff helped to found the discipline of physical chemistry as we know it today.

The usual statement of the osmotic pressure is this:

$$\pi = i \cdot M \cdot R \cdot T.$$

where

i is the van 't Hoff factor
M is the molarity
R is the gas constant, where $R = 0.08206\ \text{L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$
T is the thermodynamic temperature (formerly called absolute temperature)

where molarity means moles per liter as usual. The factor i = 2 for NaCl since each "molecule" becomes 2 in solution.

4. Example from http://www2.ucdsb.on.ca/tiss/stretton/CHEM4/APProperties_Solutions.html

Osmotic pressures can be very high even in dilute solutions.

Example: A very dilute solution, 0.0010 M sugar in water, is separated from pure water by an osmotic membrane. What osmotic pressure developed at 25°C or 298 K? The gas constant R = 0.0821 L atm / mol K.

Solution: Apply the molarity equation from above:

$\Pi = MRT$

$= 0.0010 \frac{\cancel{\text{mol}}}{\cancel{\text{L}}} \times 0.0821 \frac{\cancel{\text{L}}\ \text{atm}}{\cancel{\text{molK}}} \times 298\ \cancel{\text{K}}$

$= 0.024$ atm

The osmotic pressure is 0.024 atm.

Mercury has a density of 13.59 g/mL. Since the density of sugar water in this solution is basically equivalent to pure water we can convert 0.024 atm into the the equivilant expressed in inches of water. 0.024 atm will support a colulm of water **10 inches high**. A **0.1 M sugar solution**, still relatively dilute, could support a column 100 times as high or 1000 inches, or about **83 ft high**. Thus osmosis is a part of the explanation for the rise of sap in trees.

5. It is always pointed out that osmosis involves the number of molecules, is unrelated to molecular weight.

6. Watson has a panel on this subject on page 517. The point is that cells need active ion pumps to keep osmotic pressures under control.

7. In the context of **blood capillaries**, we have several new terms, but it is the same subject. The claim is that blood contains more protein molecules than are present in the extracell matrix outside the blood. If there were none outside, then these interior proteins tend to "pull in water" and this seems to be a pressure pushing water into the capillary from the outside. See excellent nursing animation here:

http://www.nottingham.ac.uk/nursing/sonet/rlos/bioproc/starlings/4.html

This is just our osmotic pressure, but in this context it is called **oncotic pressure**. If you add up all the concentrations of molecules inside the blood that can't get through the epithelium, you arrive at the interior "oncotic pressure π_c where c = capillary. The sum outside is π_i where i = interstitial. While oncotic pressure pulls water in, hydrostatic pressure (difference on the two sides) pushes water out. The stuff pushed out by hydrostatic pressure is called **filtrate**.

The balance involved here is summarized in **Starling's Formula**: [he was 1896] and I take this from http://www.anaesthesiamcq.com/FluidBook/fl4_2.php :

Starling Equation

$$J_V = K_f [(P_c - P_i) - \sigma(\pi_c - \pi_i)]$$

where:

J_V	Net fluid flux
K_f	Filtration coefficient
P_c	Capillary hydrostatic pressure
P_i	Interstitial hydrostatic pressure
σ	Reflection coefficient
π_c	Capillary oncotic pressure
π_i	Interstitial oncotic pressure

and

$[(P_c - P_i) - \sigma(\pi_c - \pi_i)]$ is the Net driving pressure

The factor σ is in the range [0,1] and is a accounts for the fact that certain molecules can in fact pass through the epithelium, reducing the nominal oncotic pressure. Kf is a proportionality constant .

The **filtration coefficient** consists of two components as the net fluid flux is dependent on:

- the area of the capillary walls where the transfer occurs

- the permeability of the capillary wall to water. (This permeability factor is usually considered in terms of the 'hydraulic conductivity' of the wall.)

The filtration coefficient is the product of these two components: **Kf = Area x Hydraulic conductivity**

A 'leaky' capillary (eg due to histamine) would have a high filtration coefficient. The glomerular capillaries are naturally very leaky as this is necessary for their function; they have a high filtration coefficient.

Here are some typical values for the four drivers of the water flux:

Typical values of Starling Forces in Systemic Capillaries (mmHg)		
	Arteriolar end of capillary	**Venous end of capillary**
Capillary hydrostatic pressure	25	10
Interstitial hydrostatic pressure	-6	-6
Capillary oncotic pressure	25	25
Interstitial oncotic pressure	5	5

The negative pressure for interstitial is relative to atmosphere outside the body (as are all these pressures). Not sure what makes it negative, perhaps suction of veins?

8. This brings up the topic of **edema**. Edema means increased interstitial water pressure outside the capillaries which causes **swelling**.

[mod.L., a. Gr. o°δγλα (–λασ–) swelling, swollen condition, f. o→δ□–ειμ to swell.]

According to wiki

Edema has five pathophysiologic causes. It can be due to **increased hydrostatic pressure**, **reduced oncotic pressure**, lymphatic obstruction, **sodium retention**, or **inflammation**.[1]

The first two causes we understand from the above discussion to this point.

When inflammation occurs, certain molecules moves out of the blood into the interstitial which reduces the net oncotic pressure pushing in, so the balance is offset and pressure builds up on the outside and that is edema.

In our Minagar paper #22 we learned about two kinds of cerebral edema.

1) **cytotoxic** edema: caused by failed ion pumps, lack of oxygen, **ischemia**, intracell water **entrapment** , should have low D and therefore low ADC

2) **vasogenic** edema: caused by **BBB rupture** (inflammatory lesions like MS, tumors, trauma), should have high D and ADC since water between cells that can move.

In the first, lack of oxygen causes cell respiration to weaken, ion pumps slow down, ion concentrations vary from normal, and this causes a change in the osmotic pressures and causes water to pile up in the interstitial tissue, or perhaps inside cells in the brain, I am not sure.

I recall corneal edema from contact lens wear, not sure what the detailed mechanism is here, but it could involve the cytotoxic thing mentioned above.