BME 5742 Biosystems Modeling and Control

Lecture 30

Osmosis

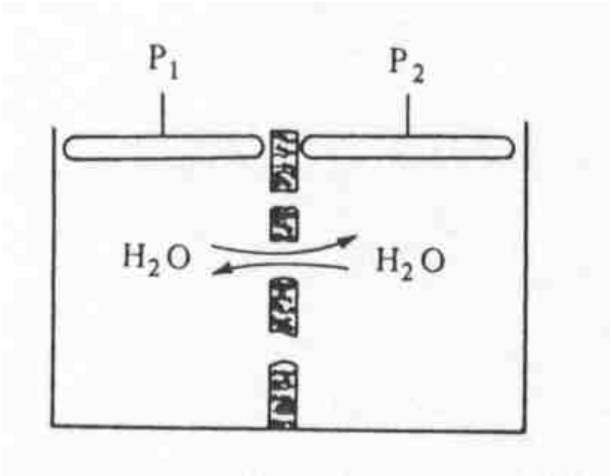
Reference

- Textbook by Hoppensteadt and Peskin, Chapter 3.

What is Osmosis?

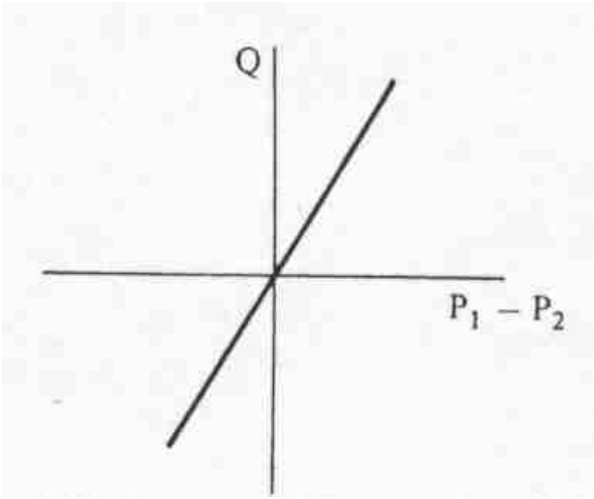
- Osmosis is the process by which water distributes itself among compartments, separated by semi-permeable membranes.
- The membranes allow the water to move freely back and forth, but they do not allow the passage of certain solutes.
- Process stops when osmotic equilibrium is established.

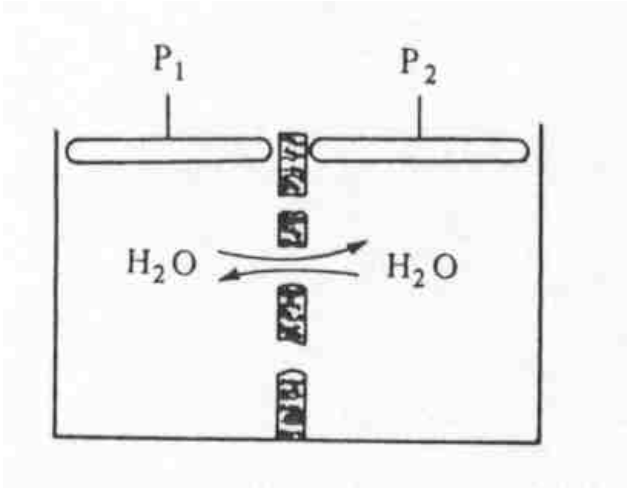
Intuitive Illustration of Osmotic Pressure -1



- Two chambers are filled with water.
- Chambers are separated by a rigid membrane.
- Pores in membrane allow water to flow back and forth.
- Pistons can apply external pressure on each chamber.

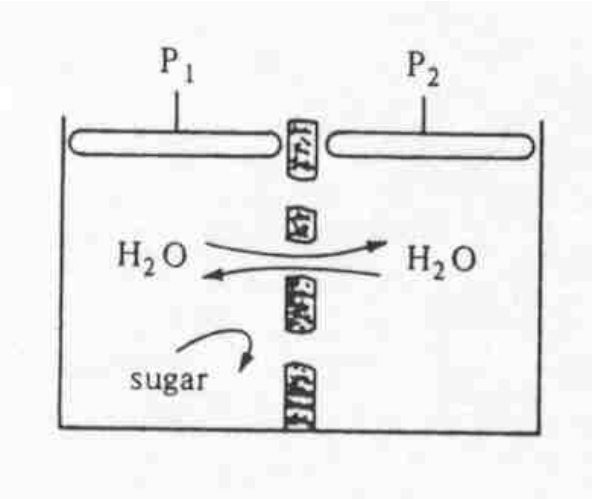
Intuitive Illustration of Osmotic Pressure -2





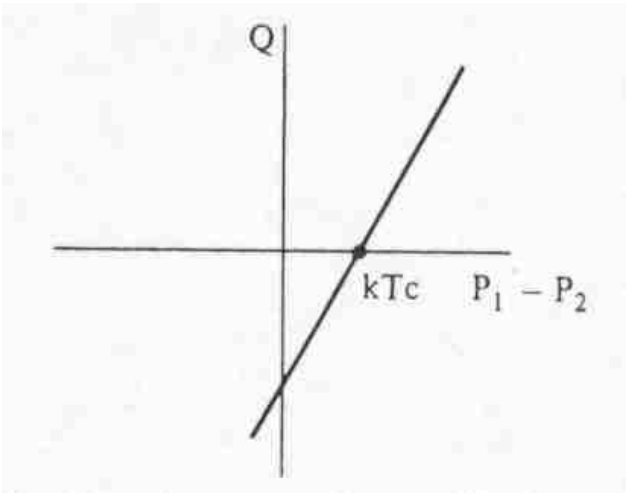
- Flow rate through the membrane is linearly proportional to the applied pressure difference:
- $P_1 - P_2 = RQ$ where R is the flow resistance of the membrane.

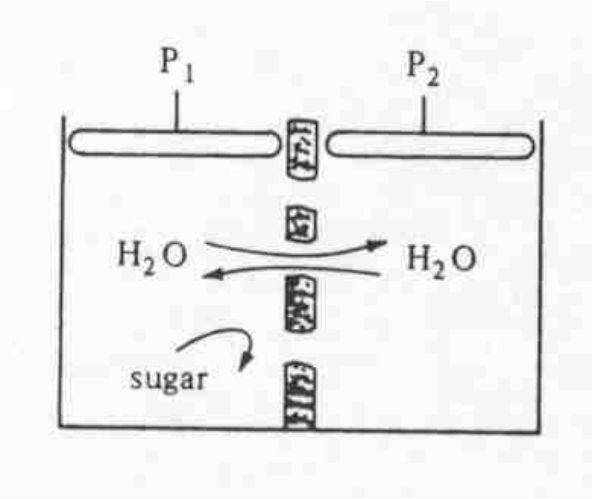
Intuitive Illustration of Osmotic Pressure -3



- Now we consider the membrane to be semi-permeable: Pores allow water to flow in and out, however pores are too small for the sugar molecules to go through.
- What happens?

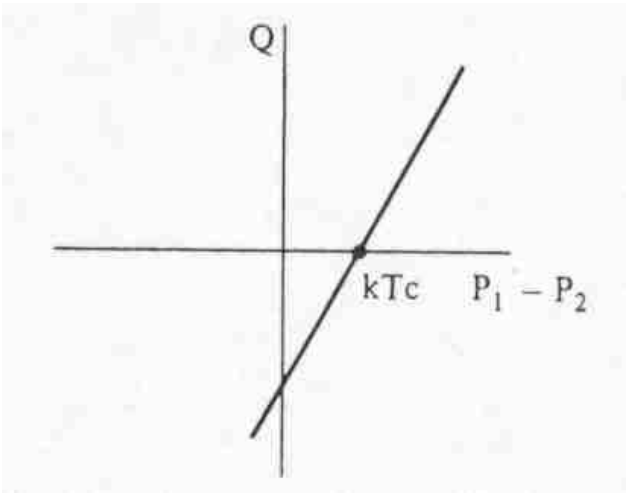
Intuitive Illustration of Osmotic Pressure -4

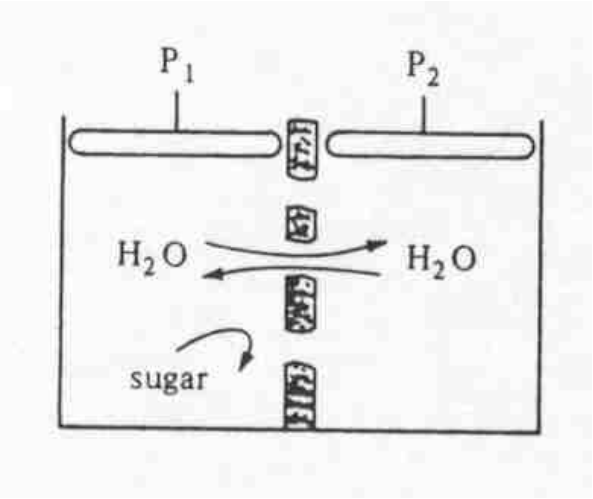




- Let the sugar concentration be c. The dissolved sugar's partial pressure is therefore P_{sugar}=KTc.
- If c=0 (no sugar) and P_1>P_2 then Q>0. Water is flowing from the left chamber to the right.

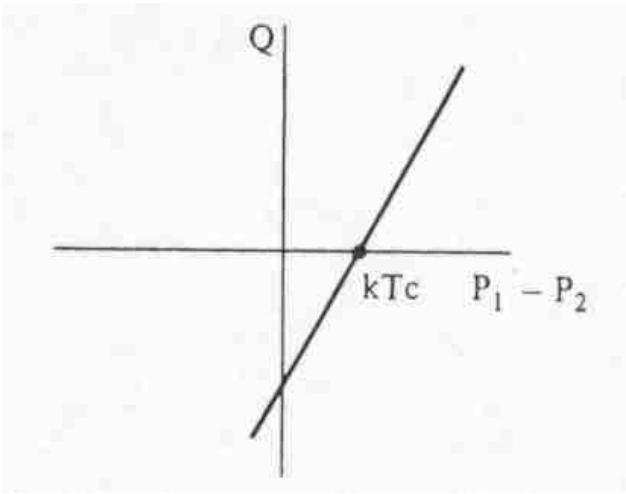
Intuitive Illustration of Osmotic Pressure -5

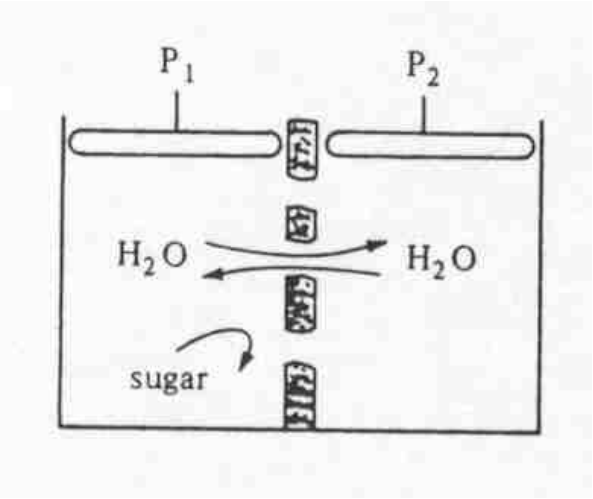




- If $P_1=P_2$ and $c\neq 0$, then, of course, water diffuses from the right chamber to the left.
- This is like saying that the sugar in the left chamber applies a “negative pressure” of -KTc.

Intuitive Illustration of Osmotic Pressure -6





- Therefore, we have, in general:
- $P_1 - P_2 - KTc = RQ$.
- The pressure KTc is called osmotic pressure.
- Water flux due to osmotic pressure is called osmosis.

Osmotic Pressure Formulas

$$P_{osmotic} = KTc = KT\frac{n}{V_1} = RTc$$

- Same mathematical structure as for Ideal Gas Law.
- If [c]=molecules/volume, then we use the KTc version. If [c]=moles/volume then we use the RTc version. $R=KN_A$ (universal gas constant).

Osmoles

- Osmosis depends on the number of molecules and not on the mass of the particles.
- Osmole = Number of solute particles.
- 1osm=1g molecular weight (a mole) of an undissociated solute. Examples:
- 180g of glucose = 1 mole of glucose = 1osm of glucose because glucose does not dissociate in water.
- 58.5g of NaCl = 1 mole of NaCl = 2osm of NaCl, because, NaCl dissociates into 2 moles of osmotically active ions in water.
- 2.5mmol $CaCl_2$ = 7.5 mosm $CaCl_2$

Osmolality and Osmolarity

- Osmolality: solute particles / 1kg of water.
- A solution with 1 osmole of solute dissolved in 1kg of water has osmolality of 1.
- Osmolarity: solute particles / 1liter of aqueous solution.
- Osmolality is harder to assess than osmolarity, because we need to know how much water is in the solution.
- On the other hand, osmolality is temperature-independent whereas osmolarity is temperature-dependent.
- In the human body, osmolarity and osmolality differ by less than 1%.

If solute is present on both sides of the membrane:

- Let c_1 be the solute concentration in Chamber 1, and c_2 that in Chamber 2. Then:
- $P_1 - P_2 - KT(c_1 - c_2) = RQ$
- The concentration difference between the two solutions determines their relative osmotic pressure.

If chambers contain a mixture of solutes:

- Osmotic pressure is determined by the number of independently moving solute particles per unit volume.
- Therefore, in a mixture of solutes all osmotic partial pressures add up.
- Example: If NaCl is dissolved in water, the Na^+ and Cl^- ions move independently, and the osmotic pressure of the solution equals $KT[Na^+] + KT[Cl^-]$.

Cellular Osmotic Equilibrium Facts

- There is an osmotic equilibrium between ICF and ECF.
- Na^+ and Cl^- constitute 80% of ECF osmolality.
- K^+ and phosphates constitute 75% of ICF osmolality.
- There is electrical neutrality within compartments.

Volume Regulation of Body Fluid Compartments

- There is always osmotic equilibrium between ECF and ICF.
- Cell volume is determined by mass of intracellular solutes such as K^+.
- ECF Volume is determined by mass of extracellular solutes such as Na^+ and Cl^-.
- Sodium is the primary determinant of ECF volume (ECF volume is proportional to ECF Na mass)