AP Biology   Name: _____

Chapter 5: Membrane Structure and Function   Date: _____

Diffusion and Osmosis   Period: _____

Modeling Diffusion and Osmosis

BACKGROUND

Cells must move materials through membranes and throughout cytoplasm in order to maintain homeostasis. The movement is regulated because cellular membranes, including the plasma and organelle membranes, are selectively permeable. Membranes are phospholipid bilayers containing embedded proteins; the phospholipid fatty acids limit the movement of water because of their hydrophobic characteristics.

The cellular environment is aqueous, meaning that the solutes (e.g., salts, organic molecules) dissolve in water, which is the solvent. Water may pass slowly through the membrane by osmosis or through specialized protein channels called aquaporins. Aquaporins allow the water to move more quickly than it would through osmosis. Most other substances, such as ions, move through protein channels, while larger molecules, including carbohydrates, move through transport proteins.

The simplest form of movement is diffusion, in which solutes move from an area of high concentration to an area of low concentration; diffusion is directly related to molecular kinetic energy. Diffusion does not require energy input by cells. The movement of a solute from an area of low concentration to an area of high concentration requires energy input in the form of ATP and protein carriers called pumps.

Water moves through membranes by diffusion; the movement of water through membranes is called osmosis. Like solutes, water moves down its concentration gradient. Water moves from areas of high potential (high free water concentration) and low solute concentration to areas of low potential (low free water concentration)

In non-walled cells, such as animal cells, the movement of water into and out of a cell is affected by the relative solute concentration on either side of the plasma membrane. As water moves out of the cell, the cell shrinks; if water moves into the cell, it swells and may eventually burst. In walled cells, including fungal and plant cells, osmosis is affected not only by the solute concentration, but also by the resistance to water movement in the cell by the cell wall. This resistance is called turgor pressure. The presence of a cell wall prevents the cells from bursting as water enters; however, pressure builds up inside the cell and affects the rate of osmosis.

Water movement in plants is important in water transport from the roots into the shoots and leaves. You likely will explore this specialized movement called transpiration in another lab investigation.

UNDERSTANDING WATER POTENTIAL

Water potential predicts which way water diffuses through plant tissues and is abbreviated by the Greek letter psi (ψ). Water potential is the free energy per mole of water and is calculated from two major components: (1) the solute potential (ψ_S), which is dependent on solute concentration, and (2) the pressure potential (ψ_P), which results from the exertion of pressure—either positive or negative (tension) — on a solution. The solute potential is also called the osmotic potential.

$$\psi = \psi P + \psi S$$

Water Potential = Pressure Potential + Solute Potential

Water moves from an area of higher water potential or higher free energy to an area of lower water potential or lower free energy. Water potential measures the tendency of water to diffuse from one compartment to another compartment.
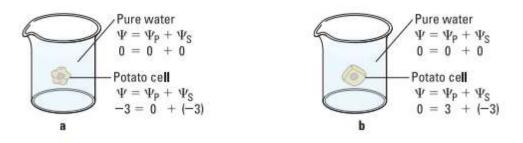
The water potential of pure water in an open beaker is zero (ψ = 0) because both the solute and pressure potentials are zero ($\psi_S = 0$; $\psi_P = 0$). An increase in positive pressure raises the pressure potential and the water potential. The addition of solute to the water lowers the solute potential and therefore decreases the water potential. This means that a solution at atmospheric pressure has a negative water potential due to the solute.

The solute potential (ψ_S) = $- iCRT$, where i is the ionization constant, C is the molar concentration, R is the pressure constant (R = 0.0831 liter bars/mole-K), and T is the temperature in K (273 + °C).

A 0.15 M solution of sucrose at atmospheric pressure (ψ_P = 0) and 25°C has an osmotic potential of -3.7 bars and a water potential of -3.7 bars. A bar is a metric measure of pressure and is the same as 1 atmosphere at sea level. A 0.15 M NaCl solution contains 2 ions, Na+ and Cl-; therefore i = 2 and the water potential = -7.4 bars.

When a cell's cytoplasm is separated from pure water by a selectively permeable membrane, water moves from the surrounding area, where the water potential is higher (ψ = 0), into the cell, where water potential is lower because of solutes in the cytoplasm (ψ is negative). It is assumed that the solute is not diffusing (Figure 1a). The movement of water into the cell causes the cell to swell, and the cell membrane pushes against the cell wall to produce an increase in pressure. This pressure, which counteracts the diffusion of water into the cell, is called turgor pressure.

Over time, enough positive turgor pressure builds up to oppose the more negative solute potential of the cell. Eventually, the water potential of the cell equals the water potential of the pure water outside the cell (ψ of cell = ψ of pure water = 0). At this point, a dynamic equilibrium is reached and net water movement ceases (Figure 1b).

Figures 1a-b. Plant cell in pure water. The water potential was calculated at the beginning of the experiment (a) and after water movement reached dynamic equilibrium and the net water movement was zero (b).

If solute is added to the water surrounding the plant cell, the water potential of the solution surrounding the cell decreases. If enough solute is added, the water potential outside the cell is equal to the water potential inside the cell, and there will be no net movement of water. However, the solute concentrations inside and outside the cell are not equal, because the water potential inside the cell results from the combination of both the turgor pressure (ψ_P) and the solute pressure (ψ_S). (See Figure 2.)

PROCEDURE 1	This investigation consists of two parts. In Procedure 1, you create models of living cells to explore osmosis and diffusion. You finish by observing osmosis in living cells (Procedure 2). Both sections of the investigation provide opportunities for you to design and conduct your own experiments.

ANSWER →

These questions are designed to help you understand kinetic energy, osmosis, and diffusion and to prepare for your investigations.

3. What is kinetic energy, and how does it differ from potential energy?

4. What environmental factors affect kinetic energy and diffusion?

5. How do these factors alter diffusion rates?

ANSWER →

6. Why are gradients important in diffusion and osmosis?

7. What is the explanation for the fact that most cells are small and have cell membranes with many convolutions?

8. Will water move into or out of a plant cell if the cell has a higher water potential than the surrounding environment?

9. What would happen if you applied saltwater to a plant?

10. How does a plant cell control its internal (turgor) pressure?

OBJECTIVES

You are in the hospital and need intravenous fluids. You read the label on the IV bag, which lists all of the solutes in the water. Discuss the questions below with your partner.

-   Why is it important for an IV solution to have salts in it?
-   What would happen if you were given pure water in an IV?
-   How would you determine the best concentration of solutes to give a patient in need of fluids before you introduced the fluids into the patient's body?

In this experiment, you will create models of living cells using dialysis tubing. Like cell membranes, dialysis tubing is made from a material that is selectively permeable to water and some solutes. You will fill your model cells with different solutions and determine the rate of diffusion.

11. How can you use weights of the filled cell models to determine the rate and direction of diffusion? What would be an appropriate control for the procedure you just described?

ANSWER →

12. Suppose you could test other things besides weights of the dialysis tubes. How could you determine the rates and directions of diffusion of water, sucrose, NaCl, glucose, and ovalbumin?

13. Will protein diffuse? Will it affect the rate of diffusion of other molecules?

MATERIALS

- Distilled or tap water
- 1 M sucrose
- 1 M NaCl
- 1 M glucose
- 5% ovalbumin (egg white protein)
- 20 cm-long dialysis tubing
- Cups
- Balances

STEP 1
Choose up to four pairs of different solutions. One solution from each pair will be in the model cell of dialysis tubing, and the other will be outside the cell in the cup. Your fifth model cell will have water inside and outside; this is your control. Before starting, use your knowledge about solute gradients to predict whether the water will diffuse into or out of the cell. Make sure you label the cups to indicate what solution is inside the cell and inside the cup.

Observing Osmosis in Living Cells

The interactions between selectively permeable membranes, water, and solutes are important in cellular and organismal functions. For example, water and nutrients move from plant roots to the leaves and shoots because of differences in water potentials. Based upon what you know and what you have learned about osmosis, diffusion, and water potential in the course of your investigations, think about these questions.

- What would happen if you applied saltwater to the roots of a plant? Why?
- What are two different ways a plant could control turgor pressure, a name for internal water potential within its cells? Is this a sufficient definition for turgor pressure?
- Will water move into or out of a plant cell if the cell has a higher water potential than its surrounding environment?

PROCEDURE 2

Step 1

Start by looking at a single leaf blade from either *Elodea* (a water plant) or a leaflike structure from *Mnium hornum* (a moss) under the light microscope. If you need assistance, your teacher will show you how to place specimens on a slide.

22. Where is the cell membrane in relation to the cell wall? Can you see the two structures easily? Why or why not?

23. What parts of the cell that you see control the water concentration inside the cell?

Back in Procedure 2 you tested diffusion and osmosis properties of several solutions. Now you are going to determine how they affect plant cell turgor pressure.

24. What changes do you expect to see when the cells are exposed to the solutions?

ANSWER →

25. How will you know if a particular treatment is increasing turgor pressure? If it is reducing turgor pressure?

26. How could you determine which solution is isotonic to the cells?

Step 2

Test the four solutions from Procedure 2 and find out if what you predicted is what happens. When you are done, ask other students what they saw. Be sure to record all of your procedures, calculations, and observations in the space below in an organized manner.