Cell Membrane Properties

Purpose of the lab:
- review the structure and function of the cell membrane
- understand the three types of transport across a membrane, and the special case of osmosis using Elodea cell membranes

Structure of the Cell Membrane

Phospholipids are the most abundant lipids in the cell membrane. A phospholipid consists of a polar, hydrophilic head (attracted to water) and a pair of nonpolar, hydrophobic tails (repelled by water).

The cell membrane is a phospholipid bilayer, in which the hydrophilic heads are exposed to the watery environment outside and inside the cell, and the hydrophobic tails are shielded from water.

The fluid mosaic model is the present working model of the membrane. According to this model, the membrane is a mosaic of protein molecules bobbing in a fluid bilayer of phospholipids. These proteins determine most of the membrane’s specific functions.

A number of other molecules are associated with the surface of the cell membrane, such as glycolipids and cytoskeletal filaments. These serve in functions such as cell-cell recognition, and maintaining cell shape.

Types of Membrane Transport

In the course of a cell’s metabolism, a variety of molecules must pass between the intracellular cytoplasm and the extracellular environment. This transport is regulated by the cell membrane’s structure and function.

There are three types of transport mechanisms across the cell membrane:

1. Passive transport (also called passive diffusion)
   - osmosis is a special case of passive transport

2. Facilitated diffusion

3. Active transport
In the absence of any barrier, there is a tendency for molecules of a substance to "spread out", with molecules moving from an area of high concentration to an area of low concentration. For example, if a drop of red dye is placed in a glass of water, dye molecules will diffuse into water, and water molecules into the drop of dye. Eventually, both dye and water are evenly dispersed.

Passive Diffusion

When a biological membrane is present, a substance will also diffuse from where it is more concentrated to where it is less concentrated, as long as the pores of the membrane are large enough for the substance to pass. Diffusion "down the concentration gradient" leads to a dynamic equilibrium, in which the solute molecules continue to cross the membrane, but at equal rates in both directions.

Membrane Permeability

The cell membrane is a selectively permeable membrane: it lets some molecules pass through by passive diffusion, but not others. There are 4 factors that determine the permeability of a molecule:

1. Lipid solubility is the most important factor in determining a molecule's permeability. Hydrophobic molecules, such as hydrocarbons, carbon dioxide, and oxygen, can dissolve in the lipid bilayer and cross it with ease.

2. Molecular size: larger molecules are less permeable due to two factors: the lower kinetic energy of large molecules, and the hindrance due to small pore sizes in the membrane.

3. Polarity: Polar molecules tend to be hydrophilic, and therefore do not pass readily through the membrane. However, very small molecules that are polar but uncharged, such as water, can pass through the membrane readily.
Membrane Permeability

Charge: charged molecules are usually hydrophilic, and in aqueous solution they are surrounded by a coat of water (hydration shell). The hydration shell increases the size of the molecule, further impeding movement across the membrane.

Passive Diffusion: Osmosis

Because the easy passage of water through a biological membrane is such an important process, it has its own name: osmosis.

As with any other molecule, water also moves down its concentration gradient.

Let’s say we have two sugar solutions of different concentrations that are separated by a porous membrane that is not permeable to the sugar, but is permeable to water.

What will happen?

Water diffuses from where it is more concentrated, to where it is less concentrated, until the concentration of water is the same on both sides of the membrane.

When the concentration of water is the same on both sides of the membrane, the solutions are said to be isotonic to each other.

When the concentration of water is greater on one side of the membrane, that solution is said to be hypotonic.

When the concentration of water is less on one side of the membrane, that solution is said to be hypertonic.

The survival of a cell depends on balancing water uptake and loss. Let’s apply what we know about osmosis to living cells.

Animal cells do not have rigid cell walls. An animal cell fares best in an isotonic environment, where the influx of water equals the efflux of water.
Passive Diffusion: Osmosis: Application to Living Cells

When placed in a hypotonic solution (a solution in which the concentration of water is greater than that inside the cell), water will enter an animal cell via osmosis. Because the cell membrane is not rigid, the cell will take on a turgid appearance.

When placed in a hypertonic solution (a solution in which the concentration of water is less than that inside the cell), water will leave an animal cell via osmosis. Because the cell membrane is not rigid, the cell will take on a shriveled appearance.

Plant Cell

Now let’s consider a plant cell, which has a rigid cell wall. When placed in an hypotonic solution, water will enter the cell. The cell wall will eventually exert a back pressure that opposes further water uptake. The cell has a turgid appearance, which is normal and healthy.

In an isotonic environment, water enters and leaves the cell at equal rates. The cell has a flaccid, or limp, appearance, which causes the plant to wilt.

If placed in a hypertonic solution, water will leave the cell. As the plant cell shrinks, its cell membrane pulls away from the cell wall. This phenomenon is called plasmolysis, and the cell is said to be plasmolyzed.

In today’s lab, you will examine the effect of a series of alcohols on the osmotic condition of Elodea, a common aquatic plant.

When the cells are in their normal, hypotonic environment, they have a normal, turgid appearance.
Passive Diffusion: Osmosis: Application to Living Cells

When placed in a hypertonic environment, the cells undergo plasmolysis.

The cell membrane pulls away from the cell wall, so that the chloroplasts and cytoplasm appear “bailed up” inside the rigid cell wall.

Membrane Permeability of a Series of Alcohols in *Elodea*

In today’s lab, you will be testing a series of 6 alcohols and assessing the degree to which each causes plasmolysis:

None? Slight? Moderate? Severe?

(This is an example of severe plasmolysis.)

The 6 alcohols that you will be working with are:

- Methanol
- Ethanol
- Ethylene Glycol
- 1-Propanol
- Propylene Glycol
- Glycerol

Membrane Permeability of a Series of Alcohols in *Elodea*

Remember that MOLECULAR SIZE is one factor that determines the permeability of a molecule through a biological membrane. Here, you can see that the molecules are “ranked” according to size, from small to large:

- Methanol $\text{CH}_3\text{OH}$
- Ethanol $\text{CH}_3\text{CH}_2\text{OH}$
- Ethylene Glycol $\text{HOCH}_2\text{CH}_2\text{OH}$
- 1-Propanol $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
- Propylene Glycol $\text{CH}_3\text{CH(OH)}\text{CH}_2\text{OH}$
- Glycerol $\text{HOCH}_2\text{CH(OH)}\text{CH}_2\text{OH}$

IF membrane permeability were dependent ONLY upon molecular size, you would expect that the larger the molecule, the greater the degree of plasmolysis it would cause.

Let’s assume we place an *Elodea* leaf in a solution with small molecules, such as methanol.

Because the small molecules can easily pass through the spaces between the phospholipid molecules in the bilayer, they will quickly move down their concentration gradient and establish equilibrium on both sides of the membrane.
Membrane Permeability of a Series of Alcohols in *Elodea*

Because this equilibrium is established so quickly, there is no visible effect on the water balance of the cell, i.e., there is NO plasmolysis.

Membrane Permeability of a Series of Alcohols in *Elodea*

**In contrast, let’s next assume we place an *Elodea* leaf in a solution with large molecules, such as propylene glycol.**

What might you expect to happen, IF membrane permeability were only dependent on the size of the molecule?

Cell Membrane

= propylene glycol, CH₃CH(OH)CH₂OH

Membrane Permeability of a Series of Alcohols in *Elodea*

It would take a long time for the large molecules to establish an equilibrium concentration on both sides of the membrane, because they have difficulty moving through the membrane.

Membrane Permeability of a Series of Alcohols in *Elodea*

Because of this disequilibrium, the intracellular cytoplasm is hypotonic with respect to the extracellular environment.

By osmosis, water will then leave the cell, moving down its concentration gradient, from the hypotonic, intracellular cytoplasm to the hypertonic, extracellular environment, until it achieves an equilibrium between the inside and outside of the cell.

As water moves down its concentration gradient, the *Elodea* cells become plasmolyzed.
Membrane Permeability of a Series of Alcohols in *Elodea*

After a period of time, the large molecules, which continue to move down their concentration gradient, will eventually establish equilibrium on both sides of the membrane.

As the alcohol molecules eventually enter the cell, water will also re-enter the cell, resulting in *deplasmolysis*.

In the preceding discussion, we have focused on **MOLECULAR SIZE** as it relates to the permeability of a substance, and hence to its effect on plasmolysis and deplasmolysis.

However, remember that the primary factor that influences a substance’s permeability is its **Lipid Solubility**.

One measure of a molecule’s lipid solubility is the **Ether : Water Partition Coefficient**.

This is simply a ratio of a substance’s solubility in lipid to its solubility in water.

Let’s go back to the list of the 6 alcohols you and your lab partner will be working with, and look at their ether : water partition coefficients:

- Methanol 0.14
- Ethanol 0.26
- Ethylene Glycol 0.0053
- 1-Propanol 1.9
- Propylene Glycol 0.018
- Glycerol 0.00066
Membrane Permeability of a Series of Alcohols in *Elodea*

Based on their ether : water partition coefficient, which alcohol would you expect to be MOST lipid-soluble?

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**Answer follows**

If you place an *Elodea* leaf in a solution containing 1-propanol, would you expect to see plasmolysis?

No. Because 1-propanol is very lipid-soluble, it will quickly move into the cell and establish an equilibrium, so there will be no visible effect on the water balance of the cell, i.e., NO plasmolysis.

Membrane Permeability of a Series of Alcohols in *Elodea*

Based on their ether : water partition coefficient, which alcohol would you expect to be LEAST lipid-soluble?

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**Answer follows**

Glycerol has the lowest ether:water partition coefficient, and is therefore the least lipid-soluble.
Membrane Permeability of a Series of Alcohols in Elodea

If you place an Elodea leaf in a solution containing glycerol, would you expect to see plasmolysis?

Answer follows

Yes. Because glycerol has extremely low solubility in lipid, very few, if any, molecules will be able to move across the cell membrane. This results in severe plasmolysis.

Membrane Permeability of a Series of Alcohols in Elodea

In order to make hypotheses about which alcohols might cause plasmolysis, and the severity of the plasmolysis, you should RANK the alcohols in terms of their lipid solubility.

Methanol 0.14
Ethanol 0.26
Ethylene Glycol 0.0053
1-Propanol 1.9
Propylene Glycol 0.018
Glycerol 0.00066

Go ahead and do this now, before continuing any further.

Membrane Permeability of a Series of Alcohols in Elodea

In performing today’s lab exercises, the 4 students in each row should work together. One pair should work with 3 of the 6 alcohols, and the other pair should work with the remaining 3 alcohols.

A good separation would be:

methanol
1-propanol
glycerol
ethanol
ethylene glycol
propylene glycol

Types of Membrane Transport

Until now, we have been discussing passive transport, of which osmosis is a special case involving water.

There are two additional types of transport mechanisms across the cell membrane:

1. Passive transport
   a. Osmosis
2. Facilitated diffusion
3. Active transport

Facilitated Diffusion

As we have seen, some molecules cannot pass through the bilayer on their own. Carrier proteins may bind a specific molecule and, as a result, change their own shape, passing the molecule through the middle of the protein to the other side of the membrane.
Passive Transport and Facilitated Diffusion

Passive transport and facilitated diffusion do NOT require ATP. Instead, they take place without the input of additional energy, because of the physical and chemical properties of the cell membrane.

Active Transport

The final mechanism of transport across the cell membrane DOES require the input of ATP. For this reason, it is called ACTIVE TRANSPORT.

Active Transport

With energy provided by ATP, transport proteins embedded in the cell membrane can move solutes AGAINST their concentration gradient. This type of transport allows cells to concentrate certain molecules that may not be present in high concentrations in the surrounding fluid, such as the concentration of Ca$^{2+}$ in the sarcoplasmic reticulum of muscles.

The Introduction is finished!