Passive Transport

Inquire: Diffusion and Osmosis

Overview

The two forms of passive transport, diffusion and osmosis, move materials of small molecular weight across membranes. Substances diffuse from higher to lower concentration areas, and this process continues until the substance evenly distributes itself in a system. In solutions containing more than one substance, each molecule type diffuses according to its own concentration gradient, independent of how other substances diffuse. Many factors can affect the diffusion rate, such as the concentration gradient, the particle sizes, and the system's temperature.

In living systems, the plasma membrane mediates substances, diffusing in and out of cells. Some materials diffuse readily through the membrane, but others are hindered and only can pass through due to specialized proteins such as channels and transporters. The chemistry of living things occurs in aqueous solutions, and balancing the concentrations of those solutions is an ongoing problem. In living systems, diffusing some substances would be slow or difficult without membrane proteins that facilitate transport.

Osmosis is the diffusion of water through a semipermeable membrane down its concentration gradient. In the beaker on the left, the solution on the right side of the membrane is hypertonic.

Big Question: What is passive transport?

Watch: Factors that Affect Diffusion

Molecules move constantly in a random manner at a rate that depends on their mass, their environment, and the amount of thermal energy they possess, which in turn is a function of temperature. This movement accounts for molecule diffusion through whatever medium in which they are localized. A substance moves into any space available until it evenly distributes itself throughout. After a substance
has diffused completely through a space, removing its concentration gradient, molecules will still move around in the space, but there will be no net movement of the number of molecules from one area to another. We call this lack of a concentration gradient, in which the substance has no net movement, dynamic equilibrium.

The most direct forms of membrane transport are passive. Passive transport is a naturally occurring phenomenon and does not require the cell to exert any of its energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration. There are two passive transport forms: diffusion and osmosis. You might have heard of the joke “learn through osmosis.” People usually say this when someone falls asleep on their book while studying. They are implying that the person sleeping will absorb the information in the book through their heads. Obviously, this can’t really happen. Osmosis actually refers to the passive transport of water through the cell membrane. On the other hand, diffusion refers to the movement of molecules from an area of high concentration to an area of low concentration. Essentially, diffusion is how molecules are evenly spread out in a space.

Imagine a glass of water. Now imagine dropping food coloring in that water. If you leave the water alone, after some time, all of the water will be an even color. This is a great example of diffusion in action; the high concentration of food coloring eventually spreads evenly throughout the water making it all one color.

Read: Passive Transport

Overview
Plasma membranes must allow certain substances to enter and leave a cell, preventing some harmful materials from entering and some essential materials from leaving. In other words, plasma membranes are selectively permeable — they allow some substances to pass through, but not others. If they were to lose this selectivity, the cell would no longer be able to sustain itself, and it would be destroyed.

Some cells require larger amounts of specific substances and they must have a way of obtaining these materials from extracellular fluids. This may happen passively, as certain materials move back and forth, or the cell may have special mechanisms that facilitate transport. Some materials are so important to a cell that it will spend some of its energy to obtain these materials. Red blood cells use some of their energy doing just that. Most cells spend the majority of their energy to maintain an imbalance of sodium and potassium ions between the cell's interior and exterior, as well as on protein synthesis. A physical space in which there is a single substance concentration range has a concentration gradient.

Selective Permeability
Plasma membranes are asymmetric, meaning the membrane's interior is not identical to its exterior. There is a considerable difference between the array of phospholipids and proteins between the two leaflets that form a membrane. On the membrane's interior, some proteins serve to anchor the membrane to cytoskeleton fibers. There are peripheral proteins on the membrane's exterior that bind extracellular matrix elements. Carbohydrates, attached to lipids or proteins, are also on the plasma membrane's exterior surface. These carbohydrate complexes help the cell bind required substances in the extracellular fluid. This adds considerably to plasma membrane's selective nature.
The plasma membrane's exterior surface is not identical to its interior surface.

Plasma membranes have hydrophilic and hydrophobic regions. This characteristic helps move some materials through the membrane and hinders the movement of others. Non-polar and lipid-soluble materials with a low molecular weight can easily slip through the membrane's hydrophobic lipid core. Substances such as the fat-soluble vitamins A, D, E, and K readily pass through the plasma membranes in the digestive tract and other tissues. Fat-soluble drugs and hormones also gain easy entry into cells and readily transport themselves into the body's tissues and organs. Oxygen and carbon dioxide molecules have no charge and pass through membranes by simple diffusion.

Polar substances present problems for the membrane. While some polar molecules connect easily with the cell's outside, they cannot readily pass through the plasma membrane's lipid core. Additionally, while small ions could easily slip through the spaces in the membrane's mosaic, their charge prevents them from doing so. Ions such as sodium, potassium, calcium, and chloride must have special means of penetrating plasma membranes. Simple sugars and amino acids also need the help of various transmembrane proteins (channels) to transport themselves across plasma membranes.

**Diffusion**

**Diffusion** is a passive process of transport. A single substance moves from a high concentration to a low concentration area until the concentration is equal across a space. Materials move within the cell's cytosol by diffusion, and certain materials move through the plasma membrane by diffusion. Diffusion expends no energy. On the contrary, concentration gradients are a form of potential energy, which dissipates as the gradient is eliminated.
Each separate substance in a medium, such as the extracellular fluid, has its own concentration gradient, independent of other materials’ concentration gradients. In addition, each substance will diffuse according to its own gradient. Within a system, there will be different diffusion rates of various substances in the medium.

Several factors affect the diffusion rate:

- Extent of the concentration gradient: The greater the difference in concentration, the more rapid the diffusion. The closer the distribution of the material gets to equilibrium, the slower the diffusion rate.
- Mass of the diffusing molecules: Heavier molecules move more slowly; therefore, they diffuse slower. The reverse is true for lighter molecules.
- Temperature: Higher temperatures increase the energy and therefore the molecules' movement, increasing the diffusion rate. Lower temperatures decrease the molecules' energy, thus decreasing the diffusion rate.
- Solvent density: As the density of a solvent increases, the diffusion rate decreases. The molecules slow down because they have a more difficult time passing through the denser medium. If the medium is less dense, diffusion increases. Because cells primarily use diffusion to move materials within the cytoplasm, any increase in the cytoplasm's density will inhibit the movement of the materials. An example of this is a person experiencing dehydration. As the body’s cells lose water, the diffusion rate decreases in the cytoplasm, and the cells’ functions deteriorate. Neurons tend to be very sensitive to this effect. Dehydration frequently leads to unconsciousness and possibly coma because of the decrease in diffusion rate within the cells.
- Solubility: Nonpolar or lipid-soluble materials pass through plasma membranes more easily than polar materials, allowing a faster diffusion rate.
- Surface area and plasma membrane thickness: Increased surface area increases the diffusion rate; whereas, a thicker membrane reduces it.
- Distance travelled: The greater the distance that a substance must travel, the slower the diffusion rate. This places an upper limitation on cell size. A large, spherical cell will die because nutrients or waste cannot reach or leave the cell’s center, respectively. Therefore, cells must either be small in size, as in the case of many prokaryotes, or be flattened, as with many single-celled eukaryotes.

Facilitated transport

In facilitated transport, or facilitated diffusion, materials diffuse across the plasma membrane with the help of membrane proteins. A concentration gradient exists that would allow these materials to diffuse into the cell without expending cellular energy. However, these materials are polar molecule ions that the cell membrane's hydrophobic parts repel. Facilitated transport proteins shield these materials from the membrane's repulsive force, allowing them to diffuse into the cell.

The transported material first attaches to protein or glycoprotein receptors on the plasma membrane's exterior surface. This allows the removal of extracellular fluid material that the cell needs. The substances then pass to specific integral proteins that facilitate their passage. Some of these integral proteins are collections of beta-pleated sheets that form a pore or channel through the phospholipid bilayer. Others are carrier proteins which bind with the substance and aid its diffusion through the membrane.
Channels

The integral proteins involved in facilitated transport are transport proteins, and they function as either channels for the material or carriers. In both cases, they are transmembrane proteins. Channels are specific for the transported substance. Channel proteins have hydrophilic domains exposed to the intracellular and extracellular fluids. In addition, they have a hydrophilic channel through their core that provides a hydrated opening through the membrane layers. Passage through the channel allows polar compounds to avoid the plasma membrane's nonpolar central layer that would otherwise slow or prevent their entry into the cell. Aquaporins are channel proteins that allow water to pass through the membrane at a very high rate.

Channel proteins are either open at all times or they are “gated,” regulating the channel's opening. When a particular ion attaches to the channel protein, it may control the opening, or other mechanisms or substances may be involved. In some tissues, sodium and chloride ions pass freely through open channels; whereas, in other tissues, a gate must open to allow passage.

Osmosis

Osmosis is the movement of water through a semipermeable membrane according to the water's concentration gradient across the membrane, which is inversely proportional to the solutes' concentration. While diffusion transports material across membranes and within cells, osmosis only transports water across a membrane, and the membrane limits the solutes' diffusion in the water. Not surprisingly, the aquaporins that facilitate water movement play a large role in osmosis, most prominently in red blood cells and the membranes of kidney tubules.
Reflect: Diffusion

Poll

Which scenario do you think best describes diffusion?

- You put green food coloring into a glass of water. You do not stir the water or mess with it in any way. Later, you look at the glass and all of the water is green.
- A friend sitting across the room opens a bottle of nail polish remover, a very stinky nail product. Shortly after they open the bottle, you smell the product.
- You fall asleep while studying. The next morning you know everything.
- You put sugar in your tea. You do not stir the tea or mess with it in any way. Later, the tea tastes sweet when you drink it.
- You leave the cap off of your soda. Later, all of the carbonation is gone.

Expand: Tonicity in Living Systems

Overview

Tonicity describes how an extracellular solution can change a cell's volume by affecting osmosis. A solution's tonicity often directly correlates with the solution's osmolarity. Osmolarity describes the solution's total solute concentration. Scientists use three terms — hypotonic, isotonic, and hypertonic — to relate the cell's osmolarity to the extracellular fluid's osmolarity that contains the cells.

Hypotonic Solutions

In a hypotonic situation, the extracellular fluid has lower osmolarity than the fluid inside the cell, and water enters the cell. In living systems, the point of reference is always the cytoplasm, so the prefix hypo-means that the extracellular fluid has a lower solute concentration, or a lower osmolarity, than the cell cytoplasm. It also means that the extracellular fluid has a higher water concentration in the solution than the cell does. In this situation, water will follow its concentration gradient and enter the cell.

Hypertonic Solutions

As for a hypertonic solution, the prefix hyper- refers to the extracellular fluid having a higher osmolarity than the cell’s cytoplasm; therefore, the fluid contains less water than the cell does. Because the cell has a relatively higher water concentration, water will leave the cell.

Isotonic Solutions

In an isotonic solution, the extracellular fluid has the same osmolarity as the cell. If the cell's osmolarity matches that of the extracellular fluid, there will be no net movement of water in or out of the cell, although water will still move in and out.

Tonicity and Regulation

Blood cells and plant cells in hypertonic, isotonic, and hypotonic solutions take on characteristic appearances.
In a hypotonic environment, water enters a cell, and the cell swells. In an isotonic condition, the relative solute and solvent concentrations are equal on both membrane sides. There is no net water movement; therefore, there is no change in the cell's size. In a hypertonic solution, water leaves a cell and the cell shrinks. If either the hypo- or hyper- condition goes to excess, the cell’s functions become compromised, and the cell may be destroyed.

Various living things have ways of controlling the effects of osmosis — a mechanism we call osmoregulation. Some organisms, such as plants, fungi, bacteria, and some protists, have cell walls that surround the plasma membrane and prevent cell lysis in a hypotonic solution. The plasma membrane can only expand to the cell wall's limit, so the cell will not lyse. The cytoplasm in plants is always slightly hypertonic to the cellular environment, and water will always enter a cell if water is available. This water inflow produces turgor pressure, which stiffens the plant's cell walls. In nonwoody plants, turgor pressure supports the plant. Conversely, if you do not water the plant, the extracellular fluid will become hypertonic, causing water to leave the cell. In this condition, the cell does not shrink because the cell wall is not flexible. However, the cell membrane detaches from the wall and constricts the cytoplasm. We call this plasmolysis. Plants lose turgor pressure in this condition and wilt.
Without adequate water, the plant on the left has lost turgor pressure, visible in its wilting. Watering the plant (right) will restore the turgor pressure. (credit: Victor M. Vicente Selvas)

Many marine invertebrates have internal salt levels matched to their environments, making them isotonic with the water in which they live. Fish, however, must spend approximately five percent of their metabolic energy maintaining osmotic homeostasis. Freshwater fish live in an environment that is hypotonic to their cells. These fish actively take in salt through their gills and excrete diluted urine to rid themselves of excess water. Saltwater fish live in the reverse environment, which is hypertonic to their cells, and they secrete salt through their gills and excrete highly concentrated urine.

In vertebrates, the kidneys regulate the water amount in the body. Osmoreceptors are specialized cells in the brain that monitor solute concentration in the blood. If the solute levels increase beyond a certain range, a hormone is released that slows water loss through the kidneys and dilutes the blood to safer levels. Animals also have high albumin concentrations, which the liver produces, in their blood. This protein is too large to pass easily through plasma membranes and is a major factor in controlling the osmotic pressures applied to tissues.

Lesson Toolbox

Additional Resources and Readings

In Da Club - Membranes & Transport: Crash Course Biology #5
  - A Crash Course video covering osmosis and diffusion
    - https://www.youtube.com/watch?v=dPKvHrD1eS4&t=144s

Diffusion
  - A gif illustrating the diffusion process in solutions
    - https://commons.wikimedia.org/wiki/File:Dispersion.gif

Egg Osmosis
  - A video demonstrating osmosis with an experiment you can try at home
    - https://www.youtube.com/watch?v=SSS3EtKAzYc

Lesson Glossary

aquaporins: channel proteins that allow water to pass through the membrane at a very high rate
channel proteins: membrane protein that allows a substance to pass through its hollow core across the plasma membrane
concentration gradient: area of high concentration adjacent to an area of low concentration
**diffusion**: passive transport process of low-molecular weight material according to its concentration gradient

**facilitated transport**: process by which material moves down a concentration gradient (from high to low concentration) using integral membrane proteins

**hypertonic**: situation in which extracellular fluid has a higher osmolarity than the fluid inside the cell, resulting in water moving out of the cell

**hypotonic**: situation in which extracellular fluid has a lower osmolarity than the fluid inside the cell, resulting in water moving into the cell

**isotonic**: situation in which the extracellular fluid has the same osmolarity as the fluid inside the cell, resulting in no net water movement in or out of the cell

**osmolarity**: total amount of substances dissolved in a specific amount of solution

**osmoregulation**: mechanism for controlling the effects of osmosis in living things

**osmosis**: transport of water through a semipermeable membrane according to the water's concentration gradient across the membrane that results from the presence of solute that cannot pass through the membrane

**plasmolysis**: detaching the cell membrane from the cell wall and constricting the cell membrane when a plant cell is in a hypertonic solution

**selectively permeable**: membrane characteristic that allows some substances through

**tonicity**: amount of solute in a solution

**transport proteins**: membrane protein that facilitates a substance's passage across a membrane by binding it

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**Check Your Knowledge**

1. In osmosis, water always moves from an area of lower water concentration to one of higher concentration.
   - A. True
   - B. False

2. Farmers need to consider the salinity of soil, because in high saline soil, water will be drawn out of root cells causing the cells to shrivel and the plant to die.
   - A. True
   - B. False

3. Active transport moves substances down their concentration gradients. They may cross the plasma membrane with the aid of channel proteins.
   - A. True
   - B. False

**Answer Key:**

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**Citations**

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