PLASMA MEMBRANE AND TRANSPORT MECHANISMS

A. PLASMA MEMBRANE

- Serves as the boundary between the cell's internal and external environments. Regulates all substances that enter and exits the cell
- Exhibits selective permeability, which is why it is referred to as a semi-permeable membrane

A.1. Structure and Organization

The main body of the plasma membrane is composed of an amphipathic molecule known as a Phospholipid. Amphipathic molecules are those that exhibit the unique characteristic of having *both* hydrophilic (water-loving) and hydrophobic (water-fearing) parts. Below you can see the parts of a phospholipid:

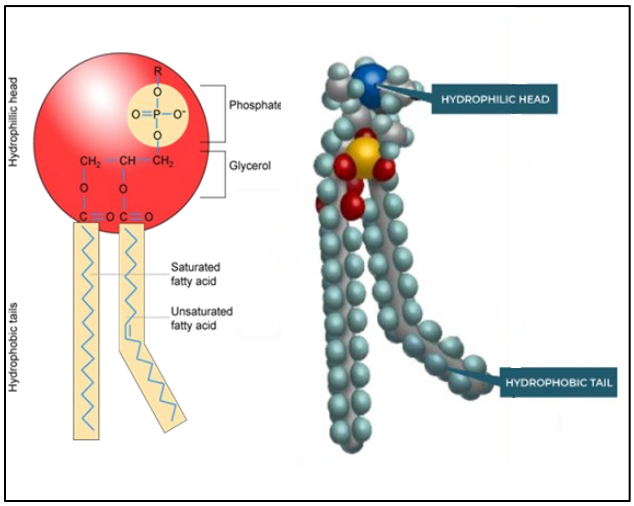

Figure 1.0. Structural and Space-filling Model of a Phospholipid
The left model shows the structural formula of the molecule. You can see the individual elements and their arrangement and how they contribute to the shape of the molecule. The right image shows how the molecule occupies space.
Source: https://bio.libretexts.org and http://www.ebiody.com

This unique structure allows the plasma membrane to adopt a bilayer structure wherein the hydrophilic surface is facing both the aqueous external environment and cytosol. Additionally, because of its hydrophobic properties the tails form an internal layer. These factors cause the plasma membrane to be semi-permeable to certain substances.

A.2. Structures of the Membrane

The plasma membrane is represented using a model known as the fluid mosaic. Its name is derived from the diverse proteins and other macromolecules embedded within the membrane, which causes the membrane to appear like a mosaic. The embedded macromolecules are able to move along and across the membrane regularly, which is why it is referred to as "fluid."

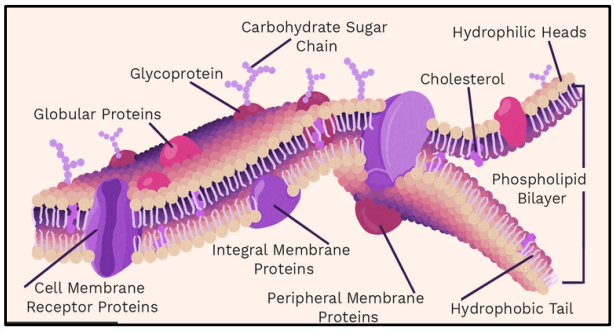

Figure 1.1. *Plasma Membrane Components*
The model shows how the components of the plasma membrane are placed in relation to each other.
Source: https://www.thoughtco.com/

The structures, which can either be found superficially attached to the outside layer of the membrane (peripheral) or found embedded within the bilayer (integral), have specific functions in the plasma membrane. These components can be divided into three (3) categories based on their function:

- **Transmembrane Proteins**

  These are proteins that regulate the movement of molecules across the membrane. These proteins form the transport mechanisms of the cell. They are composed of carriers, channels, and receptor proteins.

- **Interior protein network**
  Determines and maintains the structure and form of the plasma membrane. They are responsible for the shape of the cell and the attachment of macromolecules in the membrane. Spectrins and Clathrins fall under these categories.

- **Cell-surface markers**
  These are responsible for the recognition of foreign and local (self) cells and tissues. These markers are crucial for histocompatibility of the immune system. The markers responsible are glycoproteins and glycolipids.

A.3 Proteins and Protein Complexes

The diverse composition of a cell's plasma membrane aids its function as a selectively permeable barrier, determine the overall shape of the cell, and also ensure the stability and fluidity of the membrane. One (1) of the most crucial molecules in the plasma membrane are proteins. Proteins and protein complexes are responsible for the majority of internal and external interactions. There are six (6) classes of membrane proteins, and each serves a specific function:

- **Transporters (channels/carriers)**

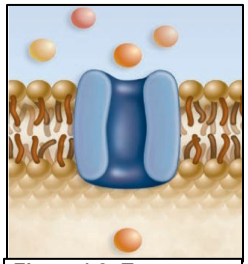

Figure 1.2. *Transporter*
Source: *Biology, 2017.*

These proteins are responsible for the movement of molecules/solutes across the membrane. Channels and carries may come in the form as open channels that is selective to a particular molecule, or as a carrier that shuttles the molecule across by changing its shape.

- **Enzymes**

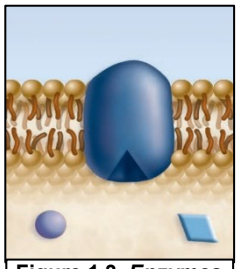

Figure 1.3. *Enzymes*
Source: *Biology, 2017.*

Chemical reactions needed by the cell for metabolic functions require specialized proteins called enzymes. Some enzymes have active sites exposed to the environment to react with substances which eventually elicit a chemical reaction in the cell. Other enzymes may line together as a team that reacts in a sequential pattern; these teams of enzymes form metabolic pathways in the cell.

- **Cell-surface receptors**

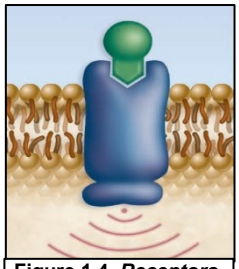

Figure 1.4. *Receptors*
Source: *Biology, 2017.*

Detects chemical messages from the environment to elicit reactions. The messages come as molecules and attach to the binding site shaped specifically for the signal. The signaling molecule may cause the protein receptor to change shape in order to relay the message inside the cell.

- **Cell-surface identity markers**

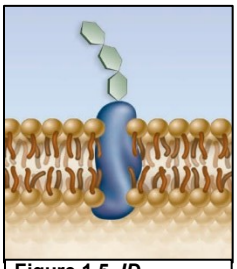

Figure 1.5. *ID Markers*
Source: *Biology, 2017.*

Identity markers are combinations of surface proteins and protein complexes (e.g., glycoproteins) that specify the type and origin of the cell. These markers bind to each other for recognition purposes. Interactions are usually short.

- **Cell-to-cell adhesion proteins**

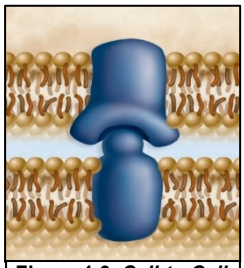

Figure 1.6. *Cell-to-Cell*
Source: *Biology, 2017.*

These are the bonds and junctions between cells. Bonds may be permanent or temporary depending on the location, function, and type of cells being connected. *These junctions were briefly described in the previous handout (e.g. gap junction, tight junctions).*

- **Attachment to the Cytoskeleton**

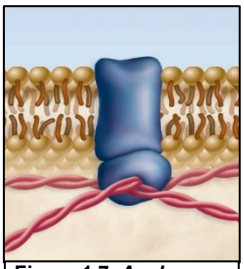

Figure 1.7. *Anchors*
Source: *Biology, 2017.*

These are responsible for anchoring other surface proteins to the cytoskeleton and extracellular matrix. Proteins attach to microfilaments non-covalently to maintain shape, stability, and coordinate chemical/mechanical changes.

B. TRANSPORT MECHANISMS

- Molecules and solutes constantly pass through the cell as chemical reactions occur (e.g., respiration requires oxygen to enter cells and carbon dioxide to move out).
- Transport mechanisms allow the cell to regulate what solutes enter/exit the cell and the quantity being transported.
- The type and number of transport mechanisms present vary depending on the type of cell. For example, cells in the small intestine require numerous transport mechanisms that are able to move macromolecules, such as glucose across the membrane. Meanwhile, these types of transport mechanism may appear in fewer quantities in cells that line the lungs.
- Transport mechanisms are broadly categorized into three (3) types. Each category has subcategories depending on the characteristic of the protein and the solute being transported.

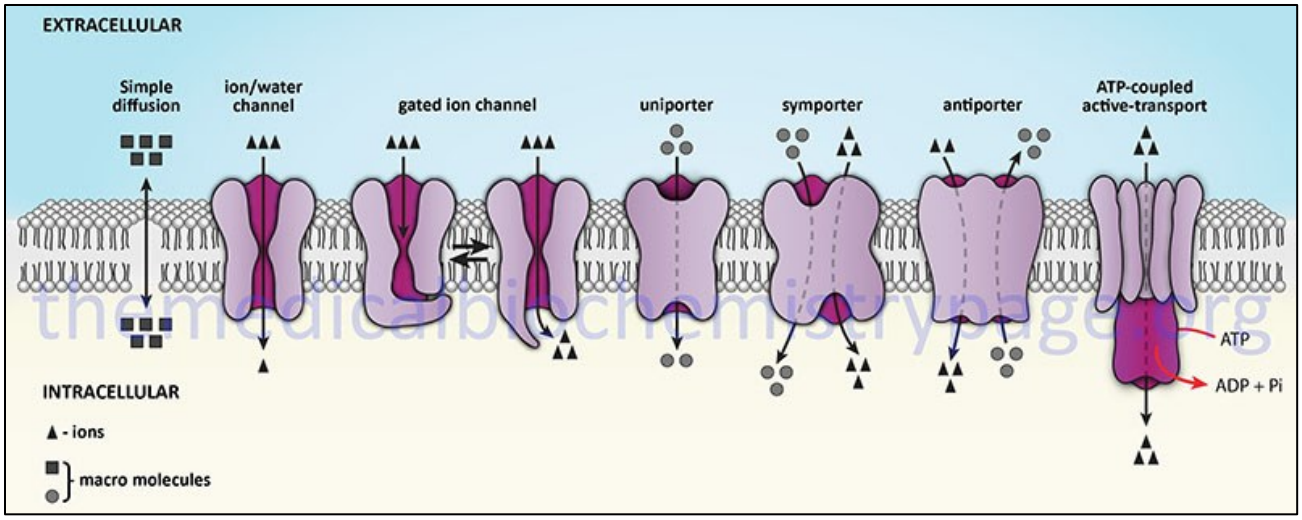

Figure 2.0. ***Transport Mechanisms***
Visualization of the transport mechanisms present in cells. The images show passive and active transport. Active transport is often used to transport large, polar, molecules across the membrane since they would not be able to pass through the membrane alone.
Source: *https://themedicalbiochemistrypage.org*

B.1 Passive Transport

This type of transport relies on the concentration gradient of solutes to move them across the plasma membrane. No energy will be spent to move the solutes across. Passive transport can be further subdivided into the following categories:

- **Simple Diffusion**

  The movement of ions and molecules from high concentrations to low concentrations is known as diffusion. This applies to lipid soluble molecules and ions that can pass freely through the membrane. No proteins or energy is involved in this mechanism.

  Simple diffusion applies to small, non-polar molecules such as oxygen and hormones. Once the concentration gradient has been equalized, the molecules will still move however there will be no net change in their direction.

The principle of simple diffusion can be easily observed by adding a drop of dye in a glass of water.

Gases, hydrophobic molecules, and small polar molecules can pass through via simple diffusion. Large polar molecules and charged molecules are unable to pass via simple diffusion.

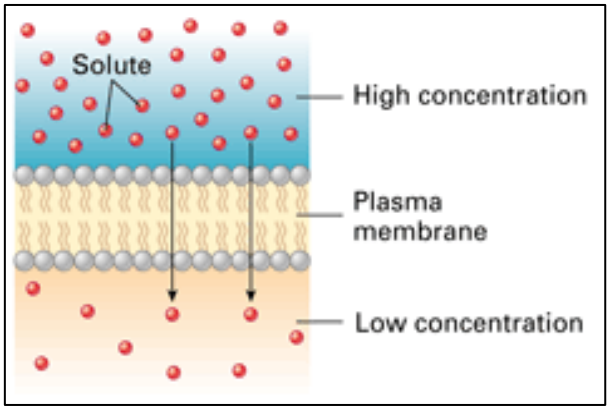

Figure 2.1. ***Simple Diffusion***
Solutes are able to pass through the plasma membrane if they are small and non-polar (oxygen). Small polar molecules such as ethanol will also be able to pass through the membrane but with slightly lower rates than small non-polar molecules. For large, water-soluble, polar molecules such as glucose, movement via diffusion is not possible. The same goes for charged molecules.
Source: http://bodell.mtchs.org

- **Facilitated Diffusion**

  Some small molecules may still be unable to pass due to their charge. These small, charged molecules, such as K^+, are repelled by the interior non-polar tails of the plasma membrane. To combat this, integral proteins (specifically called ion channels) that are lined with hydrophilic molecules inside aid the charged ions to move across. Proteins manage and assist the movement of solutes across the membrane, which is why this is referred to as facilitated diffusion.

  Channel vs. Carrier Proteins

  As mentioned earlier, facilitated diffusion makes use of either channel proteins or carrier proteins.

  Channel proteins provide a small, hydrophilic passageway for specific molecules and ions. Some channels can remain open most of the time (leak channels), while others can be opened or closed depending on the presence of a stimulus (something that triggers a reaction in the cell). The latter is referred to as gated channels and can react to a chemical or electrical stimulus.

  Carrier proteins, on the other hand, require the molecule being transported to attach itself to the carrier protein. The protein will then change its shape (conformational change) to shuttle the molecule across the membrane; such a change may be triggered by the attachment or release of a molecule. The rate by which carrier proteins transport molecules is different from the rate of simple diffusion. In simple diffusion, so long as the concentration is high on one (1) end the rate of diffusion will also increase. However, in carrier proteins rate of transport will depend on how many carriers are available. Even if the concentration increases on one (1) side, it will not affect the rate of attachment and transport of molecules. This event is known as saturation.

  Facilitated diffusion still falls under passive transport because it does not require the cell to expend energy, rather it requires three (3) conditions to be met: (a) there should be a concentration gradient on either side of the membrane; (b) the channel must be open or a carrier must be available; and (c) there must be a stimulus (whether chemical or electric) to open a channel.

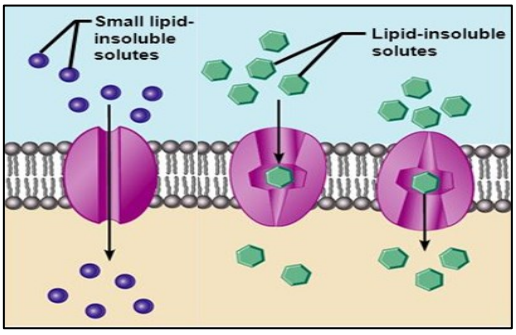

Figure 2.2. Facilitated Diffusion
Facilitated diffusion allows charged ions to pass through the plasma membrane via ion channels. Large, polar molecules are also able to pass through via carrier proteins. Though these channels are able to transport polar molecules across, they still require a concentration gradient to determine the direction of the movement. By following the concentration gradient, the cell does not expend energy, and this is therefore classified as passive transport.
Source: *Pearson Education, Benjamin Cummings 2007*

- **Osmosis**

  The cytoplasm and external environment of a cell is a mixture of ions and molecules which are dissolved in water forming an aqueous solution. Water is the solvent, while the molecules and ions are the solutes. Osmosis is the movement of water from high concentration of solutes to low concentration across membranes. This movement is influenced by the presence of solutes and their ability to pass through the membrane.

  Water molecules interact with solutes by bonding with them and creating a hydrogen shell. If a solute cannot freely pass through a membrane, the bonded water molecules are no longer considered as free and cannot pass through as well. Due to the concentration of solutes on one (1) side of the membrane, there is now a concentration gradient among the free water molecules. This causes water to move in the direction of the solutes until the number of free water molecules is equal, known as osmotic balance.

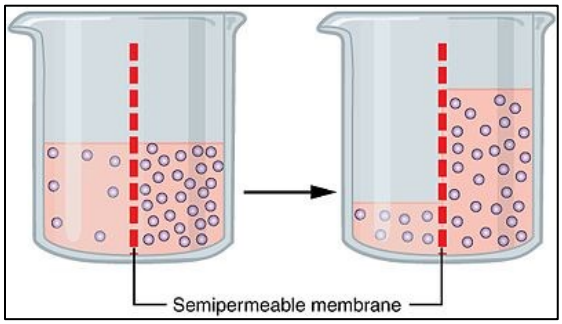

Figure 2.3. ***How Osmosis Works***
If solutes cannot move across the membrane to be diffused, water moves to dilute it and equalize the concentration gradient. Though the left side of the beaker has less water, the concentration of solutes is the same on both sides.
Source: http://www.trunity.net

Tonicity

In cells, the difference in osmotic concentration which leads to the movement of water is known as tonicity. The solution which has a higher concentration of solutes is described as hypertonic, while the solution with low concentration of solutes is hypotonic. If there is no difference in osmotic concentration, then both solutions are described as isotonic.

Hypertonicity: If animal cells were placed in hypertonic solutions, the water inside the cell would rush out to try and balance the concentration gradient. This causes the cells to shrivel and "dry."

Hypotonicity: If animal cells were placed in hypotonic solutions, the concentration gradient formed by the solutes inside the cell would cause water from the environment to rush inside. This causes the cell to swell and eventually burts, or lyse.

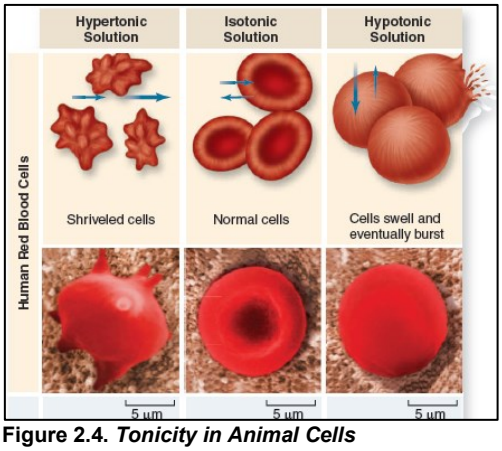

Figure 2.4. ***Tonicity in Animal Cells***
Source: *Biology, 2017.*

Plant cells are affected differently with tonicity. Since the inside of the cell is naturally hypertonic due to the large

amounts of solutes located in the central vacuole, constant osmotic pressure is being exerted onto the plasma membrane causing it to be pushed firmly against the cell wall. This internal pressure is known as turgor pressure and provides plant cells their normal turgid appearance.

If plants are not placed in hypotonic solutions, they will not appear as turgid. If placed in an isotonic solution, the lowered turgor pressure causes the plant to appear flaccid. However, if placed in a hypertonic solution, the plasma membrane shrinks away from the cell wall.

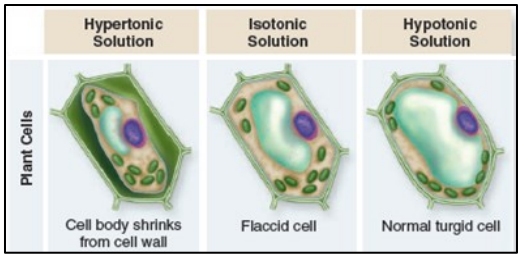

Figure 2.5. ***Tonicity in Animal Cells***
Source: *Biology, 2017.*

Aquaporins

Water is an example of a polar molecule that is able to cross the plasma membrane in small quantities. However, since our cells are suspended in an aqueous environment, it is expected that water should be able to pass through the cell freely. This is facilitated by specialized protein channels known as aquaporins. These channels allow water molecules to move across the membrane in large quantities.

B.2 Active Transport

This type of transport mechanism relies on the expense of cell energy, Adenosine triphosphate (ATP). This expenditure is needed to move molecules *against* their concentration gradient to maintain internal conditions. The most common example of active transport is the Sodium-Potassium pump. Active transport makes use of protein transporters similar to facilitated diffusion in the sense that the molecule needs to bind with the protein receptor via the active site. Active transport proteins can vary in their direction of transport and where they get their energy.

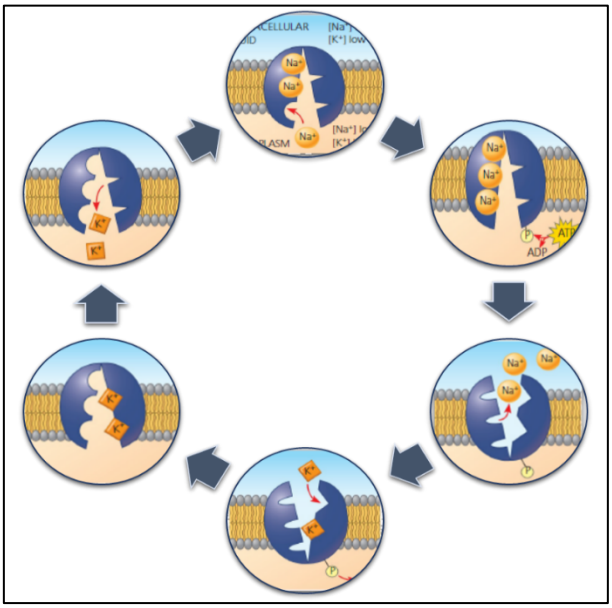

Figure 2.6. ***The Sodium-Potassium Pump***

Three (3) Na^+ ions from inside the cell attach to a carrier protein which has an affinity to the shape of the molecule. It is then stimulated by phosphorylation of ATP (the last phosphate tail is broken off ATP and attaches itself to the protein; this transfer releases large amounts of energy to power the mechanism). As the protein undergoes conformational change to transport sodium outside the cell, two (2) potassium ions attach to the new shape of the active site. As the energy from the attached phosphate is lost, the protein reverts to its original shape, thereby transporting the potassium ions inside the cell.
Source: *(Reece, et al., 2014)*

Active Transport According to Energy

- **Primary Active Transport**
  Primary active transport is an intentional and uphill mode of transport where a transport protein directly uses energy from ATP phosphorylation. An example of this would be the transport of sodium ions from inside the cell to the outside.

- **Secondary Active Transport**
  This is usually seen as the aftermath of primary active transport. A molecule is transported due to the difference in energy from the phosphorylation of energy – it does **not** use the energy directly. An example of this would be the transport of potassium ions from outside the cell to inside as the protein reverts its shape due to the loss of the phosphate group.

Active Transport According to Direction

- **Coupled/Co-transport**
  This method of transport is when one (1) protein shuttles two (2) different molecules across the membrane in the same direction. Most often, the movement is initiated by one (1) of the molecules, and the second molecule simply attaches to the same transport protein and joins the movement. Both molecules must have an affinity for the transport protein, which is now referred to as a symporter.

- **Counter-transport**
  This method of transport occurs when one (1) transporter moves two (2) different molecules across the membrane in different directions. Counter-transport is often a combination of primary and secondary active transport (as seen in the sodium-potassium pump). Movement may be simultaneous (both molecules may move at the same time) or in sequence (one (1) molecule is transported first, then the next one (1) follows after). Both molecules must have an affinity for the transport protein, which is now referred to as an antiporter. A protein may transport a single molecule against its concentration gradient. In this case, the protein is referred to as a uniporter regardless of the direction it moves the molecule.

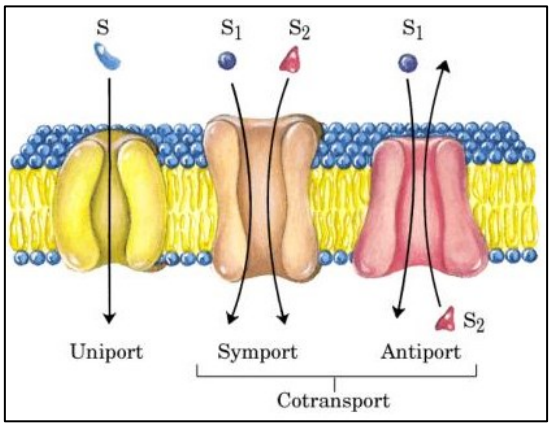

Figure 2.7. ***Active Transport According to Direction***
Source: biochem.arizona.edu

B.3 Bulk or Vascular Transport

Bulk transport refers to the movement of large molecules or quantities of substances into or out of the cell through vesicles. This process requires energy (ATP) and is essential for transporting macromolecules,

fluids, and particles that cannot pass through transport proteins or lipid membranes.

Bulk transport mechanisms are divided into two main types: Endocytosis and Exocytosis.

Endocytosis

This is the process by which cells engulf external substances by enclosing them in a portion of the plasma membrane, which then pinches off to form an internal vesicle.

There are three types of endocytosis:

a. **Pinocytosis** – Known as "cell drinking." The cell engulfs extracellular fluid and dissolved solutes into small vesicles. This is a non-specific process, meaning the cell takes in whatever is in the surrounding fluid.

b. **Phagocytosis** – Known as "cell eating." The cell engulfs large particles such as debris, foreign substances, or microorganisms. A phagosome forms and later fuses with a lysosome for digestion. This process is common in immune cells like macrophages.

c. **Receptor-mediated endocytosis** – This is a highly specific process where cells use receptor proteins on the plasma membrane to capture specific target molecules (ligands). Once bound, the membrane forms a vesicle containing the ligand-receptor complex.

d. **Exocytosis**

Exocytosis is the process by which cells expel materials in vesicles that fuse with the plasma membrane. This is commonly used to secrete hormones, enzymes, or waste materials. The vesicle membrane becomes part of the plasma membrane, maintaining membrane integrity.

DEFINITIONS BOX

Plasma Membrane	Hydrophilic
Hydrophobic	Fluid-mosaic
Transmembrane	Carriers
Channels	Transporter
Receptor	Solute
Passive Transport	Active Transport
Facilitated Diffusion	Diffusion
Concentration Gradient	ATP
Gated Channels	Conformation
Osmosis	Tonicity
Aquaporin	Symporter
Antiporter	Uniporter

References

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