

Biology for Engineers
BIO 2101

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1 Structure of the Plasma Membrane

1.1 Hydrophilic and Hydrophobic Regions

The plasma membrane consists of a phospholipid bilayer with distinct hydrophilic (water-loving) and hydrophobic (water-fearing) regions. The hydrophilic heads of the phospholipids face the aqueous environment both inside and outside the cell, while the hydrophobic tails are oriented inward, shielded from water.

1.2 Fluid Mosaic Model

This model depicts the plasma membrane as a dynamic and fluid structure with a mosaic of various proteins embedded within the lipid bilayer. The proteins are not static but rather move and interact within the membrane.

1.3 Amphipathic Phospholipids

Phospholipids, the primary components of the membrane, are amphipathic molecules, meaning they have both hydrophilic and hydrophobic regions. This dual nature allows them to form the bilayer structure, with the hydrophilic heads facing the aqueous environments and the hydrophobic tails shielded in the interior.

2 Membrane Models

2.1 Davson-Danielli Sandwich Model

Initially proposed that the membrane consisted of a phospholipid bilayer sandwiched between two layers of protein. However, this model was later disproven by experimental evidence.

2.2 Fluid Mosaic Model

This prevailing model suggests that the membrane is more fluid and dynamic, with proteins dispersed throughout the lipid bilayer. Freeze-fracture studies supported this model by revealing the presence of membrane proteins embedded within the phospholipid bilayer.

3 Movement within the Membrane

3.1 Lateral Movement of Phospholipids

Phospholipids can move laterally within the bilayer, allowing for flexibility and adaptation of the membrane structure. This lateral movement occurs at a rapid rate, with phospholipids moving approximately 10^7 times per second.

3.2 Movement of Proteins

Membrane proteins can also drift within the lipid bilayer, albeit at a slower rate compared to phospholipids. Experiments demonstrating the mixing of membrane proteins from different cells suggest that proteins are not fixed in one location but rather have some degree of mobility.

4 Factors Affecting Membrane Fluidity

4.1 Hydrocarbon Tail Composition

The composition of the hydrocarbon tails of phospholipids influences membrane fluidity. Phospholipids with unsaturated hydrocarbon tails, which contain double bonds and kinks, confer greater fluidity to the membrane compared to those with saturated tails.

4.2 Temperature

Temperature also affects membrane fluidity, with higher temperatures increasing fluidity by promoting greater motion of phospholipids and proteins.

5 Functions of Membrane Proteins

5.1 Transport

Membrane proteins facilitate the transport of ions, molecules, and nutrients across the membrane through channels or carrier proteins.

5.2 Enzymatic Activity

Some membrane proteins act as enzymes, catalyzing specific chemical reactions at the cell surface.

5.3 Signal Transduction

Receptor proteins on the membrane transmit signals from the extracellular environment to the interior of the cell, initiating cellular responses.

5.4 Cell-Cell Recognition

Glycoproteins on the cell surface serve as identification tags, allowing cells to recognize and interact with each other.

5.5 Intercellular Joining

Membrane proteins mediate the formation of cell junctions, such as gap junctions and tight junctions, which connect adjacent cells.

5.6 Attachment to Cytoskeleton

Membrane proteins anchor the cytoskeleton to the plasma membrane, providing structural support and stability to the cell.

6 Permeability of the Lipid Bilayer

6.1 Selective Permeability

The lipid bilayer selectively allows certain molecules to pass through while restricting the passage of others. Lipid-soluble molecules and small, nonpolar molecules can diffuse freely across the membrane, whereas polar molecules and ions require specific transport mechanisms.

7 Passive Transport

7.1 Diffusion

The passive movement of molecules from an area of higher concentration to an area of lower concentration, driven by the concentration gradient. This process allows small, nonpolar molecules like oxygen and carbon dioxide to diffuse directly through the lipid bilayer.

7.2 Osmosis

The passive diffusion of water across a selectively permeable membrane, from an area of lower solute concentration to an area of higher solute concentration, or from higher free water concentration to lower free water concentration.

7.3 Facilitated Diffusion

The passive movement of molecules across the membrane facilitated by transport proteins, such as channel proteins and carrier proteins, which provide specific pathways for molecules to cross the membrane.

8 Active Transport

8.1 Requires Energy

Active transport mechanisms utilize energy, typically in the form of ATP, to move molecules against their concentration gradient, from areas of lower concentration to areas of higher concentration. This process allows cells to maintain concentration gradients and perform vital functions such as nutrient uptake and ion transport.

8.2 Examples

The sodium-potassium pump is a prominent example of active transport, which actively transports sodium ions out of the cell and potassium ions into the cell against their respective concentration gradients.

9 Endocytosis and Exocytosis

9.1 Phagocytosis

The process by which cells engulf large particles or pathogens by forming vesicles called phagosomes. Specialized cells, such as macrophages, utilize phagocytosis to engulf and digest foreign invaders.

9.2 Pinocytosis

Also known as 'cell drinking' pinocytosis involves the nonspecific uptake of extracellular fluid and dissolved solutes into vesicles called pinosomes.

9.3 Receptor-Mediated Endocytosis

A highly specific form of endocytosis in which extracellular molecules bind to specific receptor proteins on the cell surface, triggering the formation of coated vesicles that transport the ligand-receptor complexes into the cell.

10 Factors Affecting Transport

10.1 Chemical Gradient

The concentration gradient of a solute determines the direction of passive transport, with molecules moving from areas of higher concentration to areas of lower concentration.

10.2 Electrical Force

The movement of ions across the membrane is influenced by electrical gradients, with positively charged ions attracted to regions of negative charge and vice versa.

10.3 Rate of Transport

The rate of transport across the membrane depends on factors such as the steepness of the concentration gradient, the permeability of the membrane to the solute, and the presence of charges on the solute molecules.

11 Summary of Passive and Active Transport

11.1 Passive Transport

Involves the movement of molecules down their concentration gradient without the expenditure of energy by the cell. Diffusion, osmosis, and facilitated diffusion are examples of passive transport mechanisms.

11.2 Active Transport

Requires the input of energy, typically in the form of ATP, to move molecules against their concentration gradient. Active transport mechanisms include the sodium-potassium pump and other ATP-driven pumps.

12 Bioelectric Potentials and Membrane Potential

12.1 Bioelectric Potentials

12.1.1 Definition

Bioelectric potentials are intricate ionic voltages that arise from the electrochemical activity within specialized cells throughout the body.

12.1.2 Associated Activities

These potentials orchestrate a symphony of physiological activities, ranging from the transmission of nerve impulses to the rhythm of the heart, the complexity of brain function, and the intricacies of muscle contractions.

12.2 Membrane Potential

12.2.1 Electrical Neutrality

Despite the intricate dance of bioelectric potentials, the body maintains an overarching state of electrical neutrality.

12.2.2 Membrane Potential

Within each cell, there exists a delicate balance of electrical forces, manifesting as a membrane potential—a voltage disparity across the cellular membrane.

12.2.3 Ion Concentration Gradient

This delicate equilibrium arises from the unequal distribution of ions, particularly sodium (Na^+), potassium (K^+), and chloride (Cl^-), between the inner and outer realms of the cell.

12.3 Ionic Composition of Body Fluids

12.3.1 Conductive Body Fluids

Enveloping cells lie conductive fluids teeming with ions, each playing its part in the symphony of cellular function.

12.3.2 Membrane Permeability

Remarkably, certain cells, particularly excitable ones, selectively allow the passage of potassium and chloride ions while staunchly guarding against the ingress of sodium ions.

12.3.3 Equilibrium Potential

This selective barrier establishes an equilibrium, maintaining a negative charge within the cell and a positive charge without.

12.4 Nernst Equation

12.4.1 Equilibrium Potential

Delving into the molecular intricacies, the equilibrium potential emerges—a delicate balance where ion movements reach equilibrium.

12.4.2 Calculation

Through the wizardry of the Nernst equation, one can compute the equilibrium potential for any ion based on its concentration gradient and charge.

12.4.3 Simplified Form

At the ambient temperature of our earthly abode, the equation condenses into a more palatable form, offering insights into the electrochemical balance.

12.5 Resting Membrane Potential

12.5.1 Equilibrium Reached

At rest, cells find themselves in a state of equilibrium, their membrane potential steadfastly maintaining until perturbed.

12.5.2 Polarization

This tranquil state is characterized by polarization—a negative charge ensconced within, juxtaposed with a positive exterior.

12.6 Action Potential

12.6.1 Initiation

When the stage is set for excitement, sodium ions eagerly rush in, disrupting the delicate equilibrium and ushering in a state of excitement.

12.6.2 Depolarization

The influx of sodium heralds depolarization, as the cell membrane sheds its negative cloak and embraces a transient positivity—an event known as the action potential.

12.6.3 Repolarization

Yet, balance must be restored, and so potassium ions exit the stage, bringing the curtain down on depolarization and restoring the negative charge within—a process known as repolarization.

12.6.4 Hyperpolarization & Refractory Period

Briefly, the stage darkens as hyperpolarization takes hold, rendering the cell refractory to further excitement.

12.7 Properties of Action Potentials

12.7.1 All-or-None

Action potentials unfold in a binary fashion—either all or none—initiated by a threshold voltage and characterized by a constant amplitude and velocity of propagation.

12.7.2 Threshold

It is this threshold that marks the beginning of the electrical symphony, setting the stage for the intricate dance of ions and the rhythmic pulse of cellular life.