Cell Biology: Cell Membranes and Transmembrane Transport

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Detailed Study Guide

A. Plasma Membrane Structure and Properties

1. **Phospholipid Bilayer:**
- **Amphipathic Nature:** Explain why phospholipids spontaneously form a bilayer in an aqueous environment.
- **Polar Head:** Identify the component that makes the head polar and its interaction with water.
- **Nonpolar Tails:** Identify the component that makes the tails nonpolar and their interaction with water.
- **Hydrophilic vs. Hydrophobic:** Define these terms in the context of the phospholipid bilayer.
- **Fluidity:** Describe the movement of phospholipids within the bilayer (lateral movement vs. flip-flop) and the factors affecting membrane fluidity (saturated vs. unsaturated fatty acids, cholesterol).

1. **Fluid Mosaic Model:**
- Define the fluid mosaic model.
- Provide experimental evidence supporting the fluid mosaic model (e.g., cell fusion experiment).

1. **Membrane Proteins:**
- **General Characteristics:** Describe how proteins are incorporated into the membrane and their general properties (not chemically bonded to phospholipids, can move).
- **Categories of Membrane Proteins:Peripheral Proteins:** Location and association with the membrane.
- **Integral Proteins:** Location and association with the membrane (sticking partially or completely through).
- **Transmembrane Proteins:** A special type of integral protein that spans the entire membrane. Explain why transport proteins must be transmembrane.

- **Factors Maintaining Protein Position:** Explain how hydrophobic and hydrophilic amino acid regions keep proteins in place within the membrane.
- **Membrane Polarity:** Discuss the concept of membrane polarity (two sides being different) and evidence from freeze fracturing.

1. **Functions of Membrane Proteins:**

- **Transport:** Facilitating the movement of substances across the membrane.
- **Enzymatic Activity:** Catalyzing reactions while embedded in the membrane.
- **Signal Transduction:** Receiving and relaying chemical signals from outside to inside the cell. Differentiate how polar and non-polar signaling molecules interact with receptors.
- **Cell-to-Cell Recognition:** Identifying other cells, often involving glycoproteins (sugars attached to proteins).
- **Intercellular Joining:** Connecting adjacent cells (e.g., desmosomes).
- **Attachment to Cytoskeleton and Extracellular Matrix (ECM):** Anchoring the membrane and providing structural support.

1. **Membrane Synthesis and Recycling:**

- Describe the role of the Rough ER and Golgi apparatus in synthesizing and embedding proteins into the plasma membrane via vesicles.
- Explain the process of "upregulation" and "downregulation" of receptors.

B. Cellular Transport Mechanisms

1. **Three Major Categories of Transport Processes:**

- **Active Transport:** Requires additional energy; moves substances against their concentration gradient.
- **Passive Transport:** Energy is built into the system (gradient); does not require additional energy; moves substances down their concentration gradient.
- **Vesicular Transport:** Involves vesicles for bulk transport.

1. **Gradients:**

- **Definition:** A difference in measurements at two different places (e.g., pressure, electrical potential, concentration).
- **Energy Storage:** Explain how gradients represent a form of stored energy.

1. **Passive Transport (Diffusion):**

- **Definition of Diffusion:** Movement of particles from high to low concentration.
- **Brownian Motion:** Explain how random molecular movement leads to net directional movement.
- **Requirements for Diffusion:**Presence of a gradient.
- A way for the particle to get from point A to point B (permeability of the membrane).
- **Simple Diffusion:** Movement directly through the phospholipid bilayer. Identify the characteristics of particles that can undergo simple diffusion (small and non-polar).
- **Facilitated Diffusion:** Movement with the help of transport proteins (channels or carriers). Still passive (down the gradient).

1. **Special Case of Diffusion: Osmosis:**

- **Definition:** Diffusion of solvent (water in biological systems) across a selectively permeable membrane.
- **Two Requirements for Osmosis:**Movement of solvent, not solute.
- Movement through a selectively permeable membrane (permeable to solvent, impermeable to solute).
- **Direction of Water Movement:** Explain water movement relative to solute concentration (low solute to high solute) and water concentration (high water to low water).
- **Equilibrium:** How osmosis reaches equilibrium (equal water concentration or opposing forces like gravity).

1. **Tonicity (Describing the Environment):**

- **Definition:** Refers to the tendency for osmosis to occur through a cell membrane, always describing the *environment* surrounding the cell, not the cell itself.
- **Hypertonic Solution:**Definition (solute and water concentration relative to the cell).
- Effect on animal cells (crenation).
- Effect on plant cells (plasmolysis).
- **Hypotonic Solution:**Definition (solute and water concentration relative to the cell).
- Effect on animal cells (lysis).
- Effect on plant cells (turgid, ideal state).
- **Isotonic Solution:**Definition (solute and water concentration relative to the cell).
- Effect on animal cells (ideal state).
- Effect on plant cells (flaccid).

1. **Active Transport:**

- **Definition:** Moves substances against their concentration gradient; requires additional energy (e.g., ATP).
- **Role of Carrier Proteins (Pumps):** Explain why only carrier proteins (pumps) can perform active transport.
- **Primary Active Transport:**Directly uses an energy source (e.g., ATP) to power the pump.
- Example: Sodium-Potassium Exchange Pump (antiporter). Explain its function and energy expenditure.
- Example: Proton pump.
- **Secondary Active Transport (Cotransport):**Uses the energy stored in a pre-existing ion gradient (established by primary active transport) to move another substance against its gradient.
- No direct ATP expenditure for the secondary transport.
- Example: Sucrose-proton cotransporter (symporter). Explain how the proton gradient powers sucrose transport.
- **Types of Carrier Proteins:Uniporter:** Transports one type of particle.
- **Cotransporter:** Transports two different types of particles.
- **Symporter:** Moves two different things in the same direction.
- **Antiporter:** Moves two different things in opposite directions.

1. **Vesicular Transport:**

- **Exocytosis:** Outward bulk transport via vesicles.
- **Endocytosis:** Inward bulk transport via vesicles.

- **Phagocytosis:** "Cell eating" (ingestion of solid particles).
- **Pinocytosis:** "Cell drinking" (ingestion of liquid samples).
- **Receptor-Mediated Endocytosis:** Specific uptake of substances after binding to receptors, leading to vesicle formation.

II. Quiz

Instructions: Answer each question in 2-3 sentences.

1. Explain why phospholipids spontaneously form a bilayer in an aqueous environment without the involvement of living organisms.
2. Describe the key distinction between peripheral and integral membrane proteins regarding their association with the phospholipid bilayer.
3. What is the fluid mosaic model of the plasma membrane, and what experimental evidence supports this model?
4. Differentiate between simple diffusion and facilitated diffusion. What characteristic of a molecule would necessitate facilitated diffusion?
5. Define osmosis. What two specific conditions must be met for a diffusion process to be classified as osmosis?
6. A red blood cell is placed in a hypotonic solution. Describe what will happen to the cell and explain why, using the concept of water movement.
7. How do animal cells maintain proper membrane fluidity when temperatures drop, and what role do saturated fatty acids play in this adjustment?
8. Explain the concept of "signal transduction" in the context of membrane proteins. Why must receptors for polar signaling molecules be transmembrane proteins?
9. Describe the difference between primary active transport and secondary active transport, specifically focusing on their immediate energy sources.
10. Compare and contrast channel proteins and carrier proteins in terms of their mechanism of transport and whether they can perform active transport.

III. Answer Key

1. Phospholipids are amphipathic, meaning they have both a polar (hydrophilic) head and non-polar (hydrophobic) tails. In water, the polar heads arrange themselves to face the water, while the non-polar tails orient inwards, away from the water, spontaneously forming a bilayer to minimize unfavorable interactions.
2. Peripheral proteins are associated with only one surface (monolayer) of the phospholipid bilayer, attached to the heads. Integral proteins, on the other hand, penetrate at least partially into the hydrophobic interior of the bilayer, associating with the non-polar tails.
3. The fluid mosaic model describes the plasma membrane as a dynamic, fluid structure composed of a "mosaic" of proteins embedded within a flowing lipid bilayer. Experimental evidence, such as the cell fusion experiment where human and mouse cell

membrane proteins mixed after fusion, supports this model by demonstrating the lateral movement of membrane components.

4. Simple diffusion is the direct passage of small, non-polar molecules through the phospholipid bilayer down their concentration gradient. Facilitated diffusion also moves molecules down their gradient but requires the assistance of a transport protein (channel or carrier) because the molecules are either too large or too polar to pass directly.
5. Osmosis is the special case of diffusion involving the movement of solvent (water in biological systems) across a selectively permeable membrane. The two conditions are: (1) the substance moving must be the solvent, not a solute, and (2) the movement must occur across a selectively permeable membrane.
6. When a red blood cell is placed in a hypotonic solution, the external environment has a lower solute concentration (and thus higher water concentration) than the cell's interior. Water will move by osmosis from the hypotonic solution into the cell, causing the red blood cell to swell and eventually burst (lysis) due to the lack of a rigid cell wall.
7. When temperatures drop, membranes tend to become more solid and less fluid. Animal cells respond by incorporating more unsaturated fatty acids into their phospholipids. Unsaturated fatty acids have kinks in their tails, preventing tight packing and thereby increasing membrane fluidity to counteract the cold-induced tightening.
8. Signal transduction is the process where a signaling molecule binds to a receptor on the cell surface, causing a conformational change in the receptor that relays a message into the cell's interior without the signaling molecule entering. Receptors for polar signaling molecules must be transmembrane because polar molecules cannot cross the non-polar lipid bilayer, so the receptor needs an extracellular binding site and an intracellular domain to transmit the signal.
9. Primary active transport directly uses an energy source (most commonly ATP) to power a pump that moves substances against their gradient, establishing a concentration gradient. Secondary active transport, conversely, does not directly use ATP but instead harnesses the potential energy stored in an existing ion gradient (often created by primary active transport) to cotransport another substance against its own gradient.
10. Channel proteins form hollow tunnels through the membrane, allowing specific substances to pass through directly when open. Carrier proteins bind to the transported substance and undergo a conformational change to move it across the membrane. Channel proteins can only facilitate passive transport (diffusion), whereas carrier proteins can facilitate both passive transport (facilitated diffusion) and active transport (as pumps).

IV. Essay Format Questions

1. Discuss the "fluid mosaic model" of the plasma membrane, detailing its major components (phospholipids, proteins, cholesterol), their arrangement, and the dynamic nature implied by "fluid" and "mosaic." Provide an example of how the membrane's fluidity is biologically regulated and why this regulation is critical for cell function.

2. Compare and contrast the three major categories of cellular transport: passive transport, active transport, and vesicular transport. For each category, describe the driving force, the types of molecules transported, and specific examples, highlighting the role of the plasma membrane in each process.
3. Explain the concept of tonicity and its implications for animal and plant cells when placed in hypertonic, hypotonic, and isotonic environments. Be sure to define each term in relation to solute and water concentration, describe the resulting water movement, and explain the morphological changes (or lack thereof) in both cell types, using specific terminology where appropriate.
4. Detail the diverse functions of membrane-bound proteins beyond simple transport. Choose at least three distinct functions (e.g., enzymatic activity, signal transduction, cell-to-cell recognition, attachment) and for each, describe how the protein's structure and location within the membrane enable its specific role in cellular processes.
5. Describe the mechanisms of primary and secondary active transport, providing a specific biological example for each. Explain how energy is utilized (directly or indirectly) to move substances against their concentration gradients, and discuss the interdependence of these two processes in maintaining cellular homeostasis.

V. Glossary of Key Terms

- **Active Transport:** The movement of substances across a cell membrane against their concentration gradient, requiring the expenditure of additional cellular energy.
- **Amphipathic:** A molecule possessing both hydrophilic (water-loving) and hydrophobic (water-fearing) properties, such as a phospholipid.
- **Antiporter:** A type of cotransporter that moves two different substances across a membrane in opposite directions.
- **Aqueous Solution:** A solution in which water is the solvent.
- **Brownian Motion:** The random movement of particles suspended in a fluid (a liquid or a gas) resulting from their collision with the fast-moving atoms or molecules in the fluid.
- **Carrier Protein:** A type of transport protein that binds to a specific molecule and undergoes a conformational change to move the molecule across the membrane; can be involved in both passive and active transport.
- **Channel Protein:** A type of transport protein that forms a hydrophilic pore or tunnel through the membrane, allowing specific ions or small molecules to pass through; typically involved in facilitated diffusion.
- **Concentration Gradient:** A difference in the concentration of a substance between two regions.
- **Contractile Vacuole:** A specialized organelle in some freshwater protists that pumps excess water out of the cell, preventing lysis in a hypotonic environment.
- **Cotransporter:** A transport protein that simultaneously moves two different substances across a membrane.
- **Crenation:** The shriveling of an animal cell due to water loss when placed in a hypertonic solution.

- **Diffusion:** The passive movement of molecules from an area of higher concentration to an area of lower concentration.
- **Endocytosis:** The process by which a cell takes in substances from outside by engulfing them in a vesicle; inward vesicular transport.
- **Enzymatic Activity:** The function of membrane proteins that act as catalysts for biochemical reactions within or on the membrane.
- **Exocytosis:** The process by which a cell releases substances to the outside by fusing a vesicle with the plasma membrane; outward vesicular transport.
- **Facilitated Diffusion:** The passive movement of molecules across a cell membrane with the help of a transport protein, but still down their concentration gradient.
- **Fatty Acid Tails:** The long, nonpolar hydrocarbon chains that form the hydrophobic part of a phospholipid.
- **Flaccid:** The state of a plant cell in an isotonic environment, where the plasma membrane is not pressing against the cell wall, resulting in a limp appearance.
- **Fluid Mosaic Model:** The widely accepted model for the structure of the plasma membrane, depicting it as a fluid lipid bilayer with embedded and associated proteins.
- **Freeze Fracturing:** A technique used to split the phospholipid bilayer, revealing the internal structure and distribution of integral proteins within the membrane.
- **Gated Channel:** A channel protein that can be opened or closed in response to specific stimuli, controlling the passage of ions or molecules.
- **Gradients:** Differences in physical or chemical properties (e.g., concentration, pressure, electrical charge) across a space, representing stored potential energy.
- **Hydrocarbon:** An organic compound consisting entirely of hydrogen and carbon atoms, typically non-polar.
- **Hydrophilic:** "Water-loving"; describes substances that are attracted to and dissolve in water, often due to polarity.
- **Hydrophobic:** "Water-fearing"; describes substances that repel water and do not dissolve in it, typically non-polar.
- **Hypertonic Solution:** An external solution that has a higher solute concentration (and thus lower water concentration) than the cell's cytoplasm.
- **Hypotonic Solution:** An external solution that has a lower solute concentration (and thus higher water concentration) than the cell's cytoplasm.
- **Integral Proteins:** Membrane proteins that are embedded within the lipid bilayer, either partially or completely spanning it.
- **Intercellular Joining:** The function of membrane proteins that form connections or junctions between adjacent cells.
- **Isotonic Solution:** An external solution that has the same solute concentration (and thus water concentration) as the cell's cytoplasm.
- **Lian (Ligand):** A molecule that binds specifically to another larger molecule, often a protein, typically causing a conformational change in the larger molecule.
- **Lysis:** The bursting or rupture of a cell, typically an animal cell, due to excessive water intake in a hypotonic environment.
- **Monolayer:** A single layer of phospholipid molecules. The plasma membrane is a bilayer (two monolayers).

- **Non-Gated Channels:** Channel proteins that are always open, allowing continuous passage of specific substances.
- **Osmosis:** The diffusion of water (solvent) across a selectively permeable membrane from an area of higher water concentration (lower solute concentration) to an area of lower water concentration (higher solute concentration).
- **Passive Transport:** The movement of substances across a cell membrane down their concentration gradient, which does not require additional cellular energy beyond the inherent energy of the gradient.
- **Peripheral Proteins:** Membrane proteins that are loosely associated with the surface of the lipid bilayer, not embedded within it.
- **Phagocytosis:** A type of endocytosis where the cell engulfs large solid particles, often referred to as "cell eating."
- **Phospholipid:** A lipid molecule that is the main component of cell membranes, composed of a hydrophilic head (containing a phosphate group) and two hydrophobic fatty acid tails.
- **Pinocytosis:** A type of endocytosis where the cell takes in small amounts of extracellular fluid and dissolved solutes, often referred to as "cell drinking."
- **Plasma Membrane:** The selectively permeable outer boundary of a cell that separates its interior from the external environment.
- **Plasmolysis:** The process in plant cells where the plasma membrane pulls away from the cell wall due to water loss in a hypertonic environment, leading to wilting.
- **Polar Head:** The hydrophilic portion of a phospholipid, containing a phosphate group, that faces the aqueous environment.
- **Primary Active Transport:** Active transport where the energy (e.g., from ATP hydrolysis) is directly used to power the pump.
- **Proton Pump:** A type of primary active transport pump that actively transports hydrogen ions (protons) across a membrane, creating a proton gradient.
- **Receptor-Mediated Endocytosis:** A specific type of endocytosis where external substances bind to specific receptors on the cell surface, triggering the formation of a vesicle to internalize the substance.
- **Saturated Fatty Acid:** A fatty acid where all carbon-carbon bonds are single bonds, allowing for maximum hydrogen saturation and resulting in a straight, tightly packed structure.
- **Secondary Active Transport:** Active transport that indirectly uses energy by coupling the movement of one substance down its gradient (which was established by primary active transport) to the movement of another substance against its gradient.
- **Selectively Permeable Membrane:** A membrane that allows certain molecules or ions to pass through it by means of active or passive transport, but restricts others.
- **Signal Transduction:** The process by which a cell converts an external signal into a response within the cell, often involving a membrane receptor.
- **Simple Diffusion:** The passive movement of small, non-polar molecules directly across the lipid bilayer without the aid of transport proteins.
- **Solute:** A substance that is dissolved in a solvent to form a solution.

- **Solvent:** The substance in which a solute is dissolved to form a solution (e.g., water in biological systems).
- **Symporter:** A type of cotransporter that moves two different substances across a membrane in the same direction.
- **Tenicity (Tonicity):** A measure of the effective osmotic pressure gradient of water potential of two solutions separated by a partially permeable membrane; describes the *environment* relative to the cell.
- **Transmembrane Protein:** An integral protein that spans the entire width of the phospholipid bilayer, with parts exposed on both sides of the membrane.
- **Transport Proteins:** General term for membrane proteins that facilitate the movement of substances across the plasma membrane.
- **Turgid:** The state of a plant cell that is swollen and firm due to water uptake by osmosis in a hypotonic environment, where the plasma membrane presses against the cell wall.
- **Uniporter:** A transport protein that moves only one type of substance across a membrane at a time.
- **Unsaturated Fatty Acid:** A fatty acid that contains one or more carbon-carbon double bonds, causing kinks in the hydrocarbon chain and preventing tight packing, leading to increased fluidity.
- **Vesicular Transport:** The bulk transport of substances into or out of a cell through the formation or fusion of vesicles with the plasma membrane.