CHAPTER 6: MEMBRANES

CHAPTER SYNOPSIS

Phospholipids are the foundation of all known biological membranes. The characteristic lipid bilayer forms as a result of the interactions among nonpolar phospholipid tails, polar phospholipid heads, and the surrounding water. The nonpolar tails face inward toward each other while the polar heads face outward toward the water. The arrangement of the lipid bilayer is stable, yet fluid. The membranes of living organisms are assembled from four components. The lipid bilayer provides an impermeable flexible matrix in which the other components are arranged. Transmembrane proteins that float within the bilayer are channels through which various molecules pass. A supporting fiber network, anchored to the actin filament cytoskeleton, prevents these channels from moving.

All of the cell's activities are in one way or another tied to the membrane that separates its interior from the environment. Net diffusion occurs when the materials on one side of the membrane have a different concentration than the materials on the other side. Facilitated transport of materials is necessary to control the entrance and exit of particular molecules. Facilitated diffusion is a simple process that utilizes protein carriers that are specific to certain molecules. It is a passive process driven by the concentration of molecules on the inside and the outside of the membrane. Osmosis is a specialized form of diffusion associated specifically with the movement of water molecules. Many cells are isosmotic to the environment to avoid excessive inward or outward movement of water. Other cells must constantly export water from their interior to accommodate the natural inward movement. Most plant cells, on the other hand, are hyperosmotic with respect to their immediate environment. The resulting osmotic pressure within the cell pushes the cytoplasm against the cell wall and makes a plant cell rigid.

Large molecules enter the cell by endocytosis, a nonselective process. Endocytosis of particulate material is called phagocytosis while endocytosis of liquid material is called pinocytosis. Exocytosis is the reverse mechanism and is used by plants to construct the cell wall and by animals to secrete various internally produced chemicals. Receptor-mediated endocytosis is a complicated mechanism that involves the transport of materials via coated vesicles. Some molecules are transported into or out of the cell independent of concentration. This process requires the expenditure of energy in the form of ATP and is called active transport. Such transport channels are coupled to a sodium-potassium pump. The proton pump produces ATP through two special transmembrane protein channels through a process called chemiosmosis.

CHAPTER OBJECTIVES

- Understand the biochemistry of phospholipids and how they are organized into membranes.
- Know the function of each of the four components of a cell membrane.
- Differentiate among diffusion, facilitated transport, facilitated diffusion, osmosis, and active transport.
- Describe the six classes of membrane proteins and how each interacts with the membrane.
- Describe solution and solute movement into and out of a cell under hyperosmotic, hyposmotic, or isosmotic conditions.
- Explain and give examples of endocytosis, phagocytosis, pinocytosis, receptor-mediated endocytosis, and exocytosis.
- Understand the importance of selective permeability in biological systems.

- Describe the operation of the sodium-potassium pump and the proton pump.
- Understand the importance of coupled channels, cotransport, and countertransport.

KEY TERMS

active transport
aquaporin
aqueous solution
antiport
carrier (membrane)
chemiosmosis
cotransport
cotransport process
countertransport
diffusion
endocytosis
exocytosis
facilitated diffusion
fluid-mosaic model
hydrostatic pressure
hyperosmotic
hyposmotic
ion channel
isosmotic
lipid bilayer
osmosis
osmotic concentration
osmotic pressure
phospholipid
plasma membrane
proton pump
selective permeability
sodium-potassium pump
solute
solvent
symport
transmembrane protein
turgor pressure

CHAPTER OUTLINE

6.0 Introduction

I. CELLS INTERACT WITH THEIR ENVIRONMENT

A. Certain Materials Pass Through Membrane Passageways

B. Plasma Membrane Is Lipid Sheet with Embedded Proteins fig 6.1

6.1 Biological membranes are fluid layers of lipids

I. THE PHOSPHOLIPID BILAYER

A. Membrane's Lipid Layer Is Composed of Phospholipids fig 6.2

B. Phospholipids
1. Form the foundation of cell membranes
   a. Backbone is a three-carbon glycerol molecule
   b. Attach to three fatty acid chains in a fat molecule
   c. Attach to two fatty acid chains in a phospholipid molecule
   d. Phosphate group attaches a polar organic alcohol to the third carbon
2. One end of the molecule is strongly nonpolar and water insoluble
3. The other end is strongly polar and water soluble
4. Phospholipids are diagrammed as a polar head with two nonpolar tails fig 6.2b

C. Phospholipids Form Bilayer Sheets
1. Interactions between phospholipids and water
   a. Nonpolar tails are pushed away from water molecules
   b. Nonpolar tails cannot form hydrogen bonds with water
   c. Water molecules form bonds with each other excluding nonpolar tails
2. Spontaneously form a lipid bilayer fig 6.3
   a. Polar heads face water on either side
   b. Nonpolar tails face inward toward each other
3. Lipid bilayer sheets are the foundation of biological membranes
   a. Nonpolar interior repels water-soluble molecules
   b. Proteins in the lipid bilayer allow passage of polar molecules

II. THE LIPID BILAYER IS FLUID

A. Lipid Molecules Move within the Stable Bilayer
1. Hydrogen bonding of water holds lipid layer together
2. Phospholipids and unanchored proteins move freely within membrane fig 6.4

B. Fluidity of Membrane Depends on Alignment of Phospholipid Tails
1. Closely aligned tails create less fluid membranes
2. Less closely aligned tails create more fluid membranes
   a. Associated with double-bonded carbons in the tail chain fig 3.13b
   b. May contain short lipids that prevent contact between tails
3. Steroid lipids change fluidity with temperature

6.2 Proteins embedded within the plasma membrane determine its character

I. THE FLUID MOSAIC MODEL

A. Plasma Membrane Composed of Lipids and Globular Proteins
1. First thought a protein layer coated both surfaces of the lipid bilayer
2. Was the widely accepted Davson-Danielli model of 1935
3. Model not workable due to insolubility of membrane proteins
   a. Nonpolar proteins would separate polar portions of lipid from water
   b. Bilayer would then dissolve

B. Improved Model Inserted Proteins within Lipid Bilayer
1. Singer and Nicolson revision of 1972
2. Nonpolar segments of proteins in contact with nonpolar interior of bilayer
3. Polar portions protrude from membrane surface
4. Called the fluid mosaic model fig 6.5

C. Components of the Cell Membrane tbl 6.1
1. Lipid bilayer
   a. Other components distributed within foundation
   b. Provides a flexible matrix which is a barrier to permeability
2. Transmembrane proteins
   a. Move within the lipid bilayer, not located in fixed positions
   b. Provide passageways through which molecules and information pass
3. Network of supporting fibers
   a. Structurally supported by proteins like spectrin
   b. Connects membrane proteins to cell's actin filament cytoskeleton
   c. Control lateral motion of key membrane proteins
4. Exterior proteins and glycolipids
   a. Membranes assembled in the ER, transferred to the Golgi
   b. Golgi adds glycocalyx, chains of sugars, to membrane proteins and lipids
   c. Sugar molecules function as cell identity markers

II. EXAMINING CELL MEMBRANES

A. Viewing Thin Sections
1. Tissue placed in hard matrix like epoxy fig 6.6
2. Cut into thin sections with microtome
3. Shavings of epoxy and tissue placed on grid
4. Beam of electrons directed through sample on grid in TEM
5. Resolution good enough to show double layers of membrane

B. Viewing 3-D Surfaces
   1. Tissue is often freeze-fractured, produces crack between layers
   2. Structures associated with membrane stick to one side or other
   3. Membrane halves coated with electron-attracting metal forming a cast
   4. Cast examined under TEM

III. KINDS OF MEMBRANE PROTEINS

A. Advantages of Flexible Design of the Mosaic Model
   1. Broad range of interactions between membrane and environment
   2. Mostly associated with presence of proteins fig 6.7

B. Six Key Classes of Membrane Proteins
   1. Transporters
      a. Membrane selects what substances will enter
      b. Take up molecules present in high concentration
   2. Enzymes
      a. Chemical reactions carried out on interior surface of membrane
      b. Enzymes attached directly to membrane
   3. Cell surface receptors
      a. Membranes sensitive to chemical messages
      b. Receptor proteins on surface act as antennae
   4. Cell surface identity markers
      a. Markers on membrane identify cells to other cells
      b. Act as specific ID tags
   5. Cell adhesion proteins
      a. Cells use certain proteins to glue themselves to one another
      b. Some are detachable, others are permanent
   6. Attachments to the cytoskeleton
      a. Surface proteins may interact with other cells
      b. Often linked to cytoskeleton by proteins

IV. STRUCTURE OF MEMBRANE PROTEINS

A. Anchoring Proteins is the Bilayer
   1. Membrane proteins attached to external surface by anchoring substance
      a. Phospholipid molecule called phosphatidylinositol
      b. Proteins move about tethered to phospholipid
   2. Other proteins completely traverse bilayer
      a. Part of protein extends through bilayer
      b. May be nonpolar helix or β-pleated sheets of nonpolar amino acids fig 6.8
      c. Nonpolar portion held within interior of bilayer
      d. Polar ends protrude from both sides of membrane

B. Extending Proteins across the Bilayer
   1. Transmembrane proteins traverse bilayer in different ways
   2. Anchors
      a. Proteins attach spectrin of cytoplasm to membrane interior fig 6.9
      b. Receptors for extracellular signals are also single-pass anchors
      c. Portion of receptor that sticks outward binds with molecules
      d. Binding induces changes in part of protein on the inside
   3. Channels fig 6.10
      a. Proteins that wind back and forth through the membrane
      b. Locked into shape by several helical segments

c. Create a hole in the membrane like that in a donut
d. Example: Photosynthesis transmembrane protein
e. Forms crescent-shaped channel through membrane
f. Water-soluble molecules pass through these channels
g. Each channel admits only certain substances

4. Pores
   a. Non-polar β-pleated sheet transmembrane proteins
   b. Characteristic motif where sheets fold back over themselves
   c. Form a pore called a β-barrel
   d. Examples include porins of bacterial outer membranes fig 6.11

6.3 Passive transport across membranes moves down the concentration gradient

I. DIFFUSION

A. Molecules Dissolved in Water Are in Constant Random Motion
1. Process called diffusion fig 6.12
2. Causes net movement from higher to lower concentration
3. Equilibrium when there is uniform concentration

B. Facilitated Transport
1. Polar molecules cannot pass through nonpolar interior of phospholipid bilayer
   a. Pass through special channels in plasma membrane
   b. Inside of channel is polar, facilitates transport of polar molecules
   c. Each channel only allows passage of certain, selective material
2. Results in selective permeability

C. Diffusion of Ions through Channels
1. Ions move across membrane through channels
   a. Ions are solutes with unequal number of protons and electrons
   b. Cations are positive due to excess of protons
   c. Anions are negative with excess of electrons
2. Ions interact with polar molecules of water
3. Due to charge, ions are repelled by non-polar lipid bilayer interior
4. Ion channels have water-filled pore across membrane
   a. No interaction between channel and ion
   b. Net movement dependent on concentration and voltage

II. FACILITATED DIFFUSION fig 6.13

A. Carriers Transport Solutes Across the Membrane
1. Selective carriers allow passage of specific molecules in both directions
2. Facilitate movement with physical binding
3. Direction of net movement dependent on concentration gradient
4. Net movement from high concentration to low concentration

B. Facilitated Diffusion in Red Blood Cells
1. RBC carrier protein transports Cl^- one way, HCO_3^- the other way
2. RBC glucose transporter
   a. Adds phosphate to newly entering glucose
   b. As a charged molecule it cannot pass back out
   c. Not a channel, transport due to molecule shape change

C. Transport through Selective Channels Saturate
   1. Rate of movement can become saturated
      a. Increasing concentration affects movement only to a certain point
      b. When all carriers are occupied, diffusion reaches its limit
      c. Capacity of the transport system is at maximum
   2. Prevents buildup of unwanted materials
   3. Essential characteristics
      a. Specific to certain molecules with a given carrier
      b. Passive process driven by internal and external concentrations
      c. System may become saturated when all carriers are in use

III. OSMOSIS

A. Cytoplasm of Cell is an Aqueous Solution
   1. A mixture of water and molecules
   2. Solvent: Water, most common molecules in the solution
   3. Solute: Other molecules dissolved in the water

B. Molecules Diffuse down a Concentration Gradient
   1. Both water and molecules diffuse from regions of high to low concentration
   2. Membrane prevents equal motion of solvent and solute
      a. Many solutes cannot pass through biological membranes
      b. Example: Ions, sugars, materials that are not lipid soluble
   3. Highly polar water molecules cannot pass through lipid bilayer
      a. Water travels through aquaporins, specialized water channels
      b. Amphibian egg experiment
         1) Place egg in hypotonic spring water, does not swell
         2) Inject aquaporin mRNA into egg, channel proteins expressed, egg swells
   4. Dissolved solutes interact with water molecules
      a. Form hydration shells around charged solute
      b. Solutes move from high to low concentration when a gradient exists
      c. Hydration shells of water molecules move with ions
   5. If solutions separated by membrane
      a. Hydration shell water molecules move with diffusing ions
      b. Results in net water movement towards low solute
   6. Osmosis: Diffusion with net movement of water across a membrane fig 6.14
   7. Concentration of all solutes establishes osmotic concentration
      a. Solution with higher concentration is hyperosmotic
      b. Solution with lower concentration is hyposmotic
      c. Solutions with equal concentrations are isosmotic
   8. Cellular changes fig 6.15
      a. Shrinks (looses water) when hyposmotic to environment
      b. Swells (gains water) when hyperosmotic to environment

C. Osmotic Pressure
   1. Hydrostatic pressure of cytoplasm pushes against cell membrane
   2. Osmotic pressure: Force required to stop osmosis across membrane fig 6.16
   3. Equilibrium between osmotic concentration difference and pressure
      a. When pressure is too high most unsupported cells burst
      b. Cells with cell walls can withstand pressure and will not burst

D. Maintaining Osmotic Balance
   1. Many cells adjust to being hyperosmotic to environment
   2. Extrusion
      a. Example: Contractile vacuole of *Paramecium*
      b. Vacuole collects water, transports to point near cell surface
      c. Pore opens to outside
      d. Vacuole contracts and pumps water out of cell
   3. Isosmotic solutions
      a. Many cells adjust internal solute concentration to match environment
      b. Cells are isosmotic with environment
      c. Multicellular organisms similarly regulate composition of body fluids
      d. Terrestrial animals bathe cells in isosmotic solution
   4. Turgor
      a. Plant cells are hyperosmotic with respect to their immediate environment
      b. Possess a high solute concentration within the central vacuole
      c. Turgor pressure: Internal pressure of plant cells
      d. Pressure pushes cytoplasm against cell wall, causes rigidity

6.4 Bulk transport utilizes endocytosis

I. BULK PASSAGE INTO AND OUT OF THE CELL

A. Endocytosis fig 6.17
   1. Fuel for cells are large molecules that cannot cross the membrane
   2. Employ process that envelopes food particles with part of membrane
   3. Three types: Phagocytosis, pinocytosis, receptor-mediated endocytosis
   4. Phagocytosis and pinocytosis
      a. Phagocytosis: Material brought in is particulate
      b. Pinocytosis: Material is liquid, contains dissolved molecules
   5. Receptor-mediated endocytosis
      a. Associated with transport of specific macromolecules
      b. Indented pits in plasma membrane coated with clathrin fig 6.18
         1) Hook-like receptor molecule inside the pit
         2) Pit closes over when proper molecule enters
         3) Forms internal vesicle
      c. Trap released when particular target molecule is present
      d. Initiates endocytosis
      e. Process is highly specific, very fast
   6. Process through which low density lipoprotein (LDL) is taken up
      a. LDL molecules bring cholesterol into cell, incorporated into membranes
      b. Receptors lack tails in hypercholesteremia
      c. Receptors not caught in clathrin-coated pits
      d. Cholesterol remains in bloodstream, not taken up by cells
      e. Coats blood vessels, contributes to heart attacks
   7. Fluid-phase endocytosis is same process with fluids

B. Exocytosis
   1. Reverse of endocytosis
   2. Materials extruded from cell by discharge from surface vesicles fig 6.19
   3. Utilized by plants to construct cell wall
   4. Includes protist contractile vacuole discharge
   5. Used by animal cells to secrete chemical materials

6.5 Active transport across membranes is powered by energy from ATP

I. ACTIVE TRANSPORT

A. Diffusion, Facilitated Diffusion, and Osmosis Are Passive Processes

B. Transport of Molecules Can Occur Against Concentration Gradient
1. Expends energy
2. Involves highly selective protein carriers
3. Molecules moved may be ions, sugars, amino acids, or nucleotides fig 6.20
4. Enables cell to concentrate materials inside itself
5. Allows cell to export materials even if concentrated on outside

C. The Sodium-Potassium Pump
1. Cells maintain low internal concentration of sodium: Pump it out fig 6.21
2. Cells maintain high internal concentration of potassium: Pump it in
3. Energy provided by adenosine triphosphate (ATP)
4. Associated with conformational changes in transmembrane protein
   a. Step 1: Three molecules of Na^+ bind to cytoplasmic subunits
   b. Step 2: Complex binds, cleaves one ATP; ADP released, P*i* remains bound
   c. Step 3: Three Na^+ molecules move across channel and are released on outside
   d. Step 4: Complex binds two K^+ molecules
   e. Step 5: P*i* released,
   f. Step 6: Reverts to original conformation, disassociates K^+, released to the inside
5. Process removes three Na^+ and brings in two K^+

II. COUPLED TRANSPORT

A. Some Channels Indirectly Use ATP
1. Cotransport (also called coupled transport)
   a. Accumulate molecules against concentration gradient
   b. Moves molecules and Na^+ together
2. Composed of two components
   a. Establishing the down gradient uses ATP
   b. Traversing the up gradient through cotransport/coupled channels

B. Establishing the *Down* Gradient
1. The Sodium-potassium pump
   a. Actively pumps sodium ions out of cell, uses ATP
   b. Establishes gradient where sodium is lower inside cell
2. The proton pump
   a. Pumps protons (H^+) across membrane, expends energy
   b. Creates proton gradient with more H^+ on outside of membrane
   c. Diffusion drives protons back down concentration gradient
   d. Protons return by other channel

C. Traversing the *Up* Gradient
1. Accumulate amino acids and sugars against concentration gradient
2. Cotransport moves molecules and Na^+ together fig 6.22
   a. Na^+ and molecule both bind to symport transmembrane protein on outside of cell
   b. Both translocated to interior of cell
   c. Na^+ moves down its concentration gradient
   d. Molecule moves up its concentration gradient

3. Countertransport couples Na^+ movement with Ca^{++} or H^+
   a. Na^+ and molecule bind to same antiport transport protein
   b. Bind on opposite sides of membrane
   c. Na^+ moves down its gradient
   d. Molecule extruded up its concentration gradient
4. Down gradient from proton pump used in ATP production fig 6.23
   a. Cell expends energy to produce ATP, energy-storing molecule
   b. Process called chemiosmosis

D. Summarization of Mechanisms for Transport Across Membranes tbl 6.2

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

One could develop a lengthy comparison of a cell and its organelles to a community with respect to energy, transportation, communication, growth, and so forth.

Stress the fluidity of the plasma membrane and the regular replacement of its components to ensure constant integrity. It is as though one could remove a chipped brick from a house and replace it with a new one. A completely fluid house would have doors, windows, and walls that moved with respect to the current needs of the occupants and the appearance of the environment.

Membrane fluidity is related to the presence of saturated and unsaturated fatty acids in the phospholipid tails. Saturated fats are like books stacked tightly on a shelf. They can't readily be moved from shelf to shelf and are very rigidly organized. Warped books (unsaturated fats), on the other hand, can't be as closely packed. It is easier to get one's fingers between the books and move them around.

Do not be confused that a 3-D surface view of a membrane is viewed in a transmission electron microscope rather than a scanning one. The resolution of the TEM is far better (down to 2μ), but only a very thin section can be viewed, unlike the SEM which can be used to examine very thick specimens and even whole objects like protozoa, insects, leaves, and flowers. To examine cell membranes and still satisfy the thin layer requirement, it is the cast of the surface that is viewed under the TEM, not the cell surface itself — as would occur if one examined the coated surface of a cryofractured cell with the SEM.

Be careful to present hyposmotic/hyperosmotic as being relative to one another. A solution cannot simply be hyposmotic unless it is compared to another solution. A cell may be hyposmotic to its solution, but the solution is also hyperosmotic to the cell.

The types of movement of molecules through a membrane are more readily remembered when the students understand what the names mean. Simple diffusion is just that, nothing else assists it. Facilitated diffusion requires the presence of channels that aid in the passage of molecules. Active transport is like any active versus passive mechanism, it requires the expenditure of energy.

It is important that students begin to understand how ATP is generated as it will come up again (most notably in the next set of chapters regarding metabolism). Similarly, cell surface receptors and cell surface markers will be discussed in greater depth in a later chapter entitled The Immune System.

VISUAL RESOURCES:

Diffusion can be demonstrated by placing mothballs or perfume in one corner of the lecture hall before lecture begins. As time progresses, have students raise their hands (or colored flags) when they smell the odor.

Gortex® is a material that is unidirectionally permeable to water. It allows moisture to pass from the inside (of a jacket or tent) outward, but does not allow rain to penetrate inward.