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Leslie P. Gartner
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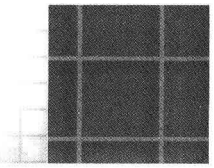

Preface

We were very pleased with the reception of the fourth edition of this book, as well as with the many favorable comments we received from students who used it in preparation for the USMLE Step 1 or as an outline and study guide for their histology and/or cell biology courses in professional schools or undergraduate colleges.

All of the chapters have been revised and updated to incorporate current information, and we have attempted to refine the content of the text to present National Board–driven material as succinctly as possible but still retain the emphasis on the relationship between cell structure and function through the vehicle of cell and molecular biology. A tremendous amount of material has been compressed into a concise but highly comprehensive presentation using some new and revised illustrations. The relevancy of cell biology and histology to clinical practice is illustrated by the presence of clinical considerations at the end of each chapter.

The greatest change that occurred in the evolution of this book from its previous edition is that we have provided references for each question, allowing the reader to return to the relevant section of the book to reinforce his or her grasp of the material there. We have also added 57 new images and relevant questions to the CD-ROM. The major impetus for the inclusion of the electronic medium continues to be the ability to present the student with color photomicrographs and with a number of additional USMLE Step 1–type questions without an exorbitant increase in the cost of the book. We believe that the included CD-ROM serves a very important purpose in preparing the student not only for the USMLE Step 1 but also for didactic and practical examinations in the histology and/or cell biology course.

As always, we welcome comments, suggestions, and constructive criticism of this book. These may be addressed to our editors at Lippincott Williams & Wilkins or directly to us by e-mail to lgartner@umaryland.edu.

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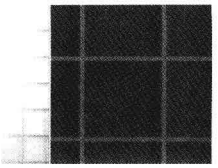

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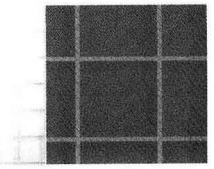

Contents

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CHAPTER 1

Plasma Membrane

I. Overview—The Plasma Membrane (plasmalemma; cell membrane)

A. Structure. The plasma membrane is approximately 7.5 nm thick and consists of a **lipid bilayer** and associated **proteins.**

1. The **inner leaflet** of the plasma membrane faces the cytoplasm, and the **outer leaflet** faces the extracellular environment.
2. The plasma membrane displays a trilaminar (**unit membrane**) structure that is evident when examined by transmission electron microscopy (TEM).

B. Function

1. The plasma membrane envelops the cell and maintains its structural and functional integrity.
2. It acts as a **semipermeable** membrane between the cytoplasm and the external environment.
3. It permits the cell to recognize macromolecules and other cells and to be recognized by other cells.
4. It participates in the transduction of extracellular signals into intracellular events.

II. Fluid Mosaic Model of the Plasma Membrane

A. The **lipid bilayer** (Fig. 1-1) is freely permeable to small, lipid-soluble, nonpolar molecules but is impermeable to ions.

1. ***Molecular structure.*** The lipid bilayer is composed of phospholipids, glycolipids, and cholesterol.
   a. ***Phospholipids*** are **amphipathic** molecules consisting of one polar (**hydrophilic**) head and two nonpolar (**hydrophobic**) fatty acyl tails.
   b. The two leaflets are not identical; instead the distribution of the various types of phospholipids is asymmetrical.
      (1) The **polar head** of each molecule faces the membrane surface, whereas the **tails** project into the interior of the membrane, facing each other.
      (2) The **tails** of the two leaflets form weak bonds that attach the two leaflets to each other.

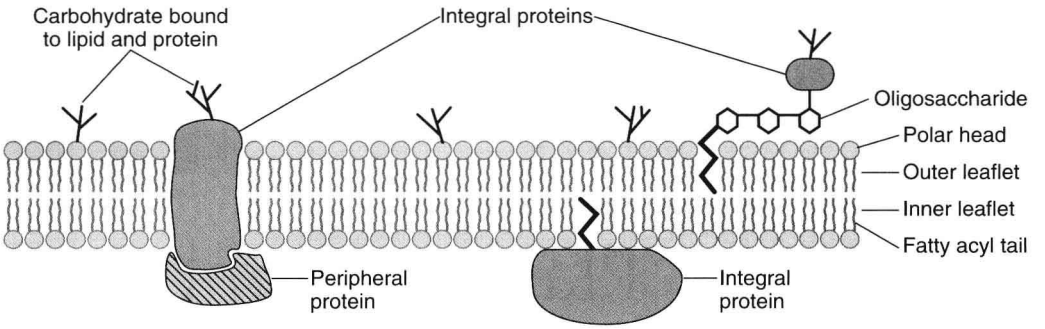

Figure 1-1 The plasma membrane showing the outer (*top*) and inner (*bottom*) leaflets of the unit membrane. The hydrophobic fatty acyl tails and the polar heads of the phospholipids constitute the lipid bilayer. Integral proteins are embedded in the lipid bilayer. Peripheral proteins are located primarily on the cytoplasmic aspect of the inner leaflet and are attached by noncovalent interactions to integral proteins.

c. ***Glycolipids*** are restricted to the extracellular aspect of the outer leaflet. **Polar carbohydrate residues** of glycolipids extend from the outer leaflet into the extracellular space and form part of the **glycocalyx.**
d. Cholesterol, constituting 2% of plasmalemma lipids, is present in both leaflets and helps maintain the structural integrity of the membrane.
e. Cholesterol and phospholipids can form microdomains, known as rafts, which can affect the movement of integral proteins of the plasmalemma.

2. ***Fluidity*** of the lipid bilayer is crucial to **exocytosis, endocytosis, membrane trafficking,** and **membrane biogenesis.**
   a. Fluidity **increases** with increased temperature and with decreased saturation of the fatty acyl tails.
   b. Fluidity **decreases** with an increase in the membrane's cholesterol content.

B. Membrane proteins (Fig. 1-1) include integral proteins and peripheral proteins and constitute approximately 50% of the plasma membrane composition.

1. ***Integral proteins*** are dissolved in the lipid bilayer.
   a. ***Transmembrane proteins*** span the entire thickness of the plasma membrane and function as membrane **receptors** and **transport proteins.**
      (1) Most transmembrane proteins are **glycoproteins.**
      (2) Transmembrane proteins are **amphipathic** and contain **hydrophilic** and **hydrophobic** amino acids, some of which interact with the hydrocarbon tails of the membrane phospholipids.
      (3) Most transmembrane proteins are folded so that they pass back and forth across the plasmalemma; therefore, they are also known as **multipass proteins.**
   b. Integral proteins may also be anchored to the inner (or occasionally outer) leaflet via fatty acyl or prenyl groups.
   c. In freeze-fracture preparations, integral proteins remain preferentially attached to the **P-face,** the outer (protoplasmic face) surface of the inner leaflet, rather than the **E-face** (extracellular face) (Fig. 1-2).
2. ***Peripheral proteins*** do not extend into the lipid bilayer.
   a. These proteins are located on the cytoplasmic aspect of the inner leaflet.
   b. The outer leaflets of some cells possess covalently linked glycolipids to which peripheral proteins are anchored; these peripheral proteins thus project into the **extracellular space.**

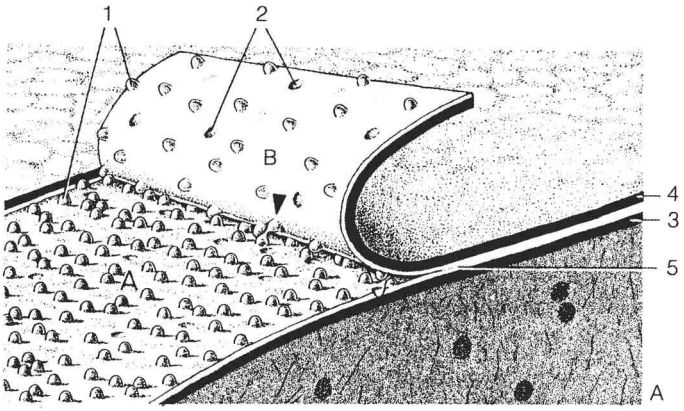

Figure 1-2 Freeze-fracturing cleaves the plasma membrane (5). The impressions (2) of the transmembrane proteins are evident on the E-face between the inner (3) and outer leaflets (4). The integral proteins (1) remain preferentially attached to the P-face (*A*), the external surface of the inner leaflet; fewer proteins remain associated with the E-face (*B*), the internal surface of the outer leaflet. The arrowhead indicates a transmembrane protein attached to both E-face and P-face. (Reprinted with permission from Krstic RV: Ultrastruktur der Saugertierzelle. Berlin, Springer Verlag, 1976, p 177.)

c. Peripheral proteins bind to the phospholipid polar groups or integral proteins of the membrane via noncovalent interactions.
d. They usually function as part of the **cytoskeleton** or as part of an **intracellular second messenger system.**
e. They include a group of anionic, calcium-dependent, lipid-binding proteins known as **annexins**, which act to modify the relationships of other peripheral proteins with the lipid bilayer.

3. ***Functional characteristics of membrane proteins***
   a. ***The lipid-to-protein ratio*** (by weight) in plasma membranes ranges from 1:1 in most cells to as much as 4:1 in myelin.
   b. Some membrane proteins **diffuse laterally** in the lipid bilayer; others are **immobile** and are held in place by cytoskeletal components.

C. **Glycocalyx** (**cell coat**), located on the outer surface of the outer leaflet of the plasmalemma, varies in appearance (fuzziness) and thickness (up to 50 nm).

1. ***Composition.*** The glycocalyx consists of polar oligosaccharide side chains linked covalently to most proteins and some lipids (glycolipids) of the plasmalemma. It also contains **proteoglycans** (**glycosaminoglycans** bound to integral proteins).
2. ***Function***
   a. The glycocalyx aids in **attachment** of some cells (e.g., fibroblasts but not epithelial cells) to extracellular matrix components.
   b. It **binds** antigens and enzymes to the cell surface.
   c. It facilitates **cell-cell recognition** and **interaction.**
   d. It **protects cells** from injury by preventing contact with inappropriate substances.
   e. It assists T cells and antigen-presenting cells in **aligning** with each other in the proper fashion and aids in preventing inappropriate enzymatic cleavage of receptors and ligands.

III. Plasma Membrane Transport Processes

These processes include transport of a single molecule (uniport) or cotransport of two different molecules in the same (symport) or opposite (antiport) direction.

A. Passive transport (Fig. 1-3) includes **simple** and **facilitated diffusion.** Neither of these processes requires energy because molecules move across the plasma membrane **down a concentration or electrochemical gradient.**

1. ***Simple diffusion*** transports small nonpolar molecules (e.g., oxygen and nitrogen) and small, uncharged, polar molecules (e.g., water, carbon dioxide, and glycerol). It exhibits little specificity, and the diffusion rate is proportional to the concentration gradient of the diffusing molecule.
2. ***Facilitated diffusion*** occurs via **ion channels** and/or **carrier proteins,** structures that exhibit **specificity** for the transported molecules. Not only is it faster than simple diffusion, but it is also responsible for providing a pathway for ions and large polar molecules to traverse membranes that would otherwise be impermeable to them.
   a. ***Ion channel proteins*** are multipass transmembrane proteins that form small aqueous pores across membranes through which specific small water-soluble molecules and ions pass down an electrochemical gradient (**passive transport**).
   b. ***Aquaporins*** are channels designed for the rapid transport of water across the cell membrane without permitting an accompanying flow of protons to pass through the channels. They accomplish this by forcing the water molecules to flip-flop halfway down the channel, so that water molecules enter aquaporins with their oxygen leading into the channel and leave with their oxygen trailing the hydrogen atoms.
   c. ***Carrier proteins*** are multipass transmembrane proteins that undergo reversible conformational changes to transport specific molecules across the membrane; these proteins function in both passive transport and **active transport.**

B. Active transport is an **energy-requiring process** that transports a molecule **against** an electrochemical gradient via carrier proteins.

1. ***Na^+-K^+ pump***
   a. ***Mechanism.*** The Na^+-K^+ pump involves the **antiport** transport of Na^+ and K^+ mediated by the carrier protein, **Na^+-K^+ adenosine triphosphatase** (**ATPase**).

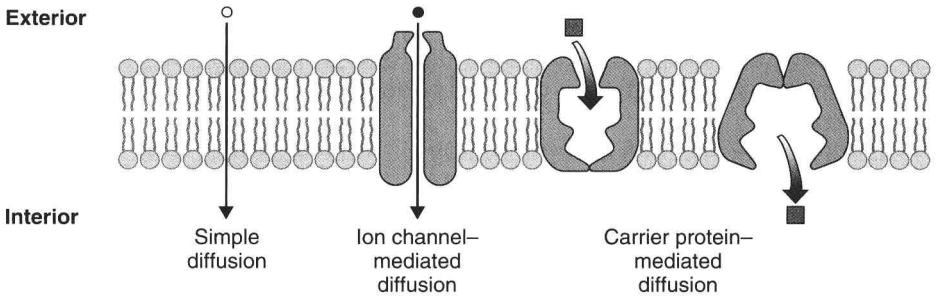

Figure 1-3 Passive transport of molecules across plasma membranes by simple diffusion (*left*) and by either of the two types of facilitated diffusion mediated by ion channel proteins (*center*) and carrier proteins (*right*).

(1) Three sodium ions are pumped **out** of the cell and two potassium ions are pumped **into** the cell.
(2) The hydrolysis of a single ATP molecule by the Na^+-K^+ ATPase is required to transport five ions.

b. ***Function***
(1) The primary function is to **maintain constant cell volume** by decreasing the intracellular ion concentration (and thus the osmotic pressure) and increasing the extracellular ion concentration, thus decreasing the flow of water into the cell.
(2) The Na^+-K^+ pump also plays a minor role in the maintenance of a **potential difference** across the plasma membrane.

2. ***Glucose transport*** involves the **symport** movement of glucose across an epithelium (**transepithelial transport**). Transport is frequently powered by an electrochemical Na^+ gradient, which drives carrier proteins located at specific regions of the cell surface.

C. **Facilitated diffusion of ions** can occur via ion channel proteins or ionophores.

1. Selective ion channel proteins permit only certain ions to traverse them.
a. ***K^+ leak channels*** are the most common ion channels. These channels are ungated and leak K^+, the ions most responsible for establishing a potential difference across the plasmalemma.
b. ***Gated ion channels*** open only transiently in response to various stimuli. They include the following types:
(1) *Voltage-gated channels* open when the potential difference across the membrane changes (e.g., voltage-gated **Na^+** channels, which function in the generation of action potentials; see Chapter 9 VIII B 1 e).
(2) *Mechanically gated channels* open in response to a mechanical stimulus (e.g., the tactile response of the hair cells in the inner ear).
(3) *Ligand-gated channels* open in response to the binding of a **signaling molecule** or **ion.** These channels include neurotransmitter-gated channels, nucleotide-gated channels, and G protein–gated K^+ channels of cardiac muscle cells.
2. ***Ionophores*** are molecules that form a complex with ions and insert into the lipid bilayer to transport those ions across the membrane.

IV. Cell-to-Cell Communication

A. **Signaling molecules,** secreted by signaling cells, are directed to target cells, and in this fashion these molecules function in cell-to-cell communication. Examples include neurotransmitters, which are released into the synaptic cleft (see Chapter 8 IV A 1 b and Chapter 9 IV B 5); endocrine hormones, which are carried in the bloodstream and act on distant target cells; and hormones released into the intercellular space, which act on nearby cells (**paracrine hormones**) or on the releasing cell itself (**autocrine hormones**).

1. ***Lipid-soluble signaling molecules*** penetrate the plasma membrane and bind to *receptors within the cytoplasm* or inside the **nucleus,** activating intracellular messengers. Examples include hormones that influence gene transcription.
2. ***Hydrophilic signaling molecules*** bind to and activate **cell-surface receptors** (as do some lipid-soluble signaling molecules) and have diverse physiologic effects

(see Chapter 13). Examples include neurotransmitters and numerous hormones (e.g., serotonin, thyroid-stimulating hormone, insulin).

B. Membrane receptors are primarily glycoproteins. They are located on the cell surface, and specific signaling molecules bind to them.

1. ***Function***
   a. Membrane receptors **control plasmalemma permeability** by regulating the conformation of ion channel proteins.
   b. They **regulate the entry of molecules** into the cell (e.g., the delivery of cholesterol via low-density lipoprotein receptors).
   c. They **bind extracellular matrix molecules** to the cytoskeleton via **integrins**, which are essential for cell–matrix interactions.
   d. They **act as transducers** to translate extracellular events into an intracellular response via the second messenger systems.
   e. They permit pathogens that mimic normal ligands to enter cells.
2. ***Types of membrane receptors***
   a. ***Channel-linked receptors*** bind a signaling molecule that temporarily opens or closes the gate, permitting or inhibiting the movement of ions across the cell membrane. Examples include **nicotinic acetylcholine receptors** on the muscle-cell sarcolemma at the myoneural junction (see Chapter 8 IV A).
   b. ***Catalytic receptors*** are single-pass transmembrane proteins.
      (1) Their extracellular moiety is a receptor, and their **cytoplasmic component** is a protein kinase.
      (2) Some catalytic receptors lack an extracytoplasmic moiety and as a result are continuously activated; such defective receptors are coded for by some **oncogenes.**
      (3) Examples of catalytic receptors include the following:
         (a) **Insulin** binds to its receptor, which **autophosphorylates.** The cell then takes up the insulin–receptor complex by **endocytosis**, enabling the complex to function within the cell.
         (b) **Growth factors** (e.g., epidermal growth factor, platelet-derived growth factor) bind to specific catalytic receptors and induce mitosis.
   c. ***G protein–linked receptors are*** transmembrane proteins associated with an ion channel or with an enzyme that is bound to the cytoplasmic surface of the cell membrane.
      (1) These receptors interact with **heterotrimeric G protein** (guanosine triphosphate [GTP]) binding regulatory protein] after binding of a signaling molecule. This interaction results in the activation of **intracellular second messengers,** the most common of which are cyclic adenosine monophosphate (**cAMP**) and $\mathbf{Ca^{2+}}$.
      (2) Examples include the following:
         (a) **Heterotrimeric G proteins** (Table 1-1), which are folded in such a fashion that they make seven passes as they penetrate the cell membrane. They include stimulatory G protein ($\mathbf{G_s}$) (Fig. 1-4), inhibitory G protein ($\mathbf{G_i}$), phospholipase C activator G protein ($\mathbf{G_p}$), olfactory-specific G protein ($\mathbf{G_{olf}}$), and transducin ($\mathbf{G_t}$).
         (b) **Monomeric G proteins (low-molecular-weight G proteins)**, are small single-chain proteins that also function in signal transduction.
            (i) Various subtypes resemble Ras, Rho, Rab, and ARF proteins.

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