COMPONENTS AND STRUCTURE OF CELL MEMBRANES*

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Based on Components and Structure† by
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Introduction

The American Heritage Dictionary defines a membrane as a 'thin pliable layer of plant or animal tissue covering or separating structures or organs'. The impression this description leaves is one of the plastic wrap covering a hamburger. By this definition, membranes are static, tough, impenetrable, and visible. Yet, nothing could be further from the truth. The entire concept of dynamic behavior is missing from this definition, yet dynamics is what makes membranes both essential for life and so difficult to study.

William Stillwell, An Introduction to Biological Membranes: From Bilayers to Rafts, pg. 1, 2013

A cell’s plasma membrane defines the cell, outlines its borders, and determines the nature of its interaction with its environment. As Stillwell says above, without membranes there would be no life; they are as essential to life as DNA or proteins. Cells exclude some substances, take in others, and excrete still others, all in controlled quantities. The plasma membrane must be very flexible to allow certain cells, such as red blood cells and white blood cells, to change shape as they pass through narrow capillaries. These are the more obvious functions of a plasma membrane. In addition, the surface of the plasma membrane carries markers that allow cells to recognize one another, which is vital for tissue and organ formation during early development, and which later plays a role in the “self” versus “non-self” distinction of the immune response.

Among the most sophisticated functions of the plasma membrane is the ability to transmit signals by means of complex, integral proteins known as membrane receptors. These proteins (and occasionally, lipids) act both as receivers of extracellular inputs and as activators of intracellular processes. These membrane receptors provide extracellular attachment sites for effectors like hormones and growth factors, and they activate intracellular response cascades when their effectors are bound. Occasionally, receptors are hijacked by viruses (HIV, human immunodeficiency virus, is one example) that use them to gain entry into cells, and at times, the genes encoding receptors become mutated, causing the process of signal transduction to malfunction with disastrous consequences.

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1 Fluid Mosaic Model

The existence of the plasma membrane was identified in the 1890s, and its chemical components were identified in 1915. The principal components identified at that time were lipids and proteins. The first widely accepted model of the plasma membrane’s structure was proposed in 1935 by Hugh Davson and James Danielli; it was based on the “railroad track” appearance of the plasma membrane in early electron micrographs. They theorized that the structure of the plasma membrane resembles a sandwich, with protein being analogous to the bread, and lipids being analogous to the filling. In the 1950s, advances in microscopy, notably transmission electron microscopy (TEM), allowed researchers to see that the core of the plasma membrane consisted of a double, rather than a single, layer. A new model that better explains both the microscopic observations and the function of that plasma membrane was proposed by S.J. Singer and Garth L. Nicolson in 1972.

The explanation proposed by Singer and Nicolson, and based on the work of many others such as Harden McConnell, is called the fluid mosaic model. The model has evolved somewhat over time, but it still best accounts for the structure and functions of the plasma membrane as we now understand them. The fluid mosaic model describes the structure of the plasma membrane as a mosaic of components—including phospholipids, cholesterol, proteins, and carbohydrates—that gives the membrane a fluid character. Plasma membranes range from 5 to 10 nm in thickness. For comparison, human red blood cells, visible via light microscopy, are approximately 8 µm wide, or approximately 1,000 times wider than a plasma membrane. The membrane does look a bit like a sandwich (Figure 1).

Figure 1: The fluid mosaic model of the plasma membrane describes the plasma membrane as a fluid combination of phospholipids, cholesterol, and proteins. Carbohydrates attached to lipids (glycolipids) and to proteins (glycoproteins) extend from the outward-facing surface of the membrane.

The principal components of a plasma membrane are lipids (phospholipids and cholesterol), proteins, and carbohydrates attached to some of the lipids and some of the proteins. A phospholipid is a molecule consisting of glycerol, two fatty acids, and a phosphate-linked head group. Cholesterol, another lipid composed of four fused carbon rings, is found alongside the phospholipids in the core of the membrane. The
proportions of proteins, lipids, and carbohydrates in the plasma membrane vary with cell type, but for a
typical human cell, protein accounts for about 50 percent of the composition by mass, lipids (of all types)
account for about 40 percent of the composition by mass, with the remaining 10 percent of the composition
by mass being carbohydrates. However, the concentration of proteins and lipids varies with different cell
membranes. For example, myelin, an outgrowth of the membrane of specialized cells that insulates the axons
of the peripheral nerves, contains only 18 percent protein and 76 percent lipid. The mitochondrial inner
membrane contains 76 percent protein and only 24 percent lipid. The plasma membrane of human red blood
cells is 30 percent lipid. Carbohydrates are present only on the exterior surface of the plasma membrane
and are attached to proteins, forming glycoproteins, or attached to lipids, forming glycolipids.

1.1 Phospholipids
The main fabric of the membrane is composed of amphiphilic, phospholipid molecules. The hydrophilic
or “water-loving” areas of these molecules (which look like a collection of balls in an artist’s rendition of the
model) (Figure 1) are in contact with the aqueous fluid both inside and outside the cell. Hydrophobic,
or water-hating molecules, tend to be non-polar. They interact with other non-polar molecules in chemical
reactions, but generally do not interact with polar molecules. When placed in water, hydrophobic molecules
tend to form a ball or cluster. The hydrophilic regions of the phospholipids tend to form hydrogen bonds with
water and other polar molecules on both the exterior and interior of the cell. Thus, the membrane surfaces
that face the interior and exterior of the cell are hydrophilic. In contrast, the interior of the cell membrane
is hydrophobic and will not interact with water. Therefore, phospholipids form an excellent two-layer cell
membrane that separates fluid within the cell from the fluid outside of the cell.

A phospholipid molecule (Figure 2) consists of a three-carbon glycerol backbone with two fatty acid
molecules attached to carbons 1 and 2, and a phosphate-containing group attached to the third carbon.
This arrangement gives the overall molecule an area described as its head (the phosphate-containing group),
which has a polar character or negative charge, and an area called the tail (the fatty acids), which has no
charge. The head can form hydrogen bonds, but the tail cannot. A molecule with this arrangement of a
positively or negatively charged area and an uncharged, or non-polar, area is referred to as amphiphilic or
“dual-loving.”
Figure 2: This phospholipid molecule is composed of a hydrophilic head and two hydrophobic tails. The hydrophilic head group consists of a phosphate-containing group attached to a glycerol molecule. The hydrophobic tails, each containing either a saturated or an unsaturated fatty acid, are long hydrocarbon chains.

This characteristic is vital to the structure of a plasma membrane because, in water, phospholipids tend to become arranged with their hydrophobic tails facing each other and their hydrophilic heads facing out. In this way, they form a lipid bilayer—a barrier composed of a double layer of phospholipids that separates the water and other materials on one side of the barrier from the water and other materials on the other side. In fact, phospholipids heated in an aqueous solution tend to spontaneously form small spheres or droplets (called micelles or liposomes), with their hydrophilic heads forming the exterior and their hydrophobic tails on the inside (Figure 3).
1.2 Proteins

Proteins make up the second major component of plasma membranes. Integral proteins (some specialized types are called integrins) are, as their name suggests, integrated completely into the membrane structure, and their hydrophobic membrane-spanning regions interact with the hydrophobic region of the phospholipid bilayer (Figure 1). Single-pass integral membrane proteins usually have a hydrophobic transmembrane segment that consists of 20–25 amino acids. Some span only part of the membrane—associating with a...
single layer—while others stretch from one side of the membrane to the other, and are exposed on either side. Some complex proteins are composed of up to 12 segments of a single protein, which are extensively folded and embedded in the membrane (Figure 4). This type of protein has a hydrophilic region or regions, and one or several mildly hydrophobic regions. This arrangement of regions of the protein tends to orient the protein alongside the phospholipids, with the hydrophobic region of the protein adjacent to the tails of the phospholipids and the hydrophilic region or regions of the protein protruding from the membrane and in contact with the cytosol or extracellular fluid.

Figure 4: Integral membranes proteins may have one or more alpha-helices that span the membrane (examples 1 and 2), or they may have beta-sheets that span the membrane (example 3). (credit: "Foo-bar"/Wikimedia Commons)

Peripheral proteins are found on the exterior and interior surfaces of membranes, attached either to integral proteins or to phospholipids. Peripheral proteins, along with integral proteins, may serve as enzymes, as structural attachments for the fibers of the cytoskeleton, or as part of the cell’s recognition sites. These are sometimes referred to as “cell-specific” proteins. The body recognizes its own proteins and attacks foreign proteins associated with invasive pathogens.