Chapter 5: Homeostasis and Transport
Lesson 5.1: Cell Structures Involved in Cell Transport

It could easily be said that a cell is the fundamental unit of life, the smallest unit capable of life or the structural and functional unit necessary for life. But whatever it is, a cell is necessary for life. Cell membranes enable organisms to maintain homeostasis by regulating the materials that may enter or leave a cell. Some materials easily cross the cell membrane without the input of energy; other materials require energy input in order to cross through the cell membrane. Those materials that can pass without the input of energy do so via a process known as passive transport. The materials that cross the cell membrane using energy input do so by a process known as active transport. The ability of cells to exchange materials with their environment involves a variety of molecular processes and is essential to cell function. This chapter will discuss some of the fundamental molecular processes of the cell material exchanges, with lessons that include the cell structure, transport in and out of the cell, energy metabolism, and cell homeostatic mechanisms.

Lesson Objectives
• Describe the structure and function of the plasma membrane in relation to cell transport.
• Identify the types of membrane proteins involved in cell transport.
• Identify the roles of the cytoplasm and cytoskeleton in cell transport.
• Identify the role of the endomembrane system in eukaryotic organisms in cell transport.
• Discuss special transport structure of plant cells.
• Outline the role of cell transport in homeostasis.

Vocabulary
• aquaporin
• carrier protein
• channel protein
• cytoplasmic streaming
• endomembrane system
• gated channel
• integral protein
• ion channel
• peripheral protein
• plasmodesma
• semi-permeability (selective permeability)
• transport protein
FROM OUTSIDE TO INSIDE
The Plasma Membrane

The plasma membrane (cell membrane) forms a barrier between the cytoplasm inside the cell and the environment outside the cell. It protects and supports the cell and also controls everything that enters and leaves the cell. It allows only certain substances to pass through, while keeping others in or out. The ability to allow only certain molecules in or out of the cell is referred to as selective permeability or semipermeability.

The most important substance that cells need to be permeable to is water since most of the molecules essential for life are soluble. In addition to water, a constant flow of inorganic ions; such as, sodium (Na+), potassium (K+), calcium (Ca2+), and chlorine (Cl−) move into and out of the cell and act as electrolytes (an electrically conductive medium) that regulate the electric charge on cells and the flow of water across their membranes. Also oxygen needs to be able to enter cells freely so that they can help release the energy that powers cellular reactions. Hormones need to be able to cross the plasma membrane to transmit messages. Sugars, amino acids, and other nutrients need to enter cells to supply energy and building material for cell components, while metabolic waste need to be able to exit cells to avoid a potentially toxic environment inside the cell. All of these substances enter and leave the cell at different rates. To understand how the plasma membrane controls what crosses into or out of the cell, you need to know its composition.

The Phospholipid Bilayer

The plasma membrane is composed mainly of phospholipids and proteins. The phospholipids in the plasma membrane are arranged in two layers, called a phospholipid bilayer. The plasma membrane with its embedded proteins is a fluid mosaic-like structure that allows the membrane’s lipids and proteins to move laterally within the bilayer, like a sailboat on the ocean. As shown in Figure 5.1, each phospholipid molecule has a head and two tails. The head “loves” water (hydrophilic) and the tails “hate” water (hydrophobic). The water-hating tails are on the interior of the membrane, whereas the water-loving heads point outwards, toward either the cytoplasm or the fluid that surrounds the cell. Molecules that are hydrophobic or nonpolar, like carbon dioxide and oxygen, can easily pass through the plasma membrane, if they are small enough, because they are water-hating like the interior of the membrane. Molecules that are hydrophilic or polar, on the other hand, cannot pass through the plasma membrane—at least not without help—because they are water-loving like the exterior of the membrane. These water-loving molecules are usually helped across the plasma membrane through certain embedded membrane proteins, see Figure 5.2 below.

Figure 5.1 Phospholipid Bilayer. The phospholipid bilayer consists of two layers of phospholipids (left), with a hydrophobic, or water-hating, interior and a hydrophilic, or water-loving, exterior. A single phospholipid molecule is depicted on the right.

Figure 5.2 Membrane proteins: protein channel and integral protein (outlined by oval shapes) embedded within the phospholipid bilayers of the plasma membrane help water-loving molecules cross the plasma membrane.
Proteins Embedded in the Plasma Membrane

The plasma membrane has several types of proteins associated with its phospholipid bilayer. There are peripheral proteins that are loosely bound to the surface of the plasma membrane or to part of an integral protein, these types of proteins can be seen in Figure 5.2 and are not actively involved in cell transport processes. Integral proteins are transmembrane proteins, which means that they are proteins with hydrophobic regions that extend into and often completely span the hydrophobic interior of the plasma membrane. The outer regions of integral proteins are hydrophilic and can easily make contact with aqueous solution on either side of the plasma membrane. Certain types of integral proteins are actively involved in cell transport processes.

There are many different types of integral proteins involved in cell transport. Transport proteins are integral proteins that allow ions and a variety of polar molecules to cross the plasma membrane without coming in to contact with the lipid bilayer. Special transport proteins called channel proteins have hydrophilic channels that allow certain molecules and ions to pass through them. For example, some water molecules cross through channel proteins known as aquaporins. Ions pass through transport proteins known as ion channels. Some ion channels are electrogenic pumps that generate voltage across a membrane. ATP synthase that you learned about in the chapter on photosynthesis and cellular respiration is an electrogenic pump. Other ion channels are gated channels that open and close in response to a stimulus. In addition to being channel proteins, transport proteins are sometimes carrier proteins, these type of transport proteins hold onto the molecules passing through them and change shape as a way to move the molecules across the membrane, see Figure 5.3.

![Figure 5.3: (a) Some substances are able to move down their concentration gradient across the plasma membrane with the aid of protein channels or carrier proteins. Carrier proteins change shape as they move molecules across the membrane. (b) Electrogenic pumps generate voltage across a membrane. (c) Gated channels open and close in response to stimulus, the diagram on the right depicts a gated channel which is signaled by a ligand (a molecule that binds specifically to another molecule) to open.](image)

Cytoplasm’s Role in Intracellular Transport

Cytoplasm is found inside the cell’s plasma membrane. It is clear in color and has a gel-like appearance. It is composed mainly of water and also contains enzymes, salts, organelles, and various organic molecules. Enzymes in the cytoplasm help dissolve cellular waste for cell export, while the salts found in the cytoplasm are excellent conductors of electricity and create a medium for vesicular transport.
transport within the cell. Vesicular transport is used by cells to transport macromolecules into and out of the cell and will be discussed later in this chapter. In general, the role of the cytoplasmic intracellular transport is to help move materials around the cell. This movement is accomplished by cytoplasmic streaming, also called protoplasmic streaming, see Figure 5.4. Cytoplasmic streaming is the movement and churning of the fluid substance within a plant or animal cell that speeds up the distribution and transport of nutrients, proteins and organelles within the cell.

An animation of cytoplasmic streaming can be viewed at the following link: http://highered.mcgraw-hill.com/sites/9834092339/student_view0/chapter4/animation__cytoplasmic_streaming. html.

Figure 5.4: Cytoplasmic streaming in plants. A layer of cytoplasm moves around the cell, over a structure of actin filaments; organelle transport is enabled by myosin motors attached to them to drive their movement.

**Role of Cytoskeleton in the Cytoplasm**

The role and structure of cytoskeleton in prokaryotic organisms is still being studied by scientists. Crisscrossing the cytoplasm of eukaryotic organisms are cytoskeletons, which consists of three different types of threadlike structures: microfilaments, intermediate filaments, and microtubules. Two of these three structures function to aid intracellular transport within the cytoplasm.

Microfilaments and microtubules are both components of intracellular transport. Microfilaments are composed of a protein called actin and are the thinnest filaments of the cytoskeleton. They act like a track within the cytoplasm for the movement of myosin molecules that attach themselves to the microfilaments and “walk” along them. Myosin molecules are motor proteins that are involved in eukaryotic motility processes, usually in combination with actin-based motility like that found in the cytoplasm. Vesicle movements within the cytoplasm are aided by myosin molecules. Microtubules also help with vesicle intracellular cell transport. They provide tracks for vesicle movement within the cell from one organelle to another. The tracks provided for intracellular transport by microfilaments and microtubules can be seen in Figure 5.5.

Figure 5.5: Microfilaments and microtubules of a cell’s cytoskeleton act as tracks to aid in intracellular transport.
The endomembrane system in eukaryotic cells

Eukaryotic cells have an internal membrane system referred to as the endomembrane system that separates and compartmentalizes the interrelated yet different cellular functions of a variety of organelles, thus creating an organized division of labor. The organelles of the endomembrane system are the nuclear envelope, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi apparatus, lysosomes, endosomes, vesicles, vacuoles, and plasma membrane. Some of these organelles of the cell have a direct connection to one another, like the nuclear envelope to the endoplasmic reticulum. Other organelles, like the endoplasmic reticulum and Golgi apparatus, without a direct connection transport materials to one another through vesicles. The vesicles usually bud off of the sending organelle and fuse with the receiving organelle. The structures of the endomembrane system can be seen in Figure 5.6 below.

Figure 5.6: The transport of molecules into and out of a cell requires a complex endomembrane system and several different cellular transport processes.

The endoplasmic reticulum (ER) is an organelle that helps make and transport proteins and lipids. It is connected to the pores of the nuclear envelope. There are two types of endoplasmic reticulum: rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER).

---Rough Endoplasmic Reticulum (RER)---

It is called the rough endoplasmic reticulum because it is studded with ribosomes and is involved in protein synthesis, the production and transport of new membrane, and the modification and transport of newly formed proteins within the cell. The proteins synthesized on the RER are transported to other locations through vesicles formed in the SER.

---Smooth Endoplasmic Reticulum (SER)---

The smooth endoplasmic reticulum is not studded with ribosomes thus it is called smooth. The SER contains enzymes for lipid biosynthesis (change to phospholipids and steroids). It also forms transition vesicles that travel along microtubular tracks in the cytoplasm to transport molecules made in the RER to the Golgi apparatus.
The Golgi Apparatus

The Golgi apparatus is a large organelle that processes proteins and prepares them for use both inside and outside the cell. It receives proteins from the ER that have been transported in vesicles, packages and labels them, and then sends them on to their next destinations in another set of vesicles. The Golgi apparatus is also involved in the transport of lipids around the cell. At the link below, you can watch an animation showing how the Golgi apparatus does all these jobs.


Vesicles

Vesicles are sac-like organelles that store and transport large molecules; such as proteins and polysaccharides into and out of the cell. The vesicles that pinch off from the membranes of the ER and Golgi apparatus (see Figure 5.7) are transport vesicles that transport protein and lipid molecules to the plasma membrane and fuse with it. Once the vesicle is fused with the membrane it becomes part of the plasma membrane and is now able to empty its contents outside of the cell through a process known as exocytosis. Other vesicles are formed when large molecules form a deep pocket on the extracellular side of the plasma membrane. As the pocket enlarges it pinches in and forms a vesicle that now contains the large molecule that was once outside of the cell. This process is called endocytosis. Both endocytosis and exocytosis modes of transport will be discussed in greater detail later in this chapter.

Figure 5.7: On the left a large molecule pushes against the cell membrane forming a deep pocket that pinches itself off forming a vesicle known as an endosome in eukaryotic cells. On the right a secretory vesicle fuses with the cell membrane inside the cell and then opens to export the molecules outside of the cell.

Lysosomes and Endosomes

Lysosomes are formed by budding off of the Golgi apparatus and are infused with hydrolytic enzymes. Lysosomes are the digestive vesicles of the cell. They contain enzymes called hydrolases that digest proteins, nucleic acids, lipids, and complex sugars. Vesicles that enter the cell through a process called endocytosis are sent to lysosomes so that their contents can be processed. Lysosomes break down and disarm many potentially pathogenic and foreign materials and expel them outside the cell through a process called exocytosis.

Endosomes are the vesicles that are formed during endocytosis which allow materials from outside the cell to enter the cell. They are formed when the cell’s plasma membrane folds inward to surround macromolecules, encircles them, and brings them into the cell by pinching off the membrane at their point of entry. Vesicles larger than 100 nanometers in size are referred to as vacuoles.
Special Transport Structure in Plant Cells

Plant cells have several structures that are not found in animal cells, especially a cell wall. The cell wall is a rigid layer that surrounds the plasma membrane of a plant cell. It supports and protects the cell. Tiny holes, or pores, in the cell wall called plasmodesmata (singular, plasmodesma) form open channels through which strands of cytosol connect between adjacent cells, see Figure 5.8. The plasmodesmata allow water, nutrients, and other substances to move into and out of the cells.

Figure 5.8: Plasmodesmata between adjacent cells allow water, nutrients, and other substances to pass between them.

Homeostasis and Cell Function

For a cell to function normally, a stable state must be maintained inside the cell. For example, the concentration of salts, nutrients, and other substances must be kept within a certain range. The process of maintaining stable conditions inside a cell (or an entire organism) is homeostasis. Homeostasis requires constant adjustments, because conditions are always changing both inside and outside the cell. The structures and processes described in this lesson and the next lesson play important roles in homeostasis and are considered homeostatic mechanisms. By moving substances into and out of cells, they keep conditions within normal ranges and maintain homeostatic regulation inside the cells and the organism as a whole. If homeostatic mechanisms fail to maintain homeostatic regulation, disease or death of a cell or organism may follow.

Lesson Summary

• A major role of the plasma membrane is transporting substances into and out of the cell.
• The plasma membrane is selectively permeable, allowing only certain substances to pass through.
• Proteins embedded within the plasma membrane help to move hydrophilic, polar molecules into the cell.
• The cytoplasm is the internal medium for cell transport.
• Vesicles aid in the import and export of macromolecules.
• Plant cells have special transport structures that are not found in animal cells, called plasmodesmata.
• Cell transport helps cells maintain homeostasis by keeping conditions within normal ranges inside all of an organism’s cells.
• If homeostatic mechanisms fail, homeostatic regulation may fluctuate and disease or death of a cell or organism can follow.
References/ Multimedia Resources


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