Projector Center

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Active Transport

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Over the past 10 years our concept of the plasma membrane has changed considerably from the simple three-layered structure surrounding the cell to that of a fluid mosaic model. This model of the membrane consists of a fluid phospholipid bilayer with a mosaic of interspersed proteins embedded in the lipid layers. Some proteins extend through both lipid layers, while others may extend only halfway or be loosely bound to the surface of the membrane. Chemical analysis of several kinds of membranes reveals that most contain about 50 percent protein and 50 percent lipid. Membranes surrounding cytoplasmic organelles or specialized cells may have percentages which vary from this 1:1 ratio. The inner membranes of the mitochondria, for example, contain 75 percent protein and only 25 percent lipid. Membranes of nerve cells often contain 90 percent lipid and 10 percent protein. The fluid mosaic model explains many of the known facts about membrane functions, but much remains unknown about both its structure and its interactions with the kinetic activity of ions and molecules in order to sustain the necessary conditions for the living cell.

The movement of substances between cells and the surrounding environment occurs in three general ways: diffusion, transport by protein carriers, and endocytosis or exocytosis. The movement of substances by diffusion does not require the input of cellular energy. The difference between active and passive (facilitated) transport by protein carriers may be distinguished on the basis of energy expenditure by the cell. Both endocytosis and exocytosis require energy and the formation of vacuoles.

Movement by Diffusion

The establishment of a concentration gradient due to a higher concentration of molecules results in the diffusion of molecules into the cell through one of the membrane components depending on the size and chemical nature of the molecule. Oxygen, carbon dioxide and other lipid soluble molecules, such as alcohol or benzene pass through the lipid portion of the thin 7.5 nm membrane (about 25 times the thickness of a water molecule.) Water and certain other small ions are thought by some investigators to pass through protein lined "pores." Small electrically charged ions would not be permitted such passage if these protein pores had a positive charge similar to the membrane itself. The positive ions would be repelled and negative ions would at first be attracted but then held at the surface.

Transport by Protein Carriers

The fact that some small molecules pass with ease, while others either pass through with difficulty or not at all, has resulted in the membrane being regarded as selectively permeable. When various sugars of identical molecular size are present both inside and outside a cell, certain ones cross the membrane hundreds of times faster than others. Observations also show that sugars and amino acids are able to diffuse through the membranes of cells that have been metabolically suppressed. This and other evidence indicates that the passage of these molecules is facilitated by a protein carrier without the expenditure of cellular energy. These carriers are thought to be highly specific and able to combine with only certain molecules. This facilitated diffusion, assisted by protein carriers, operates under the same basic rules as does simple diffusion since a substance still moves only from an area of higher concentration to an area of lower concentration.

In contrast to facilitated diffusion, active transport requires the use of ATP energy by the carrier protein in order to move ions or molecules through the cell membrane against a concentration gradient, accumulating either inside or outside the cell in a region of higher concentration. This process is considered to be responsible for the accumulation of an excess amount of a solute within the cells, such as the increase in the potassium ion concentration on the inside of the cell membrane (a thousand times greater than on the outside of the membrane.) Other examples include the high concentration of iodine in the cells of the thyroid gland, the virtual removal of sodium from urine by the cells lining the kidney tubules, and the total absorption of sugar by intestinal cells of the gut.

Subjecting cells to an increased ion concentration results in an increase in ion uptake, but only to a point. Raising the concentration above a certain point does not increase the uptake. Graphically, the results of such experiments produce a saturation curve similar to the activity of an enzyme. The manner in which ions seemingly compete for a carrier suggests to some investigators a situation analogous to an enzyme-substrate complex. When a variety of similar ions, such as potassium, rubidium and cesium are presented to the cell the uptake of any ion in the group is slower than when the ion is alone. The same is true of calcium, strontium and barium. Interestingly, other close chemical relatives show no competition. Sodium, although similar to cesium, rubidium and potassium, does not compete with these ions during uptake. The fact that active transport across a membrane can be thought of as an enzymatic activity has prompted some to give the protein carriers an enzymatic name—permeases.

The energy used by the protein carrier might be necessary for the attach-

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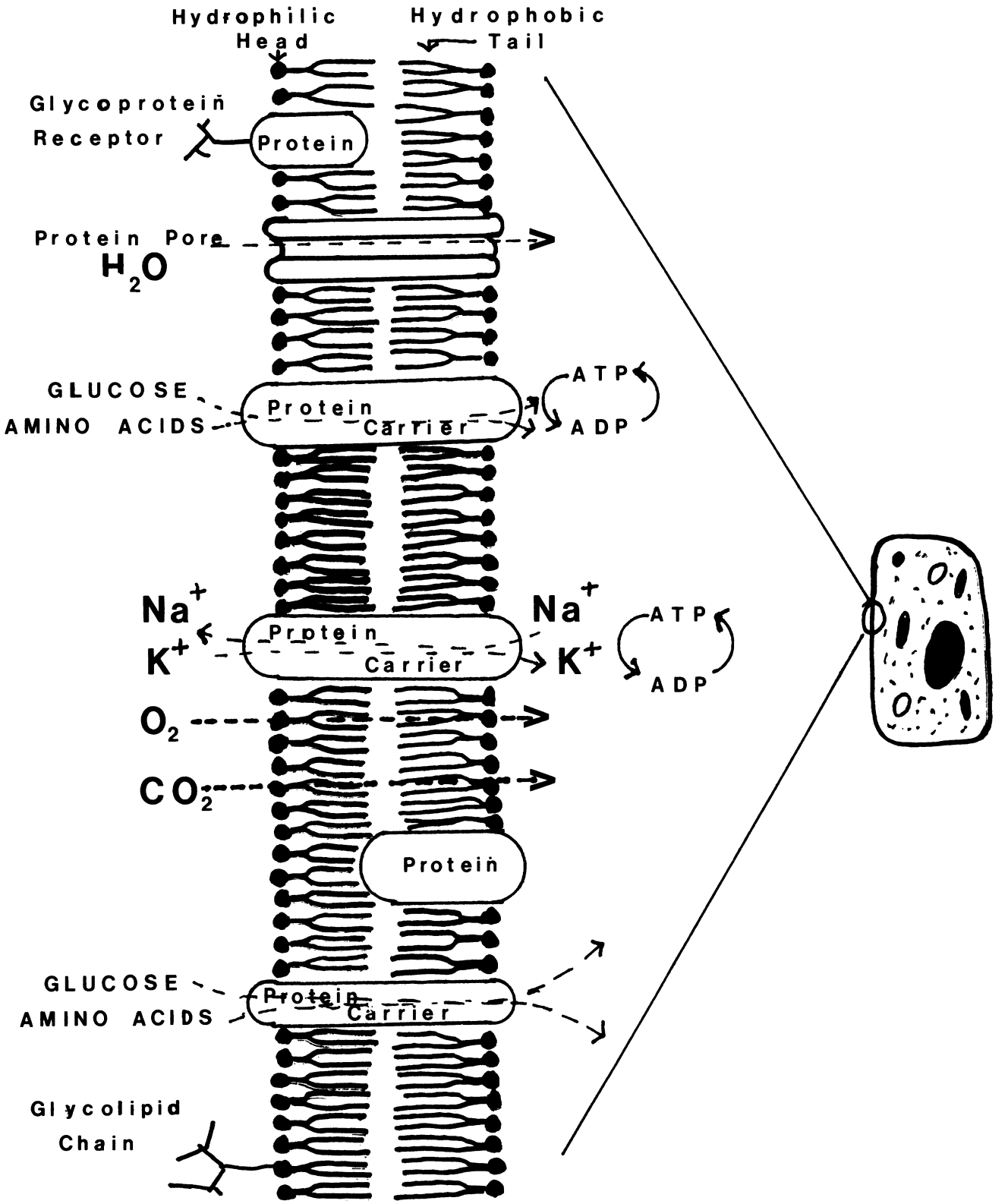
ACTIVE TRANSPORT



ment of the molecule or ion, to change the shape of the carrier, to release the molecule, or a combination of all three. The expended energy results in the passage of the ion across the membrane and renders the carrier useless for further active transport until a high energy phosphate is provided by another molecule of ATP. It is not surprising, therefore, that cells involved primarily with active transport, such as those in the kidney, have a large number of mitochondria near the membrane surface where active transport is occurring.

One type of active transport found in all cells, but especially important in muscle and nerve cells, involves the accumulation of sodium ions outside the cell and a corresponding accumulation of potassium ions within the cell. Since these two events are linked together, they are usually referred to as the sodium-potassium pump. The "pump" is thought to be a protein molecule carrier capable of combining with both the sodium and potassium ions. The external portion of the carrier allows the potassium ions to enter the cell while the internal part of the carrier assists the sodium ion to exit the membrane. The shape of the protein may be capable of changing its configuration to accomplish this feat using ATP energy released by the ATPase enzyme. Recent clinical investigations indicate a correlation between obesity and low levels of ATPase. This condition could result in a low metabolic rate since the NA+/K+ exchange is estimated to account for 20 to 50 percent of the body's total heat production and consumes considerable calories.

Endocytosis

Endocytosis, although not directly related to active transport, can be more adequately explained using the fluid mosaic membrane model. At various locations over the surface of the membrane there are receptor molecules with irregular protrusions extending beyond the cell. (These molecules are identified on the transparency masters as glycoprotein and glycolipid receptors.) These receptors are specific for larger required molecules. The receptor molecules are capable of diffusing over the surface of the cell by moving among the lipid molecules making up the outer layer of the membrane. This receptor molecule may contact the required molecule and form a receptor-molecule complex.

As this receptor-molecule complex continues to move over the undulating, irregular membrane surface, it will eventually reach an indented, pit-like region. After moving into the pit-like region, a type of invagination occurs around the receptor-molecule complex with some of the membrane's lipid molecules forming a lipid sphere. It should be noted that this sphere has the hydrophobic lipid tail ends oriented outward making it soluble within the membrane. This sphere can move across the membrane to the cytoplasmic side. Again, the mosaic model provides an explanation of the spreading of the lipid molecules on the inner membrane surface. This in turn allows either for the foreign molecule to be released into the cytoplasm or for the vesicle to pass into the cytoplasm and transfer the molecule to a specific cell organelle. The lipid molecules that make up this transporting vesicle again become part of the membrane structure after the required molecule is released from the receptor-molecule complex.

In summary, the fluid mosaic membrane model appears to resemble a flexible, undulating lipid bilayer with randomly positioned protein molecules extending partially or completely through the bilayer. Most biologically important organic molecules are insoluble in the center of the bilayer and thus the barrier properties of the membrane. To pass through this nearly impermeable barrier, many compounds require the aid of ATP and a protein molecule acting in some role as a carrier.

Suggested Readings

Bretscher, M.S. (1985). The molecules of the cell membrane. *Scientific American, 253,* 100-108

Unwin, N. & Henderson, R. (1984). The structure of proteins in biological membranes. *Scientific American, 250,* 78-94.

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