Theme 6. Structure and transport function of human cells membranes

Problems
Physics identification excitable tissues functions electric nature for physics diagnose methods substantiation and safe human treatment.

Attendance prerequisite checklist. Note! Answer in writing to perform

Answer to the questions
1. Identify human cells plasma as electric conductor.
2. Define diffusion phenomenon.
3. What are the major ions determining electric currents across human cells membranes?
4. What are two ions transport mechanisms across human neurons membranes?
5. Specify structures that transport ions across human neurons membranes.

Information resources
1. https://courses.lumenlearning.com/boundless-ap/chapter/transport-across-membranes/
2. https://www.biotopics.co.uk/A15/Transport_across_cell_membranes.html
Test and quantification of human body excitable tissues physiological processes by the registration of electrical signals from a body surface. Electrocardiography
3. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/dipole.html
4. https://www.examfear.com/notes/Class-12/Physics/Electrostatic-Potential/815/Electrostatic-Potential-due-to-an-Electric-Dipole.htm
3. https://www.slideserve.com/milo/the-electric-dipole

Introduction

Structure of the plasma membrane. Each cell of human body is encased in a tiny bubble of membrane. This membrane has about the consistency of salad oil. The plasma membrane turns out to be very well-suited to its job, salad oil texture and all.

The plasma membrane not only defines the borders of the cell, but also allows the cell to interact with its environment in a controlled way. Cells must be able to exclude, take in, and excrete various substances, all in specific amounts. In addition, they must able to communicate with other cells, identifying themselves and sharing information.

To perform these roles, the plasma membrane needs lipids, which make a semi-permeable barrier between the cell and its environment. It also needs proteins, which are involved in cross-membrane transport and cell communication, and carbohydrates (sugars and sugar chains), which decorate both the proteins and lipids and help cells recognize each other.

Fluid mosaic model. The currently accepted **fluid mosaic model** for the structure of the plasma membrane was first proposed in 1972. This model has evolved over time, but it still provides a good basic description of the structure and behavior of membranes in many cells.

According to the fluid mosaic model, the plasma membrane is a mosaic of components—primarily, phospholipids, cholesterol, and proteins—that move freely and fluidly in the plane of the membrane. In other words, a diagram of the membrane like the one below (fig. 1) is just a snapshot of a dynamic process in which phospholipids and proteins are continually sliding past one another.

Image of the plasma membrane modified from OpenStax Biology (fig. 1), shows the phospholipid bilayer with peripheral and integral membrane proteins, glycoproteins that is proteins with a carbohydrate attached, glycolipids that is lipids with a carbohydrate attached, and cholesterol molecules.

The principal components of the plasma membrane are lipids - phospholipids and cholesterol, proteins, and carbohydrate groups that are attached to some of the lipids and proteins.

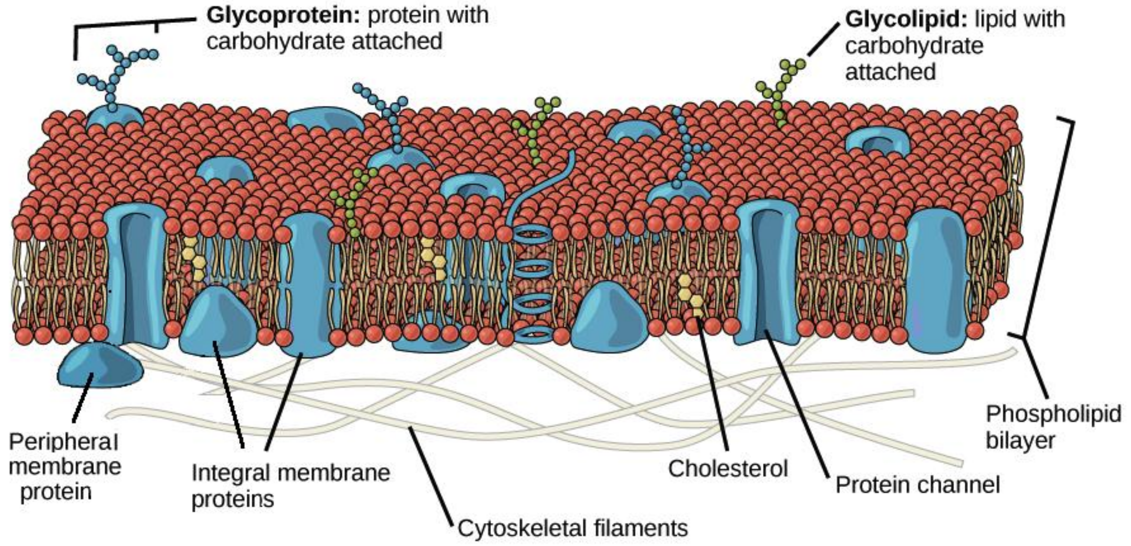

Figure 1

A **phospholipid** is a lipid made of glycerol, two fatty acid tails, and a phosphate-linked head group. Biological membranes usually involve two layers of phospholipids with their tails pointing inward, an arrangement called a **phospholipid bilayer**.

Cholesterol, another lipid composed of four fused carbon rings, is found alongside phospholipids in the core of the membrane.

Membrane proteins may extend partway into the plasma membrane, cross the membrane entirely, or be loosely attached to its inside or outside face.

Carbohydrate groups are present only on the outer surface of the plasma membrane and are attached to proteins, forming **glycoproteins**, or lipids, forming **glycolipids**.

The proportions of proteins, lipids, and carbohydrates in the plasma membrane vary between different types of cells. For a typical human cell, however, proteins account for about 50 percent of the composition by mass, lipids of all types account for about 40 percent, and the remaining 10 percent comes from carbohydrates.

Table. The components of the plasma membrane (modified from OpenStax Biology)

Component	Location
Phospholipids	Main fabric of the membrane
Cholesterol	Tucked between the hydrophobic tails of the membrane phospholipids
Integral proteins	Embedded in the phospholipid bilayer; may or may not extend through both layers
Peripheral proteins	On the inner or outer surface of the phospholipid bilayer, but not embedded in its hydrophobic core
Carbohydrates	Attached to proteins or lipids on the extracellular side of the membrane (forming glycoproteins and glycolipids)

The cell membrane is selectively permeable to ions and organic molecules and controls the movement of substances in and out of cells.

The movement of substances across the membrane can be either "passive", occurring without the input of cellular energy, or "active", requiring the cell to expend energy in transporting it. The membrane also maintains the cell potential. The cell membrane thus works as a selective filter that allows only certain things to come inside or go outside the cell. The cell employs a number of transport mechanisms that involve biological membranes.

Passive transport. In order to understand *how* substances move passively across a cell membrane, it is necessary to understand concentration gradients and diffusion. A **concentration gradient** is the difference in concentration of a substance across a space. Molecules (or ions) will spread/diffuse from where they are more concentrated to where they are less concentrated until they are equally distributed in that space. When molecules move in this way, they are said to move *down* their concentration gradient, from high concentration to low concentration.

Diffusion is the movement of particles from an area of higher concentration to an area of lower concentration.

If the substances can move across the cell membrane without the cell expending energy, the movement of molecules is called passive transport.

Solutes dissolved in water on either side of the cell membrane will tend to diffuse down their concentration gradients, but because most substances cannot pass freely through the lipid bilayer of the cell membrane, their movement is restricted to protein channels and specialized transport mechanisms in the membrane.

Characteristics of simple diffusion:
- is the only form of transport across cell membranes that is not carrier-mediated;
- occurs down an electrical gradient("downhill");
- does not require metabolic energy and therefore is passive.
- diffusion can be measured using the **Fick's law**:

$$\mathbf{Flux = - P \cdot A \cdot (C_1 - C_2)}$$

where **Flux** is the rate at which a material diffuses through a membrane, mol/s; **P** is the **permeability coefficient**, cm/s; **A** is the area of the membrane, cm^2; $\mathbf{C_1}$**,** $\mathbf{C_2}$ are the concentrations of the material on the inside and outside of the membrane, respectively, mmol/l.

The equation for the mean squared displacement $\mathbf{x^2}$ in one direction is: $\mathbf{x^2 = 2\,D\,t}$,
where **D** is called the diffusion constant (coefficient). Similar equations hold to $\mathbf{y^2}$ and $\mathbf{z^2}$. The value of **D** depends on the nature of the diffusing atom or molecule and choice of the solvent or medium.

Facilitated diffusion is the diffusion process used for those substances that cannot cross the lipid bilayer due to their size, charge, and/or polarity but do so down their concentration gradients (fig. 1). As an example, even though sodium ions (Na^+) are highly concentrated outside of cells, these electrolytes are charged and cannot pass through the nonpolar lipid bilayer of the membrane. Their diffusion is facilitated by membrane proteins that form sodium channels or "pores", so that Na+ ions can move down their concentration gradient from outside the cells to inside the cells.

Osmosis. Osmolarity
- is the concentration of **osmotically active** particles in a solution;
- is a colligative property that can be measured by freezing point depression;
- can be calculated using the following equation:

$$\mathbf{Osmolarity = g \cdot C}$$

where **Osmolarity** is the concentration of particles, osm/l; **g** is the number of particles in solution, osm/mol; **C** is the concentration, mol/l.

Two solutions that have the **same** calculated osmolarity are **isosmotic**. If two solutions have different calculated osmolarities, the solution with the **higher** osmolarity is **hyperosmotic** and the solution with **lower** osmolarity is **hyposmotic**.

Osmosis is the flow of water across a semipermeable membrane from a solution with low solute concentration to solution with high solute concentration, or down an osmotic pressure gradient.

The **osmotic pressure** across the membrane can be calculated using the **van't Hoff equation**:

$$\boldsymbol{\pi} \mathbf{= g \cdot R \cdot T \cdot C}$$

where $\boldsymbol{\pi}$ is the osmotic pressure, mm Hg; **g** is the number of particles in solution, osm/l; **R** is the gas constant, R = 62 mm Hg l/mol K; **T** is the absolute temperature, K; **C** is the concentration, mol/l.

Two solutions having the **same** effective osmotic pressure are **isotonic** because no water flows across a semipermeable membrane separating them. If two solutions separated by semipermeable membrane have different osmotic pressures, the solution with the **higher** effective osmotic pressure is **hypertonic** and the solution with the **lower** effective osmotic pressure is **hypotonic** solution.

The **flow of water** caused by osmotic pressure differences can be calculated using the osmotic flow equation:

$$\mathbf{Flow = \delta \cdot L \cdot A \cdot (\pi_1 - \pi_2)}$$

where δ is the reflection coefficient $\delta = 1 - P_{solute}/P_{water}$, where P_{solute} and P_{water} are the membrane permeabilities of the solute and solvent, respectively; **L** is the **hydraulic conductivity** of the membrane, $l/s/cm^2$ /mm Hg; **A** is the area of the membrane, cm^2; π_1, π_2 are the osmotic pressures on either side of the membrane, mm Hg .

Active Transport. For all of the transport methods described above, the cell expends no energy. Membrane proteins that aid in the passive transport of substances do so without the use of ATP. During primary active transport, ATP is required to move a substance across a membrane, with the help of membrane protein, and against its concentration gradient.

One of the most common types of active transport involves proteins that serve as pumps (fig. 2). The **sodium-potassium pump**, which is also called Na^+/K^+ ATPase, transports sodium out of a cell while moving potassium into the cell. The Na^+/K^+ pump is an important ion pump found in the membranes of all cells. The activity of these pumps in nerve cells is so great that it accounts for the majority of their ATP usage.

Active transport pumps can also work together with other active or passive transport systems to move substances across the membrane. For example, the sodium-potassium pump maintains a high concentration of sodium ions outside of the cell. Therefore, if the cell needs sodium ions, all it has to do is open a passive sodium channel, as the concentration gradient of the sodium ions will drive them to diffuse into the cell. In this way, the action of an active transport pump the sodium-potassium pump powers the passive transport of sodium ions by creating a concentration gradient. When active transport powers the transport of another substance in this way, it is called secondary active transport.

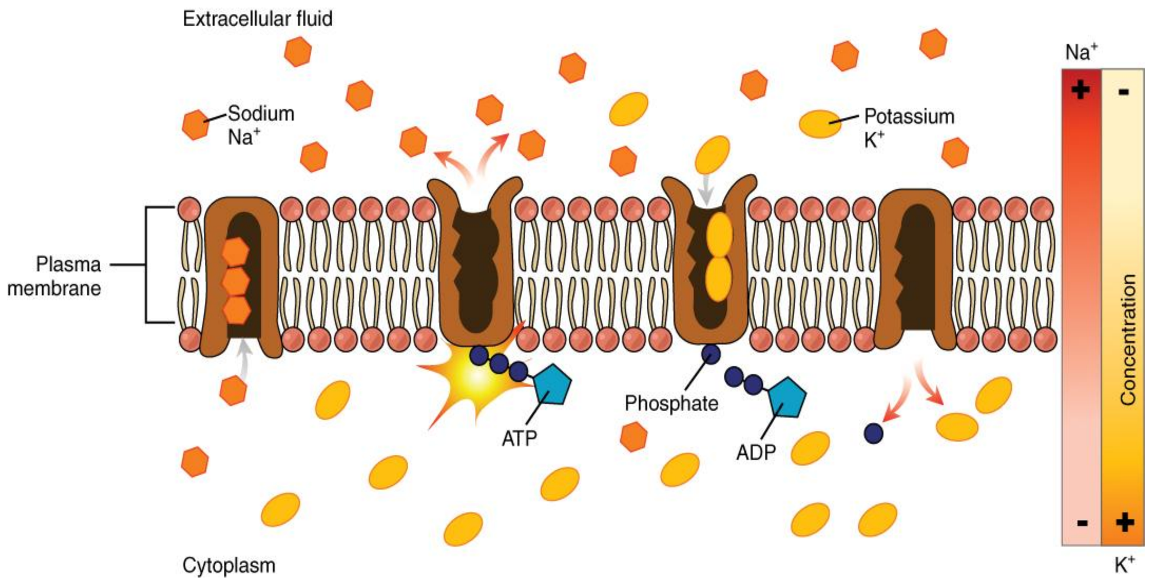

Figure 2