TOPIC 5.A. Transport Phenomena

Spatial heterogeneity of values of system parameters (temperature, pressure, concentration, electric potential, etc.) results in transport phenomena. Transfer physical quantity occurs in the opposite direction of the gradient, and the system ultimately will pass to the equilibrium state.

Exercise 5.1a. Define the following terms:

Flux of some quantity is____

____

Flux density is____

____

Gradient of any physical quantity is____

____

Exercise 5.2a. Fill in the table:

Transport phenomenon	The parameter which determines the transport	Law (name)	Equation
Diffusion			(5.1a)
Viscosity			(5.2a)
Thermal conductivity			(5.3a)

Exercise 5.3a. Specify arrows the accordance between the physical quantity and the formula for its calculation:

1) Diffusion coefficient	a) $\eta = \frac{1}{3}\langle\lambda\rangle\langle\upsilon\rangle\rho\left[Pa\cdot s\right]$ (5.4a)
2) Coefficient of viscosity	b) $\kappa = \frac{1}{3}\langle\lambda\rangle\langle\upsilon\rangle\rho C_{Vm}\left[W\cdot m^{-1}\cdot K^{-1}\right]$ (5.5a)
3) Thermal conductivity coefficient	c) $D = \frac{1}{3}\langle\lambda\rangle\langle\upsilon\rangle\left[m^2\cdot s^{-1}\right]$ (5.6a)

Exercise 5.4a. After analyzing the Exercise 5.3 write down the relation between transport coefficients:

(5.7a)

Transport coefficients determined by the mean free path of molecules, the mean distance that a molecule passes between two collisions:

$$\langle\lambda\rangle = \frac{1}{\sqrt{2}\pi\sigma^2 n_V}, \quad [m] \qquad (5.8a)$$

where σ is an effective diameter of molecules (the minimum distance that can get close to centers of two molecules); n_V is *the concentration of molecules*.

The average time between two successive collisions of molecules τ can be found by dividing the mean free path of molecules by their mean speed: $\tau = \frac{\langle \lambda \rangle}{\langle \upsilon \rangle}$. (5.9a)

Example of problem solution.

Calculate the time during which air with mass m = 720 mg diffuse from soil to the atmosphere through the surface with area S = 1 m^2, if the air diffusion coefficient is D = 0.04 cm^2·s^{-1} and density gradient is $\frac{\Delta\rho}{\Delta x} = -0.50\times10^{-6}$ g·cm^{-4}.

Data:

S = 1 m^2

m = 720 mg = 720×10^{-6} kg

D = 0.04 cm^2·s^{-1} = 0.04×10^{-4} m^2·s^{-1}

$\frac{\Delta\rho}{\Delta x} = -0.50\times10^{-6}$ g·cm^{-4}= = -0.05 kg·m^{-4}

t = ?

Solution:

The mass of gas transported as a result of diffusion, obeys Fick`s law:

$$m = -D\,\frac{\Delta\rho}{\Delta x}St$$

Express the time from the Fick`s law: $t = -\frac{m}{D(\Delta\rho/\Delta x)S}$.

Make calculations of diffusion time:

$$t = -\frac{7.2\times10^{-4}}{4\times10^{-6}\times(-0.05)\times1} = 3.60\times10^{3}\ \text{s} = 1\ \text{hour}.$$

Answer: Diffusion occurred within one hour.

Problem 5.5a. At what pressure the mean free path of hydrogen molecules is 2.5 cm if the gas temperature is 67 °C? The effective diameter of a hydrogen molecule is 0.28 nm.

Data:

Solution:

Answer: ____________________

Problem 5.6a. Calculate how many times dynamic viscosity coefficient of carbon dioxide differs from nitrogen one if both gases are at the same temperature and the same pressure. The effective diameters of gas molecules are also identical.

Data:

Solution:

Answer: ____

Problem 5.7a. Calculate the thermal conductivity coefficient of nitrogen gas, if under the same conditions the coefficient of dynamic viscosity for this gas is 10 μPa·s.

Data:	***Solution:***

Answer: ____

Control questions

1. Show the interrelation between transport coefficients.
2. Gradient of any physical quantity is...
3. What do you know about viscosity of medicines?
4. What methods of measuring viscosity do you know?
5. Surface tension of liquid medications.
6. Surface-active substances.

Individual assignments

1. At what temperature mean free path of air molecules is equal to 9.3×10^{-8} m? The effective diameter of air molecules is 3×10^{-10} m. The pressure is normal.
2. Calculate the mean number of collisions per unit of time ν molecules of carbon dioxide at 100 °C, if the mean free path of molecules $\langle\lambda\rangle = 0.03$ nm.
3. Find the thermal conductivity coefficient of hydrogen, if it is known that under the same conditions the coefficient of viscosity for it is equal to 8.6 μPa·s.
4. Find coefficient of viscosity of nitrogen under the normal conditions, if its diffusion coefficient is equal to 1.42×10^{-5} $m^2 \cdot s^{-1}$.
5. For what time will amount of heat equals to 2 kJ pass through the animal`s muscles with cross-section area 1 dm^2 and thickness 10 mm at the temperature is 38 °C. Ambient temperature is 15 °C. Thermal conductivity coefficient of the muscle is 5.7×10^{-2} $W \cdot m^{-1} \cdot K^{-1}$.
6. What mass of carbon dioxide will diffuse from soil to atmosphere per 1 hour through the surface of the beds with width 50 cm and a length 18 m if the visible surface of the beds is 1.5 times less than soil surface obtained by loosening it? Do you need some additional data to solve this problem?
7. For what time will 720 mg of carbon dioxide diffuse from black soil into the atmosphere through 1 m^2 of its surface if density gradient is 10 $g \cdot cm^{-1}$? The diffusion coefficient is equal to 0.04 $cm \cdot s^{-1}$.

TOPIC 5.B. Transport of Substances Through Biological Membranes

The topic covers the information on the structure of biological membranes, transport of substances through them, generation and propagation of nerve impulse, reception processes and transformations of energy. Biological membranes serve many functions in an organism. They enclose dividing a cell into separate regions, compartments, that allows the cell to maintain a nonequilibrium state of a biosystem. The topic is especially important for pharmacy because the efficiency of medicines greatly depends on their ability to penetrate into tissues that in its turn is determined by permeability of biological membranes to the medicines.

Exercise 5.1b. Give detailed answers to the following questions.

Biological membranes have the following properties:

____

____

____

Semipermeability is ____

____

Membrane fluidity ____

____

Types of membrane lipid motion:

1) Simple motion
   a. ______________________________
   b. ______________________________
   c. ______________________________
2) Composite motion
   a. Lateral diffusion is ___________________________
      ____
   b. Flip-flop gap is ______________________________
      ____

In this regard, biological membranes serve the following functions in biosystems:

____

____

____

____

Transport function is one of the most important functions of biological membranes. The most vital activity processes, such as absorption, excretion, propagation of nerve impulse, muscle contraction, ATP synthesis, etc. are bound up with movement of substances through membranes. Schematically, types of membrane transport can be represented as follows:

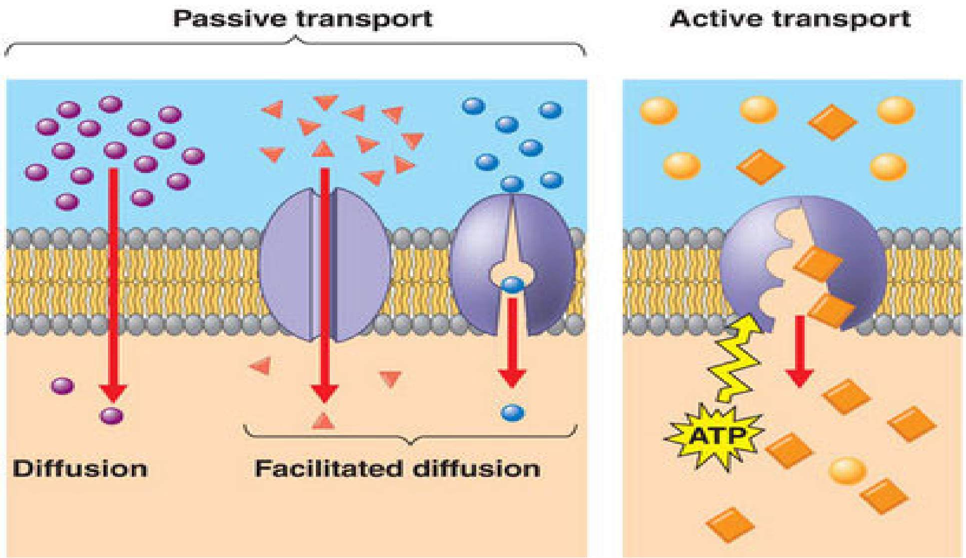

Fig. 5.1b. Types of membrane transport

Exercise 5.2b. Define the following terms and write down the answers.

Passive transport is ____

____

Active transport is ____

____

There are following types of passive transport: ______________________________

____

Simple diffusion is ____

Osmosis is ____

Transport of substances through the membrane channels is ______________________

____

Facilitated diffusion is ____

____

There are following types of active transport: ______________________________

____

Ion channels are ____

____

Passive Transport Across the Membrane

They say that there is a *concentration gradient* if in two different regions of space the concentrations of the same substance are not equal. In this case, we will observe the phenomenon of diffusion or *passive transport* of the substance from an area of higher concentration to an area with lower concentration. This phenomenon will occur spontaneously (without energy consumption) until concentration of the substance in the two regions become the same and the total flow of the substance is zero. In a case of living cells such equilibrium may not be achieved if substances are continuously synthesized or are spent in a course of chemical reactions in some part of space Passive transport of a substance along an axis is described by the *Fick's Law*:

$$J = -D\frac{dc}{dx}, \quad (5.1b)$$

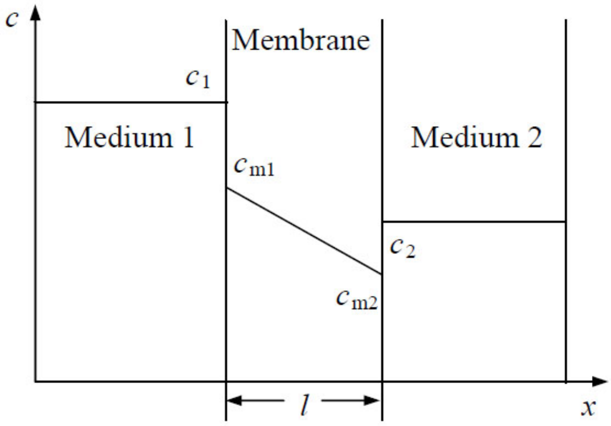

Fig. 5.2b. Schematic representation of diffusion of substances between the cell and the external environment

where J is the *substance flux*. The flux is numerically equal to the quantity M of a substance transported per unit time t through a unit surface A perpendicular to the transport direction. Its units of measurement are $[J]$ = mol / (m^2·s);

D is the *diffusion coefficient.* Its units of measurement are $[D]$ = m^2/s;

dc/dx is the gradient of concentration in the x direction. The sign "–" means that the flux is directed towards a low concentration area, i.e. results in decrease in the concentration gradient.

When considering the passive transport of uncharged particles through the membrane we can take gradient of concentrations as constant $\frac{dc}{dx} = \frac{c_o^m - c_i^m}{l}$, where l is thickness of the membrane. Substituting this expression into the Fick's Law (5.1b) we obtain:

$$J = -D\frac{c_o^m - c_i^m}{l} = -DK\frac{c_o - c_i}{l}. \quad (5.2b)$$

Let's introduce a concept of a coefficient of distribution of the substance between the membrane and the ambient medium:

$$K = \frac{c_o^m}{c_o} = \frac{c_i^m}{c_i}. \quad (5.3b)$$

where c_o and c_i are concentrations of substance ***i***nside and ***o***utside the cell, respectively. The distribution coefficient K has no units of measurement. *Permeability coefficient* is defined as:

$$P = \frac{DK}{l}. \quad (5.4b)$$

Problem 5.3b. A flat bilayer membrane of thickness l = 10 nm divides a chamber into two parts in which there is a substance of concentrations c_1 = 2 mmol L^{-1} and c_2 = 30 mmol L^{-1}. The substance flux through the membrane is $J = 0.8\times10^{-3}$ mmol m^{-2} s^{-1}. Calculate the diffusion coefficient D of this substance if it is known that its distribution coefficient is K = 0.05.

Data:	***Solution:***

Answer: ____

Problem 5.4b. Calculate the coefficient of permeability for the substance which flow through the membrane is J = 5×10^{-5} mol/(m^2·s). The concentration of the substance inside the cell is 1.8 ×10^{-4} mmol·L^{-1} and outside the cell is 3×10^{-5} mmol·L^{-1}.

Data:	***Solution:***

Answer: ____

Nernst Potential

In a living organism, there are ion solutions on both sides of a membrane. The concentrations of the same ion on both sides of the membrane often differ from each other. One of reasons of existence and maintenance of these concentration gradients is different permeability of the membrane to different ions. In this case the concentration gradient of a substance can be maintained by potential difference across the membrane (the so-called *transmembrane potential difference*). The value of *transmembrane potential difference* can be obtained by *Nernst equation*:

$$\Delta\varphi = \varphi_i - \varphi_o = \frac{RT}{zF}\ln\frac{c_o}{c_i}, \qquad (5.5b)$$

where φ is the electrical potential measured in Volts;

T is thermodynamic temperature measured in Kelvin degrees;

z is the integer charge of the ion: K^+; Na^+; Cl^-; Ca^{2+};

c_o and c_i are concentrations of substance ***i***nside and ***o***utside the cell, respectively;

F = 9.65×10^4 C/mol is Faraday's constant; R = 8.314 J/(K·mol) is the molar gas constant.

Problem 5.5b. A semipermeable membrane divides two solutions of positive univalent ions of concentrations c_1 = 50 mmol·L^{-1} and c_2 = 500 mmol·L^{-1}. Find a potential difference across the membrane at a temperature of t = 37 °C.

Data:	***Solution:***

Answer: ____

Problem 5.6b. Two solutions of lithium ions are divided by a flat bilayer membrane. Calculate ratio of ion concentrations in the solutions at which the equilibrium potential difference is $\Delta\varphi$ = 116 mV. The medium temperature is t = 20 °C.

Data:	***Solution:***

Answer: ____

Problem 5.7b. How many times an extracellular concentration c_o of sodium ions must exceed their intracellular concentration c_i in order to set Nernst potential to $\Delta\varphi$ = +50 mV at a temperature of t = 27 °C.

Data:	***Solution:***

Answer: ____

Active Transport Through the Membrane

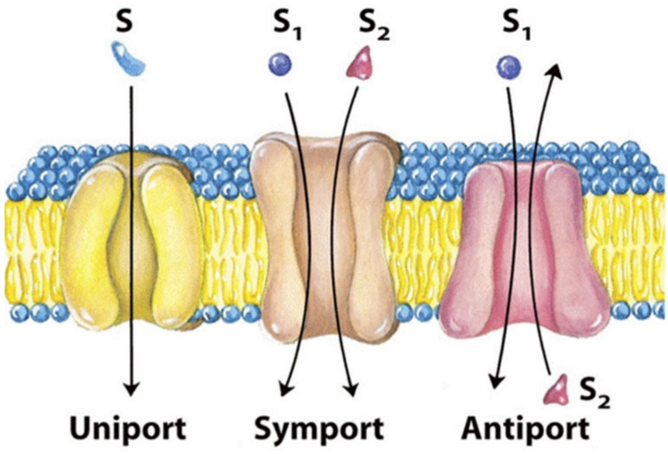

Fig. 5.3b. Secondary active transport.

Exercise 5.8b. Complete definitions. Help yourself with picture.

Secondary active transport is ____

____

Uniport transports ____

____

Cotransport is ____

____

Symport transports ____

____

Antiport transports ____

____

Exercise 5.9b. Match the type of transport and the way in which it occurs:

Primary active transport	using any ion electrochemical potential gradient energy
Secondary active transport	performed using the energy of ATP

Control questions

1. Liposomes and their prospects for use in pharmacy.
2. How do you understand the concept of a concentration gradient? Describe in your own words.
3. What process is described by the Nernst equation?
4. What is the difference between the active transport of substances from passive?
5. What states are called the liquid-crystal and gel states of the membrane?

Individual assignments

1. A biomembrane of thickness 8 nm divides a compartment into two parts in which there is a substance of concentrations $c_1 = 4$ mmol L^{-1} and $c_2 = 35$ mmol L^{-1}. The substance flux through the membrane equals to 1.2×10^{-3} mmol m^{-2} s^{-1}. Calculate the diffusion coefficient of this substance if $K = 0.16$.
2. The concentration of the substance inside the cell is 26 mmol L^{-1}; its concentration outside the cells is = 3.2 mmol L^{-1}. The substance flux through a membrane which thickness is 9.6 nm, is $J = 1.48\times10^{-3}$ mmol m^{-2} s^{-1}. Calculate the diffusion coefficient of this substance if it is known that its distribution coefficient is 0.33.
3. Calculate the distribution coefficient K of the substance through a membrane if the membrane thickness is 8 μm, the diffusion coefficient of a substance is $D = 65\times10^{-9}$ m^2/s, the permeability coefficient of the substance is $P = 1.17$ m/s.
4. The membrane thickness is 8.75 nm, the diffusion coefficient of a substance is 90.12×10^{-9} m^2/s, the permeability coefficient of the substance is $P = 10$ m/s. Calculate the distribution K of the substance.
5. A semipermeable membrane divides two solutions of univalent ions of concentrations $c_1 = 30$ mmol L^{-1} and $c_2 = 340$ mmol L^{-1}. Find a potential difference across the membrane at a temperature of $t = 32$ °C.
6. Two solutions of lithium ions are divided by a flat bilayer membrane. Calculate ratio of ion concentrations in the solutions at which the equilibrium potential difference is $\Delta\varphi = 96$ mV. The medium temperature is $t = 26$ °C.
7. How many times an extracellular concentration c_o of sodium ions must exceed their intracellular concentration c_i in order to set Nernst potential to $\Delta\varphi = +62$ mV at a temperature of $t = 30$ °C.