Subject 7. Colligative properties of solutions

1. Importance

Colligative properties of solutions (diffusion, osmosis) are vital for the organism. Osmosis stipulates distribution of water and nutrients among different organs and tissues of the organism. Osmosis depends on the nature of membranes. Transportation of nutrients is possible due to selective permeability of membranes. Inside the cell, osmotic pressure is bigger than in the extracellular fluid. Osmometric, criometric, and ebulliometric methods are used to study biological liquids, to measure their osmolality, average molecular mass of proteins and other physiologically active compounds.

Competences

Ability of abstract thinking, analysis and synthesis, ability to learn.

Ability to apply knowledge in practical situations.

Ability to choose strategy of communication; ability to work in a team; skills of interpersonal interaction.

Ability to excercise self-control and maintain healthy lifestyle, ability to adapt and act in new situations.

Motivation and persistence in following goals.

Skills in using information and communication technologies.

Ability to assess and ensure quality of performed work.

Strive to preserve the environment.

Ability to assess results of laboratory and practical experiments.

Ability to solve standard problems and to solve practical problems in the course of training.

2. Concrete aims

Analyze relationship of colligative properties and concentration of solutions.

Prepare isotonic solutions.

3. Basic knowledge, skills necessary for studying the subject (interdisciplinary integration)

Previous subjects	Obtained skills

1. Chemistry and Physics (school course)	Understand the concept "osmosis". Have knowledge of solutions of electrolytes, nonelectrolytes and their dissociation. Theory of electrolytic dissociation.
2. Medical and Biological Physics	Understand diffusion and its rate.
3. Medical Biology	Understand osmotic and oncotic pressure, turgor
4. Foreign language for professional purposes	Have perfect knowledge of English language. Be able to communicate in English language both orally and in writing.
5. Safety, basics of bioethics and biosafety	Seek to preserve the environment.

4. Tasks for independent work during preparation for the class and in class.

4.1. The list of key terms, parameters, characteristics which the student is to learn while preparing for classes:

Term	Definition
1. Colligative properties of the diluted solutions	These are properties that only depend on the number of particles in a solution, but not on their nature, size, shape, weight.
2. Raoult's law	Relative pressure depression of saturated vapor of the solvent over a solution is proportional to the molar fraction of the solute.
3. Osmosis	It is unilateral diffusion of molecules of the solvent through a semipermeable membrane from a solution with smaller concentration to a solution with bigger concentration of the solute.
4. Osmotic pressure	Excessive hydrostatic pressure in a vessel with a solution at which osmotic equilibrium is established.
5. Vant Hoff's law	Osmotic pressure of a solution is directly proportional to its molar concentration and absolute temperature.
6. Isotonic solutions	Solutions with identical osmotic pressure.
7. Osmotic pressure of	7.7 – 8.1 atm.

blood plasma	
8. Oncotic pressure	Pressure created by high-molecular biologically active compounds, mostly proteins albumins (0.03 – 0.04 atm).
9. Plasmolysis	Reduction of volume of erythrocytes at introduction of hypertonic solutions to blood plasma.
10. Hemolysis	Destruction of erythrocyte membranes when hypotonic solution is introduced to blood plasma that is followed by hemoglobin leakage in plasma.

4.2. Theoretical questions for the lesson:

1. Colligative properties of diluted solutions of non-electrolytes:

a) Relative depression of the saturated vapor pressure of the solvent over a solution. Raoult's law;

b) Boiling point elevation and freezing point depression of solutions compared to pure solvents. Criometry, ebulliometry.

c) Osmosis. Osmotic pressure. Van't Hoff's law. Hemolysis and plasmolysis.

2. Colligative properties of diluted solutions of electrolytes. Isotonic coefficient. Hypo-, hyper- and isotonic solutions in medical practice.

3. Role of osmosis in biological systems. Osmotic pressure of blood plasma. Oncotic pressure.

4.3. Practical work (task) done by students in class

1. Prepare 500 ml of 0.9% NaCl solution that is isotonic to blood.

2. What mass of NaCl is to be taken to prepare 200 g of a solution that is isotonic to blood.

3. Calculate what mass of glucose is to be taken to prepare 100 g of 4.5% solution that is isotonic to blood.

4. Calculate what mass of water is to be taken to prepare 50 mL of 0.9% solution of NaCl, if the density of the solution is 1 g/mL.

5. Calculate what mass of water should be taken to prepare 200 g of 4.5% glucose solution.

Contents of the subject (abstract):

1. Colligative properties of diluted solutions of nonelectrolytes:

Colligative properties of diluted solutions are the properties that depend only on the number of particles in a solution, but not on their nature, shape, size, weight. The following properties are colligative properties of diluted solutions of nonelectrolytes:

a) depression of pressure of saturated vapor of the solvent over a solution compared to pressure of its saturated vapor over the pure solvent;

b) boiling point elevation of a solution compared to that of the pure solvent;

c) freezing point depression of a solution compared to that of the pure solvent;

d) osmosis, osmotic pressure;

e) diffusion.

a) Relative depression of the saturated vapor pressure of the solvent over a solution. Raoult's law.

It is a depression of pressure of saturated vapor of the solvent over a solution compared to pressure of its saturated vapor over the pure solvent.

Pressure of saturated vapor is the pressure of that part of vapor that is in equlibrium with the liquid at the temperature.

Raoult's law:

Relative pressure depression of saturated vapor of the solvent over a solution is proportional to the molar fraction of the solute.

$$\frac{\Delta p}{p_0} = \chi,$$

where Δp is pressure depression of saturated vapor of the solvent over a solution;

p_0 is pressure of saturated vapor over the pure solvent;

χ is the mole fraction of the solute.

b) Boiling point elevation and freezing point depression of solutions compared to pure solvents. Criometry, ebulliometry.

- Boiling point elevation of a solution compared to that of the pure solvent.

Boiling temperature of a liquid is the temperature at which the pressure of saturated vapor of the solvent over a liquid is equal to atmospheric pressure (101.3 kPa).

The difference between boiling temperature of a solution and boiling temperature of the solvent (water) is **boiling point elevation** (ΔT_b): $\Delta T_b = T_{b\ solution} - T_{b\ water}$.

Second Raoult's law:

Boiling point elevation of a solution is directly proportional to the molality of the solute:

$$\Delta T_b = K_e \cdot C_m$$

Ebulliometry is the method of research based on measurement of boiling point elevation of a solution compared to boiling temperature of the pure solvent.

- Freezing point depression of a solution compared to that of the pure solvent.

Freezing temperature of a liquid is the temperature at which the pressure of saturated vapor of over a liquid is equal to vapor pressure over the solid phase of the substance.

The difference between freezing temperature of the solvent (water) and freezing temperature of the solution is **freezing point depression** (ΔT_f): $\Delta T_f = T_{f\ water} - T_{f\ solution}$.

Second Raoult's law:

Freezing point depression of a solution is directly proportional to the molality of the solute:

$\Delta T_f = K_c \cdot C_m$

Criometry is the method of research based on measurement of freezing point depression of a solution compared to freezing temperature of the pure solvent.

c) Osmosis. Osmotic pressure. Van't Hoff's law. Hemolysis and plasmolysis.

Osmosis is unilateral diffusion of molecules of the solvent through a semipermeable membrane from a solution with smaller concentration to a solution with bigger concentration of the solute.

Osmosis can be observed in an osmometer.

Osmotic pressure is the excessive hydrostatic pressure in a vessel with a solution at which osmotic equilibrium is established.

Vant Hoff's law:

Osmotic pressure of a solution is directly proportional to its molar concentration and absolute temperature.

Mathematical expression of the law:

$$\boldsymbol{\pi = CRT,}$$

where π is the osmotic pressure of solution;

C is molarity of the solution;

R is the universal gas constant (8.31 J / mol·K);

T is absolute temperature.

Plasmolysis is a decrease of volume of erythrocytes (shrinking) at an introduction of hypertonic solutions to blood plasma.

Hemolysis is destruction of erythrocyte membranes when hypotonic solution is introduced to blood plasma that is followed by hemoglobin leakage in plasma.

2. Colligative properties of diluted solutions of electrolytes. Isotonic coefficient. Hypo-, hyper- and isotonic solutions in medical practice.

Vant Hoff measured colligative properties of the diluted solutions of electrolytes experimentally. He found out that in all cases they were greater than those calculated from the relevant equations. Thus, Vant Hoff introduced the **isotonic coefficient *i***.

Van't Hoff's isotonic coefficient allows to account for the effect of the increase in the number of particles in solutions of electrolytes due to their dissociation on colligative properties of solutions.

The value of the isotonic coefficient depends on the nature of the electrolyte and its concentration in a solution.

The coefficient also depends on dissociation degree of the electrolyte **α** and the number of ions **n** that are furnished upon dissociation of the electrolyte:

$$\boldsymbol{i = 1 + \alpha\,(n - 1)}$$

Solutions with identical osmotic pressure are **isotonic**.

Hypertonic solution has a bigger osmotic pressure than another solution.

Hypotonic solution has a smaller osmotic pressure than another solution.

In medical practice, solutions with osmotic pressure equal to osmotic pressure of blood plasma (7.7 – 8.2 atm) are isotonic. These are a 0.9% NaCl solution or 4.5 - 5% glucose solution.

3. Role of osmosis in biological systems. Osmotic pressure of blood plasma. Oncotic pressure.

All biological liquids are water solutions of inorganic and organic substances. They have certain osmotic pressure that is maintained at a constant level. **Osmotic pressure of blood plasma** in the human body is 770 - 821 kPa (7.7 – 8.2 atm). About 60% of osmotic pressure of blood is produced by Na^+ and Cl^- ions, and a very small part of it is produced by proteins. The pressure produced by high molecular biologically active compounds is called **oncotic pressure**. It makes 0.5% of the total osmotic pressure (3.04 – 4.05 kPa or 0.03 – 0.04 atm) and is mostly produced by albumins.

Materials for self control:

A. Tasks for self control:

1. When is the first solution hypertonic to the second one?
   a) 5 *M* sucrose and 5 *M* urea;
   b) 1 *M* glucose and 0.1 *M* sucrose;
   c) 0.1 *M* sucrose and 0.08 *M* potassium nitrate;
   d) 0.1 *M* potassium nitrate and 0.8 *M* calcium chloride.
2. Over which of the solutions is the pressure of the saturated water vapor the biggest and leads to the smallest boiling temperature of the solution?
a) 0.4 *M* calcium chloride;
b) 1 *M* potassium chloride;
c) 0.4 *M* urea;
d) 1.0 *M* sucrose.
3. Which one of the following solutions is hypertonic:
a) 10% NaCl
b) 5% glucose
c) 0.1% NaCl
d) 0.9% NaCl
4. What happens to erythrocytes placed in a 1% glucose solution?
a) hemolysis
b) plasmolysis
c) endoosmosis
d) diffusion
5. An intravenous introduction of a hypertonic solution of NaCl causes:
a) plasmolysis of erythrocytes
b) diffusion of erythrocytes
c) hemolysis of erythrocytes
d) turgor of erythrocytes

B. Practical tasks for self control:

1. A solution contains 18g of solute in 500 mL water. Its osmotic pressure is 0.0456 MPa at 0°C. Calculate the molar mass of the solute.

2. The osmotic pressure of blood plasma at 37° C is 0.77 MPa. How much sucrose is needed to prepare 0.5L solution isotonic to blood.

Literature

Main:

1. Medical Chemistry: textbook / V.O. Kalibabchuk, V.I. Halynska, V.I. Hryshchenko et al.; edited by Prof. V.O. Kalibabchuk – Kyiv: "Medicine", 2010 – 224 p. (P. 62 – 73).

Informational resources:

2. www. pdmu, edu.ua
https://med-chemistry.pdmu.edu.ua/

(Web page of Poltava State Medical University).