

МІНІСТЕРСТВО ОХОРОНИ ЗДОРОВ'Я УКРАЇНИ
ХАРКІВСЬКИЙ НАЦІОНАЛЬНИЙ МЕДИЧНИЙ УНІВЕРСИТЕТ

**VALUES CHARACTERIZING QUANTITATIVE COMPOSITION OF
SOLUTIONS. PREPARATION OF SOLUTIONS. COLLIGATIVE
PROPERTIES OF SOLUTIONS**

Methodical instructions for 1st year students' self-work
in Medical Chemistry

**ВЕЛИЧИНИ, ЩО ХАРАКТЕРИЗУЮТЬ КІЛЬКІСНИЙ СКЛАД
РОЗЧИНІВ. ПРИГОТУВАННЯ РОЗЧИНІВ. КОЛІГАТИВНІ
ВЛАСТИВОСТІ РОЗЧИНІВ**

Методичні вказівки для самостійної роботи студентів 1-го курсу
з медичної хімії

Затверджено
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Values characterizing quantitative composition of solutions. Preparation of solutions. Colligative properties of solutions: methodical instructions for 1st year students' self-work in Medical Chemistry / compiled by A.O. Syrovaya, O.S. Kalinenko, V.N. Petyunina, S.V. Andreeva, V.O. Makarov S.N. Kozub, L.V. Lukianova, T.S. Tishakova, O.L. Levashova, O.O. Zavada, E.V. Savelieva, N.N. Kopoteva, N.N. Chalenko, M.O. Vodolazhenko. – Kharkiv: KhNMU, 2017. – 24 p.

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Величини, що характеризують кількісний склад розчинів. Приготування розчинів. Колігативні властивості розчинів: метод. вказ. для студентів 1-го курсу / уклад. Г.О. Сирова, О.С. Каліненко, В.М. Петюніна, В.О. Макаров, С.В. Андрєєва, Л.В. Лук'янова, С.М. Козуб, Т.С.Тішакова, О.Л. Левашова, О.О. Завада, О.В. Савельєва, Н.В. Копотєва, Н.М. Чаленко, М.О. Водолаженко. – Харків: ХНМУ, 2017. – 24 с.

Укладачі:

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Subject “Values characterizing quantitative composition of solutions. Preparation of solutions. Colligative properties of solutions”

1. Number of hours 4

2. Material and methodological support.

Tables:

1. Scheme of structure of the subject.
2. Methods of expression of solutions' concentration.
2. Formulas for calculation solutions' concentrations.
- a) Material support: chemicals, laboratory glassware;
- b) Methodological support: posters, methodical instructions, text-books, lectures.
4. Van't Hoff's law.
5. Raoult's law.
6. Isotonic coefficient.
7. Colligative properties in biomedical researches.
8. Hemolysis and plasmolysis of cells.
9. Scheme of osmometer.

Multimedia support (presentations, scientific films)

Education literature:

1. Medical chemistry: textbook / V.O. Kalibabchuk, V.I. Halynska, L.I. Hryshchenko et al.; – Kyiv : AUS Medicine Publishing, 2010. – 224 p.
2. Fundamentals of medical chemistry: manual for students' self-work / A.O. Syrovaya, E.R. Grabovetskaya, L.G. Shapoval. – Kharkiv: KhNMU, 2015. – 196 p.
3. Medical chemistry. Adapted concise course: manual for students' self-work manual for students' self-work / A.O. Syrovaya, E.R. Grabovetskaya, L.G. Shapoval. - Kharkiv: KhNMU, 2013. – 160 p.
4. Medical chemistry: workbook for self-work of first-year students of medical and dentistry faculties / compiled by A. O. Syrovaya, V. N. Petunina, V. A. Makarov et al. – Kharkiv : KhNMU, 2017. – 72 p.
5. Values characterizing quantitative composition of solutions. Preparation of solutions. Colligative properties of solutions. - Methodical instructions for 1st year

students' self-work in Medical Chemistry / compiled by A. O. Syrovaya, O.S. Kalinenko, V.N. Petyunina et al. – Kharkiv : KhNMU, 2017. – 24 p.

6. Individual tasks for students' self-control of knowledge in Medical Chemistry / A.O. Syrovaya, L.G. Shapoval, et al. – Kharkiv: KhNMU, 2014. –50 p.

7. Text of lecture.

Laboratory utensils and reagents for laboratory work "Growth of Traube's artificial cell" (support with test tubes, 5 ml pipettes, crystalline potassium hexacyanoferrate(II), 5% copper sulfate).

3. **Substantiation for the subject.**

All vitally important processes in the organism take place in the solutions. Water is a solvent comprising about 60% to 80% of total body weight (45—50 l per 70 kg of body weight). Intensively functioning organs like lungs, kidneys, brain, heart, liver etc. rich in water particularly.

Concentration is a qualitative feature of a solution, that's why ability to estimate it, conversion from one type of concentration expression to another is necessary when studying many medico-biological disciplines.

Colligative properties are important in study of life activity of the organism, for example, osmotic pressure is an important factor in determining the distribution of water and nutrients between the various organs and tissues. Isotonic and hypertonic solutions are widely used in medical practice. Determination of colligative properties of biological fluids is used in biomedical researches (osmometry, cryometry, ebulliometry).

4. **The purpose of the subject:**

- general: to explain the common physical and chemical laws underlying the processes of life, to be able to characterize qualitative composition of solutions and to prepare solutions with given concentration;

- specific: to be able to prepare solutions with known concentrations, to analyze the relationship between concentration and colligative properties of solutions; to study the methods of osmometry, cryometry, ebulliometry and their use in biomedical researches.

a) **to know:** most common type of concentration expression, the role of water and aqueous solutions in the metabolism of the organism, colligative properties of solutions,

Raoult's law and its corollary, the laws of osmosis and diffusion, osmotic pressure, van't Hoff's law, characteristic features of colligative properties in electrolyte solutions, theoretical fundamentals of osmometry, cryometry, and ebulliometry, peculiarities of osmosis in the living organism, processes of hemolysis and plasmolysis.

b) **to be able to:** calculate concentrations of the solutions, prepare solutions with known concentrations, calculate osmotic pressure in solutions of varying concentration, depression in solutions, molar mass of physiologically active substances on the basis of the values of the osmotic pressure or depression; classify solutions based on values of osmotic pressure; predict what happens to a cell placed in a hypotonic, isotonic, hypertonic solution.

c) **practical skills:**

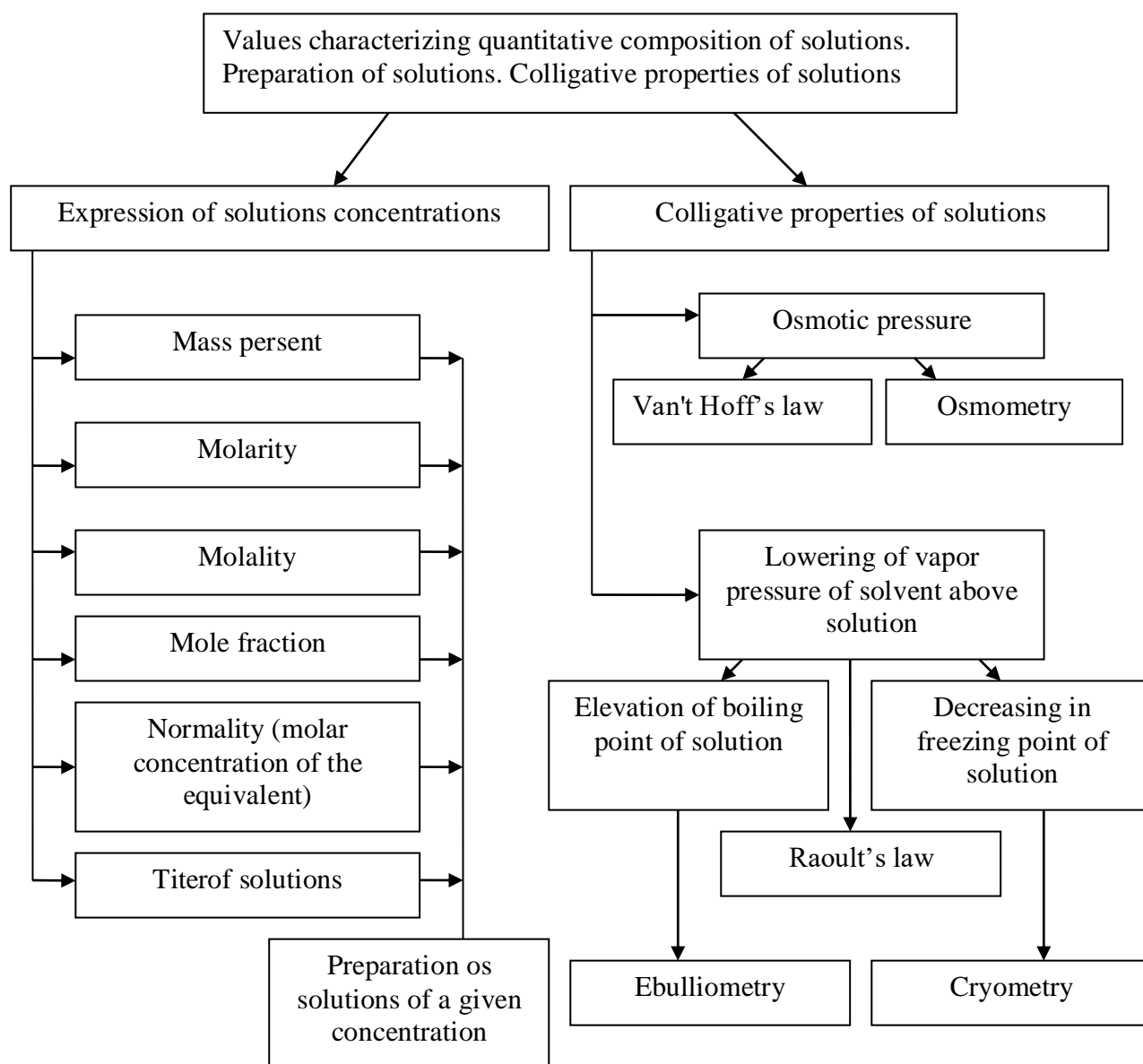
- to calculate concentrations of the solutions and to prepare solutions with known concentrations

- to calculate the osmotic pressure, depression in solutions, molar masses of physiologically active substances on the basis of the values of osmotic pressure or depression;

- to classify solutions based on values of osmotic pressure and concentration;

- to predict what will happen with the cell placed in a hypotonic, isotonic, and hypertonic solution.

5. Scheme of structure of the subject.



6. Plan of students' work.

No	Stage	Time, min	Educational and visual aids	Location
1.	Motivational characteristics and plan of the subject. Answers to the students' questions	20	Text-book (work-book)	Class room
2.	Incoming control	20		
3.	Students' self-work with methodical literature, solution of learning tasks	60	Methodical instructions for students, lecture note, text book for students' self-work, reference data, posters	
4.	Laboratory work	45	Reagents, equipment	
5.	Final control	20		
6.	Analysis and conclusions	10		
7.	Home work	5		

7. Tasks for self-work:

- List of questions to be studied:

1. Classification of the solutions.
2. Mechanism of the dissolution. Energetic effect of the dissolution.
3. Dissolution of the solutions.
4. Solubility of gases in the liquid.
5. Solubility of the solid and liquid substances in the liquid.
6. Values characterizing quantitative composition of solutions.
7. Colligative properties of dilute solutions of non-electrolytes:
 - 1) Osmosis and osmotic pressure. Van't Hoff's law.
 - 2) Lowering of vapor pressure of the solvent above the solution. Raoult's law.
 - 3) Depression in freezing point and elevation of boiling point of solutions.
8. Colligative properties of electrolytes. Isotonic coefficient.
9. Role of osmosis in biological systems. Properties of semi-permeable membranes. Oncotic pressure. Hemolysis and plasmolysis.

10. Osmometry, cryometry, and ebulliometry; their use in biomedical researches.

1. Classification of the solutions.

A *solution* is a homogeneous mixture consisting of two and more components and interaction products. Solutions can be liquid, solid or gas. Liquid solutions are important for medical professionals such as blood, lymph, intercellular lymph, and other biological liquids which are the complex mixtures of biologically active substances (proteins, carbohydrates, salts etc.). The degree of dispersion of substances in the solutions can be different. Particle size is a very important feature which causes many physical and chemical properties of the solutions. According to the particle size solutions can be classified as: a) true solutions (particle size is less than 10^{-9} m), which can be ionic and molecular depending on whether the solute dissociates on ions or molecules or stays in molecular state; b) colloidal solutions (particle size is from 10^{-7} to 10^{-9} m) are heterogeneous and have interface between phases - solute (dispersed phase) and solvent (dispersion medium).

Solutions of high molecular weight compounds (HMC) have properties both true solution and colloidal solution (particle size is more than 10^{-9} m).

2. Mechanism of the dissolution. Energetic effect of the dissolution.

There are two theories based on the structure of the substance: physical and chemical. According to the physical theory solvent (water) is regarded as indifferent medium in which solute molecules distribute uniformly. Interaction between solvent and solute is absent, which is typical for ideal solutions, infinitely diluted. This theory refers solutions to mechanical mixtures.

There is interaction between solute and solvent in true solutions that was proven by the thermal effects and changes in volume (usually decreasing). This was reflected in the chemical theory (solvation theory) of solutions developed by Mendeleev (1887). According to this theory chemical processes associated with the interaction of the solute with the solvent and physical processes associated with diffusion and uniform distribution of one substance in another medium play an important role in the process of dissolution. Unstable compounds called solvates (if the solvent is water, the compounds are called hydrates), which are in a state of equilibrium, form as a result of interaction

between the solvent and the solute. Substance decomposition into hydrated ions associates with the phenomenon of ionization (generation of ions). Let's consider the scheme of dissolution mechanism of the solids on the example of sodium chloride dissolution in water. Sodium chloride is formed by ionic bond. When it is dissolved dipoles of water molecules are oriented around salt as follows: negative poles of water dipoles turn towards the positive center of NaCl molecule, and positive poles — to the side of negative center of the molecule and attract them to itself. Due to this process, chemical bonds between the ions in the molecule weakened, and then broken - positively and negatively charged ions form. Water molecules come into ion-dipole interactions with these ions, forming hydrated ions (hydrates).

Thus, dissolution is a combination of two processes: solvation (hydration) and ionization.

Thermodynamically process of dissolution for solids in water can be represented by the equation:

$$\Delta H_{\text{dis}} = \Delta U_{\text{cr.l}} + \Delta H_{\text{hydr}}$$

where ΔH_{dis} — molar enthalpy of dissolution; $\Delta U_{\text{cr.l}}$ — energy of crystal lattice; ΔH_{hydr} — enthalpy of hydration.

Depending on the magnitude relation $\Delta U_{\text{cr.l}}$ and ΔH_{hydr} dissolution process can be endothermic or exothermic. Destruction of solute structure, which is accompanied by the bonds opening, needs energy consumption. Formation of solvated (hydrated) ions is accompanied by the energy release. Total energetic effect depends on the ratio between released and absorbed energy. If energy consumption on the solute destruction ($\Delta U_{\text{cr.l}}$) is more than energy released at the hydration (ΔH_{hydr}), then the process is endothermic. If, vice versa ($\Delta U_{\text{cr.l}} < \Delta H_{\text{hydr}}$), then the process is exothermic.

3. Dissolution of the solutions.

Dissolution is a process which occurs at the expense of diffusion of the molecules or ions from the area with a higher concentration to the area with low concentration. As a result the substance distributes uniformly in the whole volume of the solution.

Dissolution is a bidirectional process: solid substance passes into the solution but a solute passes into solid phase. So, dissolution and crystallization occur simultaneously. When these processes proceed with the same rates — dynamic equilibrium is reached.

When this happens concentration of solute is constant at unchanged conditions. Such state is called saturation and solution is saturated.

The solubility is the ability of a substance to dissolve in a solvent. The dissolution of most solids is attended by the absorption of heat. Concentration of saturated solution at a given temperature and pressure is a measure of solubility. Le Chatelier's principle is applied to the dissolution process.

Solubility depends on temperature, pressure, nature of substance to be dissolved and solvent.

4. Solubility of gases in the liquid.

Being spontaneous the process of gas dissolution in water is always exothermic. To shift equilibrium to the side of exothermic process according to the Le Chatelier's principle the temperature must be decreased. In other words, the solubility of gas increases with the rise of pressure and decreases with the rise of the temperature.

The solubility of gases depends on their pressure because solution formation is accompanied by the decreasing of the system's volume. The solubility of gas increases with the rising of pressure and decreases with the rise of the temperature. So the solubility of gas increases with the rise of pressure. **Henry's Law** determines the quantitative dependence:

The mass of a gas that dissolves at a constant temperature in a given volume of a liquid is directly proportional to the partial pressure of the gas.

$$C = K \times p,$$

where C is the mass concentration of the gas in a saturated solution, p is the partial pressure, and K is a constant known as Henry's law constant (or Henry's coefficient). Value of coefficient K reflects dependence of solubility on the nature of gas, solvent and temperature. Law is valid under the condition of relatively small partial pressure and in the case of dilute solutions, in other words when gas and solution became ideal.

Partial pressure (p) is the pressure of one component in a mixture of gases.

According to the Dalton law, total pressure of gas mixture is equal sum of partial pressures. Henry's law states that if maintaining constant temperature to increase partial pressure then absorption of gases will occur till a solution with higher concentration of

gas in liquid is obtained. If gas mixture with a lower partial pressure is passed through the solution, evolution part of gas from liquid will occur till its concentration in the solution does not correspond to the lower partial pressure of gas.

Particular solubility corresponds every temperature in given liquid and corresponding partial pressure over the solution. This meets the conditions of gas equilibrium — saturated solution.

Knowledge of Henry's and Dalton Law allows to analyze gas exchange processes between the human organism and the environment which takes place mainly in lungs. Partial pressure of oxygen and CO₂ in breathable air is 212.2 and 0.3 GPa, correspondingly. Content of oxygen in released air is low ($P_{O_2}= 162.5$ GPa), and carbon dioxide — high ($P_{CO_2}= 40.5$ GPa) — this difference causes the gas exchange in lungs. In the process of external respiration oxygen binds with hemoglobin and in the form of oxyhemoglobin is delivered by blood flow to the cell capillaries where it is absorbed and used for oxidation of low-molecular weight compounds. Simultaneously carbon dioxide forms and with blood flow goes to the lungs where it diffuses through the walls of the alveoles, entering the composition of expired air. Oxygen diffusion process is possible in this direction at the expense of higher partial pressure in alveolar air (143.9 GPa) in comparison with the equilibrium partial pressure over the venous blood (80-87 Gpa).

Migration of carbon dioxide from venous blood to the alveolar gas space is possible due to its equilibrium partial pressure over the venous blood (61 Gpa) is higher than partial pressure of this gas in the alveolar air (52.7 Gpa).

Henry's law allows to explain reasons of so called decompression diseases, for example, Caisson disease occurs in scuba divers, pilots and others. *Caisson disease* is a pathological condition that develops due to the formation of gas bubbles in blood. When the diver goes deeper into the water, where the surrounding water pressure is greater than the air pressure at sea level, the bloodstream absorbs more gaseous particles. During the fast return to the surface, there is a sharp decrease in gas dissolution in blood. Extra quantity of gases diffuse out of the tissues and is delivered by the bloodstream to the lungs, which expel it from the body. The rapid ascent is linked to the formation of bubbles that block vessels. These bubbles can compress nerves, obstruct arteries, veins,

and lymphatic vessels, and trigger harmful chemical reactions in the blood. Supersevere conditions are observed at the cerebral vascular occlusion. The solubility of gases in liquids depends on the nature of the gas, and the nature of the solvent, complying the rule "like dissolves like".

The solubility of gases in liquids proceeds due to van der Waals or chemical equilibrium. First case is characterized by low solubility (for example, nitrogen, oxygen in water), that's why gas molecules are not polar but water is dipole. Second case is characterized by high solubility. Such substances as CO₂, NH₃, SO₂, H₂S are polar. Product of the reaction between above mentioned substances and water is electrolyte which dissociates in the solution. Solubility of gases in the electrolyte solutions is less than in a pure solvent.

A well known Russian pharmacologist Ivan Michailovich Sechenov (1859) has been discovered the relation between the gas solubility in pure water (S_0), in the electrolyte solution (S) and electrolyte concentration (a):

$$S = S_0 e^{-ka} \quad (\text{Sechenov's law})$$

where e — base of the natural logarithm, K — constant, which value depends on the nature of electrolyte, dissolved gas and temperature.

Based on the mathematical expression of Sechenov's law we can come to conclusion that solubility of gases in aqueous electrolyte solutions the smaller compared to the solubility in pure water, the greater the concentration of dissolved salts in it is. Sechenov's law allows to explain why solubility of CO₂ and O₂ in blood plasma is lower than in water. There are large quantities of components in blood plasma including ions of salts. Part water in blood plasma consumes on their hydration that's why water volume in plasma decreases and that's why solubility of oxygen and carbon dioxide in blood plasma is less that in water. Content of all components in blood plasma can be changed that also influences the solubility of O₂ and CO₂.

5. Solubility of the solid and liquid substances in the liquid.

The solubility of solid substances significantly depends on the temperature. The dissolution of most solids is attended by the absorption of heat. In the state of saturation dissolution of solid in water can be represented by the following equation:



Le Chatelier's principle was applied to this equilibrium system. According to this principle elevation of the temperature shifts the equilibrium to the endothermic reaction, i.e. towards the formation of a saturated solution. Thus, solubility of most solids increases with the elevation of temperature and vice versa.

The solubility of solids is essentially independent of pressure because at the dissolution volume of system changes slightly. According to the Le Chatelier's principle, if volumes of initial reactants are equal to volumes of reaction products then change of pressure does not influence the equilibrium of the system.

Therefore, solubility of most solids depends on the temperature and is essentially independent of pressure.

The solubility of solids also complies with the rule "like dissolves like". Polarity of the molecules is important for the dissolution of most solids. All molecules formed by ionic bond (KCl, CaCl, Na₂SO₄ etc.) are polar (dipoles). Molecules formed by nonmetals with different electronegativity and assymetrical structure are also polar. It should be noted that the polarity of the molecules, formed by covalent bond, expressed in comparison with ionic bonds is less evident. Dielectric conductivity value is used for estimation of polarity degree. The more molecular polarity the less energy consumes on the destruction of the dissolved substance and the higher solubility is.

Solubility depends on the nature of solvent: the higher dielectric conductivity of the liquid the better solvent is. For example, urine, alba, blood have higher dielectric conductivity then water. So, biological liquids and tissues are good solvents for biologically active compounds, molecules of which are polar. Ability of solids to dissolve depends on its polarity. For example, good solubility of glucose is explained by the presence of a great number of polar alcohol groups in its molecules. Liquids of different nature mix one with another in different ratios: practically insoluble (water and oil), partially miscible (water and phenol), miscible in all proportions (water and alcohol).

So, complete miscibility of alcohol in water is explained by the fact that, molecules of alcohol and water are in the form of associates. The destruction of associates of alcohol and water occurs at the dissolution. New associates, which consist of molecules of alcohol and water, form in the solution.

Molecules containing a large quantity of non-polar hydrocarbon groups are not able to attract water molecules and destruct its associates, for example, higher fatty acids, phenol etc. Due to this, the mutual solubility of polar molecules, for example phenol in water, is limited and stratification of solute and solvent occurs with respect to their specific gravity. Phenol layer has a little water but water layer has a portion of phenol. These quantities are proportional to its mutual solubility at the given temperature.

Low-polar, non-polar molecules of solute dissolve in solvents, molecules of which are low-polar or non-polar. For example, fatty acids dissolve better in ether or benzene.

After addition of a substance to a mixture which is soluble to a greater or lesser extent in both immiscible liquids, on shaking and then allowing the mixture to settle, the concentrations in each layer become constant. However, there is continual interchange of solute between the liquid layers via the interface i.e. a dynamic equilibrium is formed. The dissolution of third substance in both solvents is characterized by the partition constant in a system of specified liquids

$$K_{dis.} = C_{solute}/C_{solvent},$$

where C_{solute} is a concentration of dissolved liquid in layer (mol/l); $C_{solvent}$ is a concentration of solvent in layer (mol/l).

In diluted multicomponent solutions distribution of every solute between two phases is characterized by the individual partition constant, which value does not depend on the presence of other substances. This statement was formulated by Nernst and called distribution law. Distribution law is complied with the penetration of substances through the cellular membranes by two mechanisms:

- 1) by the dissolving in lipid layer of membrane;
- 2) through the pores of membrane.

According to the first mechanism penetration of water insoluble non-polar compounds (lipids, fatty acids and etc.) takes place. These compounds are highly soluble in the same non-polar media — lipids — and poorly soluble in water. Their accumulation in the lipid layer of the membrane is under the distribution law. Mutual

solubility of liquids is accompanied by the energy absorption, that's why with the increasing temperature mutual solubility grows.

Under the conditions of dissolution of one liquid in other volume changes insignificantly (more often it reduces). So according to the Le Chatelier's principle pressure slightly affects the value of mutual solubility.

6. Values characterizing quantitative composition of solutions.

Quantitative composition of a solution can be expressed in different ways.

Mass percent (weight percent, w) which expresses the mass of solute present in a given mass of solution. The definition of mass percent is:

$$\begin{aligned} \text{Mass percent } (\omega) &= \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\% = \\ &= \frac{\text{grams of solute}}{\text{grams of solute} + \text{grams of solvent}} \times 100\% \end{aligned}$$

Molar concentration is a number of moles of solute per unit of volume, mol/l,

$$\text{Molarity } C(x) = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{m(x)}{M(x) \cdot V(\text{solution})} ,$$

where $m(x)$ = the mass of solute x, g;

$M(x)$ = molar mass of solute x, g/mol;

$V(\text{solution})$ = volume of solution, l.

Molality is a concentration unit, which shows a relationship between moles of solute and mass of solvent. The definition of molality is

$$\text{Molality } b(x) = \frac{\text{moles of solute}}{\text{kg of solvent}} = \frac{m(x)}{M(x) \cdot m(\text{solvent})} \quad (\text{mol/kg}) ,$$

where $m(x)$ = the mass of solute x, g;

$M(x)$ = molar mass of solute x, g/mol.

Mole fraction (N_2) is the ratio of the number of moles of a substance to the total number of moles of all substances in the solution.

$$N(x) = \frac{\nu(x)}{\sum \nu(X_i)} \cdot 100\% , \quad \nu(x) = \frac{m(x)}{M(x)}$$

For 2 component system:

$$N_2 = \frac{\text{moles of solute}}{\text{moles of solute} + \text{moles of solvent}}$$

Molar concentration of the equivalent C(E) is defined as the number of equivalents of solute per liter of solution.

$$C(E) = \frac{m}{M(E) \times V},$$

where m – the mass of a substance, g;

M(E) – the molar weight of equivalent, g/mol;

V – the volume of solution, l.

Law of equivalents: masses of reacting compounds (m_1, m_2, \dots) are proportional to their equivalents ($\text{equiv}_1, \text{equiv}_2, \dots$):

$$m_1/m_2 = \text{equiv}_1/\text{equiv}_2$$

Equivalent is some real or conditional particle of matter, that in this acid-base reaction corresponds to one equivalent of hydrogen ion or one electron in Red-Ox reactions.

Upon that molecules, ions, free radicals etc are considered as real particle.

Unit of chemical equivalent is mol.

Molar mass of equivalent of solute is expressed as:

$$M(e) = M(x) \times f(x),$$

where $f(x)$ — factor of equivalence.

Factor of equivalence is a figure that indicates which part of real substance's equivalent to one hydrogen ion in this acid-base reaction or one electron in this Red-Ox reaction.

At the neutralization (acid-base reaction):

$$f_{e(\text{acid})} = 1/n(\text{H}^+)$$

where $n(\text{H}^+)$ — number of hydrogen ions in acid; f_e — factor of equivalence of acid.

For example,

$$f_e(\text{H}_2\text{SO}_4) = 1/2.$$

$$f_{e(\text{base.})} = 1/n(\text{OH}^-)$$

where $f_e(\text{base})$ — factor of equivalence of base, $n(\text{OH}^-)$ — number of hydroxyl-group.

For example,

$$f_e(\text{NaOH}) = 1.$$

$$f_e(\text{salt.}) = 1 / (B_{\text{Me}} \times n_{\text{at. Me}}),$$

where $f_e(\text{salt})$ — factor of equivalence of salt, B_{Me} — valence of metal, $n_{\text{at. Me}}$ — number of metal atoms.

For example,

$$f_e(\text{Fe}_2(\text{SO}_4)_3) = \frac{1}{3} \cdot 2 = \frac{1}{6}.$$

Titer of the solution — mass of solute in one milliliter of the solution, g/ml.

$$T(x) = m(x)/1000;$$

$$T(x) = \frac{C_e(x) \times M_e(x)}{1000}$$

Formulas for converting

– mass percent to the molar concentration mol/l

$$C(x) = \frac{10 \times \omega(x) \times d(\text{solution})}{M(x)},$$

Where d – is a density of solution, g/ml;

$\omega(x)$ – is mass percent, %;

M – the molar weight, g/mol.

– mass percent to the molar concentration of equivalent mol/l,

$$C_e(x) = \frac{10 \times \omega(x) \times d(\text{solution})}{M_e(x)},$$

– molar concentration to molar concentration of equivalent,

$$C_e(x) = C(x)/f_e(x).$$

7. Colligative properties of dilute solutions of non-electrolytes

Properties of solutions that do not depend on the nature of the components, and depend only on the amount of kinetic units in the system are called *colligative*. These include osmotic pressure, lowering of vapor pressure of solvent above solution, elevation

of boiling point and lowering of freezing point of solutions as compared with pure solvent.

If solutions of different concentrations are separated by a semipermeable membrane, the one-sided diffusion process can be observed. Membranes are numerous in the organism. These are membranes of cell and organelles (nucleus, Golgi apparatus, etc.), walls of blood vessels, envelopes of organs, etc. Membranes are different in composition, structure, pore size, and, consequently, in permeability. Some of them are permeable only for water molecules, and others are permeable also for ions and small molecules. Different permeability for ions may depend on interactions between the charged groups of membrane and these ions.

If the membrane permeable only for the solvent is placed between pure solvent and solution or between solutions of different concentrations, the process called osmosis begins.

1) Osmosis and osmotic pressure. Van't Hoff's law.

Osmosis is a one-sided diffusion of the solvent through a semipermeable membrane from pure solvent into the solution or from solution with a lower concentration into the solution with a higher concentration.

As the overpressure in the solution increases, the osmosis rate decreases and equilibrium is established when the same amount of the solvent molecules passes through the membrane in both directions. *Excessive hydrostatic pressure in the solution in comparison with the pure solvent when osmotic equilibrium is established is called osmotic pressure.*

Osmotic pressure obeys law of ideal gas pressure. Osmotic pressure is directly proportional to the molar concentration and temperature:

$$P = CRT \quad \text{van't Hoff's law.}$$

This formula does not include values which depend on the nature of the solute. Thus, the magnitude of the osmotic pressure will be the same for any substance (nonelectrolyte) at the same temperature and molar concentration.

Osmotic pressure of biological fluids is maintained at a constant level by activity of the kidneys, perspiration, water vapor content in the exhaled air, etc. **Osmotic**

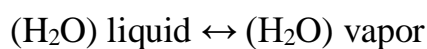
pressure of human blood is 700-800 kPa. This corresponds to the osmotic concentration in the blood plasma from 0.287 mol/L to 0.303 mol/L at 37°C.

Solutions having the same osmotic pressure are called isotonic. 0.9% NaCl solution and 5% glucose solution are isotonic regarding blood. Solutions with greater osmotic pressure are called hypertonic, those with less osmotic pressure are called hypotonic.

Oncotic pressure is part of the osmotic pressure of the blood caused by high-molecular compounds. It is 3.5 - 3.9 kPa.

2) Lowering of vapor pressure of the solvent above the solution. Raoult's law.

At a definite temperature the vapor pressure of each liquid is constant. The vapor pressure at a given temperature at which the dynamic equilibrium occurs, characterized by equal rates of evaporation and condensation of the liquid is called *saturated vapor pressure*. Saturated vapor pressure of the solvent above solution is always lower than that above pure solvent at the same temperature. This can be explained on the basis of the Le Chatelier's principle. Equilibrium is established between liquid and vapor:



When any substance is dissolved in water, the amount of liquid water decreases due to hydration, and condensation process begins. The new equilibrium is established at a lower vapor pressure. The higher is the concentration of solution, the lower is the saturated vapor pressure.

French chemist F. Raoul (1886) found that the relative lowering of solvent (P_0) vapor pressure above the solution (P) is equal to the mole fraction of solute (Raoult's law):

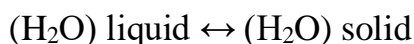
$$\frac{P_0 - P}{P_0} = N_2$$

Raoult's law shows that the solutions will boil at a higher temperature and freeze at a lower temperature than pure solvent.

3) Depression in freezing point and elevation of boiling point of solutions.

Liquid begins to boil at a temperature at which its vapor pressure is equal to external pressure. Since the vapor pressure above the solution is lower than that above the pure solvent, it will be equal to the atmospheric pressure at higher temperature.

Elevation of boiling point and lowering of freezing point is in accordance with Le Chatelier's principle:



When substance is dissolved in water, the concentration of water molecules drops, and the process of ice melting begins. The new equilibrium is established at a lower temperature. Elevation of boiling point and lowering of freezing point depend on solution concentration.

Raoul found that for dilute solutions of non-electrolytes elevation of boiling point and lowering of freezing point are proportional to the molal concentration.

$$\Delta T_{\text{freeze}} = K_k b(x)$$

$$\Delta T_{\text{boil}} = K_e b(x)$$

K_e and K_k are ebullioscopic and cryoscopic constants which depend only on nature of solvent and do not depend on nature of solute. They show how the boiling point rises or freezing point of the solution decreases if there is 1 mole of solute per 1 kg of solvent. For water: $K_e = 0,52 \text{ K} \cdot \text{kg/mol}$; $K_k = 1,86 \text{ K} \cdot \text{kg/mol}$.

8. Colligative properties of electrolytes. Isotonic coefficient

Electrolyte solutions show more pronounced colligative properties than do non-electrolytes (van't Hoff's law).

The following ratio is called isotonic coefficient:

$$i = N / N_0$$

where N is the number of particles in the electrolyte solution, N_0 is the amount of dissolved molecules.

Isotonic coefficient depends on the value of the degree of dissociation of the electrolyte and is calculated by the formula:

$$i = 1 + \alpha (v - 1)$$

where v is the number of ions in the compound, α is the degree of dissociation.

Therefore, for electrolytes:

$$P = iCRT$$

$$\Delta T_{\text{freeze}} = iK_k b(x)$$

$$\Delta T_{\text{boil}} = iK_e b(x)$$

9. Role of osmosis in biological systems. Properties of semi-permeable membranes.

Oncotic pressure. Hemolysis and plasmolysis

Osmosis plays an important role in physiological processes in the organism. Digestion and other metabolic processes are closely related to different permeability of the cell membrane for water and solutes. A membrane possesses semipermeable properties. Osmotic pressure acts as a mechanism supplying the cells with nutrients and water. The normal osmotic pressure of the blood is 700-800 kPa. This corresponds to the osmotic concentration in the blood plasma from 0.287 mol / L to 0.303 mol / L at 37 °C. Oncotic pressure is fraction of the osmotic pressure of the blood caused by high-molecular weight compounds, in particular proteins, and comprises 3.5 - 3.9 kPa.

Solutions with the same osmotic pressure are called isotonic. For example, 0.9% NaCl and 5% glucose are isotonic regarding blood. Solutions with greater osmotic pressure are called hypertonic, and those with a lower osmotic pressure are called hypotonic. Therefore, according to the law of osmosis, cell immersed in a hypertonic solution undergoes plasmolysis (shrinkage) and in a hypotonic solution hemolysis (swelling and burst) is observed. Isotonic sterile solutions should be used for organism supplying with large amounts of fluids or dilution of drugs for intravenous infusions in order to avoid plasmolysis of erythrocytes. In medical practice hypertonic solutions, e.g., 10% NaCl are used for washing of wounds.

10. Osmometry, cryometry, and ebulliometry; their use in biomedical researches

Measurement of osmotic pressure (osmometry), boiling point elevation (ebulliometry), and lowering of the freezing point (cryometry) are used to determine certain physical and chemical values. In particular, measuring of ΔT_{freeze} allows to determine the molecular weight of nonelectrolyte, and degree of dissociation of electrolyte. Measuring of depression of biological fluids (blood, lymph, urine) allows to calculate osmolarity, i.e. total concentration of all particles. Normally, the depression of blood is 0.56 K.

LABORATORY WORKS

Experiment 1. *Preparation of sodium hydroxide solution with given molar concentration of equivalent (normality).*

The purpose of the work. To be able to prepare solutions with known molar concentration of equivalent (normality).

Laboratory utensils and reagents. Technical balance, beaker, chemical cylinder, dry sodium hydroxide, distilled water.

Method of the experiment. Calculate mass of NaOH using the formula of molar concentration of equivalent. Weight it using technical balance, quantitatively transfers this sample weight into the beaker, add necessary volume of distilled water, measured by chemical cylinder, and mix.

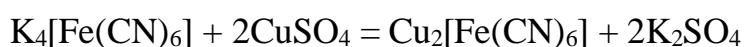
Obtained solution will be used for laboratory work on titrimetric analysis.

Experiment 2. *The rise of Traube's "artificial cell"*

The purpose of the work. To study the role of osmotic phenomena in biological systems.

Laboratory utensils and reagents. Support with test tubes, 5 ml pipettes, crystalline potassium hexacyanoferrate(II), 5% copper sulfate.

Partitions permeable for water but impermeable for the solute can be of vegetable and animal origin. One can prepare such partition artificially, using for this purpose a copper sulfate solution (II) and crystalline potassium hexacyanoferrate (II) $K_4[Fe(CN)_6]$. Reaction proceeds as follows:



Complex compound $Cu_2[Fe(CN)_6]$ possesses semipermeable properties.

Method of the experiment. Pour 5 ml of copper sulfate solution(II) in a test tube and add a small crystal of $K_4[Fe(CN)_6]$ (do not shake!). In one hour sketch formations which resemble algae.

List of practical skills.

After studying the subject student should be able to calculate concentrations of the solutions, prepare solutions with known concentrationsuse, calculate osmotic pressure, depression in solutions, the molar masses of physiologically active substances based on the values of osmotic pressure and depression; to classify solutions based on values of

osmotic pressure and concentration; predict what will happen to the cells placed in hypotonic, isotonic, hypertonic solution.

11. Tasks for knowledge control

1. Gastric juice acidity is caused by the presence of hydrochloric acid mass percent of which is 1 %. Calculate molar concentration of HCl, if density is 1 g/ml.

A — 1 mol/l; B — 0,1 mol/l; C — 0,274 mol/l.

2. Calculate mass of potassium bromide that the patient receives taking 1 table spoon of 3 % KBr solution (mass of solvent in 1 table spoon is 15 g).

A — 0,45 g; B — 0,9 g; C — 1,35 g.

3. Which solutions are isotonic regarding blood?

A. 9% NaOH

B. 10% NaCl

C. 5% $C_6H_{12}O_6$

D. 0.5% protein solution.

4. Which formula is used to calculate osmotic pressure in 0,9% NaCl solution?

A. $P = bRT$

B. $P = CRT$

C. $P = RT$.

D. $P = iCRT$

Answers: 1 - C; 2 – A; 3 - C; 4 - D.

12. Recommendations for the work results design

Algorithms for solving educational problems of class work and self-work should be recorded in the workbook. Make a protocol of laboratory work, conclusions about properties of artificial semi-permeable membrane and osmotic processes.

13. Suggested readings

V. Kalibabchuk, V. Halinska, L. Hryshenko, S. Hodzynski, T. Ovsyanikova, V. Samarski. Medical chemistry. –Kyiv AUS Medicine Publishing, 2010. – 224 p.

Навчальне видання

Величини, що характеризують кількісний склад розчинів. Приготування розчинів. Колігативні властивості розчинів

Методичні вказівки для самостійної роботи студентів 1-го курсу з медичної хімії

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