Subject 14. Obtaining, purification and properties of colloidal solutions

1. Importance

The cell of an organism is a heterogeneous colloidal system. Blood, cytoplasm, muscle cells, nerve cells, fibrils, genes, viruses are colloidal systems. Colloidal chemical processes are the basis of nutrition, growth and development of plants and animals as well as humans.

Research of properties of colloidal systems and methods of their obtaining helps to understand complex processes of life and design models of cells, biological membranes, nerve fibrils, oxygen transport etc.

Research of purification of dispersion systems has introduced such modern diagnostics and treatment methods as electrophoresis, compensatory dialysis, vividialysis, “artificial kidney”.

The problem of protection of the environment is very important. The processes of purification and regeneration of wastewater, elimination of atmosphere pollutants and smokes are based on laws of physical and colloidal chemistry.

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

Write a structure of a micelle.

Prepare colloidal solutions.

Determine the charge sign of the disperse phase particles.

Maintain laboratory protocols.

Analyze principles of methods of preparation and purification of colloidal-disperse solutions.

Explain the physico-chemical basis of hemodialysis.

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

Previous subjects	Obtained skills
1. Medical biology	Structural-chemical and functional organization of eukaryotes (cytoplasm and cytoskeleton are colloidal systems; Brownian motion).
2. Anatomy	The kidney.
3. Medical and Biological Physics	Double electric layer (DEL). Fluctuations and waves. Sound, ultrasound. Electrodes. Photometry. Interaction of light with matter. Physical processes in biological objects under the action of electric and magnetic fields. Electrokinetic phenomena. Electrophoresis. Smoluchowsky's formula for calculation of the zeta-potential.
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. Latin language and medical terminology	Know medical terminology in Latin language.
6. Life safety, basics of bioethics and biosafety	Be capable of self-regulation, lead a healthy lifestyle, be able to adapt and act in new situations. Strive 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. Disperse system.	**A disperse system** is a system in which small particles (dispersed phase) are distributed in a continuous dispersion medium.
2. Classification of disperse systems by the degree of dispersion.	1. Coarse-grained ($10^{-7} - 10^{-4}$ m). 2. Highly dispersed (colloidal solutions (sols)) ($10^{-9} - 10^{-7}$ m). 3. Molecular dispersions ($< 10^{-9}$ m).
3. Structure of colloidal particles.	**The colloidal particle** (micelle) has an aggregate, a core, a granule.
4. Electrokinetic potential of the colloidal particle.	**Electrokinetic potential** of a colloidal particle is the potential that arises in a double electric layer at the boundary of the particle relative to a liquid (at the boundary between the granule and the diffusive layer).
5. Methods of obtaining colloidal solutions.	1. Dispersion methods. 2. Condensation methods: 1) Methods of physical condensation:

	a) vapor condensation; b) solvent replacement method; 2) Methods of chemical condensation: a) a double exchange reaction; b) a hydrolysis reaction; c) an oxidation-reduction reaction. Peptization
6. Methods of purification of colloidal solutions.	1. **Dialysis** is carried out in a dializator that consists of two vessels, separated with a semipermeable membrane. 2. Electrodialysis. 3. Compensation dialysis. 4. Vividialysis. 5. Ultrafiltration.
7. Apparatus "artificial kidney".	Hemodialysis.
8. Molecular-kinetic properties of colloidal systems.	1. Brownian movement. 2. Diffusion. 3. Osmotic pressure.
9. Optical properties of colloidal systems.	1. Scattering of light. 2. Absorption of light.
10. Electrophoresis.	**Electrophoresis**–is a directed motion of particles of a dispersed phase relative to a fixed dispersion medium in a constant electric field.

4.2. Theoretical questions for the lesson:

1. Classification of disperse systems by the degree of dispersion.
2. Colloidal state. Lyophilic and lyophobic colloidal systems.
3. Structure of colloidal particles.
4. Double electric layer. Electrokinetic potential of a colloidal particle.
5. Methods of obtaining colloidal solutions.
6. Methods of purification of colloidal solutions:
   a) dialysis;
   b) electrodialysis;
   c) compensatory dialysis;
   d) vividialysis;
   e) ultrafiltration;
   e) hemodialysis and "artificial kidney".
7. Molecular-kinetic properties of colloidal systems (Brownian motion, diffusion, osmotic pressure).
8. Optical properties of colloidal systems.
9. Electrophoresis, its applications in research and practice. The Helmholtz-Smoluchowsky equation.

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

1. Obtaining of a sol by the solvent replacement method

Add 1 mL of an alcohol solution of sulfur (obtained by long-term infusion) to 10 mL distilled water in a test tube. Sulfur forms a real solution in an alcohol, but can not dissolve in water thus creating a colloidal system.

2. Obtaining of a ferric hydroxide sol by the method of hydrolysis

Add 50 mL distilled water to a conical flask and boil it. Measure out 5 mL 5% $FeCl_3$ (with a measuring test tube) and add it gradually to the boiling water.

At high temperature complete hydrolysis of ferric chloride takes place (III) and ferric hydroxide is obtained:

$$FeCl_3 + 3H_2O = Fe(OH)_3\downarrow + 3HCl.$$

The products of the hydrolysis partially react with each other:

$$Fe(OH)_3\downarrow + HCl = FeOCl + 2H_2O.$$

The obtained oxoferrous chloride (FeOCl) stabilizes colloidal particles.

The micelle formula of the $Fe(OH)_3$ sol is as following:

$$\{m[Fe(OH)_3] \cdot n\ FeO^+ \cdot (n - x)\ Cl^-\}^{x+} \cdot x\ Cl^-.$$

A clear reddish-brown sol is obtained.

3. Obtaining of a Prussian blue sol by the method of double metathesis

Add 10 mL 0.10 % potassium ferrocyanide $\mathbf{K_4[Fe(CN)_6]}$ and 1-2 drops of 2 % ferric chloride. A clear blue colloidal solution of Prussian blue $\mathbf{Fe_4[Fe(CN)_6]_3}$ is obtained.

Write the reaction between potassium ferrocyanide and ferric chloride.

Write the micelle formula of the obtained sol, taking into account that the granule has a negative charge.

4. Obtaining a ferric hydroxide sol by the method of peptization.

Add 50 mL distilled water to a flask. Add 2 mL 5 % $FeCl_3$ solution. Add gradually 5 % ammonia solution until a strong ammonia smell is felt. A brown precipitate $Fe(OH)_3$ is obtained in the reaction.

After sedimentation carefully decant off the upper layer of the liquid. Add about 30 mL distilled water to the sediment, shake well, leave to sedimentate and decant again. Repeat the procedure three times. Take two small portions of the washed precipitate (about 1 mL) and place in two test tubes. Add 10 mL water to the first test tube and 3 mL water and 2 mL 5 % $FeCl_3$ to the second test tube.

Write the reaction of formation of the ferric hydroxide precipitate. Write a micelle formula of the sol obtained with peptization in the second test tube.

Write down the results in the protocol of the laboratory assignment.

Contents of the subject (abstract):

1. Classification of disperse systems by the degree of dispersion

A disperse system is a system in which small particles (dispersed phase) are distributed in a continuous dispersion medium.

Classification of disperse systems by degree of dispersion:

1. Coarse-grained ($10^{-7} - 10^{-4}$ m).
2. Highly dispersed (colloidal solutions (sols)) ($10^{-9} - 10^{-7}$ m).
3. Molecular dispersions ($<10^{-9}$ m).

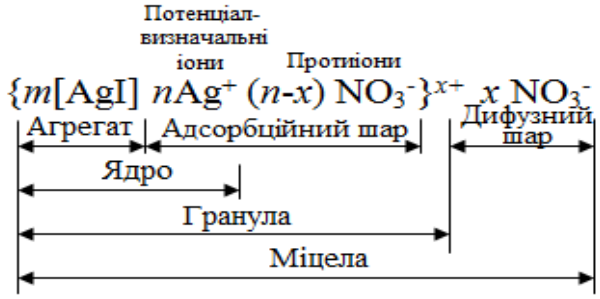
2. Colloidal state. Lyophilic and lyophobic colloidal systems

Lyophilic disperse systems are those in which there is a strong interaction of particles of a dispersed phase with the dispersion medium.

In lyophobic systems, the interaction of the disperse phase and the dispersion medium is weak.

3. Structure of colloidal particles

$AgNO_3$(excess) + KI → AgI↓ + KNO_3.



Formula of the micelle of a sol of silver iodide

4. Double electric layer. Electrokinetic potential of a colloidal particle

Double electric layer (DEL) is formed with the potential defining ions and counterions of the micelle.

Electrokinetic potential of a colloidal particle is the potential that appears in the DEL at the interface of the particle and the liquid (at the boundary between the granule and the diffusive layer).

5. Methods of obtaining colloidal solutions

1. Dispersion methods are those that employ mills to make big particles smaller.

Acoustic methods are based on the use of a directed ultrasonic field, that is, high frequency oscillations.

2. Condensation methods:

1) Methods of physical condensation:

a) condensation of vapors:

In this method, the dispersed phase and dispersion medium is are simultaneously evaporated in vacuum. The vapor mixture is then cooled and condensed.

b) method of solvent replacement. When a solution of sulfur in ethanol is mixed with water, the aggregation of sulfur molecules occurs and a sol of sulfur in water is obtained.

2) Methods of chemical condensation:

a) a double-exchange reaction:

$AgNO_3$ + KCl → AgCl↓ + KNO_3;

b) a reaction of hydrolysis:

$FeCl_3 + 3H_2O \rightarrow Fe(OH)_3\downarrow + 3HCl$;

c) an oxidation-reduction reaction:

$2H_2S + O_2 \rightarrow 2S\downarrow + 2H_2O$.

3. **Peptization** is the process of transfer of freshly prepared precipitate into colloid state under the influence of an external factor.

6. Methods of purification of colloidal solutions:

a) **dialysis** is carried out in a dialyser that consists of two vessels separated with a semipermeable membrane;

b) **electrodialysis** is the process of removal of electrolyte impurities from a colloidal solution in an electrodialyser that consists of three chambers. The middle chamber contains a colloidal solution and is separated from the side chambers with semipermeable membranes. In the side chambers, there are electrodes. The ions are removed with water that circulates in the side chambers;

c) **compensatory dialysis**: the membrane of the dialyser is washed not with a pure solvent, but rather with a solution of low molecular weight substances of such concentration, which must be maintained in the colloidal solution;

d) **vividialysis** is a method of extracting low molecular weight substances from biological fluids for purification or analysis, in which the biological fluid passes through a dialysis apparatus through pipes with semipermeable walls that are washed with a physiological solution. Harmful substances are removed from the blood into the surrounding solution;

e) **ultrafiltration** is a filtration of a colloidal solution through a membrane with an increased external pressure or in vacuum;

f) **hemodialysis and "artificial kidney"**:

Based upon the principle of vividialysis, hemodialysis is performed in the apparatus "Artificial kidney" to treat acute renal failure, poisoning, pregnancy toxicosis.

7. Molecular-kinetic properties of colloidal systems (Brownian motion, diffusion, osmotic pressure)

Brownian motion is the thermal chaotic motion of particles that occurs as a result of collision of solvent molecules with colloidal particles.

Diffusion is a spontaneous process of obtaining a uniform concentration of particles in the entire volume of the disperse system.

Osmotic pressure is proportional to the amount of particles of the dissolved substance per unit volume of the solution and does not depend on the nature and mass of the particles.

8. Optical properties of colloidal systems

Scattering of light.

Absorption of light.

9. Electrophoresis, its application in the research and practice. Helmholtz-Smoluchowsky equation

Electrophoresis is a directed motion of particles of the dispersed phase in the dispersion medium in a constant electric field.

Helmholtz-Smoluchowsky equation:

$$\upsilon = \varepsilon_0 \frac{\varepsilon \zeta E}{\eta}.$$

Materials for self control:

A. Tasks for self control:

1. Choose one best description of colloidal solutions:
   a) dispersion systems with different disperse media;
   b) dispersion systems with the particle size in the dispersed phase from 1 to 100 nm.
   c) dispersion systems with solid dispersed phase;
   d) dispersion systems that belong to homogeneous systems because of the particle size of the dispersed phase.
2. What ions are adsorbed on the surface of the nucleus in the micelle formation?
   a) the ions, which charge is opposite to the charge of the nucleus;
   b) the ions, concentration of which is the biggest in the solution;
   c) the ions, which are not components of the nucleus;
   d) the ions which are able to complete the crystal lattice of the nucleus.
3. Explain, on which processes peptization is based on.
   a) hydrolysis of peptide bonds in the disperse medium;
   b) chemical dissolution of the precipitate due to a reaction with the added electrolyte;
   c) formation of colloidal particles because of the adsorption of electrolyte ions on the particles of the precipitate;
   d) formation of colloidal particles because of the adsorption of the ions which are formed in a reaction of a part of the precipitate with the electrolyte.
4. Choose one best method to remove glucose from a colloidal solution.
   a) filtration; b) dialysis; c) electrodialysis; d) vividialysis.
5. What method of purification of colloidal solutions is used in the apparatus “the artificial kidney”.
   a) ultrafiltration; b) dialysis; c) electrodialysis; d) compensatory dialysis.

B. Practical tasks for self control:

1. Write a formula of the micelle of a sol, obtained by mixing 15 mL 0.025 *M* KCl solution and 85 mL 0.005 *M* $AgNO_3$ solution. What is the charge of the colloidal particles?

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).