PHYSICAL AND COLLOIDAL CHEMISTRY
STUDY GUIDE
for the 3rd year students of pharmaceutical faculty

(Module 2. Colloidal Chemistry)

Thematic modules 6.
Disperse Systems and Their Properties

L’VIV – 2012
### THEMATIC SCHEDULE

of practice and laboratory studies
on physical and colloidal chemistry

**Module 2. Colloidal chemistry**

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<td>Adsorption on the solid-gas and solid-solution interfaces</td>
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General information on the educational process organization of “Physical and Colloidal Chemistry” studying within the credit-module system

The educational process of physical and colloidal chemistry studying is organized according to the requirements of credit-module system within the Bologna process.

Physical and Colloidal chemistry as an educational discipline is structured into 2 modules 19 practical classes in each:

Module 1. Physical chemistry
Thematic modules:
1. Thermodynamics of chemical and phase equilibrium
2. Kinetics of chemical reaction and catalysis
3. Electrochemistry

Module 2. Colloidal chemistry
Thematic modules:
4. Physical chemistry of surface and sorption phenomena. Chromatography
5. Disperse systems and their properties
6. Physical chemistry of polymers

Laboratory records are to be kept in a bound notebook. Include in the notebook the aim of the experiments, a complete description of the work performed, all reference materials consulted, and ideas that you have related to the work, and the conclusions.

Forms of the discipline assessment

The maximum number of points assigned to students in each module (credit) - 200, including the practice and laboratory educational activity - 120 points, and the final module control - 80 points.
The assessment of trained knowledge is made on a three-point scale.
For checking the student’s educational achievements are stipulated the following types and forms of the trained knowledge control:

1) the current control;
2) the practical skills gained and the laboratory experiments carrying out assessment;
3) the final module control assessment.
The maximal assessment of current progress in a semester makes 60 % from a final assessment of knowledge on discipline, and the maximal assessment of examination makes 40 % from a final assessment of knowledge on discipline.

1. The current control is a regular check of educational trained achievements, spent by the teacher on current employment according to syllabus of the discipline. It is performed at each practice class according to specific objectives. Theoretical students’ self-preparation control is performed in writing by answering 18 multiple
choice questions in the form one-of-five, the correct answer to each is estimated at 1 point, and two numerical problems, the correct solving being estimated at 2 points. The minimum number of points that a student must gain for the crediting the theoretical part is 9 points.

2. **The practical skills gained and the laboratory experiments carrying out assessment** is performed after the laboratory work fulfilling by assessing the quality and fullness of its performance, the ability to interpret the obtained results. For the practical part of the lesson the student can get:
   - 4 points if laboratory work is completely fulfilled and the student correctly explains the experiments interpret the results and make conclusions;
   - 2 points if the laboratory work is done with some errors, the student can not fully explain and summarize the obtained results;
   - 0 points if the laboratory work is not performed or the student can not explain and summarize the obtained results.

The final score for the class is determined by the sum of the points for the current theoretical control and the laboratory experiments carrying out points as follows:

<table>
<thead>
<tr>
<th>Total points</th>
<th>Grade evaluation</th>
<th>Converting into rating points</th>
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<tbody>
<tr>
<td>&gt; 22</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>19 – 22</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>15 – 18</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>&lt; 13 points for the current theoretical control or 0 points for the laboratory experiments carrying out</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

The maximal number of points a student can get for the module is calculated by multiplying the number of points that correspond to the grade "5" to the number of topics in the module with the addition of points for individual independent work (6 points) and is equal to 120 points (6×19+6=120).

The minimal number of points a student can get for the module is calculated by multiplying the number of points that correspond to the grade "3" to the number of topics in the module (4×19=76).

3. **The final module control** is carried out on completion of the module practical classes. The students fulfilling all types of works included in the curriculum with the points number on less than 76 are allowed.

The final control is carried out in the standardized form and includes the theoretical and practical skills assessment. It should be performed in writing as 66 multiple choice questions (1 point for each correct answer) and 6 numerical problems (2 points for each in the case of being solved correctly).

The maximum points for the final module control are 80. The final module control is supposed to be credited if the student scored at least 50 points.
The discipline assessment
The discipline assessment is possible in the case of all modules credited only. The total assessment of discipline is shaped as an average of points number of the 2 modules each evaluated by summation of points for current control and experimental skills and final module control.

The points on medical chemistry conversion into the ECTS scale evaluation and 4-grade evaluation
The points on discipline may be conversed into the ECTS scale evaluation as follows:

<table>
<thead>
<tr>
<th>ECTS scale</th>
<th>Statistical index</th>
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<tbody>
<tr>
<td>A</td>
<td>The top 10 % students</td>
</tr>
<tr>
<td>B</td>
<td>Next 25 % students</td>
</tr>
<tr>
<td>C</td>
<td>Next 30 % students</td>
</tr>
<tr>
<td>D</td>
<td>Next 25 % students</td>
</tr>
<tr>
<td>E</td>
<td>The last 10 % students</td>
</tr>
<tr>
<td>FX</td>
<td>Repeated making up</td>
</tr>
<tr>
<td>F</td>
<td>The repeated course is required</td>
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</tbody>
</table>

The points on discipline may be conversed into 4-grade evaluation as follows:

<table>
<thead>
<tr>
<th>The number of points on discipline</th>
<th>The 4-grade evaluation</th>
</tr>
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<tbody>
<tr>
<td>170 and over</td>
<td>«5»</td>
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<tr>
<td>140 – 169</td>
<td>«4»</td>
</tr>
<tr>
<td>126 – 139</td>
<td>«3»</td>
</tr>
<tr>
<td>less than 126</td>
<td>«2»</td>
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</table>
Topic 1
Dispersed systems, their classification and preparation methods

1. Objectives

Colloids and colloidal systems are essential to life. Most of the substances, we come across in our daily life, are colloids. The meals we eat, the clothes we wear, the wooden furniture we use, the houses we live in, the newspapers we read, are largely composed of colloids. Following are the interesting and noteworthy examples of colloids: blue colour of the sky, fog, mist and rain, food articles: milk, butter, halwa, ice creams, fruit juices, etc., are all colloids in one form or the other. Colloids function in every body cell, in the blood, and in all body fluids, especially the intercellular fluids. Blood is a colloidal solution of an albuminooidal substance. The styptic action of alum and ferric chloride solution is due to coagulation of blood forming a clot which stops further bleeding. All life processes take place in a colloidal system, and that is true both of the normal fluids and secretions of the organism, and of the bacterial toxins, as well as, in large measure, of the reactions, which confer immunity.

2. Learning Targets:

– to learn the criteria of liophobic sols classifications;
– to get practical skills in lyophobic sols preparation;
– to learn their properties;

3. Self Study Section

3.1. Syllabus Content


3.2. Theoretical Backgrounds

Colloidal solutions are intermediate between true solutions and suspensions. The size of the colloidal particles range from $10^{-9}$ to $10^{-7}$ m. A colloidal system consists of two phases – the dispersed phase and the dispersion medium. Colloidal systems are classified in three ways depending upon physical states of the dispersed phase and dispersion medium; nature of interaction between the dispersed phase and dispersion medium, and nature of particles of dispersed phase. The colloidal systems show interesting optical, mechanical and electrical properties.
Colloidal sols can be formed by *dispersion methods* (e.g. by mechanical subdivision of larger particles or by dissolution in the case of lyophilic sols) or by *condensation methods* (from supersaturated solutions or supercooled vapours, or as the product of chemical reactions) or by a combination of these two (e.g. in an electrical discharge).

Dispersion can be done mechanically, in a *colloid mill* that grinds the substance into small, equal particles. Another method is with an electric arc. Metal electrodes are used, at a current of 5-10A and voltage of 30-40V.

When a condensation method is applied, molecules (or ions) are deposited on *nuclei*, which may be of the same chemical species as the colloid (*homogeneous nucleation*) or different (*heterogeneous nucleation*).

*Peptization* may be defined as the process of converting a precipitate into colloidal sol by shaking it with dispersion medium in the presence a small amount of electrolyte. The electrolyte used for this purpose is called peptizing agent. This method is applied, generally, to convert a freshly prepared precipitate into a colloidal sol. During peptization, the precipitate adsorbs one of the ions of the electrolyte on its surface. This causes the development of positive or negative charge on precipitates, which ultimately break up into smaller particles of the size of a colloid.

### 3.3. References


### 3.4. Self Assessment Exercises

*a) Review Questions*

1. Define the disperse systems and give their classifications according to different criteria.
2. Show the divergences between colloids and true solutions.
3. Name and explain the main methods of sols preparation. The difference between the peptization method and the dispersion and condensation methods.

4. Name the parts of the micelle structure. State the Fajans-Peneth adsorption rule. Define the potential-defining ions, nucleus, adsorptive and diffuse layers of a micelle.

5. Consider the examples of AgCl, As$_2$S$_3$, PbS lyophobic sols preparation with positively and negatively charged granules. Write down the schemes of their micelles structure.

6. Name the main methods of colloidal solutions purification. Their medicinal applications. The principle of the "artificial kidney" device operation.

7. Draw the micelle structure for Fe(OH)$_3$ sol prepared in the presence of Fe(NO$_3$)$_3$ as a nucleating agent. Show the location of zeta-potential occurrence.

8. Application of electrophoresis in medical and biological researches.

**b) Types of Numerical Problems and Their Solving Strategies**

**Numerical problem 3.** Calculate the diameter of an aerosol particles, if 120 of such particles were found in the volume of $4 \cdot 10^{-11}$ m$^3$. The mass concentration of sol is $1 \cdot 10^{-4}$ kg/m$^3$, and the dispersed phase density is $2.2 \cdot 10^3$ kg/m$^3$.

*Steps to Solution:*

The quantity of particles in the unit of volume equals:

$$\nu = \frac{n}{V}.$$  

The volume of 1 particle is equal to the ratio between the mass of 1 particle and the density of dispersed phase:

$$V_0 = \frac{m}{d} = \frac{C}{\nu \cdot d} = \frac{C \cdot V}{n \cdot d}.$$  

For the spherical particles the volume of 1 particle is:

$$V_0 = \frac{4}{3} \pi r^3.$$  

Then,

$$\frac{C \cdot V_0}{n \cdot d} = \frac{4}{3} \pi r \rightarrow r = \sqrt[3]{\frac{3 \cdot C \cdot V_0}{4 \pi \cdot n \cdot \rho}}.$$  

Calculate the radius of the spherical particles:

$$r = \sqrt[3]{\frac{3 \cdot 1 \cdot 10^{-4} \cdot 4 \cdot 10^{-11}}{4 \cdot 3.14 \cdot 120 \cdot 2.2 \cdot 10^3}} = 1.53510^{-7} \text{ m}.$$  

Calculate the diameter of the spherical particles:

$$D = 2r = 1.535 \cdot 10^{-7} \cdot 2 = 3.07 \cdot 10^{-7} \text{ m}.$$  

*Answer:* the diameter of sol particles is $3.07 \cdot 10^{-7}$ m.
c) Problems to Solve

1. For preparing of silver chloride sol 85 ml of 0.005 \( M \) silver nitrate solution were added to 15 ml of 0.025 \( M \) potassium chloride solution. Write down the formula of obtained sol micelle. What is the charge of its granule?

Answer: positive

2. What volumes of 0.029 \( \% \) NaCl solution (the density is 1 g/cm\(^3\)) and 0.001 \( N \) AgNO\(_3\) solutions should be mixed to prepare uncharged particles of AgCl sol? Draw the structure of the micelle in isoelectric state.

Answer: \( V(\text{NaCl}) : V(\text{AgNO}_3) = 1 : 4.96 \)

4. Laboratory Activities and Experiments Section

4.1. Practical Skills and Suggested Learning Activities

- to prepare lyophobic sols with physical condensation method (a solvent replacement);
- to prepare lyophobic sols with chemical condensation method under the double exchange reactions, hydrolysis and redox reactions;
- to determine the sign of particles charge by the capillary analysis method.

4.2. Experimental Guidelines

4.2.1. Preparation of sols by physical condensation (by replacing solvent)

a) Preparation of colophony sol

Pour 5 ml of distilled water into the test tube and add the solution of colophony in ethyl alcohol by drops while stirring. Record your observation. Pay attention to the opalescence - a characteristic feature of colloidal solutions. What method does a sol form with?

b) Preparation of sulfur sol

Pour 5 ml of distilled water into the test tube and add 0.5 ml of saturated solution of sulfur in ethyl alcohol while stirring. What is observed?

4.2.2. Preparation of sols by method of chemical condensation

a) Preparation of silver iodide sol by double-exchange reaction

To 100 ml of 0.002 \( M \) KI solution add while stirring 1 ml of 0.01 \( M \) of AgNO\(_3\) solution. Note the color of sol and write the micelle structure (in the excess of KI). What is the charge of the granule?

Write the structure of AgI micelle, obtained at the excess of AgNO\(_3\).

b) Preparation of Berlin blue sols with different charged granules

In two test tubes prepare Berlin blue sols from 0.005 \( M \) FeCl\(_3\) solution and 0.005 \( M \) \( K_4[\text{Fe(CN)}_6] \) solution in the following ratios:

1) 3 ml of FeCl\(_3\) and 1 ml of \( K_4[\text{Fe(CN)}_6] \);
2) 3 ml of \( K_4[\text{Fe(CN)}_6] \) and 1 ml of FeCl\(_3\).

Write the equations of reactions and the structures of the micelles for both sols. What factor is affecting the charge of the granules?
c) Preparation of iron hydroxide (III) sol by the reaction of hydrolysis
50 ml of distilled water should be heated to boiling in the flask. Add 5% FeCl₃ solution into the boiling water by drops. What is observed? Write the equations of reactions and the structure of obtained sol micelle.

d) Preparation of copper hexacyano(II)ferrate sol by double-exchange reaction
To 5 ml of 1% CuSO₄ solution add a few drops of 0.01% K₄[Fe(CN)₆] solution. Write the equation of the reaction and the structure of the obtained sol micelle. Write the micelle structure of the sol obtained in the K₄[Fe(CN)₆] excess.

e) Preparation of silicic acid sol
To 5 ml of 5% Na₂SiO₃ solution add 0.5 ml of 0.1 M HCl solution while stirring. What is the structure of the obtained sol micelle?

f) Preparation of metallic silver sol by reduction reaction
To 10 ml of 0.001 M AgNO₃ solution add 2-3 drops of 1% K₂CO₃ solution and 1 ml of freshly prepared solution of tannin (aldehyde), and heat. Yellowish-brown sol of metallic silver is formed:

\[
\text{AgNO}_3 + \text{K}_2\text{CO}_3 = \text{AgOK} + \text{KNO}_3 + \text{CO}_2 \\
\text{stabilizer}
\]

\[
2\text{AgOK} + \text{R–COH} + \text{H}_2\text{O} = 2\text{Ag↓} + \text{R–COOH} + 2\text{KOH}
\]
Write the structure of obtained sol micelle and explain the method of its preparation.

g) Preparation of manganese dioxide sol by redox reaction
To 25 ml of 0.1 M KMnO₄ solution in the flask add 10% H₂O₂ solution from the burette by small portions until the solution droplet placed on filter paper with a glass stick would not give pink spot. Write the structure of sol micelle.

h) Preparation of lead sulfide sol
To 3 ml of 1% Pb(CH₃COO)₂ solution add 3 ml of 5% Na₂S solution by drops. Record your observations, the equation of reaction and the structure of the obtained sol micelle. What is the structure of the micelle of PbS sol, obtained at the excess of Pb(CH₃COO)₂?

5. Conclusions and Interpretations. Lesson Summary

Topic 2

Dispersed systems micelles structure. The structure of the double electric layer

1. Objectives

Atmospheric soils are mainly colloidal in nature. On account of colloidal nature, soils adsorb moisture and nourishing materials.

Dispersion refers to the spatial distribution of organisms, and is a fundamental component of a species' ecology and life history. Patterns of dispersion influence
other aspects of a species' behavior and ecology. Dispersion patterns themselves are affected by the distribution of resources (including sunlight, nutrients, prey species, etc.) in the environment, as well as through the reciprocal influence of species' behavioral characteristics.

2. **Learning Targets:**
   - to learn the structure of micelle;
   - to study capillary analysis bases and its application for the determining the charge sign of colloidal drugs;
   - to get practical skills in lyophobic sols preparation;
   - to learn their properties.

3. **Self Study Section**

3.1. **Syllabus Content**

A structure of micelle. Structure of a double electric layer (DEL). The overall performance and history of development the ideas about DEL structure. Structure of a double electric layer. Electrodynamical and electrokinetic potentials.

3.2. **Theoretical Backgrounds**

According to the micellar theory of colloids solution structure, sol consists of micelles and intermicellar liquid. A *micelle* is a colloidal-sized particle formed by the association of molecules, each of which has a hydrophobic end and a hydrophilic end.

There are 3 main parts in the micelle structure: nucleus, adsorptive and diffuse layers. A *nucleating agent* is a material either added to or present in the system, which induces either homogeneous or heterogeneous nucleation.

Colloidal particles always carry an electric charge. The nature of this charge is the same on all the particles in a given colloidal solution and may be either positive or negative. The charge on the sol particles is due to preferential (selective) adsorption of ions from solution and/or due to electrical double layer formation. The sol particles acquire positive or negative charge by selective adsorption of cations or anions. When two or more ions are present in the dispersion medium, preferential adsorption of the ion common to the colloidal particle usually takes place according to the Fajans-Peneth adsorption rule. Having acquired a positive or a negative charge by selective adsorption on the surface of a colloidal particle, this layer attracts counter ions from the medium forming adsorptive and diffusive layers of counterions. According to modern views, the first layer of counterions is firmly held and is termed the adsorptive layer while the second layer is mobile which is termed the diffusive layer. Since separation of charge is a seat of potential, the charges of opposite signs on the adsorptive and diffusive parts of the double layer results in a difference in potential between these layers. This potential difference between the adsorptive layer and the diffusive layer of opposite charges is called the electrokinetic potential, or zeta potential.
3.3. References

a) Review Questions
1. Name the parts of the micelle structure. State the Fajans-Peneth adsorption rule. Define the potential-defining ions, nucleus, adsorptive and diffuse layers of a micelle.
2. Consider the examples of AgCl, As\textsubscript{2}S\textsubscript{3}, PbS lyophobic sols preparation with positively and negatively charged granules. Write down the schemes of their micelles structure.
3. Define the electrokinetical (zeta-) potential and explain the mechanism of its appearance. Explain its role in determining the stability of colloids.
4. Draw the micelle structure for Fe(OH)\textsubscript{3} sol prepared in the presence of Fe(NO\textsubscript{3})\textsubscript{3} as a nucleating agent. Show the location of zeta-potential occurrence. Draw the structure of the same micelle in isoelectric state.
5. Application of electrophoresis in medical and biological researches.

b) Types of Numerical Problems and Their Solving Strategies
Numerical problem 1. 12 ml of 0.01 M of FeCl\textsubscript{3} solution were added to 10 ml of 0.05 N K\textsubscript{4}[Fe(CN)\textsubscript{6}] solution to obtain sol of Berlin blue. Write down the formula of micelle of this sol. What is the charge of the granule?

Steps to Solution:
1. Calculate the normal concentration of 0.01 M FeCl\textsubscript{3} solution:
   \[ C_N = C_M \times 3 = 0.01 \times 3 = 0.03 \text{ mol-eq/l}. \]
2. Write down the equation of Berlin blue formation:
   \[ 4 \text{FeCl}_3 + 3 \text{K}_4[\text{Fe(CN)}_6] \rightarrow \text{Fe}_4[(\text{Fe(CN)}_6)_3] \downarrow + \Box \Box 12 \text{KCl}. \]
3. Calculate which compound is in excess and is stabilizer:
Number of mmol-eq \((\text{FeCl}_3)\) = 12 \cdot 0.02 = 0.24 \text{ mmol-eq};
Number of mmol-eq \((\text{K}_4[\text{Fe(CN)}_6])\) = 10 \cdot 0.05 = 0.5 \text{ mmol-eq}.
4. In solution there is the excess of \(\text{K}_4[\text{Fe(CN)}_6]\), which is the stabilizer. Therefore, hydrophobic \(\text{Fe}_4([\text{Fe(CN)}_6])_3\) particles will adsorb \([\text{Fe(CN)}_6]^{4-}\) ions (Fajans-Peneth adsorption rule), which determine the negative charge of the granule. \(\text{K}^+\) ions will be counterions.
5. The scheme of structure of Berlin blue micelle in this case is:
\[
\{(\text{mFe}_4([\text{Fe(CN)}_6])_3) \cdot n[\text{Fe(CN)}_6]^{4+} \}^{4n-} \cdot 4(n-x) \text{K}^+ \\
(m\text{Fe}_4([\text{Fe(CN)}_6])_3) - \text{aggregate};
\]
\[
(n\text{Fe}_4([\text{Fe(CN)}_6])_3) \cdot n[\text{Fe(CN)}_6]^{4+} - \text{nucleus};
\]
\[
\{(m\text{Fe}_4([\text{Fe(CN)}_6])_3) \cdot n[\text{Fe(CN)}_6]^{4+} \}^{4n-} \cdot 4(n-x) \text{K}^+ \}^{4x-} - \text{granule};
\]
\[
n[\text{Fe(CN)}_6]^{4-} - \text{potential determining ions};
\]
\[
4(n-x) \text{K}^+ - \text{adsorptive layer};
\]
\[
4x\text{K}^+ - \text{diffuse layer}.
\]

**Numerical problem 2.** What is the minimum volume of 0.1 % \(\text{AgNO}_3\) solution which should be added to 50 ml of 0.15 % \(\text{KI}\) solution for preparing of sol with positively charged granules?

**Steps to Solution:**

The reaction of \(\text{AgI}\) formation is:
\[
\text{AgNO}_3 + \text{KI} \rightarrow \text{AgI} + \text{KNO}_3
\]
Sol with positively charged granules will form if \(\text{AgNO}_3\) is the stabilizer of the sol. The scheme of micelle is:
\[
\{(\text{mAgI})n\text{Ag}^{+}(n-x)\text{NO}_3^-\}^{x+}x\text{NO}_3^-
\]
In this case the \(\text{AgNO}_3\) solution must be in excess.
According to the equivalent law:
\[
C_M(\text{KI}) \cdot V(\text{KI}) = C_M(\text{AgNO}_3) \cdot V(\text{AgNO}_3)
\]
The volume of \(\text{AgNO}_3\) solution is:
\[
V(\text{AgNO}_3) = \frac{C_M(\text{KI}) \cdot V(\text{KI})}{C_M(\text{AgNO}_3)}
\]
Calculate the molarity of 0.15 % \(\text{KI}\) solution:
\[
C_M(\text{KI}) = \frac{m(\text{KI})}{M(\text{KI}) \cdot V} = \frac{0.15 \text{ g}}{166 \text{ g/mol} \cdot 0.11} = 0.009 \text{ mol/l}
\]
Calculate the molarity of 0.1 % \(\text{AgNO}_3\) solution:
\[
C_M(\text{AgNO}_3) = \frac{m(\text{AgNO}_3)}{M(\text{AgNO}_3) \cdot V} = \frac{0.1 \text{ g}}{170 \text{ g/mol} \cdot 0.11} = 0.006 \text{ mol/l}
\]
Calculate the equivalent volume of \(\text{AgNO}_3\) solution:
\[
V = \frac{0.009 \text{ mol/l} \cdot 50 \text{ ml}}{0.006 \text{ mol/l}} = 75 \text{ ml}
\]
**Answer:** the minimum volume of \(\text{AgNO}_3\) solution is 76 ml.
c) Problems to Solve

1. AgI sol was obtained at slowly adding 15 ml of 0.2 % AgNO₃ solution (the density is 1 g/ml) to 20 ml of 0.01 M KI solution. Write down the formula of micelle of obtained sol. Determine the direction of its particles movement in the applied electric field.

2. What volume (in ml) of 0.005 M ZnCl₂ solution should be added to 20 ml of 0.015 M (NH₄)₂S solution to prepare ZnS sol with positively charged granules? Write down the formula of micelle of obtained sol.

   Answer: 60 ml

3. What volumes of 0.029 % NaCl solution (the density is 1 g/cm³) and 0.001 N AgNO₃ solutions should be mixed to prepare uncharged particles of AgCl sol? Draw the structure of the micelle in isoelectric state.

   Answer: \( V(\text{NaCl}) : V(\text{AgNO}_3) = 1 : 4.96 \)

4. Laboratory Activities and Experiments Section

4.1. Practical Skills and Suggested Learning Activities

– to prepare sols with the methods of direct and indirect peptization;
– to determine the sign of particles charge by the capillary analysis method;
– to prepare lyophobic sols with physical condensation method (a solvent replacement);
– to prepare lyophobic sols with chemical condensation method under the double exchange reactions, hydrolysis and redox reactions.

4.2. Experimental Guidelines

4.2.3. Preparation of sols by peptization

a) Preparation of Fe(OH)₃

Prepare the precipitate of Fe(OH)₃ by the reaction of FeCl₃ with NH₄OH. For this purpose, 1 ml of saturated FeCl₃ solution should be diluted with water to 20 ml. To the obtained solution add 5% NH₄OH solution slowly till bleaching of the liquid above the precipitate. Write the equation of the reaction. Note the color of the precipitate.

Pour away the liquid above the precipitate and rinse several times with distilled water (decantation). Washed precipitate divide into 3 test tubes and add:

into I – 10 ml of distilled water;
into II – 10 ml of 2 % FeCl₃ solution;
into III – 10 ml of 0.02 M HCl solution.

Record your observations after 10 minutes. Explain what happened with the precipitate in the second and third tubes? What are the types and mechanism of peptization? Write the structure of the prepared sols micelles.

b) Preparation of Berlin blue sol.

To 5 ml of 2% FeCl₃ solution add 1 ml of a saturated \( K_4[\text{Fe(CN)}_6] \) solution. The precipitate should be filtered and washed with distilled water. After washing
of the precipitate on the filter with 0.1 $M$ solution of oxalate acid ($\text{H}_2\text{C}_2\text{O}_4$) a blue sol of Berlin blue is filtered. Write the equation of the reaction and the structure of the sol micelle, considering that precipitate is peptized by oxalate acid due to $\text{C}_2\text{O}_4^{2-}$ ions adsorption.

4.2.4. Determination of the charge sign of colloidal particles of drugs

In colored sols the sign of particles charge can be determined by method of capillary analysis when capillaries surface of filter paper is used as charged surface. It is based on the fact that cellulose capillary walls of filter paper are negatively charged (because of dissociation of cellulose hydroxyl groups), and water that moistens the paper – positively. Place the drop of investigated sol on the piece of filter paper. After the drop absorption sol with positively charged particles is adsorbed on the paper and gives stain colored at the center and colorless on the edges; sol with negatively charged particles does not absorbe by the paper and forms an evenly colored stain.

5. Conclusions and Interpretations. Lesson Summary

Topic 3

Electro-kinetical properties of lyophobic sols

1. Objectives

All life processes take place in a colloidal system, and that is true both of the normal fluids and secretions of the organism, and of the bacterial toxins, as well as, in large measure, of the reactions, which confer immunity.

Atmospheric soils are mainly colloidal in nature. On account of colloidal nature, soils adsorb moisture and nourishing materials.

Dispersion refers to the spatial distribution of organisms, and is a fundamental component of a species' ecology and life history. Patterns of dispersion influence other aspects of a species' behavior and ecology. Dispersion patterns themselves are affected by the distribution of resources (including sunlight, nutrients, prey species, etc.) in the environment, as well as through the reciprocal influence of species' behavioral characteristics.

2. Learning Targets:

- electrical properties of dispersions, introduction to electrokinetic phenomena;
- to learn the micelle structure in isoelectric point;
- to get practical skills in zeta-potential magnitude measurements and to know how to use it for lyophobic sols stability characteristics;
- to learn electrophoresis applications in medical and biological researches.
3. Self Study Section
3.1. Syllabus Content


3.2. Theoretical Backgrounds

Colloidal particles always carry an electric charge. The nature of this charge is the same on all the particles in a given colloidal solution and may be either positive or negative. The charge on the sol particles is due to preferential (selective) adsorption of ions from solution and/or due to electrical double layer formation. The sol particles acquire positive or negative charge by selective adsorption of cations or anions. According to modern views, the first layer of counterions is firmly held and is termed the adsorptive layer while the second layer is mobile which is termed the diffusive layer. Since separation of charge is a seat of potential, the charges of opposite signs on the adsorptive and diffusive parts of the double layer results in a difference in potential between these layers. This potential difference between the adsorptive layer and the diffusive layer of opposite charges is called the electrokinetic potential, or zeta potential.

The magnitude of zeta potential is crucial in determining the stability of a colloidal suspension. When all the particles have a large negative or large positive charge they will repel each other, and so the suspension will be stable. A sol is supposed to be stable when its zeta-potential magnitude is in the range of 30–90 mV.

If the zeta potential is low the tendency for flocculation is increased. Another important consideration when discussing zeta potentials is pH; in fact, quoting a zeta potential without an accompanying pH is almost meaningless. This is due to the fact that, for suspensions of most materials, a plot of zeta potential versus pH exhibits an isoelectric point, a particular value of solution pH where the net charge on the particles is zero. At this point the suspension is highly unstable, and flocculation is at its most likely.

An important consequence of the existence of electrical charges on the surface of particles is that they interact with an applied electric field. These effects are collectively defined as electrokinetic effects. There are four distinct effects depending on the way in which the motion is induced. These are:

*Electrophoresis:* the movement of a charged particle relative to the liquid it is suspended in under the influence of an applied electric field.

*Electroosmosis:* the movement of a liquid relative to a stationary charged surface under the influence of an electric field.

*Streaming potential:* the electric field generated when a liquid is forced to flow past a stationary charged surface.
Sedimentation potential: the electric field generated when charged particles sediment.

The Helmholtz-Smoluchowski equation for zeta-potential calculation by electrophoresis method:

$$\xi = \frac{S l \eta}{\varepsilon E \varepsilon_0}$$

where $S$ – linear motion on a sol boundary, m; $l$ – distance between the electrodes in the device for electrophoresis, m; $\eta$ – viscosity of the dispersion medium, Pa·s; $\tau$ – time of electrophoresis, sec.; $E$ – electric field voltage V, $\varepsilon$ – dielectric constant of medium (=81 for water), $\varepsilon_0 = 8.85 \cdot 10^{-12}$ Fh/m – dielectric constant of vacuum.

3.3. References

a) Review Questions
1. Define the potential-defining ions, nucleus, adsorptive and diffuse layers of a micelle.
2. Consider the examples of AgCl, As$_2$S$_3$, PbS lyophobic sols preparation with positively and negatively charged granules. Write down the schemes of their micelles structure.
3. Name the main methods of colloidal solutions purification. Their medicinal applications. The principle of the "artificial kidney" device operation.
4. Give the definitions of electrophoresis and electroosmosis.
5. Draw the schematical representation of the device for electrophoresis and electroosmosis.
6. Define the electrokinetical (zeta-) potential and explain the mechanism of its appearance. Explain its role in determining the stability of colloids.
7. Draw the micelle structure for Fe(OH)$_3$ sol prepared in the presence of Fe(NO$_3$)$_3$ as a nucleating agent. Show the location of zeta-potential occurrence. Draw the structure of the same micelle in isoelectric state.

8. Application of electrophoresis in medical and biological researches.

b) Types of Numerical Problems and Their Solving Strategies

**Numerical problem 1.** Calculate the value of $\xi$-potential (in mV) for sol of collargolum using the following electrophoresis data: linear motion on a sol boundary $S=10$ mm, distance between the electrodes $l=20$ cm, electric field voltage $E=300$ V, time of electrophoresis $\tau=5$ min, viscosity of the medium $\eta=10^{-3}$ Pa·s, dielectric constant of medium $\varepsilon=81$ and dielectric constant of vacuum $\varepsilon_0=8.85 \cdot 10^{-12}$ Fh/m.

**Steps to Solution:**

According to the Helmholtz-Smoluchowski equation zeta-potential is:

$$\xi = \frac{S\eta}{\varepsilon \varepsilon_0 E \tau} = \frac{10 \cdot 10^{-3} \text{m} \cdot 20 \cdot 10^{-2} \text{m} \cdot 10^{-3} \text{Pa} \cdot \text{s}}{5 \cdot 60 \cdot 300 \text{V} \cdot 81 \cdot 8.85 \cdot 10^{-12} \text{Fh/m}} = 0.031 \text{V} = 31 \text{mV}.$$  

**Answer:** zeta-potential of sol particles is 31 mV.

c) Problems to Solve

1. AgI sol was obtained at slowly adding 15 ml of 0.2 % AgNO$_3$ solution (the density is 1 g/ml) to 20 ml of 0.01 M KI solution. Write down the formula of micelle of obtained sol. Determine the direction of its particles movement in the applied electric field.

1. Calculate electrophoretical velocity ($V$) of protargolum hydrophobic sol grnules if their zeta potential value is 50 mV. Under the electrophoresis the particles have been moved at a distance of 5.2 cm during 180 sec. The electrical field voltage gradient $H = 8 \cdot 10^{-2}$ V/m, the viscosity of the solution $\eta = 10^{-3}$ Pa·sec and constants $\varepsilon=81$ i $\varepsilon_0=8.85 \cdot 10^{-12}$ Fh/m.

**Answer:** 2.87 $\cdot$ 10$^{-6}$ mm/sec

2. Calculate zeta-potential of protein particles if under the electrophoresis its particles have been moved at a distance of 22.5 mm during 20 min at the applied voltage of 200 V. Distance between the electrodes is 15 cm. Viscosity of the solution $\eta = 10^{-3}$ Pa·sec and constants $\varepsilon=81$ i $\varepsilon_0=8.85 \cdot 10^{-12}$ Fh/m.

**Answer:** 19.6 mV

4. Laboratory Activities and Experiments Section

4.1. Practical Skills and Suggested Learning Activities

- to determine the sign of particles charge by the capillary analysis method;
- to determine the charge sign of a sol granules and zeta potential magnitude for the particles of a drug.
– to prepare lyophobic sols with chemical condensation method under the double exchange reactions, hydrolysis and redox reactions;
– to prepare sols with the methods of direct and indirect peptization.

4.2. Experimental Guidelines

4.2.1. Determination of the sign and value of zeta-potential of a medicine (hydrophobic sol directed by the teacher: protargol or collargolum) by macroelectrophoresis method

1) Into the knee A of the device for electrophoresis (see Figure 1), which is fixed in tripod, pour in intermediate fluid for a given sol to level ~ 3-5 mm above the upper edge K. Tap should be opened to let the air come out through it.
2) Turn off the tap K and place the electrodes E into both knees, but do not clamp the stoppers to let the fluid leak out.
3) Pour a given sol through the funnel B up to the top.
4) Use wire to clean the bottom end of the tube under the funnel B to remove any air bubbles.
5) Open the tap K slightly to let sol from the funnel leak slowly to the bottom of U-shaped tube and form a clear boundary between sol and intermediate fluid, which is lightweight than sol, in both knees.
6) Add some more sol into the funnel and withdraw separation boundary between sol and intermediate fluid in front of the digital divisions on the scale.
7) Turn off the tap K and record the positions of sol boundaries in both knees respectively to scales (they may not coincide).
8) Turn on the current. Write the pointer of voltmeter will show the voltage between electrodes, note the start time of electrophoresis.
9) Record the voltage value E by direct indications of voltmeter or calculate it, if the scale of the device has implicit graduation. Note, what is the voltage (300 V, 450 V or other) supplied by rectifier on the electrophoresis and where the pointer of the voltmeter stopped.
10) Stop the electrophoresis, turn off the current in 5-10 minutes (when the boundary of sol in the knee lower to 5-7 mm - Scale III). Record the end time of electrophoresis and determine the duration of current flow $\tau$.
11) By the difference between the positions of sol boundaries determine the displacement of sol particles ($S$). Note the direction (to which of the electrodes sol boundary shifted during the electrophoresis). Make a conclusion about the sign of the charge on the granules of investigated colloidal solution.
12) After switching off the current measure the distance $l$ between the electrodes using thread and ruler (by the course of the current in the U-shaped tube).
13) Pour away the solution from the U-shaped tube, rinse it with water.
14) Briefly describe the procedure of the work done and calculate the results.
15) Convert all measured values into SI system, substitute them in the formula of Helmholtz-Smoluchowski equation to calculate $\zeta$-potential:

$$\zeta = \frac{\eta \cdot l \cdot S}{\tau \cdot D \cdot E \cdot \varepsilon}.$$ 

where besides the already mentioned values $l$ (m), $S$ (m), $\tau$ (s), $E$ (V) take the viscosity $\eta = 10^{-3}$ Pa·s and $D = 81$ – dielectric constant for water, and absolute dielectric permittivity constant for vacuum $\varepsilon = 8.85 \cdot 10^{-12}$ F/m.
16) Recalculate the obtained value of $\zeta$ in volts to millivolts (mV).
17) Make a conclusion about the sign of the granules charge of investigated sol and indicate whether it is stable, comparing the obtained value of zeta-potential with the critical value (30 mV).

5. Conclusions and Interpretations. Lesson Summary

Topic 4

Molecular-kinetical and optical properties of the dispersed systems

1. Objectives

The studying of optical properties of colloid systems can provide the important information about the shape, size and structure of suspended particles and allow to determine the concentration of a sol.

Nephelometry is the technique used for determining the amount of cloudiness, or turbidity, in a solution. It is based upon the measurement of the effect of this
turbidity upon the transmission and scattering of light. Turbidity in a liquid is caused by the presence of finely divided suspended particles. In nephelometry the intensity of the scattered light is measured, while, in turbidimetry, the intensity of light transmitted through the sample is measured. The nephelometry is used for the determining of proteins concentration in urine. It is based on the proteins ability to form turbidity with sulfursalicylic acid which is proportional to the proteins content.

The ultramicroscopy allows to observe the suspended particles whose size is less than $3 \cdot 10^{-9}$ m and is used in sanitary for the determining the pollutions in the air.

2. Learning Targets:
   – to learn the theory of light dispersion and Rayleigh’s equation;
   – to learn the theoretical backgrounds of the light scattering in sols;
   – to learn the light scattering laws in law;
   – to get practical skills of sols particles concentration experimental determining by nephelometry;
   – to get practical skills in colloidal particles size calculation by the optical density of their solutions measuring;
   – to learn sols micells structure in isoelectrical point.

3. Self Study Section

3.1. Syllabus Content

Molecular - kinetic properties of dispersions. Thermal molecular motion and Brownian motion (Einstein equation), diffusion (Fick’ equation), and osmotic pressure. Viscosity of lyophobic sols. Ultracentrifugation, its using in researching of colloidal systems. Optical properties of dispersions.

3.2. Theoretical Backgrounds

Systems containing colloid particles are in some properties different from systems which are homogeneous or composed of macroscopic phases. When the beam of light is passing through a dispersed system the following phenomena may be observed: transmission, absorption, refraction, reflection and scattering of light. The prevailing of any of these processes depends on the ratio of the wavelengths of the light and the sizes of the suspended particles.

The molecular and ionic solutions are optically transparent as the beam of light is just transmitting through them. Any medium is able to absorb selectively the light waves with the certain wavelengths.

The optical properties of colloids depend on the size and structure of suspended particles and the dispersed phase concentration. The diffraction of light will be mainly observed for colloids as their particles sizes are equal about half of the initial light wavelength ($\lambda/2$). The diffraction courses the opalescence of colloids – the lusterless luminarity of soles usually with a touch of blue.
If light passes through a system containing colloid particles, part of the light is scattered and consequently the ray passage through the environment can be observed (the Tyndall effect).

Rayleigh equation shows the scattered light intensity affection with different factors:

\[
I_{scat} = 2A \pi^3 I_0 \frac{n_1^2 - n_0^2}{n_1^2 + 2n_0^2} \frac{\nu V_{particle}^2}{\lambda^4}
\]

where \( I_0 \) and \( I_{scat} \) are the intensities of the initial and scattered light beam, respectively; \( \nu \) is the number of particles of the volume \( V_{particle} \) in unit volume; \( \lambda \) is the wavelength of the incident light, \( n_0 \) is the refraction index or the dispersion medium, and \( n_1 \) is refraction index of the dispersed phase.

From this equation analysis it is obvious that:
- in order for scattered light to originate, the diffraction index of the dispersion ratio and that of the dispersion environment have to be different;
- light scattering is proportional to the number of particles in the system;
- the scattered light is proportional to the quadrate of the particles volume;
- the scattering is inversely proportional to the fourth power of the wavelength of the incident light.

The nephelometry measurements are carried out in nephelomoters. The observations should be carried out upon the dark background with the side lightening.

The nephelometer cheme:
1, 6 – cylindrical cuvetes with colloids;
2, 5 – glass cylinders;
3, 4 – prisms; 7 – ocular;
S – the source of light

The cuvetes 1 and 6 are filled with a sample and investigated colloids. The scattered light intensities are balanced for the both parts of the ocular 7 by the means of the cuvetes moving up or down. Then the levels of the cuvets ratio will be inversely proportional to the colloids concentrations and their particles volumes ratios:

\[
\frac{h_1}{h_2} = \frac{C_2}{C_1} \quad \frac{h_1}{h_2} = \frac{V_2}{V_1}
\]

(10)

If the concentration \( C \) or the dispersed phase particles size \( V \) for a sample colloid is known these quantities may be calculated for the investigated colloid:
The nephelometry is used for the determining of proteins concentration in urine. It is based on the proteins ability to form turbidity with sulfursalicylic acid which is proportional to the proteins content.

Ultramicroscopy.

With the help of a powerful source of light and the system of linzes a bright beam of light is created. A colloid is lightened with it on the dark background. Owing to the light scattering the colloidal particles become visible through the optical microscope ocular luminary points.

Ultramicroscopy allows to determine the size and shape of suspended particles directly, the rate of the particles movement, their volume concentration, observe their coagulation.

For determining the size of suspended particles (their radius $r$ for spherical particles) a certain optical volume $V$ should be fixed and the number of particles $n$ in this volume should be calculated.

Let $C$ is the dispersed phase particles mass in a volume unit, $\text{kg/m}^3$; $m$ – mass of one particle, $\text{kg}$; $V_0$ – volume of a particle, $\text{m}^3$; $d$ – the dispersed phase particles density, $\text{kg/m}^3$; $V$ – optical volume, $\text{m}^3$; $n$ – a number of particles in a volume $V$; $\nu$ – particles number in a volume unit.

Then the number of particles in a volume unit will be:

$$\nu = \frac{n}{V}$$

Mass of a particle is equal to:

$$m = \frac{C}{\nu} = \frac{CV}{n}$$

The volume of one particle is:

$$V_0 = \frac{m}{d} = \frac{CV}{nd}$$

If the shape of particles if spherical, then the volume of a particle is:

$$C_2 = C_1 \frac{h_1}{h_2} \quad V_2 = V_1 \frac{h_1}{h_2}$$ (11)
\[
\frac{4}{3} \pi r^3 = \frac{CV}{nd}
\]

Hence it is possibly to calculate the radius of the spherical particles:

\[
r = \sqrt[3]{\frac{3CV}{4\pi nd}}
\]

The ultramicroscopy allows to observe the suspended particles whose size is less than \(3 \cdot 10^{-9} \) m and is used in sanitary for the determining the pollutions in the air.

### 3.3. References


### 3.4. Self Assessment Exercises

**a) Review Questions**

1. The prevailing of light scattering or absorption and reflection depending on the sizes of the suspended particles. The Tyndall effect.
2. Write down the Rayleigh’s equation and make its analysis.
3. Which variables do influence the scattered light intensity?
5. Explain the opalescence phenomenon in disperse systems.
6. Draw the nephelometer cheme and explain the principles of its operation.
7. Define the optical density and turbidity of solutions. Show the correlation between them.
**b) Types of Numerical Problems and Their Solving Strategies**

**Numerical problem 1.** Calculate the diameter of an aerosol particles, if 120 of such particles were found in the volume of $4 \cdot 10^{-11} \text{ m}^3$. The mass concentration of sol is $1 \cdot 10^{-4} \text{ kg/m}^3$, and the dispersed phase density is $2.2 \cdot 10^3 \text{ kg/m}^3$.

**Steps to Solution:**

The quantity of particles in the unit of volume equals:

$$\nu = \frac{n}{V}.$$  

The volume of 1 particle is equal to the ratio between the mass of 1 particle and the density of dispersed phase:

$$V_0 = \frac{m}{d} = \frac{C}{\nu \cdot d} = \frac{C \cdot V}{n \cdot d}.$$  

For the spherical particles the volume of 1 particle is:

$$V_0 = \frac{4}{3} \pi r^3.$$  

Then,

$$\frac{C \cdot V_0}{n \cdot d} = \frac{4}{3} \pi r \quad \rightarrow \quad r = \left( \frac{3 \cdot C \cdot V_0}{4 \pi \cdot n \cdot \rho} \right)^{\frac{1}{3}}.$$  

Calculate the radius of the spherical particles:

$$r = \left( \frac{3 \cdot 1 \cdot 10^{-4} \cdot 4 \cdot 10^{-11}}{4 \cdot 3.14 \cdot 120 \cdot 2.2 \cdot 10^3} \right)^{\frac{1}{3}} = 1.535 \cdot 10^{-7} \text{ m}.$$  

Calculate the diameter of the spherical particles:

$$D = 2r = 1.535 \cdot 10^{-7} \cdot 2 = 3.07 \cdot 10^{-7} \text{ m}.$$  

*Answer:* the diameter of sol particles is $3.07 \cdot 10^{-7} \text{ m}$.

**Numerical problem 1.** Protargolum reference sol with the disperse phase mass percentage of 15 % was found to have the same light scattering as the analyte protargolum sol of the same dispersion ratio under nephelometry. The scattered light intensities were balanced at the cuveres levels of $H_1=15.2 \text{ mm}$ and $H_2=22.8 \text{ mm}$, respectively. Calculate the mass percentage of protargolum in the analyte solution.

**Steps to Solution:**

For single-beam nephelometer at the balanced light scattering sols concentrations would be inversely proportional to the cuvetes levels:

$$\frac{C_1}{C_2} = \frac{H_2}{H_1}.$$  

This equation may be used for the analyte sol concentration calculation if it would be transformed as: \[ C_2 = \frac{C_1 \cdot H_1}{H_2} \], \[ C_2 = \frac{1.5\% \cdot 15.2 \text{ mm}}{22.8 \text{ mm}} = 1\% \].

c) Problems to Solve

1. At ultramicroscopy investigation of gold hydrosol in volume of \( V_0 = 1.6 \cdot 10^{-11} \text{ m}^3 \)
   70 particles (\( n \)) were found. Sol concentration \( C = 7 \cdot 10^{-6} \text{ kg/m}^3 \), gold density \( d = 19.3 \cdot 10^3 \text{ kg/m}^3 \). Determine the radius of dispersed phase particles (in m) assuming their shape as spherical.
   Answer: 2.705 \cdot 10^{-8} \text{ m}

2. Protargolum reference sol with the disperse phase mass percentage of 2 % was found to have the same light scattering as the analyte protargolum sol of the same dispersion ratio under nephelometry. The scattered light intensities were balanced at the cuveres levels of \( H_1 = 26.9 \text{ mm} \) and \( H_2 = 17.9 \text{ mm} \), respectively. Calculate the mass percentage of protargolum in the analyte solution.
   Answer: 3 %

3. At ultramicroscopy investigation of sulfur hydrphobic sol in the optical volume of \( V_0 = 2 \cdot 10^{-11} \text{ m}^3 \)
   100 particles (\( n \)) were found. Sol concentration \( C = 6.5 \cdot 10^{-5} \text{ kg/m}^3 \), sulfur density \( d = 1 \cdot 10^3 \text{ kg/m}^3 \). Determine the radius of dispersed phase particles (in m) assuming their shape as spherical.
   Answer: 1.457 \cdot 10^{-7} \text{ m}

4. Laboratory Activities and Experiments Section

4.1. Practical Skills and Suggested Learning Activities

– to learn molecular-kinetics properties of dispersed systems;
– to learn the phenomena which appear while the beam of light is passing through the dispersed system;
– write down the Rayleigh’s equation and make its analysis;
– to learn the optical methods of the dispersed systems investigation;
– to study the optical methods application for the dispersed phase particles shape and size determining;
– to observe the Tyndall effect and opalescence in sols;
– to get practical skills in the sol concentration determining with optical methods.

4.2. Experimental Guidelines

4.2.1. A sol concentration determining with nephelometry

   Nephelometry measurements are made with a nephelometer to determine concentration of particulate matter in a sample. The amount of light blocked by a suspension of particles depends not only on concentration but also on size.

   For single-beam spectrophotometers, the absorbance reading from the sample must be blanked using an appropriate reference solution that does not contain the compound of interest.
In the nephelometry the light scattered by the small particles is measured at an angle to the beam incident on the cuvet. Light scattering depends on wavelength, the thickness of the solution layer, and the particles size. For macromolecules with a size close to or larger than the wavelength of incident light, sensitivity is increased by measuring forward light scatter.

Instruments are available with detectors placed at various forward angles, as well as at 90 degrees to the incident light or with the cuvetes levels varying. Monochromatic light obtains uniform scatter and minimizes sample heating.

Under nefelometry blank and test solutions are poured into the cuvetes with an opaque bottom labeled as "R" - the right and "L" – the left one. Labels on the respective cuvete and on the device should match. By regulation the levels of the cylindrical glass rods immersing into sols in cuvetes one is looking for the balancing the light intensities of both parts of the ocular’s field of view. The levels of the illuminated parts of the solutions \((H)\) may be varied by means of the cuvetes moving up or down.

When the light intensities of both parts of the ocular’s field would be balanced the following equation would become true:

\[
C_1 \cdot H_1 = C_2 \cdot H_2
\]

If the reference solution concentration \(C_1\) is known, the concentration of the analyte solution \(C_2\) may be calculated as follows:

\[
C_2 = \frac{C_1 \cdot H_1}{H_2}
\]

Determining the height of the illuminated solutions is performed using two scales marked with the letter "H" and their noniusom. The graduation value of the scale is 1 mm and the notional value of the noniusom graduation is 0.1 mm. The exact number the the second decimals of the scale is determined by which one of ten scale marks of the noniusom will coincide with any mark of a measuring scale.

However, a linear relationship between the magnitude of light absorption and the concentration is not proved for all types of solutions. In this case, the calibration curve should be plotted.

**Performance of work**

1. To get from your teacher the certain task by specifying the initial concentration of the sol.
2. Prepare the calibration solutions series by diluting the initial sol solution 2, 4, 8 and 16 times. For this purpose take away with the pipette 10 ml of the initial sol and transfer into the flask No 1. To add there with the pipette 10 ml of distilled water. So you will get 20 ml 2 times diluted solution. Then take out with the pipette 10 ml of the solution from flask No 1 and transfer into the flack No 2. Add 10 ml of the distilled water with the pipette and you will get 4 times dilution of the initial solution. Continuing the similar dilutions with water, obtain 8 and 16 times dilutions.
3. Accepting one of the dilute solutions (e.g., 4 times) as a standard, pour it into the left cuvette, install it on a fixed scale mark "H" (for example, \(H_{st} = 5.0 \text{ mm}\)), leaving it unshifted.

4. All solutions of a sol, beginning with the initial and including a standard one should be poured in turn into the right cuvette, which should be moved up or down during the measurements in order to balance the intensity of the scattered light. This may be seen as the same light intensities of both parts of the ocular’s field of view when the source of light in nephelometer is switched on.

5. For each solution to determine the average value of the right scale measurements "H" \((H_2, \text{ in } \text{mm})\).

6. To calculate the concentration of each of the diluted solutions if the standard 4 times diluted solution concentration \((C_1)\) is known taking into account its cuvette level \((H_{st}=5.0 \text{ mm})\):

\[
C_2 = \frac{C_1 \cdot H_{st}}{H_2}
\]

7. Record the obtained results into the table.

8. To plot the calibration curve in the following coordinates: the nephelometer scale mark \(H_2\) (Y-axis) as the function of a sol concentration calculated by the equation \(C_2\) (X-axis).

9. Make the conclusion about the dependence of the scattered light intensity on the analyte solution layer thickness and sol concentration.

10. To pour a sol with the unknown concentration \(C_x\) (the task) into the right cuvette of nephelometer and determine the average value of the right scale measurements "H" \((H_x, \text{ in } \text{mm})\) when the light intensities of both parts of the ocular’s field of view are balanced.

<table>
<thead>
<tr>
<th>No</th>
<th>Sol dilution</th>
<th>The nephelometer scale marks H, mm</th>
<th>Sol concentration, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&quot;L&quot; (standard cuvette)</td>
<td>cuvette &quot;R&quot; (analyte solution)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(H_{st})</td>
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<tr>
<td>6</td>
<td>task</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. To determine the analyte solution (the task) concentration \(C_x\) according the cuvette level \(H_x\) using the calibration curve.
5. Conclusions and Interpretations. Lesson Summary

Topic 5

The stability of the dispersed systems and their coagulation.
The methods of sols purification

1. Objectives

The long-term colloidal stability of dispersion will be of great importance in a number of industries such as pharmaceutical, ceramic, paints and pigments. The term “stability” can have different connotations to different applications. When applied to colloids, a stable colloidal system is one in which the particles resist flocculation or aggregation and exhibits a long shelf-life. This will depend upon the balance of the repulsive and attractive forces that exist between particles as they approach one another. If all the particles have a mutual repulsion then the dispersion will remain stable. However, if the particles have little or no repulsive force then some instability mechanism will eventually take place e.g. flocculation, aggregation etc.

Coagulation processes are widely used in the industry, for example in the electrical precipitation of smoke. They are also applied for the purification of drinking water: the water obtained from natural sources often contains suspended impurities. Alum is added to such water to coagulate the suspended impurities and make water fit for drinking purposes.

Most of the medicines are colloidal in nature. For example, argyrol is a silver sol used as an eye lotion. Colloidal antimony is used in curing kalaazar. Colloidal gold is used for intramuscular injection. Milk of magnesia, an emulsion, is used for stomach disorders. Colloidal medicines are more effective because they have large surface area and are therefore easily assimilated. So the colloidal protection in drugs manufacturing is of a great importance.

2. Learning Targets:

– to get practical skills in critical concentration of sols coagulation experimental determining;
– to learn how is it possible to calculate the coagulating ability of electrolytes with different valences ions;
– to know the protective action evaluation of polymers or hydrophilic colloids towards hydrophobic sols and to determine experimentally the protective number.

3. Self Study Section

3.1. Syllabus Content

Kinetic (sedimentation) and aggregative stability of disperse systems. The reasons of colloidal stability. Coagulation. The mechanism of electrolytes

3.2. Theoretical Backgrounds

Disperse systems stability is the ability to keep during certain time composition and main properties, such as dispersion, concentration, even distribution of dispersed phase particles in dispersion medium and way of particles interaction unchangeable. A stable colloidal system is one in which the particles resist flocculation or aggregation and exhibits a long shelf-life. This will depend upon the balance of the repulsive and attractive forces that exist between particles as they approach one another. If all the particles have a mutual repulsion then the dispersion will remain stable. However, if the particles have little or no repulsive force then some instability mechanism will eventually take place e.g. flocculation, aggregation etc.

Kinetic (sedimentation) stability of a disperse system is the conservation of particles been distributed throughout the whole volume of a system. The main conditions for kinetic stability are high dispersion and Brownian movement (motion). This stability increases with temperature increasing and decreasing of particles size.

Aggregative stability of disperse systems is the ability of a system to counteract adhesion (aggregation) of particles and keep certain degree of dispersion. The stability of the lyophobic sols is due to the presence of charged on colloidal particles. If, somehow, the charge is removed, the particles will come nearer to each other to form aggregates (or coagulate) and settle down under the force of gravity.

To coagulate lyophilic sols, it is necessary to remove charge as well as the solvent layer. This is indicated by the fact that after the addition of an electrolyte if we also add a dehydrating agent, the coagulation sets in at once due to the removal of water layer. Thus the stability of the colloidal solutions is mainly due to three reasons:

- Brownian motion;
- presence of similar charge on colloidal particles;
- solvation of colloidal particles.

The process of settling of colloidal particles is called coagulation or precipitation of the sol. Coagulation is the process of decreasing of system dispersivity due to the dispersion phase particles enlargement.

The coagulation of the lyophobic sols can be carried out in the following ways:

- by electrophoresis: the colloidal particles move towards oppositely charged electrodes, get discharged and precipitated;
- by mixing two oppositely charged sols: oppositely charged sols when mixed in almost equal proportions, neutralise their charges and get partially or completely precipitated. This type of coagulation is called mutual coagulation;
by boiling: when a sol is boiled, the adsorbed layer is disturbed due to increased collisions with the molecules of dispersion medium. This reduces the charge on the particles and ultimately lead to settling down in the form of a precipitate;

by persistent dialysis: on prolonged dialysis, traces of the electrolyte present in the sol are removed almost completely and the colloids become unstable and ultimately coagulate;

by addition of electrolytes: When excess of an electrolyte is added, the colloidal particles are precipitated. The reason is that colloids interact with ions carrying charge opposite to that present on themselves. This causes neutralisation leading to their coagulation. The ion responsible for neutralisation of charge on the particles is called the coagulating ion. A negative ion causes the precipitation of positively charged sol and vice versa.

The most important coagulation factor for soles is electrolytes influence. Only certain quantity of electrolyte causes coagulation. Minimal concentration of electrolyte in mmol that may cause 1 l of sole coagulation is called coagulation threshold (C_{thr}) or critical concentration of coagulation (C_{cr}). The beginning of coagulation first signs are system color changing, appearing of turbidity.

$$C_{cr} = \frac{V_{el} \cdot C_{el}}{V_{sole} + V_{el}},$$

where $V_{el}$ – volume of the electrolyte (l), that causes coagulation; $C_{el}$ – concentration of electrolyte (mol/l), $V_{sole}$ – volume of colloidal solution (l).

The value that is inverse to coagulation threshold is called coagulation capacity:

$$V_c = \frac{1}{C_{thr}}.$$  

Coagulation capacity is the volume of sol, for whose coagulation 1 mmol of the electrolyte is needed.

Critical concentration of coagulation value is mainly determined by the valence rather than the type of the ions with opposite charge sign to the particles. Ions with the same charge sign than the particles are of secondary importance.

According to the Schulze-Hardy rule the coagulating ability of ion increases with increasing of its charge, therefore the lowest critical concentration of coagulation have electrolytes with multi-charged coagulating ion:

$$C_{thr}(K^+) > C_{thr}(Ca^{2+}) > C_{thr}(Al^{3+}) > C_{thr}(Cl^-) > C_{thr}(SO_4^{2-}) > C_{thr}(PO_4^{3-}).$$

Coagulation threshold is inversely proportional to ion charge ($z$) raised to the power of 6: $C_{thr} = 1/z^6$.

That’s why the magnitudes of coagulation thresholds for one-, two- and three-valence ions correlate as:

$$C_1 : C_2 : C_3 = \frac{1}{1^6} : \frac{1}{2^6} : \frac{1}{3^6} = 1 : 0.0156 : 0.00137 = 730 : 11.4 : 1.$$  

For inorganic ions with the same charges their coagulating ability increases with decreasing their degree of hydration and increasing of the ion radius.
**Lyotropic, or Hofmeister Series:**

<table>
<thead>
<tr>
<th>Coagulating Ability</th>
<th>Coagulating Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺ &lt; Na⁺ &lt; K⁺ &lt; Rb⁺ &lt; Cs⁺</td>
<td>Cl⁻ &lt; Br⁻ &lt; I⁻ &lt; CNS⁻</td>
</tr>
</tbody>
</table>

According to the kind of the repulsion force two mechanisms of the colloidal stability protection take place:

− electrostatic stabilization of colloids;
− stabilization of colloids with polymers.

Polymeric stabilization of colloids involves polymeric molecules added to the dispersion medium in order to prevent the aggregation of the colloidal particles. The protective action of different polymers is expressed in terms of the protective number.

*Protective number* is the number of milligrams of dry protective substance (polymer or hydrophilic colloid) which just prevents the precipitation of 10 ml of certain sol on the addition of 1 ml of 10% NaCl solution.

### 3.3. References


### 3.4. Self Assessment Exercises

**a) Review Questions**

1. Define the reasons of colloidal stability. Kinetic (sedimentation) and aggregative stability of disperse systems.
2. Give the definition of the coagulation process. List the factors which may cause the coagulation of sols.
3. Define the coagulation threshold (critical concentration of coagulation).
4. State Schulze-Hardy rule. Explain it on some examples.
5. Explain the mutual coagulation of sols, give a few examples.
6. Explain the protective action of polymers or hydrophilic colloids towards hydrophobic sols. Define the term of the protective number.
7. Describe the protective action significance and applications in biology, medicine, pharmacy.

b) Types of Numerical Problems and Their Solving Strategies

Numerical problem 1. Calculate the critical concentration of coagulation for AgI sol, if 0.4 ml of 0.05 M BaCl₂ solution should be added for 2 ml of sole coagulation.

Steps to Solution:
1. Calculate the number of BaCl₂ moles in 0.4 ml of 0.05 M solution:
   \[ n = 0.05 \text{ mol/l} \cdot 0.4 \cdot 10^{-3} l = 0.02 \cdot 10^{-3} \text{ mol} = 0.02 \text{ mmol}. \]
2. Calculate the volume of solution after coagulation:
   \[ V = 2 + 0.4 = 2.4 \text{ ml} = 2.4 \cdot 10^{-3} \text{ l}. \]
3. Calculate the critical concentration of coagulation – the minimal number of BaCl₂ mmol which is necessary for coagulation of 1 l of sol:
   \[ C_{cr} = \frac{n}{V} = \frac{0.02 \text{ mmol}}{2.4 \cdot 10^{-3} \text{ l}} = 8.3 \text{ mmol/l}. \]
Answer: the critical concentration of coagulation is 8.3 mmol/l.

Numerical problem 2. How many millilitres of 1 M NaCl solution should be added to 500 ml of Fe(OH)₃ sol to cause its coagulation if the critical concentration of coagulation is 104·10⁻³ mol/l?

Steps to Solution:
From the equation for critical concentration of coagulation:
\[ C_{cr} = \frac{n_{el}}{V} = \frac{V_{el} \cdot C_{el}}{V_{sol} + V_{el}} \rightarrow \frac{V_{el}}{V_{sol} + V_{el}} = \frac{C_{cr}}{C_{el}} = \frac{104 \cdot 10^{-3} \text{ mol/l}}{1 \text{ mol/l}} = 104 \cdot 10^{-3}. \]
Calculate the volume of NaCl solution solving the following equation:
\[ V_{el} = 104 \cdot 10^{-3} \cdot (V_{sol} + V_{el}), \quad V_{el} - 104 \cdot 10^{-3} V_{el} = 104 \cdot 10^{-3} \cdot V_{sol}, \]
\[ 0.896 V_{el} = 52, \quad V_{el} = \frac{52}{0.896} = 58 \text{ ml}. \]
Answer: the volume of 1 M NaCl solution is 58 mmol/l.

Numerical problem 3. How many times the coagulation threshold of As₂S₃ sol will decrease if 0.5 M NaCl solution firstly been used for 10 ml of sol coagulation (1.2 ml were used for the coagulation) would be substituted with 0.036 M MgCl₂ solution (0.4 ml were needed) or 0.001 M AlCl₃ solution (0.1 ml were needed) for the same volume of sol (10 ml) coagulation.
Steps to Solution:

1. Calculate the number of mmoles of each electrolyte needed for 10 ml of Ag$_2$S$_3$ sol coagulation:
   \[ n_1(\text{NaCl}) = C(\text{NaCl}) \cdot V(\text{NaCl}) = 0.5 \times 1.2 = 0.6 \text{ mmols NaCl}; \]
   \[ n_2(\text{MgCl}_2) = C(\text{MgCl}_2) \cdot V(\text{MgCl}_2) = 0.036 \times 0.4 = 0.0144 \text{ mmols MgCl}_2; \]
   \[ n_3(\text{AlCl}_3) = C(\text{AlCl}_3) \cdot V(\text{AlCl}_3) = 0.01 \times 0.1 = 0.001 \text{ mmols AlCl}_3. \]

2. Calculate the total volumes of obtained solutions containing sol and coagulating electrolyte (V):
   \[ V_1 = V_{\text{sol}} + V(\text{NaCl}) = 10 + 1.2 = 11.2 \text{ ml} = 11.2 \times 10^{-3} \text{ l}; \]
   \[ V_2 = V_{\text{sol}} + V(\text{MgCl}_2) = 10 + 0.4 = 10.4 \text{ ml} = 10.45 \times 10^{-3} \text{ l}; \]
   \[ V_3 = V_{\text{sol}} + V(\text{AlCl}_3) = 10 + 0.1 = 10.1 \text{ ml} = 10.1 \times 10^{-3} \text{ l}. \]

3. Calculate the coagulation threshold values for each electrolyte:
   \[ C_{\text{cr1}} = \frac{n_1}{V_1} = \frac{0.6}{11.2 \times 10^{-3}} = 53.6 \text{ mmol/l NaCl}; \]
   \[ C_{\text{cr2}} = \frac{n_2}{V_2} = \frac{0.0144}{10.4 \times 10^{-3}} = 1.4 \text{ mmol/l MgCl}_2; \]
   \[ C_{\text{cr3}} = \frac{n_3}{V_3} = \frac{0.001}{10.1 \times 10^{-3}} = 0.1 \text{ mmol/l AlCl}_3. \]

4. How many times the coagulation threshold values of As$_2$S$_3$ sol will be lower for MgCl$_2$ and AlCl$_3$ than for NaCl:
   \[ \frac{C_{\text{cr1}}}{C_{\text{cr2}}} = \frac{53.6}{1.4} = 38.3 \text{ times for MgCl}_2; \]
   \[ \frac{C_{\text{cr1}}}{C_{\text{cr2}}} = \frac{53.6}{0.1} = 536 \text{ times for AlCl}_3. \]

Numerical problem 4. A sol of AgCl was prepared by adding of 10 ml of 0.03 % NaCl solution to 25 ml of 0.002 M AgNO$_3$ solution. Which electrolyte through the listed ones will have the lowest value of the critical concentration of coagulation for this sol: KBr, Ba(NO$_3$)$_2$, K$_2$CrO$_4$, MgSO$_4$, AlCl$_3$, K$_3$PO$_4$?

Steps to Solution:

1. Calculate the molar concentration of 0.03 % NaCl solution, accepting the density being equal 1 g/ml and \( M(\text{NaCl}) = 58.5 \text{ g/mol} \) using the following equation:
   \[ C_M = \frac{\omega \cdot d \cdot 10}{M(\text{NaCl})} = \frac{0.03 \cdot 1 \cdot 10}{58.5} = 0.00513 \text{ mmol/ml}. \]

2. Calculate the volume of mixed solutions:
   \[ V = V_1 + V_2 = 10 + 25 = 35 \text{ ml}. \]
3. Calculate the number of mmoles of each reactant:

\[ n_1(\text{NaCl}) = C_1 \cdot V_1 = 0.00513 \cdot 10 = 0.0513 \text{ mmol}; \]
\[ n_2(\text{AgNO}_3) = C_2 \cdot V_2 = 0.001 \cdot 25 = 0.025 \text{ mmol}. \]

4. According to the equation of reaction:

\[
\text{NaCl} + \text{AgNO}_3 \rightarrow \text{AgCl} + \text{NaNO}_3
\]

\[
0.0513 \quad 0.025
\]

NaCl is in excess, so it is the stabilizer of the sol AgCl. The formula of the micelle is:

\[
\{[m(\text{AgCl}) \cdot n\text{Cl}]^n \cdot (n-x) \text{Na}^+\}^x \cdot x\text{Na}^+
\]

5. Cations K\(^+\), Ba\(^{2+}\), Mg\(^{2+}\), Al\(^{3+}\) will cause the coagulation of this sol. According to the Schulze-Hardy rule the coagulating ability of ion increases with increasing of its charge. Therefore, the lowest value of critical concentration of coagulation has AlCl\(_3\). KBr, K\(_2\)CrO\(_4\) and K\(_3\)PO\(_4\) solutions of the same normality have the least coagulating ability.

**Numerical problem 5.** Calculate the protective number and the coagulation threshold for Al\(_2\)S\(_3\) sol with negatively charged granules if 3 ml of 0.5 % dextrin aqueous solution were added to 5.5 ml of the sol and the first signs of coagulation were observed with 1.5 ml of 2.5 \(M\) NaCl solution adding.

**Steps to Solution:**

1. Calculate the mass of dextrin in 3 ml of 0.5 % diluted solution (accepting its density being 1 g/ml):

\[
\frac{3 \cdot 0.5}{100} = 0.015 \text{ g} = 15.0 \text{ mg of dextrin}.
\]

2. Calculate the mass of dextrin needed for its protective action toward 10 ml of sol instead of 5.5 ml:

   for 5.5 ml of sol protection 15 mg of dextrin are needed
   for 10 ml \(- x \text{ mg}

\[
x = \frac{15 \cdot 10}{5.5} = 27.3 \text{ mg}.
\]

3. Find out the mass of NaCl in 1.5 ml (0.0015 l) of its 2.5 \(M\) solution, the molar mass of NaCl is 58.5 g/mol:

\[
m(\text{NaCl}) = C_M \cdot V(\text{NaCl}) \cdot M(\text{NaCl}) = 2.5 \cdot 0.0015 \cdot 58.5 = 0.219 \text{ g NaCl}.
\]

4. Calculate the protective number that is the mass of dextrin (in mg) needed for just preventing the precipitation of 10 ml of sol on the addition of 1 ml of 10% NaCl solution (or \(\approx 0.1 \text{ g of NaCl}\)):

   for 0.219 g of NaCl \(\quad 23.3 \text{ mg of dextrin re needed,}
   for 0.1 g \quad x \text{ mg}

\[
x = \frac{27.3 \cdot 0.1}{0.219} = 12.5 \text{ (mg of dextrin)}.
\]

5. Calculate the coagulation threshold for given sol:
\[ C_{cr} = \frac{C \cdot V_1}{V}, \]

where: \( C \) – the initial concentration of the coagulating electrolyte, mol/l;
\( V_1 \) – the volume of electrolyte needed for the coagulation, ml;
\( V \) – the total volume of solution, ml.

\[ C_{cr} = \frac{2.5 \cdot 1.5}{5.5 + 3.0 + 1.5} = 0.375 \text{ mol/l.} \]

c) Problems to Solve

1. How many times the coagulation threshold of AgI sol will decrease if 1 M KNO₃ solution firstly been used for 10 ml of sol coagulation (1.5 ml were used for the coagulation) would be substituted with 0.1 M Ca(NO₃)₂ solution (0.5 ml were needed) or 0.01 M Al(NO₃)₃ solution (0.2 ml were needed) for the same volume of sol (10 ml) coagulation.

Answer: the coagulation threshold would decrease 27.4 times and 665.2 times, respectively.

2. The coagulation of Al₂S₃ sol with negatively charged granules was carried out by the following electrolytes adding: KNO₃, MgCl₂ and AlCl₃. Their critical concentrations of coagulation are 50.0, 0.72, and 0.093, respectively. Calculate the coagulation capacities ration for the cations with the different valences.

Answer: 1 : 69.4 : 537.6

3. Calculate the protective number for Fe(OH)₃ sol if 5 mg of powder starch were added to 2 ml of the sol and the first signs of coagulation were observed with 0.2 ml of 10 % NaCl solution adding.

Answer: 125 mg

4. Laboratory Activities and Experiments Section

4.1. Practical Skills and Suggested Learning Activities

– to improve the skills of micelles structure composition for sols with different charges of granules;
– to get practical skills in the critical threshold calculations;
– to state and interprete Schulze-Hardy rule.

4.2. Experimental Guidelines

4.2.1. The coagulation threshold determining for iron (III) hydroxide sol

Iron (III) sol Fe(OH)₃ with positively charged granules was prepared in advance under the reaction of FeCl₃ hydrolysis. Compose the micelle structure for this sol.

For Fe(OH)₃ sol coagulation electrolytes with the different valence anions are used, for example KCl, K₂SO₄, K₃PO₄ or K₃[Fe(CN)₆] their concentrations in mol/l are: 2.5; 0.1; 0.01, respectively.

In three test tubes pour with the pipette 5 ml of the Fe(OH)₃ sol each. The respective electrolyte solution should be added from burettes drop be drop into
each test-tube until the first signs of coagulation would be observed: the turbidity appearance, color change (darkening), precipitation. Record the experimental data into the table below.

<table>
<thead>
<tr>
<th>Test tube No</th>
<th>Electrolyte added for coagulation</th>
<th>Electrolyte solution concentration $C$, mol/l</th>
<th>Coagulating ion and its valence</th>
<th>The electrolyte solution used for the coagulation $V$, ml</th>
<th>Coagulation threshold $C_{cr} = \frac{C_{el} \cdot V_{el}}{V_{sol} + V_{el}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 2. 3.</td>
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</table>

Make the conclusions which of electrolytes and ions used have the highest coagulating ability. Explain why. Calculate the coagulation capacities ration for the anions with the different valences.

4.2.2. The protective action of a polymer towards hydrophobic sol coagulation studying

In four test tubes pour with the pipette 2 ml of Fe(OH)$_3$ sol with positively charged granules each. Study the coagulation of sol in two test tubes causing it by two electrolytes adding with the anions of the different valence (two and three, respectively). The respective electrolyte solution should be added from burettes drop be drop into each test-tube until the first signs of coagulation would be observed. To the test tubes No 3 and 4 add firstly 1 ml of 0.5 % polymer solution (gelatine, starch etc.) and then study their coagulation in the same way as for the test tubes No 1 and 2. Compare the volumes of expended electrolytes solutions. Record the experimental data into the table below.

<table>
<thead>
<tr>
<th>Electrolyte used for coagulation</th>
<th>Concentration of the electrolyte solution $C$, mol/l</th>
<th>Used for coagulation $V$, ml</th>
<th>Coagulation threshold $C_{cr}$, mmol/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>without a polymer</td>
<td>without a polymer in the presence of polymeric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>polymer</td>
<td>polymer in the presence of polymer</td>
</tr>
</tbody>
</table>

Calculate the coagulation threshold values for each test tube by the equation:

$$C_{cr} = \frac{C_{el} \cdot V_{el}}{V_{sol} + V_{polymer} + V_{el}},$$

where: $C_{el}$ – concentration of the electrolyte, mol/l; $V_{sol}$, $V_{polymer}$, $V_{el}$ – the volumes of a sol, polymer and electrolyte, respectively, l.

Explain the obtained results and make the conclusion about the protective action of polymer towards sol coagulation.

4.2.3. Mutual coagulation of sols
Pour 2 ml of Fe(OH)$_3$ sol with positively charged granules into the test tube (compose the micelle structure for this sol if FeCl$_3$ was used as a nucleating agent). Add 2 ml of Berlin blue sol with negatively charged granules. Compose the micelle structure for the obtained sol with K$_4$[Fe(CN)$_6$] being used as stabilizer. What process was observed after the two sols were mixed? Record and explain your observation.

5. Conclusions and Interpretations. Lesson Summary