

## Conformations and sizes of polyethylene glycol macromolecules in water-polyethylene glycol-KI systems

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### Abstract

In this study, the kinematic viscosity of water-polyethylene glycol-KI systems at a temperature of 20°C and 0-0.05 molar fractions of KI and 0-5 g/dl of polyethylene glycol was studied and fractions of polyethylene glycol with molecular masses of 1000, 1500, 3000, 4000 and 6000 were taken. Based on the experimental values of the kinematic viscosity, the characteristic viscosity of the studied solutions in the considered concentration range of KI, the Huggins constant, the  $\alpha$  parameter included in the Mark-Kun-Having formula, the swelling coefficient of the polyethylene glycol macromolecule, the characteristic viscosity in the  $\theta$ -solvent, the chain of the polyethylene glycol macromolecule in the solution and the  $\theta$ -solvent root-mean-square distance between ends, Kuhn segment length in solution and  $\theta$ -solvent were calculated. It was determined that the polyethylene glycol macromolecule is in the form of a wash in the water-KI environment that the surrounding liquid can penetrate, and with the increase in the concentration of KI, the volume of this wash decreases and its mobility increases.

**Keywords:** KI, polyethylene glycol (PEG), characteristic viscosity, Huggins constant, swelling coefficient, Kuhn segment.

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### 1. Introduction

Polyethylene glycol (PEG) is an interesting polymer with unique properties in the aquatic environment. These properties are mainly determined by the competition

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of water and PEG in the formation of hydrogen bonds between water-water and water-PEG molecules [1-7]. There are multiple molecular mass fractions of PEG, all of which are highly soluble in water. PEG is highly soluble in water due to the fact that it forms hydrogen bonds between ether oxygen atoms and water molecules. In the water-PEG system, with an increase in temperature, the number of hydrogen bonds decreases and hydrophobic interactions between macromolecular chains increase [8-11]. When an electrolyte is added to the water-PEG system, cations of the electrolyte can destroy the existing structure in the water-PEG system and form complexes with PEG macromolecules. This leads to a weakening of the solubility of PEG in water. Since PEG has many unique properties (non-toxic, does not have a negative effect on the immune system, etc.), the study of its physico-chemical properties both in water and in the water-electrolyte system is used in pharmacology, medicine, food industry, etc. is quite significant [12-16].

The work aims to determine the stability of the PEG macromolecule in the water-PEG-KI systems and the  $\theta$ -solvents selected according to these systems, to check the sizes, to increase the intensity of the effect on the particles in the solution, in addition, to influence the conformation of the macromolecule, and to control the effect of KI on the size and intensity of its effect. For this purpose, the characteristic viscosity  $[\eta]$  of the studied aqueous solutions, the Huggins constant ( $K_H$ ), the  $\alpha$  parameter included in the Mark-Kun-Hauvink formula, the characteristic viscosity in the  $\theta$ -solvent ( $[\eta]_\theta$ ), the swelling coefficient of the PEG macromolecule ( $\beta$ ), in solution ( $\langle h \rangle$ ) and in  $\theta$ -solvent ( $\langle h_\theta \rangle$ ) is the root-mean-square distance of PEG macromolecule chain ends, Kuhn segment length in solution ( $A$ ) and  $\theta$ -solvent ( $A_\theta$ ) is calculated, and the changes of these parameters depending on the concentration of KI ( $x$ ) were analyzed.

## 2. Method of calculation

The properties of macromolecules in solution are usually studied in the case of solid polymer solutions. According to modern concepts, linearly sized dynamic macromolecules change to a wash form in solid polymer solutions. During the flow, as a result of the forward and rotational motion of the macromolecule, friction occurs between the molecules of the solvent, which causes an increase in viscosity. Characteristic viscosity is created due to the rotation of individual macromolecules during the flow. The characteristic viscosity of the solution characterizes the energy loss that occurs as a result of the rotation of polymer molecules in the solvent environment [17, 18]. Inherent viscosity is one of the main quantities in the physical chemistry of polymer solutions. By determining the characteristic viscosity of the solution, it is possible to determine the number of quantities that determine the conformation and dimensions of the macromolecule in the solution.

To determine the characteristic viscosity, the introduced viscosity ( $\eta_i$ ) is first calculated [17]:

$$\eta_i = (v_{sn} - v_{st})/v_{st}c. \quad (1)$$

Here,  $v_{sn}$  and  $v_{st}$  are the kinematic viscosities of the solution and solvent, respectively, and  $c$  is the concentration of the polymer in the solution. The concentration dependence of the introduced viscosity in solid polymer solutions is described by the Haggins equation:

$$\eta_i = [\eta] + K_H[\eta]^2c. \quad (2)$$

Here,  $[\eta] = \lim_{c \rightarrow 0}(\eta_i)$  the characteristic viscosity is called the  $K_H$  – Haggins constant and characterizes the intensity of the interaction of particles in the system [17, 18, 19]. According to equation (2), the characteristic viscosity and the Haggins constant are determined graphically from the dependence of  $\eta_i \sim c$ .

The relationship between the characteristic viscosity of the polymer solution ( $[\eta]$ ) and the molecular mass of the polymer ( $M$ ) is described by the Mark-Kuhn-Having formula [17, 20]:

$$[\eta] = KM^\alpha. \quad (3)$$

Here,  $K$  – is a constant that depends on the properties of the solute and solvent, and  $\alpha$  – is a parameter that depends on the conformation of the polymer macromolecule in solution. If we take a logarithm from each side of the expression (3), based on the received expression:

$$\ln[\eta] = \ln K + \alpha \ln M \quad (4)$$

the parameter  $\alpha$  is determined graphically from the dependence of  $\ln[\eta] \sim \ln M$ .

The value of the characteristic viscosity in the  $\theta$ -solvent is used to determine the size of the polymer macromolecule in equilibrium. It should be noted that  $\theta$ -solvent is a solvent in which all possible interactions in the solution formed during the dissolution of the polymer in that solvent compensate for each other. In the  $\theta$ -solvent, thermodynamic equilibrium is established, and the polymer molecule is unexcited. Of course, it is quite difficult to choose the necessary conditions (pressure, temperature, etc.) to practically get such a solvent. The theories are built in the  $\theta$ -solvent [17, 21]. One such theory is Flory's theory [17]. According to the Flory theory, the characteristic viscosity ( $[\eta]_\theta$ ) in a  $\theta$ -solvent is defined by the following expression:

$$[\eta]_\theta = K_\theta M^{1/2}. \quad (5)$$

Here  $K_\theta$  –  $\theta$ -constant is the molecular mass of the polymer. As can be seen from expression (5), to determine  $[\eta]_\theta$ , it is necessary to find  $K_\theta$ . We noted that  $[\eta]_\theta$  cannot be determined on the basis of experimental values, since  $\theta$  – is not solvent. However, in a good solvent,  $K_\theta$  can be found by determining the characteristic viscosity based on experimental values. In a good solvent, there are a large number of

expressions that relate the characteristic viscosity  $[\eta]$  found from viscosity measurements to  $K_\theta$  [17, 22]. For example, the relationship between  $[\eta]$  and  $K_\theta$  in the Stockmayer-Fixman formula is as follows [23]:

$$[\eta]/\sqrt{M} = K_\theta + 0.51B\Phi\sqrt{M}. \quad (6)$$

Here,  $B$  is the far-reaching parameter and is measured in liters. After determining the characteristic viscosity  $[\eta]$ , the dependence  $([\eta]/\sqrt{M}) = f(\sqrt{M})$  is established based on expression (6). From the extrapolation of the obtained straight line  $\sqrt{M} \rightarrow 0$ , the value of  $K_\theta$  is found. Knowing the value of  $K_\theta$ ,  $[\eta]_\theta$  is calculated based on the formula (5).

The dimensions of a polymer cluster are usually characterized by the root mean square distance between the chain ends of the macromolecule. We can find the mean square distance between the ends of the macromolecule chain in an arbitrary solvent ( $\langle h \rangle$ ) and  $\theta$ -solvent ( $\langle h_\theta \rangle$ ) from the Flory-Fox equation [17, 24]:

$$[\eta] = \Phi \frac{\langle h \rangle^3}{M}, [\eta]_\theta = \Phi \frac{\langle h_\theta \rangle^3}{M}. \quad (7)$$

Here,  $\Phi$  is the Flory coefficient. Flory experimentally determined that  $\Phi = 2.1 \cdot 10^{23} \text{ mol}^{-1}$  [17, 20]. The dimensions of the polymer ball can also be characterized by the hydrodynamic radius ( $R_h$  - the radius beyond which solvent molecules cannot penetrate) and the root mean square radius of inertia ( $R_g$ ). In an arbitrary solvent ( $R_h, R_g$ ) and  $\theta$ -solvent ( $R_{h\theta}, R_{g\theta}$ ), the hydrodynamic radius and the mean square inertia radius can be calculated by the following expressions, respectively [17, 18, 22]:

$$R_h = \left( \frac{3M[\eta]}{10\pi N_A} \right)^{1/3}, R_{h\theta} = \left( \frac{3M[\eta]_\theta}{10\pi N_A} \right)^{1/3}, R_g = \frac{\langle h \rangle}{\sqrt{6}}, R_{g\theta} = \frac{\langle h_\theta \rangle}{\sqrt{6}}. \quad (8)$$

The conformation of the macromolecule in solution is also characterized by parameters such as the swelling coefficient ( $\beta$ ) and the Kuhn segment length ( $A$ ). Polymer macromolecule swells  $\beta$  times in a good solvent. The coefficient of swelling is determined by this expression [17, 24]:

$$\beta = \left( \frac{[\eta]}{[\eta]_\theta} \right)^{1/3} = \frac{\langle h \rangle}{\langle h_\theta \rangle} \quad (9)$$

The mobility of the macromolecule is determined by the length of the Kuhn segment. The length of the Kuhn segment in the arbitrary solvent ( $A$ ) and the  $\theta$ -solvent ( $A_\theta$ ) is given by these expressions, respectively [18, 19]:

$$A = \frac{\langle h \rangle^2}{L} = \frac{\langle h \rangle^2}{nl_0}, A_\theta = \frac{\langle h_\theta \rangle^2}{L} = \frac{\langle h_\theta \rangle^2}{nl_0}. \quad (10)$$

Here,  $L$  is the total chain length of the macromolecule,  $n$  is the number of repeating rings in the macromolecule, or the degree of polymerization, and  $l_0$  is the contour length of the repeating ring. In [18], it was shown that the contour length of a repeating  $-CH_2 - CH_2 - O -$  ring in PEG macromolecule is  $l_0 = 2.36\text{\AA}$ .

### 3. Experiment

*Object of study and methods.* Aqueous solutions consisting of water-PEG-KI systems were selected as research objects. The compounds used are chemically pure substances. Thus, PEGs used during the research are produced by Spain's "Pan-reac", and KI by Russia's "Khimmed". In this work, the kinematic viscosity of water-PEG-KI systems was studied, the concentration range of KI was 0-0.05 molar parts, and polyethylene glycol was 0 – 5 g/dl 0-5, and fractions of polyethylene glycol with molecular masses of 1000, 1500, 3000, 4000 and 6000 were taken.

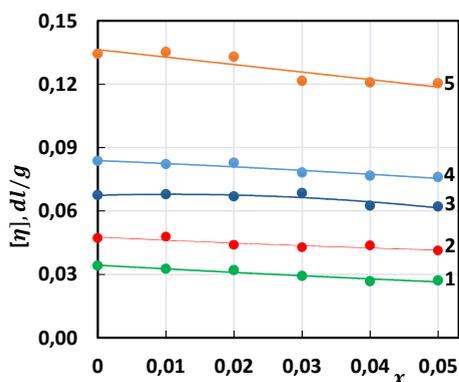
The solutions were prepared by gravimetric method. Bi-distilled water was used in the preparation of the solutions. Analytical scales manufactured by "KERN 770" were used during sample preparation and measurements were taken with an accuracy of 0.0001 g. Viscosity was measured using a CLV-2 capillary viscometer with a diameter of 0.34 mm. The experiment was conducted at normal atmospheric pressure. The liquid flow time in the viscometer was determined with an accuracy of  $\pm 0.01$  seconds. All measurements were performed three times and their average values were taken as the result of the experiment. Water was chosen as the reference liquid, and the values of water viscosity were taken from [17]. The kinematic viscosity of the solutions was measured at 20°C and the viscometer was placed in the thermostat to keep the temperature constant. The temperature was measured with an accuracy of  $\pm 0.05$ K. The maximum relative error of the experiment was 0.7%.

### 4. Results and discussion

By determining the characteristic viscosity of the solution and the Haggins constant, it is possible to obtain extensive information about many important properties of polymer solutions [17, 18, 19]. Both parameters are determined based on the dependence of the viscosity of solid polymer solutions on the concentration of the polymer [17, 20]. Very rigid chain polymer aggregates have similar shapes and sizes in aqueous solutions of various solvents. The characteristic viscosities and Haggins constants of solutions of such polymers in different solvents are almost the same. Dynamic chain polymers have different shapes and sizes in different solvents, and the values of their characteristic viscosities and Haggins constants differ significantly from each other [21]. By determining the characteristic viscosity, it is possible to determine the conformation and dimensions of the macromolecule in the solution, and by determining the Haggins constant, it is possible to determine whether the taken solvent

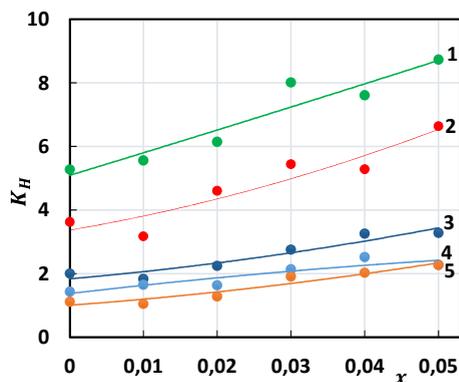
is a good or bad solvent for the given polymer [17]. Therefore, the study of the characteristic viscosity of solutions and the Haggins constant is very necessary for the study of the physicochemical properties of polymer solutions.

Figure 1 and Figure 2 show the dependence of the characteristic viscosity and Haggins constant of solutions corresponding to PEGs of different molecular mass in water-PEG-KI systems on the concentration of KI. As can be seen from Figure 1, the value of the characteristic viscosity increases with the increase in the molecular mass of PEG and decreases with the increase in the concentration of KI. As can be seen from expressions (7) and (8), the characteristic viscosity of the solution is directly proportional to the size of the macromolecule. With an increase in molecular mass, both the size of the PEG macromolecule and its interaction with more water molecules (with hydrogen bonds) make it difficult to rotate in the medium, and therefore the characteristic viscosity increases. It can be considered that the decrease of the characteristic viscosity of the solution for the considered fractional PEG depending on the concentration of KI is due to the decrease in the volume of the PEG macromolecule and the decrease in the viscosity of the solution with the increase in concentration. Thus, as the viscosity of the solution decreases with the increase in the concentration of KI at a temperature of 20°C [6] and the volume of the PEG macromolecule decreases, as a result, the rotation of the macromolecule in the medium becomes easier. Based on the variation of the characteristic viscosity of the solution depending on the molar fraction of KI, we can say that as the molar fraction of KI in the solution increases, both the conformation and the dimensions of the PEG macromolecule change to some extent.



1 – 1000, 2 – 1500, 3 – 3000, 4 – 4000, 5 – 6000

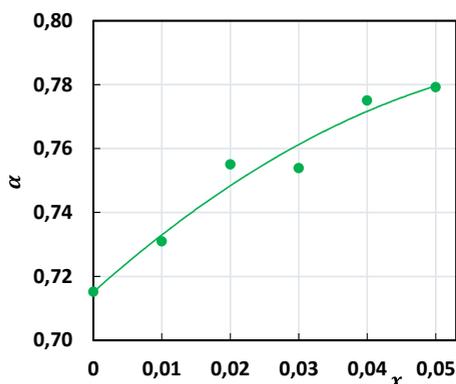
**Fig. 1.** Dependence of the characteristic viscosity on the concentration of KI for PEGs of different molecular mass in the water-PEG-KI system ( $t = 20^\circ\text{C}$ ).



**Fig. 2.** Dependence of the Haggins constant on the concentration of KI for PEGs of different molecular mass in the water-PEG-KI system ( $t = 20^\circ\text{C}$ ).

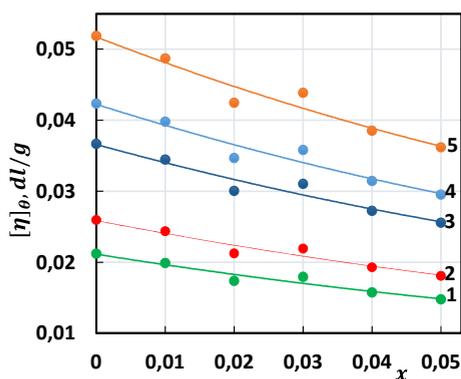
It can be seen from Figure 2 that the value of the Haggins constant for water-PEG-KI systems decreases when the molecular mass of PEG increases and increases when the molar fraction of KI in the solution increases. Based on the decrease of the value of the Haggins constant as the molecular mass increases, we can say that the water-KI system is a worse solvent for PEG with a relatively small molecular mass, and conversely, PEG with a relatively large molecular mass is better soluble in water-KI systems. This result can be explained by the hydration process of PEG macromolecules formed due to interactions between water and PEG molecules (mainly hydrogen bonds). For water-PEG-KI systems, as the molecular mass of PEG increases, the hydration number of the PEG macromolecule increases [20, 21, 25]. This, in turn, causes a decrease in the value of the Haggins constant. For a given fractional PEG, the value of the Haggins constant increases as the concentration of KI increases, indicating that the solubility of PEG in water-KI systems deteriorates depending on the concentration. This is probably due to the hydration of KI ions ( $K^+$  and  $I^-$ ) in the solution. Thus, if only PEG macromolecules were hydrated in water-PEG systems, in water-PEG-KI systems, along with PEG macromolecules,  $K^+$  and  $I^-$  ions were also subjected to hydration. Note that the ions are better hydrated compared to the PEG macromolecule, which leads to relatively poor solubility of the polymer in the water-KI solution compared to water. As the concentration of KI in the solution increases, the number of  $K^+$  and  $I^-$  ions also increases, which leads to the deterioration of the solubility of PEG in the water-KI system.

In order to determine the shape of the PEG macromolecule in the water-PEG-KI system and to investigate the effect of KI on this shape, the value of the  $\alpha$  parameter included in the Mark-Kun-Hauvink formula was determined for the water-PEG-KI system studied at a temperature of  $20^\circ\text{C}$  and different concentrations of KI (Figure 3). It can be seen from Figure 3 that the  $\alpha$  parameter takes values in the range of (0.71-0.78) for the water-PEG-KI system at a temperature of  $20^\circ\text{C}$  and in the concentration range of KI that we are looking at. This shows that the PEG micromole-



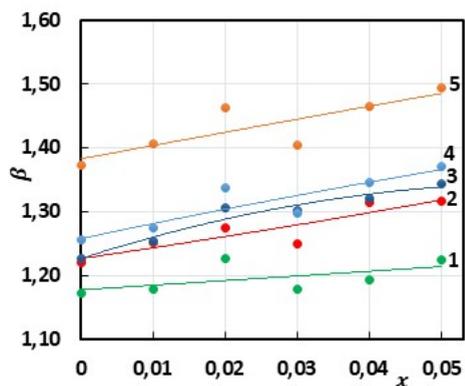
**Fig. 3.** Dependence of the parameter  $\alpha$  in the Mark-Kun-Hauvink formula on the concentration of KI in the water-PEG-KI system ( $t = 20^\circ\text{C}$ ).

Using the values of the characteristic viscosity ( $[\eta]$ ) of water-PEG-KI systems, the characteristic viscosity ( $[\eta]_0$ ) of PEG in the chosen  $\theta$ -solvent according to the studied system was calculated (Figure 4). As can be seen from Figure 4, the characteristic viscosity of the  $\theta$ -solvent selected for the water-PEG-KI system increases with the increase in the molecular mass of PEG, as in the water-PEG-KI system, and decreases with the increase in the concentration of KI. We can explain the increase of the characteristic viscosity of PEG in  $\theta$ -solvent depending on the molecular mass, analogously to the dependence of the characteristic viscosity on the molecular mass when the solvent is water-KI system. Note that thermodynamic equilibrium is established in the  $\theta$ -solvent environment and PEG macromolecules are unexcited, and in this case  $\alpha=0.5$ . We believe that the decrease of  $[\eta]_0$  with the increase in the concentration of KI for the considered molecular weight PEG is due to a partial decrease in the volume of the molecular layer and the viscosity of the  $\theta$ -solvent medium.



1 – 1000, 2 – 1500, 3 – 3000, 4 – 4000, 5 – 6000

**Fig. 4.** Dependence of the characteristic viscosity on the concentration of KI for PEGs of different masses in the PEG macromolecule with different molecular mass in system ( $t = 20^\circ\text{C}$ ).

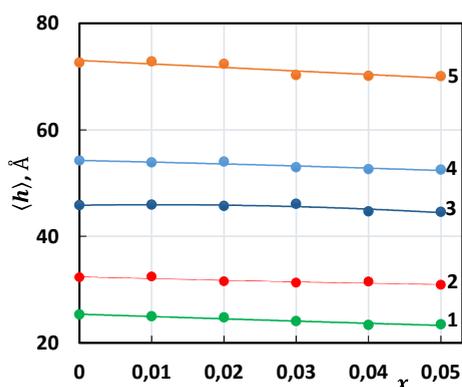


**Fig. 5.** Dependence of the swelling coefficient of the  $\theta$ -solvent selected according to the water-PEG-KI the water-PEG-KI system on the concentration of KI ( $t = 20^\circ\text{C}$ )

Since polymeric substances are composed of elastic chain macromolecules with large sizes, the physicochemical properties of their aqueous solutions differ significantly from the physicochemical properties of aqueous solutions of substances with small molecular mass [3, 16]. A water-soluble polymer retains a certain number of water molecules within its macromolecules, and these macromolecules resemble a disorderly aggregated wash [14, 15]. The hydrodynamic properties of aqueous polymer solutions depend on the size of such dispersed macromolecular aggregates [8]. The volume of macromolecular clusters (excited macromolecule) in the solution can be many times (tens, even hundreds) larger than the volume of the micromole-

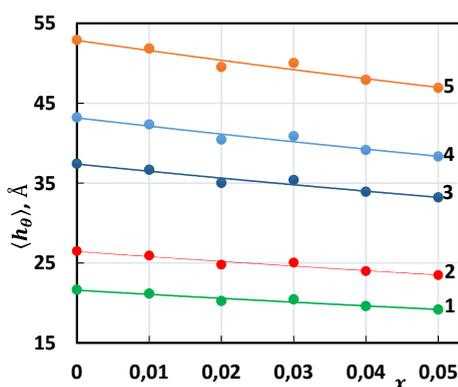
cule itself (unexcited macromolecule) [7]. One of the important parameters that determine the characteristics of a macromolecule in solution is the swelling coefficient. It was determined that  $\alpha > 0.5$  is always present in the considered concentration range for the water-PEG-KI system (Figure 3). This indicates that the size of the excited PEG macromolecule in non-ideal solvents (water-PEG-KI solution) is larger than the size of the unexcited PEG macromolecule in ideal solvents ( $\theta$ -solvent). Using the values of  $[\eta]$  and  $[\eta]_0$  for water-PEG-KI systems, the swelling coefficient ( $\beta$ ) of the PEG molecular bundle was calculated (Figure 5). As can be seen from Figure 5,  $\beta > 1$  for all considered cases, and the swelling coefficient of PEG macromolecule in water-KI systems increases with the increase of the molecular weight of PEG and the concentration of KI in the solution. It can be assumed that the increase of  $\beta$  as the molecular weight of PEG increases is related to the hydration process of PEG macromolecule. Thus, PEG with a large molecular mass has a larger hydration number [2, 10, 24]. As the molar fraction of KI in the solution increases, the increase in  $\beta$  is probably due to the negative hydration of  $K^+$  and  $I^-$  ions in the solution [17], the decrease in the viscosity of the medium [18, 23] and the conformational transformation of the macromolecule (the value of  $\alpha$  increases).

To evaluate the sizes of PEG macromolecules excited ( $\langle h \rangle$ ) in the water-PEG-KI system and unexcited ( $\langle h_\theta \rangle$ ) in the  $\theta$ -solvent selected for these systems, as well as to investigate the effect of KI on these sizes, PEG at a temperature of 20°C and different concentrations of KI the mean square distance between the ends of the macromolecule chain was determined (Figure 6 and Figure 7). The obtained results



1 – 1000, 2 – 1500, 3 – 3000, 4 – 4000, 5 – 6000

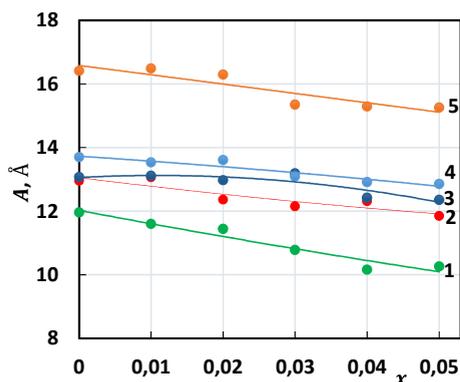
**Fig. 6.** Dependence of the mean square distance between the ends of the PEG macromolecule chain on the concentration of KI in the water-PEG-KI system ( $t = 20^\circ\text{C}$ ).



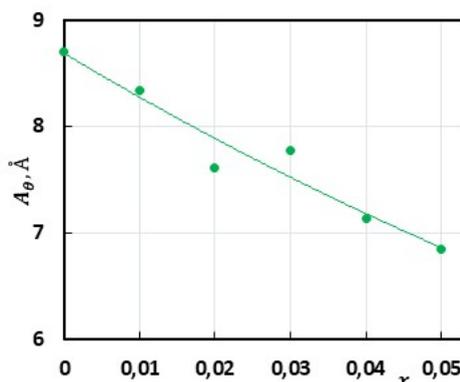
**Fig. 7.** Dependence of the root mean square distance between the ends of the PEG macromolecule chain on the concentration of KI in the  $\theta$ -solvent selected according to the water-PEG-KI system ( $t = 20^\circ\text{C}$ )

show that the mean square distance between the ends of the chain of the PEG macromolecule excited in the water-PEG-KI system and unexcited in the  $\theta$ -solvent selected for this system increases with the increase in the molecular mass of PEG and decreases with the increase in the concentration of KI in the solution. As the molecular mass increases, the increase of the parameters  $\langle h \rangle$  and  $\langle h_\theta \rangle$  is related to the increase in the volume of the macromolecular shell. Probably, as the concentration of KI increases, the decrease of  $\langle h \rangle$  and  $\langle h_\theta \rangle$  parameters is due to the decrease of the hydration number of PEG and the decrease of the volume of the macromolecular wash.

The mobility of the polymer chain has a strong influence on the properties of polymers. For example, let's note that the mobility of the polymer chain is one of the main factors affecting the solubility of polymers [17, 23]. Dynamic polymer macromolecules, which can be easily separated from each other, diffuse rapidly between solvent molecules. However, in addition to mobility, the properties of polymers also strongly depend on the mutual arrangement of macromolecules, their degree of regularity, packing in a given volume, in short, their structure [17]. To determine the mobility of the PEG macromolecule chain excited ( $A$ ) in the water-PEG-KI systems and unexcited ( $A_\theta$ ) in the  $\theta$ -solvent selected for these systems and to study the effect of KI on this mobility, the Kuhn segment of the PEG macromolecule corresponding to different concentrations of KI at a temperature of 20°C length was calculated (Figure 8 and Figure 9).



**Fig. 8.** Dependence of the Kuhn segment length on the concentration of KI in the water-PEG-KI system ( $t = 20^\circ\text{C}$ ): 1 – 1000, 2 – 1500, 3 – 3000, 4 – 4000, 5 – 6000



**Fig. 9.** Dependence of the Kuhn segment length on the concentration of KI in the selected  $\theta$ -solvent according to the water-PEG-KI system ( $t = 20^\circ\text{C}$ ).

It was determined that the length of the Kuhn segment of the excited PEG macromolecule in water-PEG-KI systems increases as the molecular mass of PEG increases and decreases as the concentration of KI in the solution increases (Figure

8). In the  $\theta$ -solvent, the length of the Kuhn segment for the unexcited PEG macromolecule does not depend on the molecular weight of PEG and decreases as the concentration of KI increases (Figure 9). Based on the values obtained for the length of the Kuhn segment, we can say that, as in water, in the water-PEG-KI system, PEG is a dynamic polymer [17, 20]. As the molecular mass of PEG increases, each macromolecule forms hydrogen bonds with more water molecules, and also because the polarity of the macromolecule increases [17] the interaction between water molecules and PEG macromolecules is at least partially strengthened. We assume that this situation leads to an increase in the length ( $A$ ) of the Kuhn segment with an increase in molecular mass in the water-KI system. In the  $\theta$ -solvent,  $A_\theta$  does not depend on the molecular mass of PEG, since the interactions between the particles in the solution do not change. When adding KI salt to water-PEG system, since  $K^+$  and  $I^-$  ions are also hydrated, the hydration number of PEG macromolecule decreases, its size decreases and its polarity decreases, as a result, the interactions between water and PEG molecules are weakened. We believe that for these reasons, as the concentration of KI in the water-PEG-KI system and  $\theta$ -solvent increases, the mobility of the PEG macromolecule increases, that is,  $A$  and  $A_\theta$  decreases.

## 5. Conclusion

The obtained results allow us to say that the PEG macromolecule is in the form of a dynamic chain-swollen shell in water-KI media as well as in water, and  $\alpha > 0.5$  and  $\beta > 1$  in all cases. As the concentration of KI in the water-PEG-KI solution increases, the solubility of PEG deteriorates, the mean square distance between the ends of the PEG macromolecule chain decreases, and the mobility of the macromolecule increases. In the  $\theta$ -solvent selected according to the water-PEG-KI system, the mean square distance between the ends of the PEG macromolecule chain decreases with the increase in the concentration of KI, and the mobility of the macromolecule increases.

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