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COMPLEXATION OF POLYETHYLENE-GLYCOL WITH THE SODIUM SALTS OF CITRIC AND SUCCINIC ACIDS IN THE AQUEOUS SOLUTIONS. STUDIES BY DYNAMIC LIGHT SCATTERING AND UV/VIS SPECTROPHOTOMETRY

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ABSTRACT

Dynamic light scattering (DLS) method in combination with the UV/VIS spectrophotometry is used to study the interaction of polyethylene- glycols with a molecular weight 6000 (PEG6000) with sodium salts of citric and succinic acids in aqueous solutions. The values of density, viscosity, refractive and diffusion indexes, the values of the hydrodynamic diameter, wavelength electronic absorption bands for PEG6000 aqueous solutions, their mixtures with succinic and citric acids are determined. It was shown that depending on the composition of the solutions the values of hydrodynamic diameter for aqueous solutions containing 1-5 wt.% PEG6000 and their mixtures with succinic and citric acids (~ 1 wt%) ranges from 3.6 to 5.2 nm. It is assumed that the formation of complexes with the sizes that are within the above range is due to the features of interaction and the structure of the complexes formed in solution.

Indexing terms/Keywords

Polyethylene-glycol, succinic acid, citric acid , dynamic light scattering, UV/-Vis - spectrophotometry

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INTRODUCTION

Among the water-soluble polymers, polyethylene -glycol (PEG) have a special place. PEGs are biocompatible, substantially non-toxic. Low molecular weight products of H- [O-CH2-CH2-]$_n$OH, called polyethylene glycols (PEGs) are used in medicine as a plasma substitutes, in pharmaceuticals, cosmetics ingredients in the manufacture of ointments and pills, household chemicals, etc. ; high molecular weight -called polyethylene oxides (PEO) are highly effective flocculants are used for preparation of water-soluble films for agriculture - the packages of seeds, fertilizers, pesticides, used in the encapsulation, are also used in household chemicals in cosmetics, in the pharmaceutical industry as coated tablets, etc. [1,2]. PEGs are capable for absorbing and transporting water molecules and this feature is of importance in industrial applications. Therefore, the investigation of the nature of interaction PEG / water, PEG complexing organic acids and their salts is very important to optimize technologies ranging from drug delivery to the treatment of fuel water and electrolytes. These studies may also contribute to the understanding of more complex nature of the interaction and functioning of proteins and enzymes [3-7]. Although the tendency of PEG to form aggregates and the presence of aggregates in aqueous solutions of polyethylene glycol is well-known facts in the literature, the effect of additives such as organic acids on the structural features and state of the agregates is practically not been studied, There is very little information about the structure of PEG chains and local clustering in aqueous solutions of PEG and their interaction with organic acids to the present time.

Over the past 10-15 years has increased the number of works that deal with physical - chemical systems based on polyethylene-glycol and organic acids such as citric acid. Dendrimers based on citric acid and polyethylene-glycols intensively investigated as novel drug delivery agents [8-14].

In this paper, the method of dynamic light scattering (DLS) in combination with the UV / VIS spectrophotometry is used to study the molecular structure of aqueous solutions of PEG and effect of sodium salts of succinic and citric acids (NaCA and NaSA, respectively) introduced into these solutions on the spectrometric characteristics of PEG/water solutions.

The experimental part

We used polyethylene-glycol with a molecular weight of 6,000 (firm "LOBA-CHEMIE", Austria), sodium salts of succinic and citric acids - from "Reahim", Russia, qualification "chemically pure" and redistilled water. Used PEGs , acids and their sodium salts were not subjected to further purification. Aqueous solutions of PEG were prepared at room temperature. Particle size and size distribution were determined by dynamic light scattering method using an analyzer LB-550, Horiba. The method is based on measurement of the diffusion rate of dispersed particles by analysis of the intensity fluctuations of the scattered light. This method allows to measure directly the diffusion coefficient of the particles dispersed in the liquid and then to calculate the particle size in dispersions[15-18]. The used analyzer allows to register the particles sizes from 0,001 to 6 microns, the changes of the size and the diffusion coefficient of the particles in the temperature range 278-343 K. The power source is 5mW and radiation wavelength - 650 nm. The correctness of the measurement results in the analysis of the particle size distribution is confirmed by measurements of the standard for calibration of the system. The viscosity of polymer solutions was measured using a Ubbelohde viscometer with a capillary diameter 0.53mm in the temperature range 20-50^{0}C . Flow time of the solvent (bi-distilled water) under these conditions was 103 seconds. PEG / water solutions with the concentration ~ 1-5wt.%PEG were studied. These solutions containing ~ 1 wt.% of sodium salts of succinic acid, citric acid were studied also. The intrinsic viscosity [η] was determined by graphical extrapolation of the values η_s /C and ln$\eta_{rel.}$ /C at infinite dilution [19]. The refractive indices of the test solutions were determine using the refractometer IRF-23 (Russia) at 20 ° C. The electronic absorption spectra (EAS) were recorded using a spectrophotometer SPECORD, Analytik, Jena using the same quartz cuvettes with a path length of 10 mm. Scanning step - 1 nm, the wavelength range - from 190 to 1100 nm.

Results and Discussion

Table 1 shows the composition of test solutions, a number of physical-chemical characteristics defined as the standard for aqueous polymer solutions and the values of the parameters determined from the DLS spectra. The table shows that the size distribution of PEG6000 macromolecules in solution PEG6000 / water containing 1-5 wt.% PEG6000 is uni-modal with a mean hydrodynamic particle diameter d_H in the range (3,6-5,2) nm. The particle size in the indicated above range is detected also with the introduction of the sodium salts of citric and succinic acids. In the table 1 the values for the diffusion coefficient of PEG6000 (1), CA-PEG6000 (2) and PEG6000-SA (3) as a function of their concentration in water are given. Comparison of these values indicates that the presence of water-soluble salts of these acids has little effect on the value of the diffusion coefficient of the particles and it is within (4,45-4,69) E^{-11} m^2 / s. Typical DLS histogram for test solutions is shown in Fig.1. Figure 2 shows the dependence of the viscosity η on the solution concentration PEG6000. In the concentration range from 1 to 5 wt.% viscosity dependence on concentration is linear. Calculated Huggins constants k_H values using the formula $\eta_{int.} = [\eta] + k_H [\eta]^2$C [19,20] show that from the thermodynamic point of view the water as a solvent is the better for complexes of acids with PEG6000 than pure PEG6000. Results obtained by the DLS, clearly indicate that the complexes dimensions increase appreciably with increasing concentration of solution PEG/water. These complexes are aggregates of molecules PEG6000. There is a marked difference in the intrinsic viscosity of the solutions before and after introduction of the sodium salts of succinic and/or citric acid in solution PEG/water. The value [η] of a PEG6000 solution with the sodium salts of succinic acid and citric acid proved to be somewhat less than the initial solution of PEG6000 (0.16; 0.12; 0.13 cm^3 /g, respectively, for water solutions PEG6000, PEG6000 + NaSA and + PEG6000 NaCA. Changing of the [η] values can be caused probably by structural reorganization of aqueous solution of PEG under influence of NaSA (NaCA).

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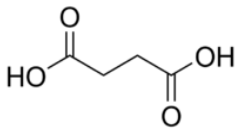
PEG6000 has a sufficiently large value of the degree of polymerization (n = M / M_0 = 136, where M = 6000, M_0 = 44 are, respectively, molecular weights and PEG6000 recurring fragment) and it is likely to be expected random coil conformation[21]. Estimated value of the hydrodynamic radius R_{Cal}. in this case, equal to 2.8 nm for PEG6000, within experimental error, is the same as the measured value.

Thus, it can be assumed that the introduction of sodium salts of succinic acid and citric acid into the PEG/Water solution leads to alter the structure of the original units PEG6000, thus changing the molecular topological structure of complexes in solution without significantly changing their size . The formation of these complexes should be seen as a result of the reaction of polyethylene glycol with acid fragments with acid fragments of dibasic (succinic) and threebasic (citric) acids of) sodium salts:

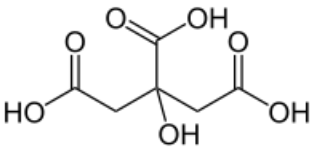
-O-CH2-CH2-O-CH2-CH2-



-O-CH2-CH2-O-CH2-CH2-

and

-O-CH2-CH2-O-CH2-CH2-



-O-CH2-CH2-O-CH2-CH2-

In aqueous solution the PEG molecule reacts with the mentioned salts is likely not in dissociated state forming the complexes through the hydrogen bonds between the hydrogen of the carboxyl groups and oxygens of PEG chain -O-CH2-CH2-O-CH2-CH2-. Note that for solutions PEG6000 + NaCA after heating to 60°C, followed by cooling to room temperature bimodal histogram in DLS is observed, indicating the presence of two types of particles with an average hydrodynamic diameter 5.2 and 10.2 nm. The part of particles with a mean hydrodynamic diameter of 10.2 nm was not more than 10% of the total number of particles. When storing the sample for 24 hours at room temperature in the DLS again observed monomodal histogram corresponding to particles with a mean hydrodynamic diameter 4.6 nm.

Fig. 4.5 presents the electronic absorption spectra (EAS) aqueous solutions PEG6000, sodium salts of succinic acid and citric acid, mixtures of aqueous solutions of these salts with PEG6000 in the UV /Vis. -region. As seen from Fig. 4 for aqueous solutions PEG6000 observed three absorption bands in the ultraviolet region, the intensity of which increases almost linearly with increasing concentration of these solutions. Markedly more intense absorption bands in the UV region observed for aqueous solutions of sodium salts of citric and succinic acids, and their mixtures with PEG6000 (Fig. 5). The same intensity of the bands was observed for the same concentration of aqueous solutions of sodium salts of these acids in mixed solutions. From Fig. 4 you can see that EAS of PEG6000 in the UV region can be clearly divided into three bands - at 200-210 nm, 210-220 nm and 280-290 nm. A linear increase in the intensity of these bands with increasing the concentration of PEG6000 in a solution of 1 wt% to 5mass.% suggests that these bands belong to PEG6000 macromolecules of the same structure. There are observed the band due to n → π * and π → π * transitions in molecules of PEG and sodium salts of succinic acid and citric acid in the ultraviolet region. The molar absorption coefficient for the PEG has a low value ( ). Therefore PEG6000 and generally PEGs compared to organic acids, in this case, succinic and citric acids has considerably weak electron absorption spectrum. The nature of electronic transitions in these molecules is described in detail in the literature [22,23]. Note that in the Visible region for these solutions bands at 740, 835 and 980 nm, which is likely due to absorption of visible light liquid water are observed [24-26].

Table 1. The composition and the physical-Chemical parameters of the studied aqueous solutions

Sample	Composition			Physical-Chemical characteristics					
	W_{PEG}, mas.%	W_{SANa} mas%	W_{CANa} mas%	Density, at 20°C, g/l	Refraction Coeff. , at 20 °C	Viscosity, Dynamic, at20° C, mPa.s	Hydrodynamic diametr of particles, d_H, nm	Number of particles (rel.)	Diffusion Coeff., E^{-11} m^2/s
1	1,0432	0,0	0,0	0,9995	1,3339	1,160	3,6	0,5859 (2000)	5,3102
2	2,0655	0,0	0,0	1,0008	1,3355	1,377	3,6	0,4824 (3000)	4,2729
3	2,7205	0,0	0,0	1,0021	1,3364	1,625	3,8	0,4103 (2000)	4,6564
4	3,9780	0,0	0,0	1,0042	1,3381	1,917	4,4	0,4724 (2000)	4,0162
5	4,9725	0,0	0,0	1,0056	1,3394	2,277	5,2	0,5369	4,0465

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								(2000)	
6	0,9929	1,1464	0,0	1,0092	1,3355	1,149	3,6	0,5270 (2000)	4,4498
7	1,9187	0,9799	0,0	1,0089	1,3362	1,356	3,8	0,4346 (2000)	3,9840
8	0,9945	0,0	0,9453	1,0077	1,3354	1,159	3,9	0,5410 (2000)	5,772
9	1,9890	0,0	1,0044	1,0095	1,3369	1,348	4,2	0,4574 (2000)	4,6874
10	0,0	1,060	0,0	1,0041	1,3337	1,005	1,6	0,5323 (2000)	5,9724
11	0,0	0,0	1,0044	1,0047	1,3340	1,006	1,8	0,4722 (2000)	4,9338
12	1,989	1,1044	0,0	1,0093	1,3368	1,351	4,0	0,4262 (2000)	4,2772
Water				0,9982	1,3330	1,002	1,2	0,5772 (3000)	5,4264

FIGURES/CAPTIONS

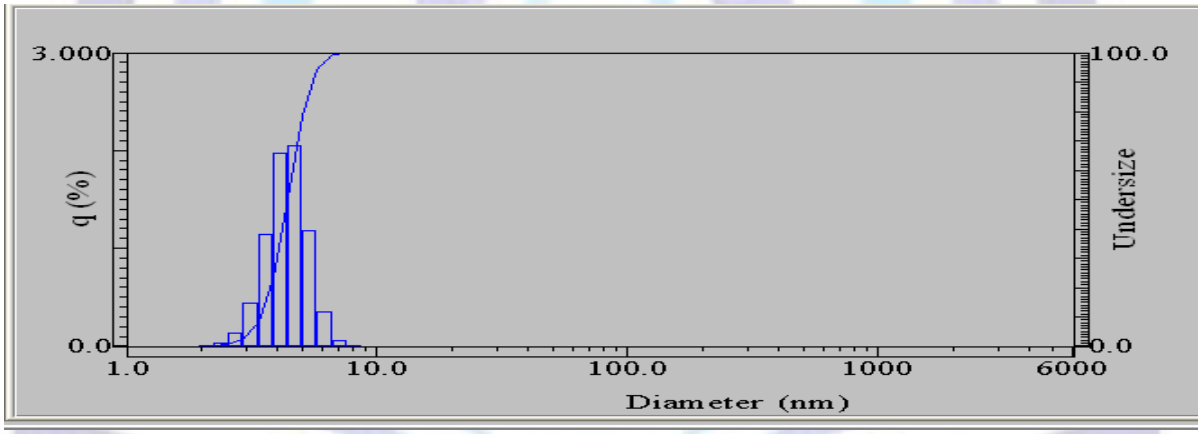

Fig 1: Histogram of the sample №2 at room temperature

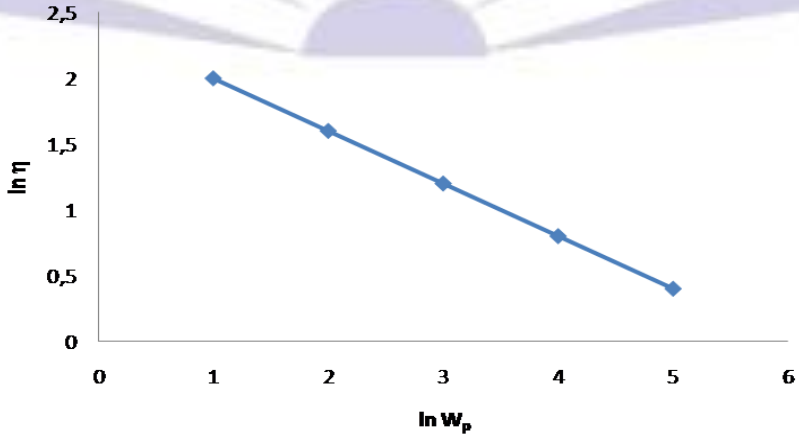

Fig 2: The dependence of the viscosity η_{pr} as a function of the concentration of PEG6000 aqueous solution

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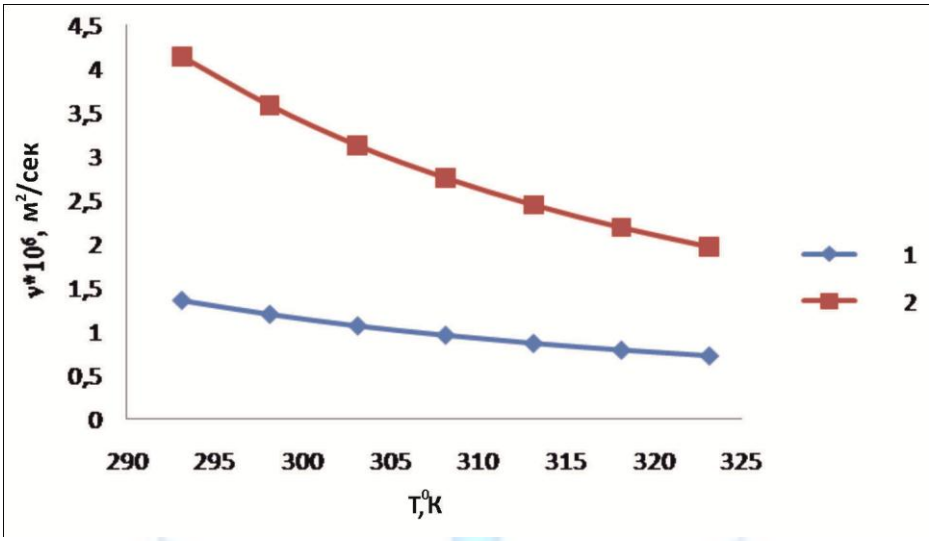

Fig 3: The dependence of the viscosity η_{pr} as a function of the temperature for the solution of PEG6000 with different concentration: 1 – 2 mas.%, 2 – 5 mas.%.

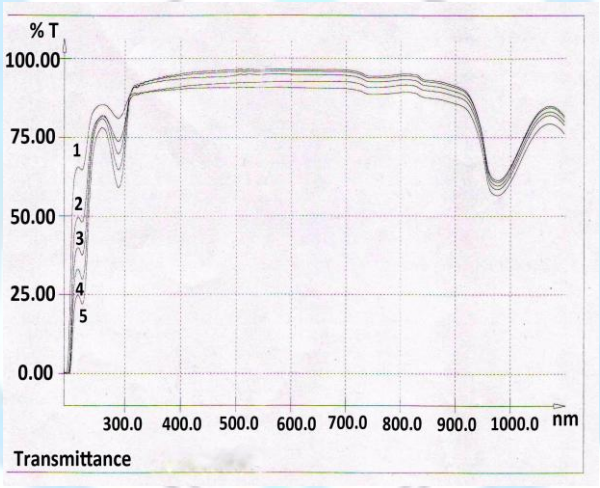

Fig 4: Electronic absorption spectra (EAS) of aqueous solution containing: 1- 1.0; 2- 2,0; 3- 3.0; 4- 4.0; 5- 5,0 mas.% of PEG6000

Fig 5: EAS of aqueous solution containing: 1 -1.0 mas.% PEG6000, 2- 1,0 mas.% sodium salt of saccinic acid; 3- 1.0 mas.% PEG6000 and 1,0 mas.% of sodium salt of saccinic acid

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REFERENCES

[1] Poly (ethylene glycol) chemistry: Biotechnical and Biomedical Applications (ed:J.M.Harris),Plenum,New York, (1992), p 385.

[2] http://www.mindfully.org/Plastic/Polymers/Polyethylene-Glycols-PEGs.htm

[3] Zaslavsky B.Yu., Gulaeva N.D., Djafarov S.F., Masimov E.A. , Miheeva L.M. Phase separation in aqueous poly(ethyleneqlycole)-$(NH_4)_2SO_4$ systems and some physical-chemical properties of the phases. J.Colloid. Interface Sci., 1990, v.89, No.5, p.679-584.

[4] Merrill, E.W., K.A. Dennison, and C. Sung, *Partitioning and diffusion of solutes inhydrogels of poly(ethylene oxide).* Biomaterials, 1993. 14(15): p. 1117-1126.

[5] Masimov E.A., Ozer M., Salamova U. Investigation of aqueous solutions of dextran-poly (ethylene glycol) and dextran-poly (vinyl pyrrolidone) near the binodial curve. Polimer Sci., v.37, №11, 1996, p.342-346.

[6] Guseynov V.I., Ismailov E.H., Masimov E.A. Relative hydrophobicity of water and aqueous salt solutions of certain polymers for medical purposes. Abstracts. XVI Mendeleev Congress on General and Applied Chemistry. Living Chemistry, Russia, Moscow 1998, pp.39-40.

[7] Annunziata O., Asherie N., Lomakin A., Pande J., Ogun O., Benedek G.B. Effect of polyethylene glycol on the liquid–liquid phase transition in aqueous protein solutions// PNAS _ October 29, 2002 _ vol.99, no. 22 _ 14165 -14170; www.pnas.org_cgi_doi_10.1073_pnas.212507199

[8] H. Namazi' , M. Adeli. Dendrimers of citric acid and poly (ethylene glycol) as the new drug-delivery agents//Biomaterials, Volume 26, Issue 10, April 2005, Pages 1175–1183; Hassan Namazi, Sanaz Motamedi, and Mina Namvari. Synthesis of New Functionalized Citric Acid-based Dendrimers as Nanocarrier Agents for Drug Delivery // Bioimpacts. 2011, 1(1): 63–69; Namazi H and Adeli M . 2003. Novel linear-globular thermoreversible hydrogel ABA type copolymers from dendritic citric acid as the A blocks and poly(ethyleneglycol) as the B block.European Polymer Journal, 39(7), 1491-1500;

[9] Liu MJ, Kono K and Frechet JMJ . 2000. Water-soluble dendritic unimolecular micelles: Their potential as drug delivery agents. Journal of Controlled Release, 65(1-2), 121-131;

[10] Crampton HL and Simanek EE . 2007; Dendrimers as drug delivery vehicles: non-covalent interactions of bioactive compounds with dendrimers. Polymer International, 56(4), 489-496;

[11] Schenning APHJ, Elissen-Roman C, Weener JW, Baars MWPL, van der and Meijer EW . 1998. Amphiphilic dendrimers as building blocks in supramolecular assemblies. Journal of the American Chemical Society, 120(32), 8199-8208;

[12] Jean-d'Amour K. Twibanire, and T. Bruce Grindley. Polyester Dendrimers: Smart Carriers for Drug DeliveryPolymers 2014, 6, 179-213;

[13] Ma X.P., Zhou ZX, Jin EL, Sun QH, Zhang B, Tang JB, et al. Facile Synthesis of Polyester Dendrimers as Drug Delivery Carriers. Macromolecules. 2013;46:37-42;

[14] Mitsuko Sakae, Tomoko Ito, Naoko Iida Tanaka, Takuro Niidome, Hironobu Yanagie and Yoshiyuki Koyama Novel Receptor-Mediated Gene Transfection Systems Comprising Plasmid / Polycation / RGD-PEG-COOH Ternary Complexes Molecular Therapy (2004) 9, S319–S319.

[15] Wen J.H.//Dynamic light scattering: Principles, measurements, and applications. Course on http://www.che.ccu.edu.tw/~rheology/DLS/outline3.htm, 9.4.2010.

[16] Dynamic Light Scattering: the Method and Some Applications. W. Brown ed.Clarendon Press. Oxford, 1993

[17] http://www.horiba.com/scientific/products/particle-characterization/downloadcenter/ brochures/;http://www.horiba.com/scientific/products/particlecharacterization/particle-size-analysis/details/lb-550 112/http://www.horiba.com/scientific/ products/ particlecharacterization/ particle-size-analysis/details/lb-550-112/; http://www. titanex.com.tw/doc/tecsupport/TN-LB DynamicLightScatteringTechnique.pdf

[18] Domnina N.S., Sergeyev Y.S., Vilbitskaya A.N. etc .// High-molecular compounds,(Russia) //A.2010, V.52, №9, pp.1570-1576.

[19] Frolov G. Course of Colloid Chemistry / G. Frolov. - M .: Chemistry, 1982. – 400 pages

[20] Lezov A.V. Molecular hydrodynamics of polymers in dilute solllutions.St.Petersburg, St. P.University, Russia, 2000, 24 ps.

[21] Tsvetkov V.N., Eskin V.E., S.Ya.Frankel. Structure of macromolecules in solution, Moscow, Russia, Nauka, 1976, 376s.

[22] Handbook of organic compounds : NIR, IR, Raman, and UV-Vis spectra featuring polymers and surfactants. Academic Press, 2001.Chemistry Library Reference: QC462.85 H36 2001 (vol. 2).T.Owen, Fundamentals of UV-visible spectroscopy, Agilent Technologies,2000, 136p; http://www.chemguide. co.uk/analysis/uvvisiblemenu.html#top

[23] Skoog, D. and Holler, F. *Principles of Instrumental Analysis.* 6th ed. Thomson Brooks/Cole. 2007, 351.

[24] Edward S. Fry. Visible and near-ultraviolet absorption spectrum of liquid water: comment.//APPLIED OPTICS / Vol.39, No.16 / 1 June 2000, pp/2743-2744: http://www1.lsbu.ac.uk/water/vibrat.html

[25] Prahl S., Optical absorption of water. Available at http://omlc.ogi.edu /spectra/water/ index.html

[26] Vaughan S. Langford , Allan J. McKinley , andTerence I. Quickenden, Temperature Dependence of the Visible Near-Infrared Absorption Spectrum of Liquid Water.//*J. Phys. Chem. A*, 2001, *105* (39), pp 8916–8921