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# Interaction of silicon nanoparticles with the molecules of bovine serum albumin in aqueous solutions

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***Abstract*. Using the method of photon-correlation spectroscopy, the coefficient of translational diffusion $D_t$ and the hydrodynamic radius $R$ of the particles in aqueous solutions of the bovine serum albumin, containing silicon nanoparticles, are determined. The character of the dependence of these parameters on the concentration of the protein indicates the absence of interaction between the studied particles in the chosen range of albumin concentrations 0.2 – 1.0 mg mL$^{-1}$.**

***Keywords***: *bovine serum albumin, silicon nanoparticles, photon-correlation spectroscopy, correlation function, translation diffusion coefficient, hydrodynamic radius, hydrogen index pH.*

## 1. Introduction

In the present-day medicine intense work is performed to study the properties of nanoparticles, aimed at their further use in the diagnostics and treatment of widespread diseases, including the oncologic ones. Among the substances that may be used for these purposes special attention is paid to silicon.

In the human organism silicon is responsible for providing the safety functions, metabolic processes, and deintoxication. On average, during a day a human consumes with food and water 3.5 mg and looses about 9 mg of silicon. The organism is unable to cover the deficit of silicon on his own, since the natural silicon compounds, surrounding us, are mostly non-active biologically and unable to participate in biochemical reactions inside a cell.

The synthesis of biologically active nanocomposite silicon-based materials gave an impetus to numerous studies of this element aimed at its use for the treatment and diagnostics of different diseases. Particularly, it was found that, owing to their biological compatibility with living tissues and ability of fast removal from the organism, the silicon nanoparticles maybe used as photosensitisers in photodynamic therapy of cancer [1].

Photosensitisers should be low-toxic, possess homogeneous and stable structure, and, above all, exhibit high selectivity of accumulation in tumours, combined with fast removal from the organism. Therefore, it is of primary importance to study the interaction of silicon nanoparticles with the basic proteins of the blood serum, especially with albumin. These studies may be performed using the methods of light scattering. The difference of the light scattering parameters in the systems 'water + silicon particles + protein' and 'water + silicon' allow the judgement about the presence or absence of aggregates, i.e., nanoclusters that can arise as a result of interaction of albumin macromolecules and silicon nanoparticles.

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## 2. Method of dynamic light scattering

Molecular motions of protein macromolecules and their aggregates under the action of the heat energy determine the dynamics of the intensity fluctuations of the scattered light in the systems under study. These motions are a combination of translational and rotational diffusion, the character of which depends on the effective size and shape of the scattering macromolecules, as well as on their intermolecular electrostatic interaction, determined by the value and character of spatial distribution of charge centres over the surface of a molecule [2 – 4].

The method of dynamic scattering of laser light (photon-correlation spectroscopy) makes it possible to measure the autocorrelation function of the intensity fluctuations of the scattered light. The consequent processing allows one to obtain the desired size distribution or the distribution of translational diffusion coefficients. The intensity fluctuations of the scattered light arise due to the inhomogeneity of the dielectric constant of the medium. In a liquid they are directly related to the fluctuations of the local concentration of particles, caused by the Brownian motion of macromolecules.

In the simplest case of a monodisperse solution containing non-interacting spherical particles of the same size, it may be shown that the power spectrum of the photocurrent is described by the Lorentz distribution [3] with the half width $\Gamma$ and the normalised autocorrelation function of intensity is exponential with the relaxation time $\tau_{rel} = 1/\Gamma$:

$$g^{(2)}(t) \approx \exp(-\Gamma t) + 1.$$

The coefficient $\Gamma$ is related with the physical parameters of the medium and the conditions of experiment as follows:

$$\Gamma = D_t q^2, \; q = k_i - k_s = \frac{4\pi n}{\lambda} \sin\frac{\theta}{2}, \; D_t = \frac{kT}{6\pi\eta R}, \qquad (1)$$

where $D_t$ is the coefficient of translation diffusion of the particles; $k_i$ and $k_s$ are the wave vectors of the incident and scattered radiation, respectively; $n$ is the refractive index of the medium; $\lambda$ is the wavelength of the scattered radiation; $\theta$ is the scattering angle; $T$ is the absolute temperature of the medium; $k$ is the Boltzmann constant; $\eta$ is the solution viscosity; $R$ is the hydrodynamic radius of the particle.

In the case of polydisperse solutions, when the particle sizes are different, the photocurrent spectrum is a continuous ensemble (integral) of Lorentz curves with different half widths. Therefore, to find the distribution of the particles over the size (diffusion coefficient), it is necessary to solve the inverse spectral problem in the form of an integral equation with the Lorentz kernel:

$$g^{(2)}(t) = [g^{(1)}(t)]^2 + 1 + \xi(t), \quad (2)$$

$$g^{(1)}(t) = \int_0^\infty P(\Gamma)\exp(-\Gamma t)\mathrm{d}\Gamma. \quad (3)$$

Here $g^{(1)}(t)$ is the normalised autocorrelation function of the signal; $P(\Gamma)$ is the distribution of the damping rates (inverse relaxation times); $\xi(t)$ is the error, associated not with the error of the photocurrent measurement or with the noises of the recording channel, but with the stochastic nature of the signal itself [3]. With the influence of the permanent experimental noise $\xi(t)$ neglected, Eqn (2), known as Siegert relation, allows calculation of $g^{(1)}(t)$ from the function $g^{(2)}(t)$, 'accumulated' by the correlator in the course of the experiment.

Integral equation (3) formulates the basic principle of data processing in the method of photon-correlation spectroscopy. This equation with respect to $P(\Gamma)$ is a Fredholm integral equation of the first kind, known in mathematics as an ill-posed problem, i.e., the problem having no algorithm for finding a rigorous solution. In this connection different approximate methods of solution are developed, many of them providing rather good results.

In the present paper the processing of the results was carried out using the DYNALS software, in which the search for the approximate solution of Eqn (3) was implemented by means of a Tikhonov regularisation method for integral equations.

## 3. Preparation of experimental samples

Nanoparticles for experimental samples were prepared by grinding the powders of crystalline and porous silicon in the planetary-type Pulverisette 7 mill (FRITSCH, Germany) during 30 min according to the technique [1]. We used the nc-cSi nanoparticles, obtained from the powder of the grinded plates of crystalline silicon (c-Si), and the nc-pSi nanoparticles, obtained from the exfoliated films of porous silicon, formed using the standard method of electrochemical etching of c-Si plates with p-type conductivity, (100) orientation of surface and the specific resistance 25 mΩ cm, in the solution HF(50 %) : $C_2H_5OH$ (the etching current density 60 mA $cm^{-2}$).

Aqueous solutions of nc-pSi and nc-cSi nanoparticles were studied, their initial concentrations being 1 and 20 g $L^{-1}$, respectively. To extract nanoparticles of the desired size we used the particles from the top fractions of colloid solutions. The particles then were processed in an ultrasonic bath with the frequency 3 kHz during 4 min with subsequent filtration (the diameter of the filter cell 450 nm). The resulting concentrations of nanoparticles were $2 \times 10^{-4}$ mg $mL^{-1}$ (nc-cSi) and $2 \times 10^{-7}$ mg $mL^{-1}$ (nc-pSi).

After the filtration the bovine serum albumin (BSA) was added to the aqueous solutions of silicon. The albumin concentration was varied from 0.2 to 1 mg $mL^{-1}$ with the step 0.2 mg $mL^{-1}$.

## 4. Experimental results

The study of the aqueous solutions of silicon, protein, and silicon with protein was carried out using the photon-correlation Photocor Complex spectrometer (Photocor Instruments, Inc., USA). The concentration dependences of the translational diffusion coefficients $D_t$ were obtained for albumin solutions with the addition of silicon, as well as for pure solutions of albumin and silicon at pH values 4.9 and 7.0 (Figs 1 and 2). The pH level 4.9 corresponds to the isoelectric point for the albumin protein, and pH 7.0 corresponds to a neutral medium. The comparison of the obtained results shows that the presence of silicon in the albumin solutions does not change the mobility of the scattering particles within the experimental error.

When pH decreases, the mobility (diffusion coefficient) of albumin molecules reduces from $5.6 \times 10^{-7}$ $cm^2s^{-1}$ in the neutral medium to $4.36 \times 10^{-7}$ $cm^2s^{-1}$ at the isoelectric point, which agrees with the results of Ref. [2]. Silicon

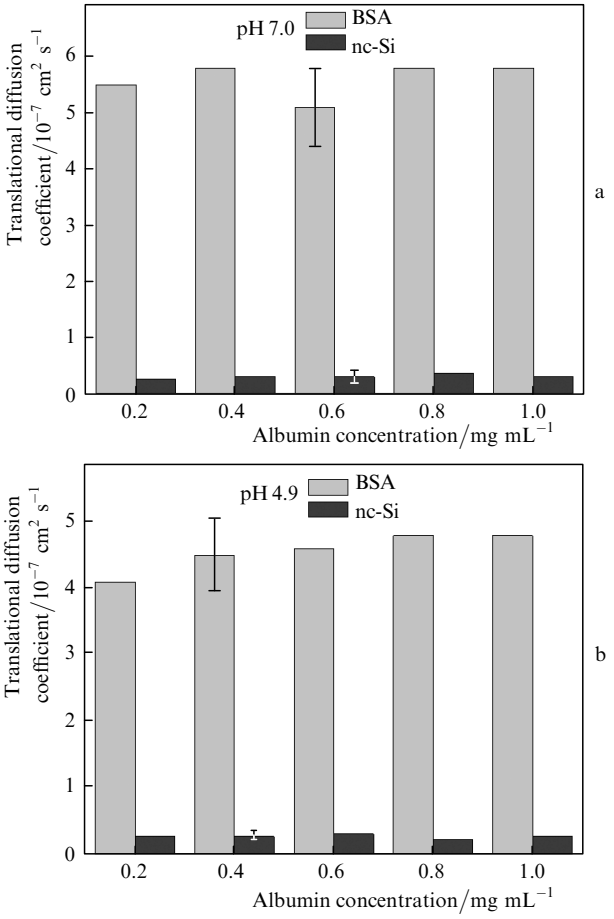


**Figure 1.** Dependence of the translational diffusion coefficient on the albumin concentration for the solutions containing nc-cSi at pH 7.0 (a) and pH 4.9 (b).

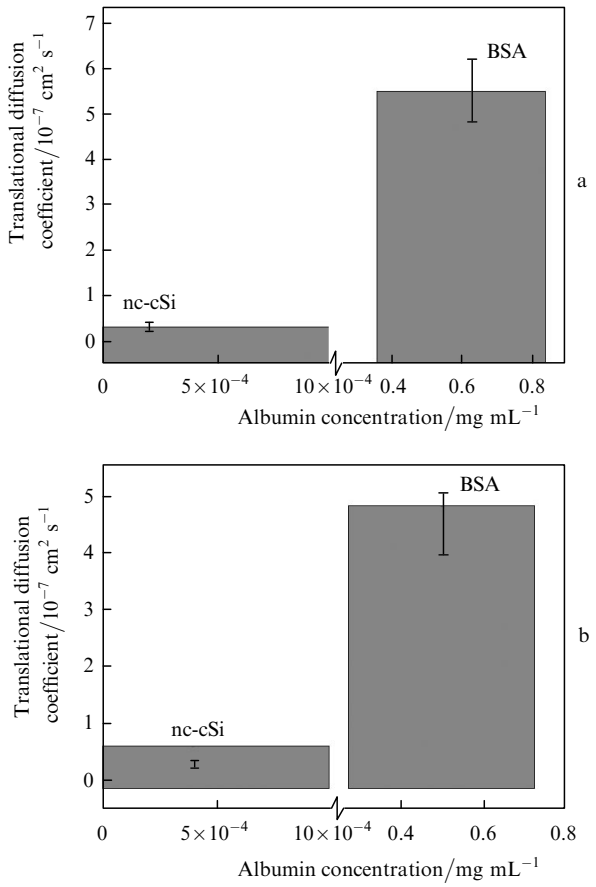


**Figure 2.** Translational diffusion coefficients for pure solutions of BSA and nc-cSi at pH 7.0 (a) and pH 4.9 (b).

nanoparticles are not sensitive to the variations in the pH value, and this agrees with the data in favour of the stability of silicon particle solutions in acidic and neutral media [1].

As seen from the obtained results, two components of the solution, i.e., the nc-cSi particles and the BSA, exist in the solution independently. We can conclude that no interaction between the silicon nanoparticles and BSA molecules is observed. Similar results were obtained for the interaction of BSA with the nc-pSi nanoparticles. In this case, like for nc-cSi, silicon-protein agglomerates were not produced. It means that the studied silicon particles at the chosen pH values do not interact with albumin and, therefore, do not affect its properties and are safe for it.

## 5. Conclusion

Using the method of dynamic scattering of light we studied the parameters of solutions of silicon nanoparticles at different values of pH and concentrations of albumin protein. Two components corresponding to two particle sizes are observed in the spectra, one of them corresponding to the size of albumin macromolecule and the other – to the nanoparticles under study. No components, indicating the appearance of aggregates of silicon with protein, were found in the studied solutions. On this base one can draw a conclusion about the absence of interaction between the albumin molecules and silicon nanoparticles in the considered range of concentrations. Probably, for bonding nc-cSi or nc-pSi with albumin it is necessary to modify the surface of silicon nanoparticles by means of some amino acids [5] in order to change the surface charge.

The discovered absence of interaction of silicon nanoparticles with protein macromolecules is interesting and may be of use in further biomedical studies.

## References

1. Timoshenko V.Yu., Kudryavtsev A.A., Osminkina L.A., Vorontsov A.S., Ryabchikov Yu.V., Belogorokhov I.A., Kovalev D., Kashkarov P.K. *Pis'ma Zh. Eksp. Teor. Fiz.*, **83** (9), 492 (2006) [*JETP Lett.*, **83** (9), 492 (2006)].
2. Petrova G.P., Petrusevich Yu.M. *Biomed. Radioelektron.*, (3), 41 (2000).
3. Cummins H.Z., Pike E.R. (Eds) *Photon Correlation and Light Beating Spectroscopy* (New York, London: Plenum Press, 1974).
4. Petrova G.P., Petrusevich Yu.M., Ten D.I. *Kvantovaya Elektron.*, **32** (10), 897 (2002) [*Quantum Electron.*, **32** (10), 897 (2002)].
5. Tasciotti E., Liu X., Bhavane R., Plant K., Leonard A.D., Price B.K., Ming-Cheng Cheng M., Decuzzi P., Tour J.M., Robertson F., Ferrari M. *Nature Nanotechnol.,* **3**, 151 (2008).