

OPTICAL CHARACTERIZATION OF 3D DISPERSE SYSTEMS WITH NANO- AND MICRO PARTICLES: LIGHT SCATTERING MATRIX ELEMENTS

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Abstract. The multiparametric analysis of simultaneous optical data for nano and micro particle systems (ensembles, colloids, dispersions) by presentation of system characteristics as N -dimensional optical parameter vectors can help to elucidate differences or changes in the state of particles, the process of particle interactions, the particle share in mixtures and so on. In this paper, the light scattering matrix elements application as vector parameters is shown on the examples of influenza virus and colibacillus dispersions. These optical parameter ND vectors can serve as the innovative research platform for sensing different particle interfaces including biological ones.

1. Introduction

Ensembles of nano- and / or micro particles can be considered as three-dimensional ($3D$) disperse systems (DS) with particles as a disperse phase in dispersive medium [1]. Multiparametric analysis of optical data for $3D$ DS can provide further progress for detailed characterization and control of $3D$ DS with particles of different nature (including biological ones). Taking into account optical theory [1-4] and results of experiments [5-20] can help to elaborate sensing elements for on-line control of $3D$ DS state. In our research [5-19] we have investigated different $3D$ DS with nano- and / or micro particles (with diameter less than 10 micrometers). It has included: a) simultaneous measurements of $3D$ DS by different compatible nondestructive optical methods such as refractometry, absorbance, fluorescence, light scattering (integral and differential, static and dynamic, unpolarized and polarized), and b) solution of inverse optical problem by different methods, and technologies of data interpretation by information-statistical theory [21]. The experience suggests that the set of optical parameters of so-called "second class" is unique for each $3D$ DS. In other words, each $3D$ DS can be characterized by N -dimensional vector in the N -dimensional space of the "second class" optical parameters (ND vector) [13]. ND vectors can reflect in "unobvious" form all peculiarities of $3D$ DS: nature (constituent substances), form, inner and surface structure of particles; distributions of particle size, number, mass, refractive index, etc.; possibilities to aggregation, destruction or interaction with another particles, and so on.

The light scattering matrix elements [2-4, 20] being "second class" parameters by definition (obtained by processing of measured values, dimensionless, mainly independent on the concentration of particles) are very perspective for multiparametric analysis of $3D$ DS. In this paper the application of light scattering matrix elements as ND vector parameters (alone

several orders (Fig. 2, a-c) and by sign (Fig. 2, d).

In our research (Fig. 3), the 3D DS state characterization as ND vector in the N -dimensional space of matrix elements in complex with other optical parameters was used in order to design optimal scheme for dispersions on-line control: the S_{11} angular data for *E. coli* strain K-802 and strain AB1157 was combined with integral light scattering data (Fig. 3). For data in Fig. 3, measurements of dispersions (4 dispersions for each strain) were made at the same conditions. The uncertainty is about 10%. It can be concluded from Fig. 3 that P_1 and P_m are less informative parameters than P_i and P_k , and it is necessary to find more informative “second class” parameters for differentiation of these 3D DS.

The bilogarithmical plots in Fig. 4 are the examples of optical data presentation in the 12D (Fig. 4a), 4D (Fig. 4b) and 16D (Fig. 4c) spaces of optical parameters for dispersions of influenza virus (strain A1-H1N1) and colibacillus cells (strain K-802). Taking into account the angular dependences of S_{11} (parameters denoted with subscription S) and S_{12} (parameters denoted with subscription P) it is possible to form ND optical parameter vectors $\mathbf{P}_S \{P_{S1}, P_{S2}, \dots, P_{SN}\}$ and $\mathbf{P}_P \{P_{P1}, P_{P2}, \dots, P_{PN}\}$ correspondingly (Fig. 4a, where $N=6$). In Fig. 4b, the four informative “second class” optical parameters from integral and differential static light scattering, P_1, P_2, P_3, P_4 , are presented. The complex 16D vectors (from Fig. 4a and Fig. 4b) are given in Fig. 4c. It can be seen that the difference in positions of *E. coli* and influenza virus dispersion characteristics is significant.

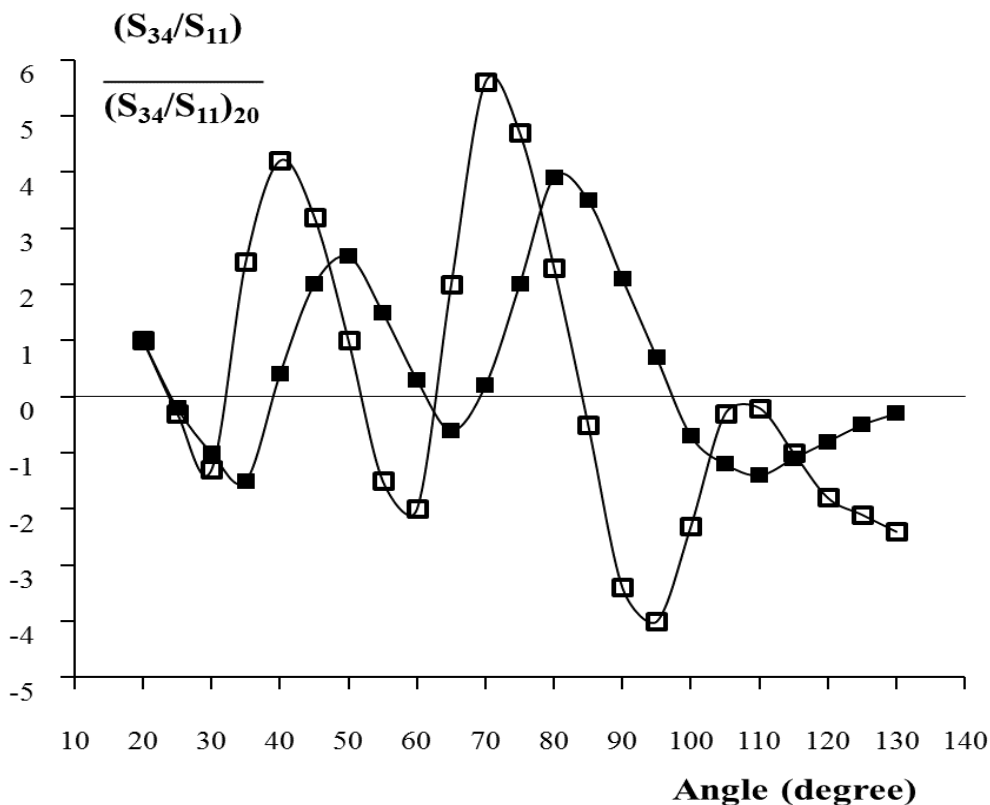


Fig. 1. Example of light scattering S_{34} matrix elements angular dependence (modified and normalized at angle 20° data from classical work [20]) for dispersions of two colibacillus strains: ■ - strain B/r, □ - strain K-12.

The classical experimental data [20] about angular dependences of S_{34} / S_{11} for *E. coli* strains B/r and K-12 were processing according N -vector approach for differentiation of dispersion states by several orders (Fig. 2a-c) and by sign (Fig. 2d).

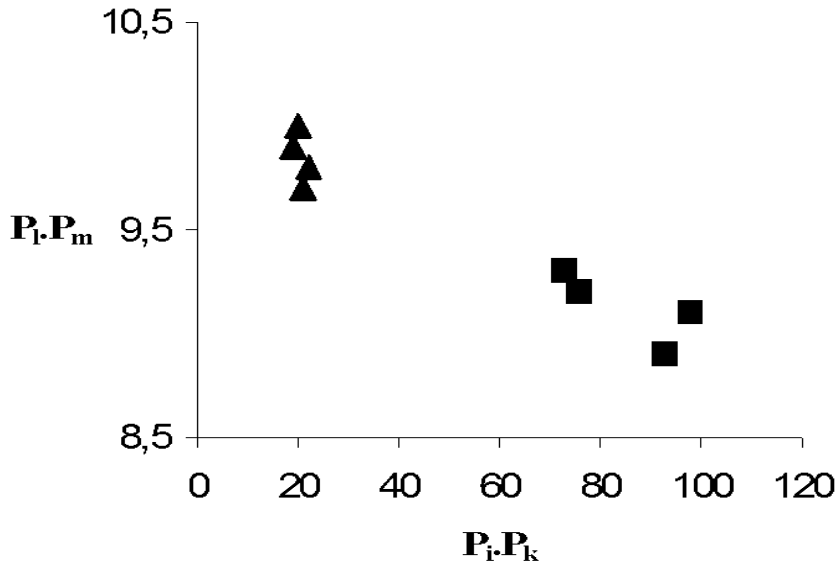


Fig. 3. Example of optical parameter *ND* vector presentation for dispersions of Escherichia coli two strains (K-802 - ▲, AB 1157 - ■) as *4D* vectors $\mathbf{P} \{P_i, P_k, P_l, P_m\}$ in *4D* space of “second class” optical parameters (including S_{11}) without any *a priori* information about cell structures and size distributions. Optical parameters are independent of cell concentration.

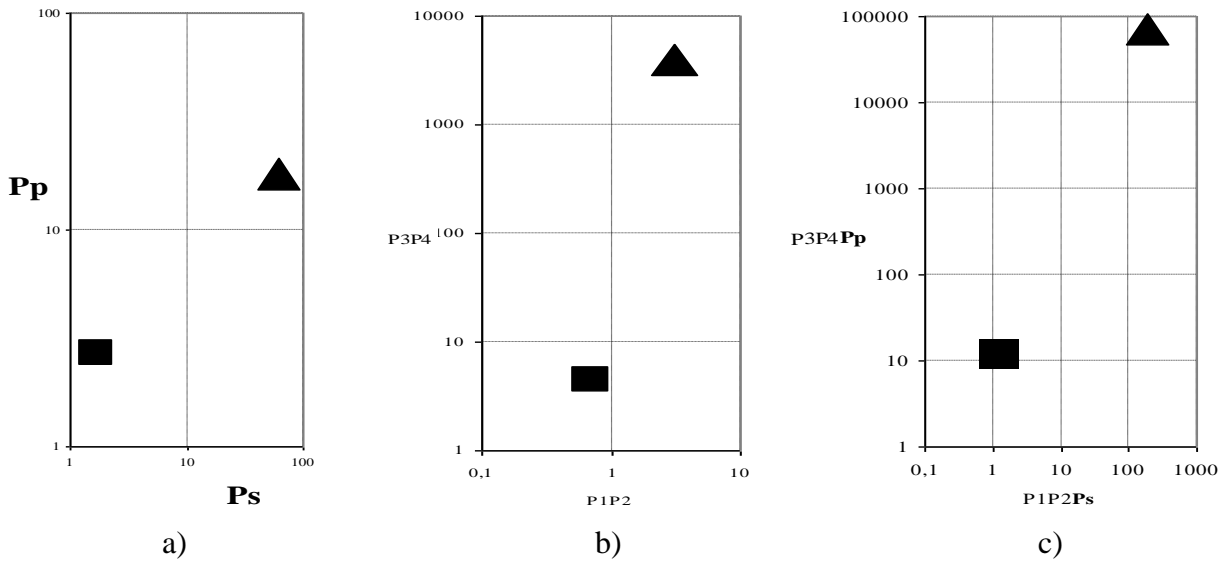


Fig. 4. Bilogarithmical plots as examples of optical parameter *ND* vector presentations for dispersions of influenza virus (strain A1-H1N1 - ▲) and colibacillus cells (strain K-802 - ■): a) as *12D* vectors $\mathbf{P}_{SP} \{P_{S1}, P_{S2}, \dots, P_{S6}, P_{P1}, P_{P2}, \dots, P_{P6}\}$, parameters denoted with subscriptions S and P were obtained from angular dependences of light scattering matrix elements S_{11} and S_{12} correspondingly; b) as *4D* vectors $\mathbf{P}_4 \{P_1, P_2, P_3, P_4\}$, parameters from integral and differential static light scattering; c) as *16D* vectors $\mathbf{P}_{16} \{P_1, P_2, P_{S1}, P_{S2}, \dots, P_{S6}, P_3, P_4, P_{P1}, P_{P2}, \dots, P_{P6}\}$. Optical data are independent of concentration of virus and cell particles.

4. Conclusion

Optical parameter *ND* vectors can reflect in "unobvious" form many peculiarities of a system state. The *3D* DS can be characterized and compared with each other by means of the *ND*

vectors. The vectors can also reflect the changes in the state of mixtures. Due to the fusion of various optical data and by the information statistical theory, it is possible to find the set of the most informative parameters and to solve the inverse physical problem on the presence of the component of interest in mixtures without any regularization. In this case, the polymodality of particle size distributions [19] is not an obstacle.

The number of parameters can be enlarged if to consider angular (Fig. 2, Fig. 4a) and wavelength dependences of experimental optical data. Optical parameter *ND* vector approach can be considered as "integral" for the study of a whole system as unity with the minimum interference. The presentation of 3D DS characteristics as optical parameter *ND* vectors can serve as the innovative research platform for sensing of particle interfaces. It also can demonstrate an awareness of the potential applications for bio- and nano-technology, medicine, industry and for the protection of environment.

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