Honorary note to celebrate the 80th birthday of professor Sándor Bárány

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In honour of the 80th birthday of Sándor Bárány

1. Biography

Prof. emeritus Dr. habil. Dr.h.c. C.Sc. D.Sc. Sándor Bárány was born on 27.02. 1937, in the village Vary, district Beregovo, Transcarpathia, that time (1920-1938) Czechoslovakia. This territory between 895-1871 and 1938-1945 belonged to Hungary, between 1871-1920 to the Austrian-Hungarian Empire, between 1945-1991 to the Soviet Union, and since 1991 to Ukraine. After the WWII Sándor found himself in another country where his name was translated as Alexander Alexandrovich. So, Sándor Bárány became AA Baran without being asked his agreement for this change. After finishing the high school with gold medal in Beregovo, he studied chemistry at the T. Shevchenko Kiev University in 1954-1959 and, as an "aspirant" (i.e. PhD student) of physical chemistry at the Institute of Physical Chemistry of the Ukrainian Academy of Sciences (1961-1964). In 1965 he defended his Candidate of Sciences (PhD) dissertation "Radiometric study of counter-ions adsorption during coagulation of lyophobic sols" (at the Institute of Physical Chemistry, Ukrainian Academy of Sciences) and in 1982 his Doctor of Sciences dissertation "Electro-surface properties and stability of polymer-containing disperse systems" (Leningrad University, USSR). In the years 1964-1991 he held positions of Researcher, Senior Researcher, Group Leader and Head of Laboratory at the Institute of Physical Chemistry and Institute of Colloid and Water Chemistry, Ukrainian Academy of Sciences, Kiev. In 1992 he was invited to join the University of Miskolc, Hungary, where Bárány served as a Science Advisor, Head of Department, Institute of Chemistry Director, and since 2007 as Professor emeritus. In 1995-1996 he has been Visiting Professor at the Georgia Institute of Technology (Atlanta, USA) and in 2007-2011 to the Technical University of Kosice (Slovakia). Between 1996 and 2006 Sándor was several times elected as an Adjunct Professor at the University Utah (Salt Lake City, USA). Since 2012 he is also a Professor of Chemistry at the Transcarpathian II. Ferenc Rákóczi Hungarian Institute, in his native town Beregovo, Ukraine.

2. Tutorial and organizational activities

Sándor taught colloid chemistry and electrochemistry of colloids at universities of Hungary, Slovakia, Ukraine, Kazakhstan, USA, Japan and Argentina as well as organic chemistry, general chemistry, water treatment and polymer chemistry at the University of Miskolc and II. F. Rákoczi Institute in Beregovo. He was an Advisor of 19 C.Sc.(PhD) and D.Sc. dissertations with students from Bulgaria, Hungary, Kazakhstan, Russia and Ukraine. He has been a Principal Investigator of two dozen national and international scientific projects, including a NSF-Hungarian Academy of Sciences, Hungarian-Israeli, Hungarian-Argentinean, Hungarian-Portuguese, four Hungarian-Russian, five Hungarian-Ukrainian bilateral scientific projects as well as a co-PI of two INTAS projects. He had several month stays at the Institute of Physical Chemistry of the DDR Academy of Sciences, Berlin (1976), Institute of Mineral Processing (Freiberg, 1977) University College London (1993) and the University of Wageningen, The Netherlands (1994) where established fruitful scientific contacts and personal life-long friendship with Professors H. Sonntag, J. Gregory, J. Lyklema, G. Fleer, L. Koopal, M. Cohen-Stuart. In April 1990 Bárány served as an UN expert on water treatment in Beijing, at the “Water Resources, Planning and Treatment” high ranked symposium.

Bárány was two times elected as an IACIS Council member (2000 and 2003). He was an Initiator and Chairman of 14 international conferences, symposia and workshops in colloid and surface chemistry, environmental protection problems, including the series of six conferences on Carpathian Euroregion Ecology, NATO ARW “Role of Interfaces in Environmental Protection”, The 2nd conference “Interfaces Against Pollution”, Hungarian-Israeli-Korean Workshop “Solid-Liquid, Liquid-Liquid Interfaces”, International Workshop “Non-equilibrium Electro-surface Phenomena”, “Ecology of Demilitarization” and others. He participated in over 150 conferences in 30 countries around the world, served as a referee of international journals: Colloid J., Colloids Surf. A., J. Colloid Interf. Sci, Adv. Colloid Interf. Sci.

3. Scientific accomplishments

Sándor during his over 50 years scientific career contributed largely to many different fields of colloid science such as ion, surfactant, polymer adsorption and colloidal stability, kinetics of coagulation by electrolytes and polyelectrolytes, structure of the electrical double layer (EDL), linear and non-linear electrophoresis, aggregation of aluminium salts hydrolysis product particles, stabilization and flocculation of dispersed particles, including cellular suspensions by polymers and their mixtures, electro-surface properties and stability of carbon nanotube suspensions. The results of this work are documented in more than 300 publications, including 7 books and 12 book chapters.

I. Sándor started his scientific activity as a university student in Prof. A. Golub's inorganic chemistry lab and published with him 2 papers devoted to synthesis and properties of complexes of lead and tin perchlorates with dioxan. Prof. Dmitrii Strazhesko, a well known Ukrainian professional on adsorption and Prof. Yuli Glazman, an internationally recognized colloid chemist were his Candidate of Science (PhD) dissertation advisors. As PhD student, he measured for the first time the correct values of adsorption of tiny amounts (micrograms per g) of counter-ions by coagulation of sols with electrolytes using a direct radioactive tracer method and put end to a half century discussion on this issue. Probably, the young generation of colloid chemists does not know that Freundlich's "adsorption" theory of colloidal stability was based on the idea of equivalent adsorption of counter-ions at the moment of coagulation (1910). H. Freundlich, K. Joachimson and G. Ettisch (Z. Phys. Chem, 141 A, 249, 1929) tried to check the theory and to measure adsorption of different ions from the difference of their concentration prior and after coagulation of hydrophobic sols using electrochemical methods. Quite different unrealistic values of adsorption have been obtained, and as a result Freundlich refused his own theory. Baran determined the counter-ions adsorption based on measurements of the radioactivity of sediments formed at coagulation concentration of different electrolytes labeled by radioactive counter-ions. He demonstrated that: (i) the adsorbed amounts of counter-ions of different charge at coagulation value of electrolytes and their binary mixtures are really equivalent, (ii) the isotherms of counter-ions adsorption by colloidal particles follows the Langmuir equation, with reaching plateau values, *see Fig.1,* (iii) prior and at coagulation values the trivalent counter-ions are fully adsorbed at particle's surfaces, i.e. there is no equilibrium concentration of multivalent ions in solution, (iv) the big highly polarisable ions such as Cs+ or J^- are adsorbed on negatively or, respectively, positively charged particles in super-equivalent amounts due to additional (to electrostatic) ion-induced dipole interactions, (v) assuming as first approximation that the plateau values of counter-ions adsorption correspond to the surface charge density, the surface coverage of a number of colloidal particles (Au, Ag, AgI, As_2S_3, Sb_2S_3, HgS, FeO(OH), MnO_2, etc.) by potential determining ions has been determined. For majority of hydrophobic colloids this coverage reaches only 1-3 %, for Au and MnO_2 – over 25 %. [1-6].

II. Sándor with his coworkers and PhD students performed a complex study of the EDL structure of over two dozen colloidal particles of *different nature* (polystyrene and melamin-formaldehyd lattices, Au, AgI, Sb_2S_3, As_2S_3, FeO(OH), ZrO_2, CeO_2, SiC, TiC, bentonite, kaolin, hydro-mica, palygorskite), *emulsion drops* (kerosene in water, industrial ET grade emulsions), *bacterial* (Escherichia Coli) and *yeast cells* (Saccharomices Cerevisiae), of *different size* (from tens of nanometer to microns) and different *form* (spherical, ellipsoidal, needle like). It included measurements of the surface charge density, electrokinetic potential, surface conductivity and, in part, low frequency dispersion of the suspension permittivity. It has been shown that for an overwhelming majority of colloids the zeta-potential values even corrected for the EDL polarization of the whole diffuse layer (by Dukhin-Semenikhin) is much less than the surface/Stern potential *(example: Fig.2)*, and the "electrokinetic charge" (i.e. the charge in the slip plane) is a small fraction of the surface charge density (typically 1-10 %) due to existence of extended solvent layers on the surface. Only for AgI particles the surface-, Stern- and zeta-potentials were found to be close to each other. Counter-ions localized in the hydro-dynamically immobilized part of the EDL, i.e. between the borders of the Stern layer and slip plane, retain in the electric field high mobility comparable to that characteristic for bulk phases [7-15].

III. Bárány and his team, in collaboration with S. Dukhin and N. Mishchuk discovered and studied in detail a new electrokinetic phenomenon, the so-called „superfast electrophoresis" or "electrophoresis of the second kind" [16-23]. This phenomenon was theoretically predicted by S. Dukhin and N. Mishchuk who have shown that besides the classical EDL, at certain circumstances around unipolar conducting dispersed particles (i.e. in which only one type of ions, or electrons, are mobile) in strong electric fields a secondary double layer containing a huge induced space charge can be formed. The interaction of this induced charge with the external electric field itself can produce electroosmotic or electrophoretic velocities (V_{ef}) greater than those predicted by the Smoluchowski's theory by one or two orders of magnitude. The Dukhin- Mishchuk theory of "superfast electrophoresis" predicts a quadratic dependence of the electrophoretic velocity of unipolar (ionically or electronically) conducting particles on the external field gradient and a linear dependence on the particle's size in strong electric fields. These are in sharp contrast to the laws of classical electrophoresis (no dependence of V_{ef} on the particle's size and linear dependence on the electric field gradient).

S. Bárány and F. Mádai developed a new method to measure the fast velocity V_{ef} of particles in strong electric fields (100-1000 V/cm) that is based on separation of the effects of sedimentation and electrophoresis using video imaging and a new flow cell and use of short electric pulses [20-23]. It has been shown that in strong external fields the V_{ef} of unipolar ion-type conducting (ion-exchanger particles and fibres, see as *example Fig.3*), electron-type conducting (magnesium and Mg/Al alloy) and semiconductor particles (graphite, activated carbon, pyrite, molybdenite) increased significantly with the electric field ($V_{ef} \sim E^2$) and the particle's size but was almost independent of the ionic strength. These trends are inconsistent with Smoluchowski's equation for dielectric particles, but are consistent with the Dukhin-Mishchuk theory of superfast electrophoresis.

IV. S. Bárány and V. Shilov developed a new theory and experimentally investigated the non-linear electrophoresis of non-conducting particles based on following considerations (not to mix up with "superfast electrophoresis" as described above) [24-27]. Non-linear electrophoresis is due to the interaction of strong electric fields with charges of the" classical" diffuse double layer. As soon as the strength of the applied field (E) increases, the processes that are non-linear with respect to E start playing an important role, determining a noticeable non-linearity of the dependence V_{ef} (E). The influence of non-linearity appears in higher than first order terms in the expansion of V_{ef} in powers of E. It has been shown that the term that follows the linear electrophoretic term in the expansion of electrophoretic velocity, is cubic with respect to the applied field and the non-linear component of the electrophoresis can be described without any reference to the ζ-potential, but rather in terms of the Dukhin number *Du* (which characterises the EDL ability for polarization), i.e. without any restrictions to other parameters of the thin EDL.

It was demonstrated that the electrophoretic velocity of non-conducting particles in strong electric fields, under conditions of non-linear electrophoresis, increases with the third power of the external field gradient and with the second power of the particles radius, i.e. particles behave quite differently compared to the classical non-linear regime. To test the theory developed, Bárány and Mádai have measured V_{ef} of non-conducting polystyrene, aluminium-oxide and semiconductor graphite particles as well *as Saccharomice cerevisiae* yeast cells as a function of the electric field strength, particle size, electrolyte concentration *(see Fig.4)* and the adsorbed polymer amount. It has been shown that V_{ef} of the particles/cells increases linearly with the field strength up to about 100 V/cm and 200 V/cm, correspondingly, without and with adsorbed polymers both in pure water and in electrolyte solutions.

In line with the theoretical predictions, in stronger fields substantial non-linear effects were recorded (V_{ef}~E^3)[24-27].

V. Parallel with the famous Dutch colloidal school, Bárány conducted pioneering and systematic investigations on the effect of adsorbed polymers and their mixtures on the electrical double layer structure of dispersed particles [13, 27-43]. There is a huge number of literature data on the relationship between the amount of added polymer and electrokinetic potential of dispersed particles. At the same time, there is only limited information about the dependence of the ζ-potential on the adsorbed amount of polymer, i.e. data on simultaneous adsorption and electrokinetic measurements. Sándor performed a complex study on the adsorption of different non-ionic polymers (polyvinyl alcohol- PVA, polyethylene glycol-PEG, polyethylene oxide -PEO, methylcellulose - MC, polyvinyl pyrrolidone -PVP) and its effect on the surface charge, surface conductivity and ζ-potential of polystyrene, aerosil, silver iodide, antimony sulphide, iron and zinc oxides, graphite, hydro-mica, titan and silicium carbides and other particles [27-38]. Also the adsorption of a dozen of anionic and cationic polyelectrolytes with different molecular mass and charge density as well as their binary mixtures and its effect on the electrokinetic potential of silica, polystyrene, Escherichia Coli cells, kaolin, bentonite, montmorrilonite and other mineral particles has been measured [27, 40-43]. The variety of effects of adsorbed polymers on the EDL structure was demonstrated. A new concept was developed according to which accumulation of macromolecular segments in the Stern layer can alter the surface charge density as a result of the appearance of “adsorption potential jumps” in the oriented layer of dipolar segments on the surface which is reflected in changes of the electrokinetic potential. Using this idea, an unusual phenomenon, namely the overcharge of the surface of positively charged particles as a result of the adsorption of ***non-ionic*** polyethylene oxide or polyvinyl alcohol has been explained [27, 28, 30, 36]. It was shown that changes in the surface charge density can also take place due to changes in ionization of surface groups or adsorption of potential-determining ions which are occurring in many systems containing oxides with adsorbed non-ionic polymers. Adsorbed segments can displace some specifically adsorbed counter-ions from the Stern layer into the diffuse part of the double layer, which increases the Stern-potential and hence the stability of the colloidal solution. This explains the initial increase in the ζ- potential of AgI particles in the presence of small amounts of added poly(ethylene oxide) [28, 30, 36]. Formation on the surface of fairly thick hydrodynamically impermeable layers of non-ionic polymers shifts the slip plane into the bulk of the liquid phase, which entails a decrease in ζ-potential and the electrostatic repulsion forces of polymer-containing particles; this mostly observed phenomenon has been widely used for calculating the hydrodynamic or “electrophoretic” thickness of polymer layers. An analysis of the influence of various complicating factors, namely polarization of the EDL, curvature of the surface and presence of electrolytes, on the calculation of the polymer layer thickness from electrophoretic data has been performed [32].

S. Bárány in collaboration with S. Dukhin performed a theoretical and experimental study on the effect of adsorbed polymers on the surface conductivity of dispersed particles [33, 39]. It has been shown that adsorption of non-ionic polymers decreases the specific surface conductivity and ionic mobility in the double layer and increases the effective radius of particles due to the presence of sufficiently thick adsorption layer with immobilized water inside. Both produce a decrease of the *Du* number which in its turn leads to a monotonic decrease in the slope of the relative electric conductivity of the dispersion K_s/K_m, (where K_s *and* K_m are the conductivities of the suspension and medium) as a function of the volume fraction of the dispersed phase *(p)*. A new method of determination of the polymer layer thickness was proposed based on the decrease in the slope of $K_s/K_m(p)$ dependencies as a result of polymer adsorption [33, 39].

Based on experimental data on the effect of adsorbed non-ionic polymers on the surface charge density, surface conductivity and electrokinetic potential of a number of particles (AgI, polystyrene, Sb_2S_3, SiC, TiC, hydro-mica), Sándor managed to estimate the fraction of the surface covered by macromolecular segments, the fraction of macromolecule segments being in direct contact with the surface and the effective (hydrodynamic) thickness of adsorbed polymer layers, using the Lyklema-Fleer –Scheutjens- Koopal-Cohen-Stuart theories and ideas on polymer adsorption and polymer layers' structure. Using these parameters, the contribution of adsorbed polymer layers to the stabilization of a number of colloidal systems has been determined [29, 34-36]. Bárány demonstrated for the first time that in mixtures of cationic and anionic polyelectrolytes, in a wide range of their composition, the ζ-potential of negatively charged particles is determined by the adsorbed amount of the anionic polymer independent of the charge density of the polyelectrolyte and the sequence of addition of the mixture components [40-43], *see Fig.5*. To explain these features, it was supposed that in the case of polyelectroyte mixture adsorption, the layer of the cationic polymer was hidden inside the much more extended anionic polymer layer. The latter determines the properties of the peripheral part of the adsorbed layers that are responsible for the electrokinetic potential of particles covered by polymer. This explains the results showing that the ζ-potential of dispersed particles in polymer mixtures depends primarily on the conformation of the same charged (anionic) polyelectrolyte on the surface.

Sándor was also first to perform a comparative study on the effect of adsorbed polymers on the electrophoresis of dispersed particles in weak and strong electric fields [25- 27]. It has been shown that the adsorption of non-ionic polymers only slightly (by about 20-40%) decreases the V_{ef} of polystyrene, graphite and aluminium-oxide particles in strong fields (100-500 V/cm). This is in contrast to the electrophoresis in weak fields (5-20 V/cm) in which adsorption of these polymers gives a drop in V_{ef} by one-two orders of magnitude. In line with the newly developed theoretical predictions [24, 25] this means that the non-linear ("cubic") electrophoresis, which arises in strong electric fields, is independent of the position of the shear plane, i.e. the ζ-potential value. It is determined mainly by the surface conductivity of particles, i.e. by the Dukhin number that characterizes the polarization of the double layer.

VI. Bárány and coworkers performed a complex study on polymer adsorption, polymer layers' structure and its impact on the laws and mechanism of stabilization of dispersed particles/nanoparticles [44-52]. The effects of different adsorbed amounts of non-ionic polymers as well as a number of cationic and anionic polyelectrolytes on the aggregation stability of hydrophobic Au, AgI and Sb_2S_3 sols, kaolin, bentonite, palygorskite and polystyrene latex suspensions have been elucidated. The observed laws were summarized as follows:

(1) A very small amount of polymer (ppm) can sufficiently increase the aggregation stability of dispersions; (2) with increasing the added amount of the polymer the stability of dispersion first decreases (flocculation) and then increases (stabilization), (3) with increasing the molecular mass *M* the stabilizing effect of nonionic polymers and the same charge polyelectrolytes increases, for oppositely charged polyelectrolytes the *M* plays a minor role; the dominant role has the charge density; (4) after attainment of a certain polymer concentration in the system, the dispersion becomes extremely stable and does not coagulate, even in the presence of concentrated electrolyte solutions; coagulation values of different counter-ions are gradually leveled out as the concentration of the polymer in the dispersion increases; *see Fig.6,* (5) a sharp increase in the stability takes place over a

narrow range of polymer contents in the system; (6) for every surface/polymer system a “critical” surface coverage exists (typically 0.4 – 1.0 mg/m^2), above which the stability of the system dramatically increases; (7) there is a linear dependence between concentration of the solid particles and the minimum amount of the polymer necessary to reach a given stability in diluted disperse systems.

Starting from the results of adsorption, electro-surface properties, viscosity and stability measurements, a relationship between the electrical double layer and adsorbed polymer layers’ structure and stability of polymer-covered particles was established. Based on the determined parameters of the EDL and polymer layers, and using the Hesselink-Vrij- Overbeek theory of interaction of adsorbed macromolecules, the contribution of different components into the total energy of interaction of particles having adsorbed different amounts of non-ionic polymers has been determined–electrostatic repulsion, structural (hydration) forces and repulsion caused by interaction of adsorbed segments (“volume restriction” and “mixing” effects) [36, 46-52]. Bárány developed an idea about the important role of structural (hydration) forces in the mechanism of stabilization of colloids covered by adsorbed hydrophilic macromolecules and estimated their contribution to the stability at different conditions [36,44, 45, 50, 52]. Depending on the surface coverage by polymers, the adsorption layers thickness and degree of hydration of adsorbed segments, these forces can serve as „strong” or „weak” factors of stabilization.

VII. Sándor and his coworkers elucidated the regularities, kinetics and mechanisms of flocculation of a big number of inorganic and cellular suspensions by polyelectrolytes and their mixtures [36, 40, 41, 43, 53-62]. He developed an idea that depending on the charge density of polyelectrolytes and stiffness of the macromolecular chain (regulated by changing the molecular structure, pH and electrolyte concentration) a transition between “polymer bridge” formation and surface charge neutralization mechanisms of flocculation of the same system can be realized.

VIII. Bárány (with I. Solomentseva and J. Gregory) is author of original studies on electro-surface properties, laws and mechanisms of aggregation of aluminum salts hydrolysis product particles (HPP) and their use in water treatment [63-67]. The size, surface area, electrokinetic potential, degree of hydration, rate of aggregation, stability and break-up of aggregates formed from particles of hydrolysis product of aluminium sulphate and chloride as well as basic aluminium sulphates and chlorides were studied as a function of the salt dosage, pH, alkalinity and ionic strength of the water, OH/Al ratio in the salt molecule as well as shear conditions of the system. A relationship between the particles’ size, degree of their hydration and electrokinetic potential, and degree and mechanisms of HPP aggregation was established. The efficiency of aluminium salts HPP in removal of bacteria from water was demonstrated. It has been shown that at sufficiently high coagulant doses the efficiency of colloids removal by "sweep" coagulation is much higher than the purification by a charge neutralisation mechanism that is characteristic for low salt doses.

IX. Sándor recently performed original studies (with N. Lebovka and M. Manilo) on adsorption and electro-surface properties, stabilization of multiwall carbon nanotubes (CNT) as well and N-doped CNT suspensions using surfactants and mineral nanoparticles. The effects of pH, electrolytes, anionic and cationic surfactants as well as artificial mineral laponite nanoparticles on the electrokinetic potential of CNTs with different surface functionalization have been determined [68-73]. Aggregation of multi-walled carbon nanotube with laponite hybrid particles in aqueous suspensions under continuous stirring at different values of mass ratio of laponite and CNTs, was investigated. Optimum conditions for stabilization of carbon nanotubes by adsorbed cationic cetyltrimethyl ammonium bromide (CTAB), laponite and their binary mixtures have been determined. Also the strength of flocs and the reversibility of aggregation of CNT + laponite nanoparticles as a function of the shear rate have been elucidated. It has been shown that there is a ratio of critical coagulation concentrations of mono-and bivalent counter-ions of≈ 5 which is an evidence of aggregation of CNT + laponite hybrid particles in the secondary minimum. A correlation between sedimentation stability of CNTs suspension and the ζ- potential of nanotubes was established.

Estimating the accomplishments of Sándor Bárány's, we have to remember that over half of his scientific carrier was realized at the Ukrainian Academy of Sciences institutions, Kiev, where he produced results at an international level under poor conditions, having used mainly homemade devices, cells and equipment. Until the late time of Gorbachov's "perestroika" Sándor was deprived the chance to publish and to participate in international conferences in the West (argument: "no experience of travelling to western countries").

4. Personal remarks

I know Sándor since 1992 when he started his activity at the University of Miskolc where I served as a Head of Department of Physical Chemistry and Dean of the Faculty of Materials Science. Bárány was two times elected as Director of the Institute of Chemistry of our faculty in 1996-2002, and as a Manager and Faculty Council Member he always fought with bureaucracy, openly and fearless expressed/defended his opinion often against the official "line". For his tutorial and scientific achievements Sándor won the Hungarian National Széchenyi scholarship (2000-2004) and was awarded the "doctor honoris causa" title from the University of Miskolc (2015). Bárány has deep and wide knowledge in different fields of chemistry, and he is always ready to help and consult anyone anytime. Many M.Sc. and PhD students, young colleagues are still visiting him from different countries to cooperate and consulting. Till now he is an organizer and active participant of a number of international conferences. Bárány is familiar and is friends with majority of the old generation's colloid chemists of the world. Sándor is a highly educated interesting person, an excellent lecturer who speaks five languages (Hungarian, Russian, Ukrainian, English and German), with profound knowledge in history, painting, classic music and world literature. And last but not least, Sándor is a good friend.

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5. Selected papers

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Figures

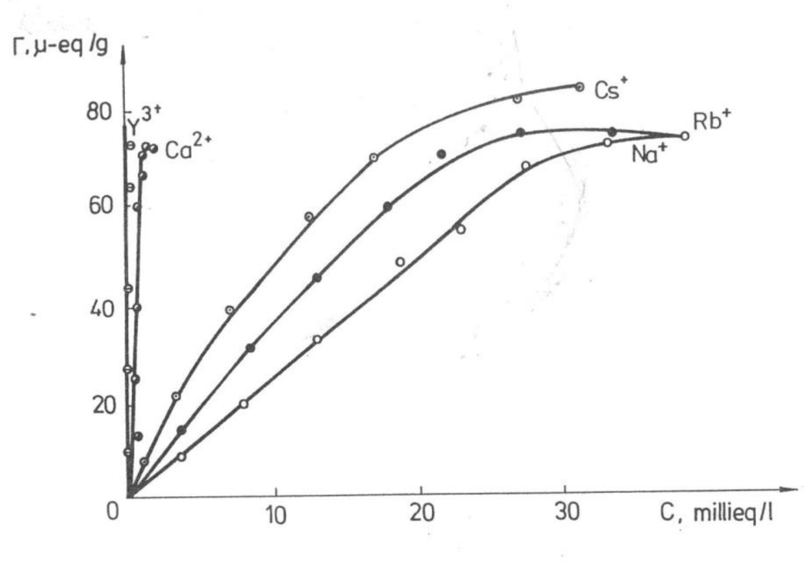

Fig.1. Adsorption isotherms of different cations on the surface of As_2S_3 sol particles measured by direct radioactive tracer method. Adopted from [14]

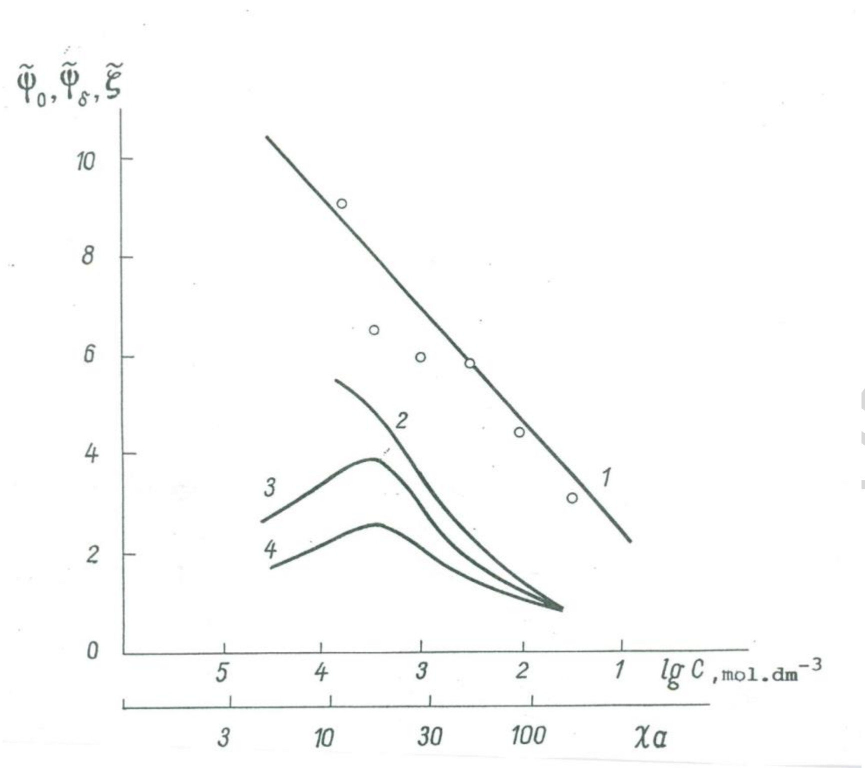

Fig.2. Dependence of the dimensionless values of the surface-Ψ_0 (1), Stern Ψ_δ–(circles around curve 1) and electrokinetic-ζ (2,3,4) potentials of polystyrene particles on the logaritm of the KCl concentration or κa values (κ-is the reciprocal Debye length and a-is the particles radius). The ζ-potentials were calculated by Smoluchowski, i.e. without taking into account the EDL polarization (curve 4), by Wiersema, i.e. accounting the polarization of the hydrodynamically mobile part of the EDL (curve 3) and by Dukhin-Semenikhin, i.e. taking into account the polarization of the whole diffuse part of the EDL (curve 2). Adopted from [7, 14]

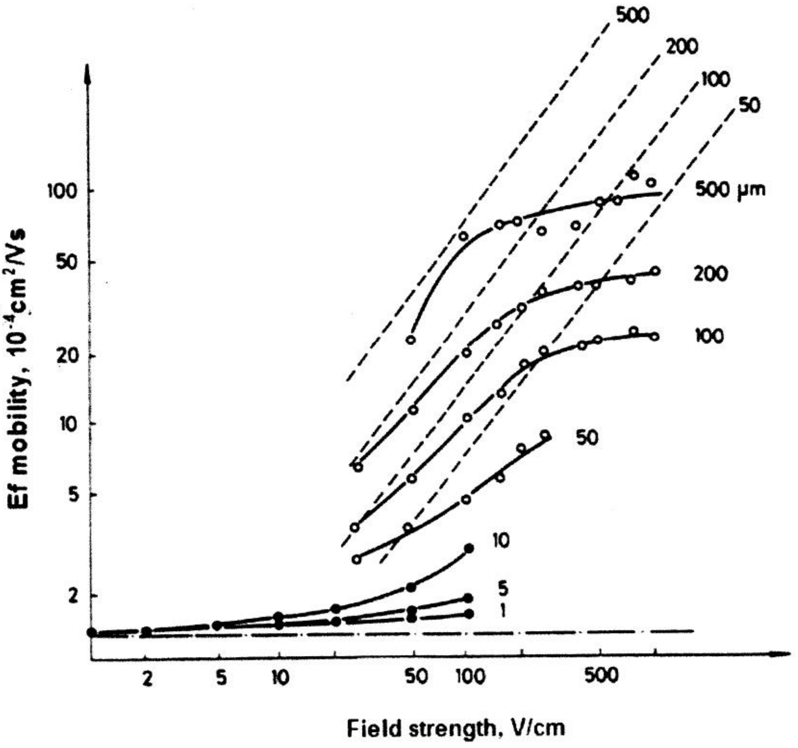

Fig.3. Double logarithmic plot of the electrophoretic mobility of cation-exchanger particles KU-2x8 of different diameter (indicated) as a function of the electric field gradient. Dotted lines represent theoretical predictions. Adopted from [21]

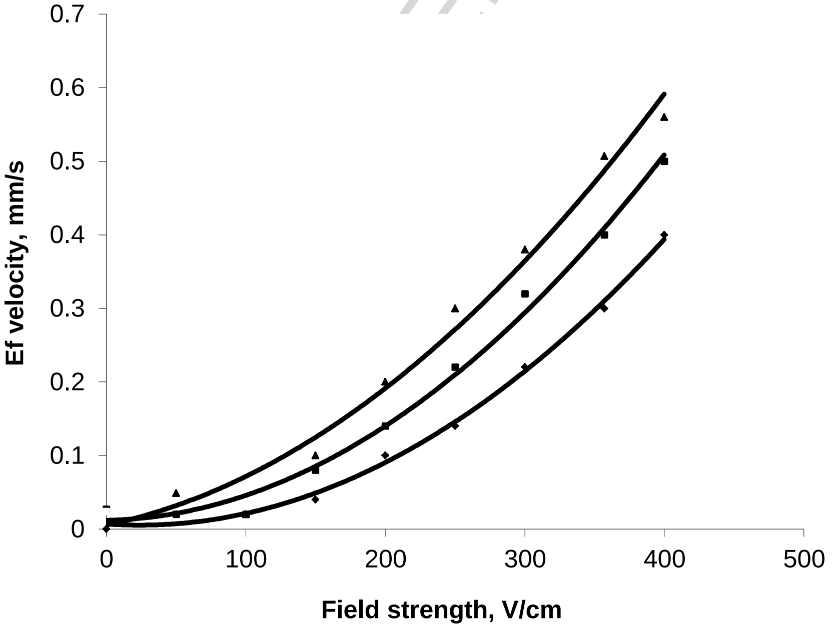

Fig.4. Field dependence of the electrophoretic velocity of PS particles of diameter 22 µm (lower curve), 30 µm (middle curve) and 50 µm (upper curve). Adopted from [23]

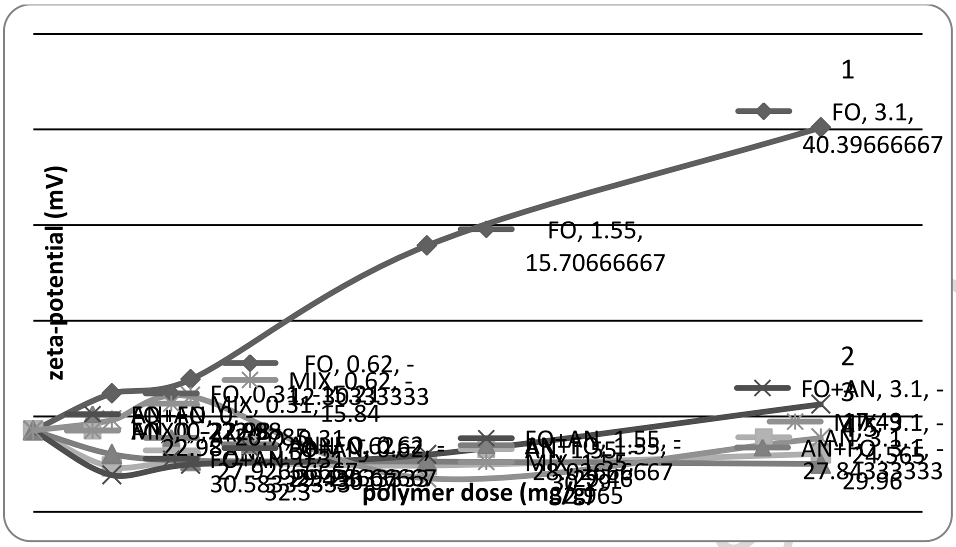

Fig.5. Dependence of the ζ- potential of bentonite particles on the added amount of (1) medium charged SNF FO 4350 cationic polymer, (2) medium charged SNF AN 935 anionic polymer, (3) after addition of 0.65 mg/g cationic polymer to the samples adsorbed different amount of anionic polymer, (4) after addition of 0.65 mg/g anionic polymer to samples pre- treated with increasing amount of cationic polymer and (5) in the event of simultaneous addition of 1:1 medium charged anionic and cationic polyelectrolyte mixture. Adopted from [40]

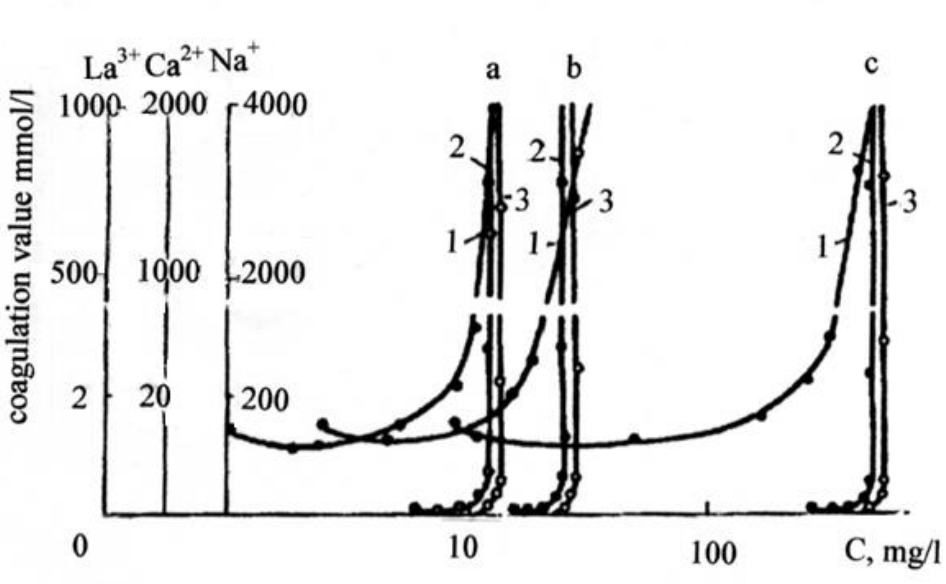

Fig.6. Coagulation values of Na$^+$ (1), Ca^{2+} (2) and La^{3+} (3) ions for Sb_2S_3 sol as a function of the added PEO amount. M= 2.3 x10^5 (a), 1.3x10^6 (b) and 2.6x10^6 (c). Adopted from [50, 52].