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HISTORY PAGES

Dedicated to the 90th anniversary of Ivanovo State University of Chemistry and Technology

Scientific activity of Ya.K. Syrkin at the Faculty of Chemistry of the Ivanovo-Voznesensk Polytechnic Institute and in the Ivanovo Institute of Chemistry and Technology (1918–1932)

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Objectives. *Preserving the continuity of scientific schools and increasing scientific motivation is critical for educating new generations of researchers. One way to solve this problem is to promote the historically significant achievements of outstanding scientists working in the field, without which the foundations of modern chemical technologies cannot be imagined. The field of physical chemistry benefited immensely from the contributions made by Professor Yakov Kivovich Syrkin. This article is devoted to the analysis of the growth of Ya.K. Syrkin as a scientist and discusses his main scientific contributions to physical and quantum chemistry.*
Methods. *The article was prepared using archival materials, bibliographic references, original texts of articles, and scientific reports.*
Results. *The article details and documents the main scientific achievements of Ya.K. Syrkin during his work at the Ivanovo-Voznesensk Polytechnic Institute and the Ivanovo Institute of Chemistry and Technology between 1918 and 1932, showing his growth and development as a young scientist through his interactions with teachers and colleagues. Syrkin's research on chemical equilibrium, reaction kinetics, thermodynamics, catalysis, solution theory, solvate effects, and colloidal systems are presented herein.*
Conclusions. *A retrospective analysis of the career of Ya.K. Syrkin shows the scope of his research interests and his ability to build on the foundations provided by great predecessors such as Gibbs, Van't Hoff, Arrhenius, Ostwald, and Nernst. A comprehensive study of fundamental and applied aspects of physical chemistry guided Syrkin's approach to understanding the importance of molecular structure and the nature of chemical bonds in all observed chemical phenomena.*

Keywords: *physical chemistry, equilibrium of heterogeneous systems, chemical kinetics, catalysis, solutions, colloidal systems, separation of liquefied gases, fabric dyeing.*

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ИСТОРИЧЕСКИЙ ОЧЕРК

90-летию Ивановского государственного химико-технологического университета посвящается

Научная деятельность Я.К. Сыркина на химическом факультете Иваново-Вознесенского политехнического института и в Ивановском химико-технологическом институте (1918–1932 гг.)

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Цель. *Сохранение преемственности научных школ, повышение мотивации к научному поиску является актуальной задачей воспитания новых поколений исследователей. Одним из путей решения этой задачи является пропаганда исторически значимых достижений выдающихся ученых, работающих в области, без которой не мыслится развитие фундаментальных основ тонких химических технологий. Такой областью являлась и является сейчас физическая химия, в развитие которой огромный вклад внес профессор Яков Кивович Сыркин. Настоящее исследование посвящено анализу становления Я.К. Сыркина как ученого и обсуждению его основных научных результатов, имеющих принципиальное значение для развития физической и квантовой химии.*
Методы. *При подготовке статьи использованы архивные материалы, библиографические справки, оригинальные тексты статей и научных отчетов.*
Результаты. *В статье подробно рассмотрены и документально подтверждены основные научные достижения Я.К. Сыркина в период его работы на химическом факультете Иваново-Вознесенского политехнического института и в Ивановском химико-технологическом институте (1918–1932 гг.), показано становление молодого ученого, его взаимодействие с учителями и коллегами. Представлены результаты исследований химического равновесия; химической кинетики; установления связи между кинетикой и термодинамикой; катализа; теории растворов; сольватных эффектов; коллоидных систем и др.*
Выводы. *Ретроспективный анализ деятельности Я.К. Сыркина показывает его становление, широту интересов, умение связать, творчески оценить и развить фундаментальные достижения великих предшественников – Гиббса, Вант-Гоффа, Аррениуса, Оствальда, Нернста и других. Разностороннее исследование фундаментальных и прикладных аспектов физической химии привело Я.К. Сыркина к пониманию ключевой роли строения молекул и природы химической связи во всех наблюдаемых химических явлениях.*

Ключевые слова: *физическая химия, равновесие гетерогенных систем, химическая кинетика, катализ, растворы, коллоидные системы, разделение сжиженных газов, крашение тканей.*

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Yakov Kivovich Syrkin was an academician of the USSR Academy of Sciences and a graduate of the Ivanovo-Voznesensk Polytechnic Institute (IVPI), which was the first technical university established in Soviet Russia, from which he graduated in September 1919 with the Diploma No. 1. After receiving a higher education diploma, Ya.K. Syrkin became a Junior Assistant at the Department of General Chemistry. In October 1918, he applied to the rector Mikhail Nikolaevich Berlov with a request for employment at the Laboratory of Inorganic Chemistry at IVPI. The institute's management considered it necessary to attract capable students as employees of the analytical laboratory, particularly one who was as

motivated and technically talented as Syrkin. The details surrounding Syrkin's time as a teacher are described in the bibliographic index [1] published for the 120th anniversary of his birth in the series entitled "Golden Fund of Chemtech."

The current publication aims to explore the early scientific activities of this academician and gain insight into the multifaceted scientific interests that enabled him to take advantage of golden opportunities in his field. Syrkin's first steps into science began in the laboratory of Petr Petrovich Budnikov[1] in which their first joint project [2] was on optimizing the conditions for gypsum setting. In this project, Syrkin and Budnikov determined the factors that influenced the rate of high temperature gypsum setting (i.e., above 400°C) in calcium sulfate semi hydrates ($CaSO_4 \cdot ½H_2O$), dihydrates ($CaSO_4 \cdot 2H_2O$), and anhydrous $CaSO_4$ (soluble and insoluble). Here, the features of a previously unreported hydrate were discussed, and the transition points between the various hydrates were established. The researchers were able to slow high temperature gypsum setting by adjusting the growth of insoluble modification, mechanical grinding, and the process of hydration of the insoluble anhydride itself.

Published in 1923, the group's work [3] on the dissociation of $CaSO_4$ would later be used to establish the chemical and physical characteristics of estrichgypsa, a type of gypsum formed when $CaSO_4$ was calcined above 800°C. Several allotropic modifications (i.e., the soluble and insoluble anhydrides) were observed at temperatures as high as 800°C, whereas changes in gypsum's chemical formula were not observed. Further temperature increases led to the formation of CaO- and $CaSO_4$-containing compounds. The purpose of this work was to determine the impact of temperature on the composition of the resulting gypsum.

Syrkin and Budnikov's research on castelromano potash [4, 5] focused on optimizing the reaction between K_2CO_3 and $Ca(OH)_2$ by determining the optimal temperature and reactant concentrations that were required for maximum product yield. Other aspects of their research included determining the route of synthesis and the conditions under which stable double salts were formed in this process. Here the duo also showed that $Ca(OH)_2$ could be replaced with other caustic agents such as $Sr(OH)_2$ and $Ba(OH)_2$.

In March 1921, Syrkin's first publication as a sole author, entitled "On the question of equilibrium in a heterogeneous system" [6], was sent to the Editorial Office of the *Izvestiya of Ivanovo-Voznesensk Polytechnic Institute*. Based on this work, an Associate Professor of the Department of Analytical Chemistry at IVPI named I.G. Zacks suggested that the then 27-year-old Syrkin, who had become the senior assistant of the Department of General Chemistry of IVPI, should focus on optimizing the reaction between $CaSO_4$ and Na_2CO_3 as this research was pivotal to water treatment processes. Here, Syrkin proved that the reversibility of the aforementioned reaction depended on the concentration of various reagents, and at a low temperature, with dilution of solutions the reversibility increased.

In January 1921, Syrkin presented a scientific report entitled "Kinetic theory and reality of a molecule" at the *Chemical Colloquium of the IPVI Chemical Faculty*, which clearly showed the direction of Syrkin's research interest in reaction kinetics and molecular structure. Between 1921 and 1931, Syrkin was employed at the Ivanovo-Voznesensk Polytechnic Institute (IVPI) and the Ivanovo Institute of Chemistry and Technology (IICT). Here, his research interests included structural elucidation and solvation of molecules, the separation of liquefied gases, and the optimization of fabric dyeing processes as well as the kinetics governing catalysis and gypsum-based reactions.

Syrkin's "On the theory of solvates" article, which was published in the *Izvestiya of Ivanovo-Voznesensk Polytechnic Institute* in 1922 [7], explored

[1] 

Petr Petrovich Budnikov (1885–1968) was a professor at the Ivanovo-Voznesensk Polytechnic Institute (IVPI) from 1918 to 1926. During this period, he served as the Head of the Department of Mineral Raw Materials of IVPI, and later as the Corresponding Member of the USSR Academy of Sciences and an academician of the Academy of Sciences of the Ukrainian SSR. He was a Doctor of Technical Sciences and held a professorship in the Department for General Technology of Silicates at the prestigious D.I. Mendeleev Moscow Institute of Chemical Technology from 1944 to 1968. Budnikov was awarded three Stalin prizes (in 1942, 1950, and 1952, in addition to ten orders and medals of the USSR. In 1965, he was awarded the title of Hero of Socialist Labor as an honored worker in Science and Technology of the USSR (1943) and the RSFSR (1964).

His research interests included the creation and characterization of anhydrite, alite, and sulfated slag cement binders, chromite–dolomite and corundum–carborundum refractory composites and the development of improved insulation materials and ceramics with special focus on the synthesis and characterization of oxide based refractory materials that possessed melting points above 2000°C. Professor Budnikov also developed state diagrams of composite $Li_2O–GeO_2$, $Al_2O_3–SiO_2$, $Al_2O_3–SiO_2–ZrO_2$, $BeO–UO_2$, $MgO–UO_2$, and $Sm_2O_3–Al_2O_3$ systems in which the physical, chemical, and thermodynamic properties, as well as the kinetic features of transformations in these systems, and the mechanisms governing sintering and recrystallization of their respective solid phases were detailed.

fundamental concepts about solvation and the chemical purity of substances, elements, or hydrate compositions that are still relevant today. This article was groundbreaking as chemists at the time were struggling to precisely define the characteristics and properties of a mixture and a chemical compound. At this time, there was no clear consensus on the applicable science to explain these definitions or account for the recorded observations of these substances in the presence of external stimuli. Should these compounds be defined from a chemical point of view, or are the laws of physics more applicable for explaining the associated phenomena? In this article, Syrkin wrote:

"*In the field of solvates, the same chemical and physical methods are not applicable. In solvates we have, so to speak, semi-physical, semi-chemical systems*."

Although scientists at the time were aware of the interactions between a solvent and a dissolved substance, many failed to precisely define this interaction and could not understand, let alone account for, the possible mechanisms governing this phenomenon. When asked to explain, Syrkin stated:

"*It seems to me that purely chemical methods, in the classical sense of the word, do not give precise and definite answers to the questions posed by the fact of solvation.*"

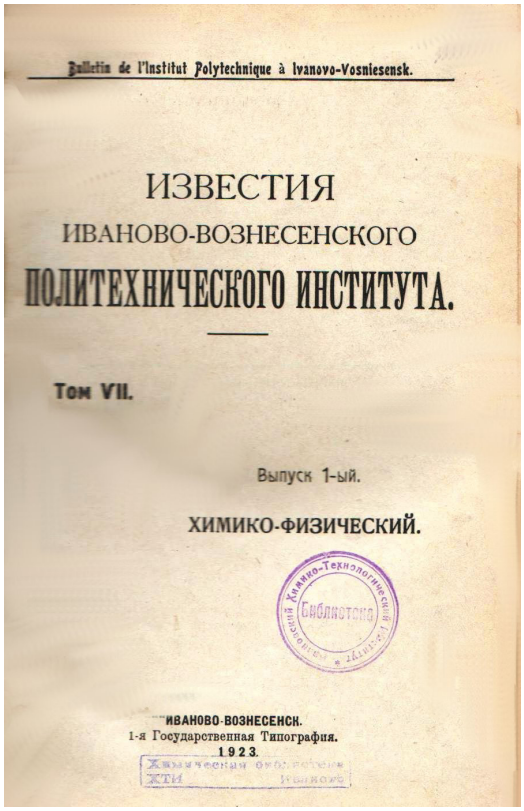
Syrkin realized that the key to answering many of these troubling questions lies in accepting the concept that compounds are capable of existing in various compositions, namely, as solvates in general and hydrates in particular. According to Syrkin, one of the main indicators of hydration was the observed change in internal pressure and the influence of internal forces that governed chemical affinity. The hydrates themselves simply represented a shell of water molecules surrounding the molecules of the dissolved substance.

It is symbolic that this article on the theory of solvates subsequently defined the scientific direction of IICT, which is still in place today. Indeed, this article laid the ground stone in creating the Department of Non-Aqueous Solutions Chemistry of the Academy of Sciences of the Soviet Union in 1980. In 1981, the department was restructured and rebranded as the Institute of Chemistry of Non-Aqueous Solutions of the Academy of Sciences of the Soviet Union (now known as the G.A. Krestov Institute of Chemistry of Solutions of the RAS). Initially, this group's main task was to study the structure of solutions and their applicability in tissue processing technology. The founding fathers of the institute were all winners of the USSR State Prize in Science and Technology (1987), namely, the Corresponding Member of the USSR Academy of Sciences G.A. Krestov, Professor B.D. Berezin, and Professor B.N. Melnikov. These scientists are renowned for their series entitled "Development of theoretical foundations of chemistry of non-aqueous solutions and their practical use," which was published between 1962 and 1985.

In 1923, the *Izvestiya of Ivanovo-Voznesensk Polytechnic Institute* published an article on the topic "Kinetic justification of chemical affinity" [8] (Figs. 1 and 2), in which an attempt was made to quantitatively describe the expression for chemical affinity. In his arguments, Syrkin critically discussed the three most important principles in the concept of chemical affinity, namely, the Berthelot principle, the theory of Guldberg and Voge, and the Nernst theorem. In his groundbreaking equation, the young scientist combined the concepts of chemical statics and kinetics:

$$K = \frac{4}{9r}\frac{\sqrt{4.5\pi R}^{\sigma^{n-1}}}{n_1!n_2}N_0^{n-1}\sqrt{\frac{\frac{n_1}{M_1}+\frac{n_2}{M_2}}{n_1+n_2}}\sqrt{T}e^{-\frac{q}{RT}} \quad (1)$$

where K is the equilibrium constant of a chemical reaction, r is the radius of the whole sphere, R is the gas constant, n is the stoichiometric coefficient


Bulletin de l'Institut Polytechnique à Ivanovo-Vosniesensk.

ИЗВЕСТИЯ
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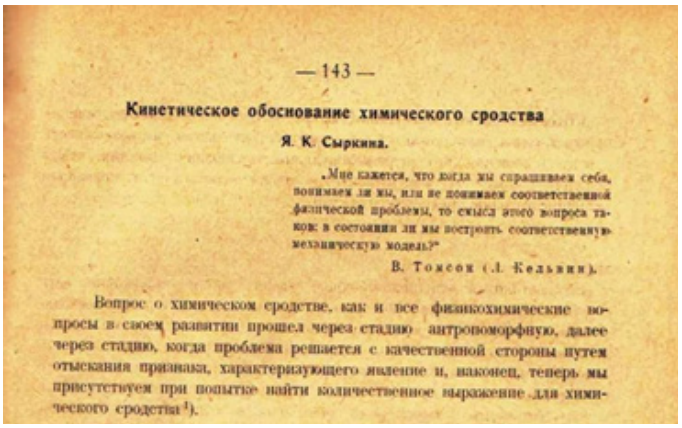
1923.

Fig. 1. Title page of the *Izvestiya of Ivanovo-Voznesensk Polytechnic Institute*.



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Кинетическое обоснование химического сродства

Я. К. Сыркина.

„Мне кажется, что когда мы спрашиваем себя, понимаем ли мы, или не понимаем соответственной физической проблемы, то смысл этого вопроса таков: в состоянии ли мы построить соответственную механическую модель?"

В. Томсон (Л. Кельвин).

Вопрос о химическом сродстве, как и все физико-химические вопросы в своем развитии прошел через стадию антропоморфную, далее через стадию, когда проблема решается с качественной стороны путем отыскания признака, характеризующего явление и, наконец, теперь мы присутствуем при попытке найти количественное выражение для химического сродства[1]).

Fig. 2. Ya.K. Syrkin's article entitled "Kinetic justification of chemical affinity."

(i.e., the number of moles), σ is the volume of the reaction sphere gas, N_0 is the Avogadro number, M is the molecular weight of the gas, T is the temperature, and q is the energy of a single molecule. In describing his equation, Syrkin emphasized that:

"*[the equation] expressed the entire chemical dynamics in the general form for processes of any order.*"

Although Equation (1) appears difficult to understand at first glance, its simplified form (2) can be obtained if we assumed that each individual process in the first part of the equation could be represented by a constant. By denoting this value with the letter ***A***, we obtain:

$$K = A\sqrt{T}e^{-\frac{q}{RT}} \quad (2)$$

In [9], expressions are given for determining the absolute entropy (3) and the chemical constant of a gas (4), which do not depend on the degree of freedom for a particular gas:

$$S_n = kN \lg \frac{(2\pi mkT)^{\frac{n}{2}} a^{n-3} V e^{1+\frac{n}{2}}}{Nh^n} \quad (3)$$

$$C^n = \lg \frac{(2\pi m)^{\frac{n}{2}} k^{1+\frac{n}{2}} a^{n-3}}{h^n} \quad (4)$$

where k is Boltzmann's constant, N is the Avogadro number, m is the mass of the molecule, T is the absolute temperature, a is the diameter of the atom, V is the volume, h is Planck's constant, and n is the degree of freedom.

The key advantages of the provisions expressed by Syrkin in this revolutionary article can be seen in the definitions of the absolute entropy of a gas and the chemical constant. When expressing the absolute entropy of gases in Syrkin's equation, the equivalence of translational and rotational quanta of energy is taken into account. In addition to universal values, the expression for a chemical constant includes only the mass of the molecule and its diameter. Syrkin noted strong correlations between the calculated and experimentally determined chemical constants of gases, particularly for molecules such as Cl_2, Br_2, and I_2.

The rapid development of industry and agriculture at the time led to chemical and technological innovations. To this end, the development of air rectification processes in 1902 to meet the growing demand for large scale oxygen production came at a fortuitous time. This was followed closely by calls to repurpose this technology for the large scale production of nitrogen to facilitate the downstream manufacturing of ammonia, calcium fertilizers, and nitrides. In response, Syrkin published a study on the large scale acquisition of nitrogen and oxygen from liquid air in the 1925 edition of the *Journal of Chemical Industry* [10]. Here, the optimal conditions under which the output of liquid oxygen was significantly increased (i.e., at a pressure of 325 atm and pre-cooling to −50°C) were detailed (Table 1).

Table 1. Experimental conditions for obtaining liquid oxygen [11]

Specific gravity, kg/m^3	479	445	421	402
Pressure, kg/cm^2	325	356	372	382
Temperature, °C	−50	−20	+2	+20
Concentration of oxygen, kg	15.6	12.4	10.4	9.1

The early period of Syrkin's scientific work on chemical kinetics [12–20] (Fig. 3), which are based on ideas about the structure of molecules, led to the publication of "On the speed of chemical reactions" in 1926 [15], in which he presented expressions for the reaction rate constants of the first, second, and third orders.

Fig. 3. Syrkin in the laboratory of the Chemical Faculty of IVPI.

Therein, an expression for the rate constant of monomolecular reactions containing molecular dimensions could be converted to expressions defining characteristic infrared frequencies (5). Additionally, he noted that bimolecular reactions (i.e., reactions between two colliding molecules) were activated at the moment of collision by a quantum of light (6). As a result, the third-order reaction rate constant was calculated based on the assumption of a three molecule collision (7):

$$k = 7.4ve^{-\frac{q}{kT}} \quad (5)$$

$$k'' = \frac{N_0 \sigma akT}{h} e^{-\frac{h\nu}{kT}} \quad (6)$$

$$k''' = \frac{N_0^2}{3r}\sqrt{\frac{2m_2 + m_1}{3m_1 m_2}} e^{-\frac{q}{kT}}, \frac{\left(\text{sm}^3\right)^2}{\text{mol}^2/\text{s}} \quad (7)$$

where m is the mass, v is the frequency, k is the rate constant, T is the absolute temperature, h is the Planck constant, N_0 is the Avogadro number, q is the heat of activation, σ is the volume of the sphere's collision, and r is the radius of the sphere.

The paper [15] also reported the possibility of rapid reactions caused by "spin-off" reactions produced during each collision. Syrkin concluded that it was impossible to use conventional kinetic methods in these cases. When the interactions were the product of a "triple" collision (i.e., reaction collisions involving three molecules), Syrkin focused on possible correlations between the "double" and "triple" collisions.

In the same year, two articles on catalysis in chemical reactions were published in the *Journal of Chemical Industry* [21, 22] in response to the rising interest in using catalysts for synthesizing dyes, nitrogen binding applications, and in various other chemical processes. Syrkin's work tried to explain the action of catalysts as a function of the reaction time using reaction kinetics:

"The catalyst does not introduce anything fundamentally new; it only changes the conditions of the process, it leads in the shortest way to the final goal, i.e., to achieve an equilibrium state of reacting and forming substances. What is achieved with a catalyst can be achieved without it, but in the latter case it will take longer."

By trying to define the features, characteristics, and regularities of individual catalytic reactions using the decomposition of ethyl acetate as an example, Syrkin showed that three different types of reactions were possible, depending on the nature of the catalyst used (Table 2):

In these publications, Syrkin was able to prove that catalysts accelerated the reaction process and also influenced the type of chemical reaction, which, in turn, affected the outcome. He demonstrated why various catalysts were not always applicable in certain chemical processes by comparing the product yields while transitioning from one catalyst to another [21]. This work sheds light on the influence of external factors such

Table 2. Decomposition of ethyl acetate based on the type of catalyst used

Reaction	Catalyst
$CH_3CO_2C_2H_5 = CH_3CO_2H + C_2H_4$	Oxide of titanium
$CH_3CO_2C_2H_5 = C_3H_8 + CO_2$	Crushed nickel
$2CH_3CO_2C_2H_5 = CH_3COCH_3 + C_2H_5OH + C_2H_4 + CO_2$	Oxide of thorium

as moisture sensitivity, catalytic stability, and production methods on a catalyst's efficiency.

In 1929, widespread recognition for his work on catalysis led to an invitation to publish in the *Technical Encyclopedia* [23] as part of a two part series in collaboration with the academician Vladimir Nikolaevich Ipatiev, a figure who was instrumental in starting the Chemical Faculty of the Ivanovo-Voznesensk Polytechnic Institute. The Encyclopedia's article, entitled "Catalysis," consists of two sections; the first part was written by the future academician Syrkin followed by Ipatiev's "Catalysis in technology."

In his work on chemical kinetics, Syrkin explored not only reactions that occurred in a gas environment. The 1927 article in the *Journal of the Russian Physical and Chemical Society* detailed the equation of chemical kinetics to explain the electron emissions in incandescent bodies [17]. Here, the process of emitting electrons from a metallic surface was equated with similar heterogeneous first order reactions, resulting in an expression for determining the number of electrons L emitted per unit of time by a unit of the surface of an incandescent body (8):

$$L = \frac{2\pi m v^3}{kT} e^{-\frac{hv}{kT}}, \quad (8)$$

where m is the mass of the electron, v is the characteristic frequency, k is Boltzmann's constant, T is the absolute temperature, and h is Planck's constant.

Syrkin's scientific contribution to the field of reaction kinetics continued with another publication in the *Technical Encyclopedia* entitled "Chemical Kinetics" in 1930. The concepts presented in this article helped researchers take advantage of the newly offered opportunities in instrumentation and pushed the boundaries of experimental possibilities.

The beginning of the 20th century saw a scientific revolution that increasingly drove researchers to expand the existing concepts, laws, and theories governing the world's natural order and to formulate groundbreaking scientific ideas. Access to better instruments and technological advancements enabled scientists to conduct experiments that were previously too difficult or impossible to perform. As a result, there was a shift in how chemists viewed the states of matter, i.e., gases, liquids, and solids, as more researchers were focused on defining these phases and the associated transitions in terms of the intermolecular forces occurring between them. Scientists began to take into account the orientation and polarization forces in definitions for gaseous and liquid molecules. A mismatch in the center of gravity of positive and negative charges led to the concept of an electric dipole. Molecules that possessed higher degrees of electrosymmetry were defined as quadrupoles, octopoles, etc. Syrkin published several reports on these molecules and their interactive forces [24, 25], in which he defined numerous methods for determining their dipole moments:

"*The dependence of the dielectric constant on temperature, electrostriction, electrostatic rotational fields, the use of viral coefficients from the equation of state, and the dependence of the dielectric constant of solutions on concentration.*"

Since previously reported methods were applicable to a limited number of studied objects and often resulted in different dipole moments for the same molecule, Syrkin proposed an expression for determining the dipole moment ***m*** in a unified manner for all substances based on the orientation forces (9):

$$m = 1.66 \times 10^{-20} \frac{T_{cr}}{\sqrt{P_{cr}}} \quad (9)$$

If the electric centers of gravity of positive and negative charges coincided, the dipole moment was defined as zero, and the molecule could no longer be considered as a dipole. Thus, such molecules were classified as quadrupoles, and their associated interactions were determined by the accompanying orientation forces. In [25], a formula for determining the quadrupole moment (10) was reported:

$$m = 10.07 \times 10^{-28} \frac{T_{cr}^{4/3}}{P_{cr}^{5/6}}, \quad (10)$$

where T_{cr} is the critical temperature and P_{cr} is the critical pressure.

These equations allowed us to calculate the dipole and quadrupole moments for most substances and, as Syrkin pointed out, were in good agreement with the experimental data obtained by other scientists. Using these results, Syrkin established some regularities in similarly constructed homologous series. For example, he noted a correlation between the dipole/quadrupole moment and the number of CH_2 groups in a molecule. As the number of CH_2 moieties increased, the dipole moment decreased, whereas the quadrupole moment increased.

As a continuation of his research on the properties of dipoles and quadrupoles, another article appeared in the *Journal of Physical Chemistry* in 1930, entitled "On the electrostatics of colloids" [26]. Therein, the stability of colloidal solutions was discussed as a function of the existing electrical forces that were responsible for the emergence, stabilization, and destruction of the colloidal

state of a system. Colloidal systems are particularly difficult to study, as minor changes in the external conditions profoundly affect their properties. Syrkin noted:

"*Of all the fields of physical chemistry, colloids are of the least reproducible experiments.*"

Syrkin's paper presented equations that have allowed us to approximate the electrostatic forces in colloidal systems. He proposed that the conditions governing electrostatic stability of these systems were closely related to the radius and charge density of the interacting molecules (see equations (11) and (12)):

$$r = d\sqrt{\frac{Ad\omega^2}{Ad\omega^2 - \gamma} - 1}, \quad (11)$$

$$\omega_{cr} = 4.48 \times 10^3 \sqrt{\gamma\sqrt{cn^2}} \quad (12)$$

where d is the thickness of the outer layer, $d = \frac{4.3 \times 10^{-8}}{\sqrt{\Sigma cn^2}}$, ω is the charge density, γ is the energy per unit area, C is the concentration, and n is the charge of the ion. Thus, the transition to true solutions (dispersion) occurred at low values of r, and a decrease in the $d\omega^2$ parameter was associated with coagulation. Here, a high critical charge density was linked with an increasingly unstable solution, high surface tension, increased molecule concentration, and more charged the ions in the solution.

In the same year, Syrkin's research interests turned to determining the frequency of infrared vibrations. At this time, there were no experimental data on the infrared vibrations of simple molecules (i.e., metals) from optical sources. The universality of the Equation (13), as detailed in [27], is defined by the ratio of a substance's density to its atomic mass, whereas the more widely used Lindemann formula (4) includes the melting point:

$$v_{cr} = 198.8 \times 10^{12} \frac{d^{2/3}}{M^{7/8}} \quad (13)$$

$$v = 2.8 \times 10^{12} T^{1/2} M^{-5/6} d^{1/2}, \quad (14)$$

where v_{cr} is the frequency of infrared vibrations, d is the density of the compound, M is the atomic weight, and T is the melting point. In this paper, the oscillation frequency (v) of various metals (i.e., Zn, Ag, Al, Cu, Pb, Hg, and Cd) and various chemical compounds were calculated. However, instead of using the atomic weight of an element or compound, Syrkin's equation featured the average value of the atomic masses of the atoms included in the compound (i.e., $(M_1 + M_2)/2$). The results obtained from Equation (13) were in good agreement with the experimental data.

Syrkin's work in understanding the fabric dyeing process was a direct response to the demands of the local textile industry. In collaboration with the future head of the Department of Chemical Technology of Fibrous Substances, P.V. Moryganov, Syrkin worked in the Laboratory of Colloid Chemistry to produce a publication for the *News of the Cotton and Paper Industry* in 1931 [28]. The reaction kinetics governing the dyeing of cotton fibers with substantial dyes was detailed in this paper. By assuming that the rate of dyeing was directly proportional to the undersaturation of the fiber with the dye, the authors presented a first order equation for calculating the speed constant k of this process (15):

$$k = \frac{1}{t} \ln \frac{A}{A - C}, \quad (15)$$

where t is the time measured from the beginning of the experiment, C is the dye concentration in time t, and A is the maximum dye concentration on the fiber (i.e., the equilibrium concentration). In this experiment, orange and oxamine pure blue were chosen as the dyes for the cotton fabric. Syrkin noted that both dyes exhibited a sharp drop in k after 15 min and that the equilibrium state, i.e., the time after which the dye concentration no longer changed, occurred after 1 hour. The paper also detailed the effects of electrolytes in the dye solution using NaCl and $ZnSO_4$. Here, the absorption of both electrolytes by the cotton fibers resulted in a change in the electrical conductivity of the solution, and the associated rate constant of the reaction was almost twice as high as the value obtained when there were no electrolytes in the dye solution.

Syrkin was a very prolific researcher, publishing more than 50 research papers during his time at IVPI–IHTI. After moving to Moscow and joining the Moscow State University of Fine Chemical Technologies in 1931, Syrkin became the Head of the Department of Physical Chemistry, a corresponding member, and then a full member of the Academy of Sciences of the Soviet Union. The Moscow State University of Fine Chemical Technologies was considered to be a real home for Syrkin during the difficult years of "resonance" of persecution.

Throughout this article, we highlighted the main scientific interests of Yakov Kivovich Syrkin. His comprehensive efforts served as the impetus for expansive scientific research at the institute, and the

Fig. 4. Members of the Academy of Sciences of the Ivanovo State University of Chemistry and Technology.

formulation of fundamental concepts in chemistry that lay the groundwork for future advancements in chemical research and technology. The memory of Yakov Syrkin is faithfully preserved by the Ivanovo State University of Chemistry and Technology (Fig. 4).

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