300 years of the Russian Academy of Sciences
145 years since the birth of P. P. Weimarn, professor at the Saint Petersburg Mining Institute

Professor P. P. Weimarn, founder of the science of nanotechnology: development of works in the field of nanodispersed metals production

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This article is dedicated to the 145th anniversary of the birth of the outstanding Russian physicochemist Peter Weimarn (1879–1935). The article is the final in the cycle of papers cited in the Large Russian Encyclopedia (dated April 5th, 2023), which review the priority scientific works of P. Weimarn in the field of nanotechnology (dispersoidology, according to Weimarn). The specific aim of the article is to compare the scientific and publication activity of Peter P. Weimarn in different periods of his activity (St. Petersburg, Mining Institute; Yekaterinburg-Vladivostok; Japan). In addition, the aim was to analyze P. Weimarn's innovations in the production of nanodispersed non-ferrous metals, especially in the period 1922–1930 in Japan, and to compare Weimarn's developments with modern methods in this field. It is revealed that the student Peter Weimarn had at least 3 joint articles with the Russian academician, Prof. N. S. Kurnakov (1860–1941), who was P. Weimarn's supervisor in 1902–1908. In his works of 1910–1915. P. Weimarn anticipated some conclusions and provisions that Associate Member of Russian Academy of Science (RAS) V. B. Aleskovsky formulated in 1952–2006. Academicians of RAS N. Kuznetsov, V. Novotortsev, V. Kalinnikov in 2012–2014 confirmed the priority of Peter Weimarn's works in the field of nanotechnology science. Currently, at the St. Petersburg Mining University, P. Weimarn's research on the extraction and production of metal nanostructures continues under the supervision of RAS Corresponding member, Prof. T. Aleksandrova. These facts show that, starting from 1902; RAS members have nurtured, confirmed the outstanding level of work for the world science and continued the research of Peter Weimarn. All this is a worthy contribution to the history of RAS to its 300th anniversary.
It has been established that after leaving St. Petersburg for the Urals (1915) and further to the East (1919–1935) the quantitative characteristics of article publication did not practically deteriorate. In 1916–1935. P. Weimarn published about 170 articles (49% of the total number (350)). More than 30 percent of all papers were published in Japan during the 1922–1930 period. Being a mining engineer, who received a serious training in metallurgy at the Mining Institute (1900–1908), in Japan Peter Weimarn purposefully developed methods for the preparation of colored solutions of nanodispersed gold. His achievements in the study of crystallization and coagulation of colloidal metals (Au, Ag, Cu, Se, etc.) were highly appreciated by his famous contemporaries in Russia, Japan and Germany, as well as by researchers in the XXI century. The formaldehyde method, developed by P. Weimarn, is actively used by nanotechnologists, and Peter Weimarn's laws are used in metallurgy, physical and colloidal chemistry in the XXI century.

Key words: Peter P. Weimarn, science priority, nanometallurgy, colloidal gold, formaldehyde method, reproducible synthesis, Russian Academy of Sciences.

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Introduction

July 18, 2024 marks the 145th anniversary of the birth of the outstanding Russian physicochemist Peter Petrovich Weimarn (1879–1935). While still a student at the St. Petersburg Mining Institute, he started publishing in foreign journals and received international recognition for his work (1906–1908) [1–3]. P. P. Weimarn's research in colloidal chemistry and physicochemistry of ultradispersed substances was highly appreciated in Russia and Japan, and Nobel laureate Wilgelm Ostwald (Germany) considered Weimarn's research as brilliant [3–5].

A new step in understanding the significance of the creative heritage of Prof. P. P. Weimarn (**Fig. 1**) was the recognition in [6–8] of the fact that "the founding father of nanotechnology should be considered our compatriot Petr Petrovich Weimarn". It should be noted that this conclusion was reached by several scientific teams from specialised institutes and universities under the leadership of Academicians of the RAS — Kuznetsov N. T., Kalinnikov V. T., Novotortsev V. M.; Corresponding members of the RAS — Zhabrev V. A., Nikolaev A. I. [9]. Profs. Margolin V. I., Tupik V. A., Lukyanov G. N., Grachev V. I., and the authors of this article [10–12] took an active part in the work in 2012–2023 to substantiate Russia's priority in nanotechnology science. Several International Symposiums "Nanophysics and Nanomaterials" ("N&N") held at St. Petersburg Mining University since 2015 have been devoted to the analysis of the scientific heritage of Prof. P. P. Weimarn and his first scientific mentor Academician N. S. Kurnakov [9]. The list of the main works on Weimarn's contribution to the development of nanotechnologies, first conducted taking into account his 1908–1914 articles in the Notes of the Mining Institute, is presented in [9, 12]. An important result of the activities of the "N&N" symposium participants to substantiate the priority of P. P. Weimarn and St. Petersburg Mining University in the field of nanotechnology was the publication of relevant articles in the Great Russian Encyclopedia [12, 13] and an entire chapter in a foreign scientific monograph [14].

Many famous scientists (M. Faraday, P. Rebinder, R. Feynman, etc.) stood at the origins of nanotechnology [7, 8]. But by the date of formulation of the concept of modern nanotechnological approach (1906–1910), goals, methodology, objects and tasks of nanotechnology as a science, Prof. P. P. Weimarn [8, 9, 15] has an unconditional priority, in our opinion. In [9] it was pointed out that, illustrating many laws and phenomena in the formation of dispersed substances, Weimarn quite often considers it on the example of obtaining highly dispersed non-ferrous metals (Cd, Ag, Cu, Te, Se) [15–17]. It is interesting that most of the papers on P. P. Weimarn's research cite his articles from 1906–1915, when he studied at the Mining Institute (until 1908) and then worked as a Prof. there at the Department of Physical Chemistry. Publications by profs. at Japanese universities where he worked in exile in 1922-1930 were no exception [4], including a book by K. Tamaru, published in Japan in 1977 and republished in Moscow in 1983 [5]. But the list of P. P. Weimarn's publications of 1916–1930, according to the data of the article — obituary [1], includes hundreds of foreign articles. Weimarn's specific studies in this "non-Petersburg" period of activity, described in the articles, were practically not analysed in detail in the available scientific literature. First of all, it concerns the methods developed by Weimarn for obtaining nanodispersed metals and their relation to modern methods in this field.

The aim of this article is to make a comparative analysis of scientific and publication activity of P. P. Weimarn in different periods of his activity, as well as to trace the development of Weimarn's research in 1922–1930 on the production of nanodispersed metals, comparing it with modern approaches in this field.

Research results

Analyses of several hundred publications on various sources [1, 3, 12] allowed us to discover an interesting fact. It turned out that Weimarn and his first scientific mentor Prof. N. S. Kurnakov (later Academician since 1913) have at least 3 joint papers. The first paper, which studied the green hydrate forms of manganese cyanide and the structure of barium sulfate precipitate, was published in the *Journal of the Russian Physico-Chemical Society* (1902, Vol. 34, No. 5). Information about this article "Green hydrate forms manganese thiocyanate oxide" has been mentioned many times by historians of science [1, 2]. Less known is the joint article "Intermediate products of the reaction between barium and sulfate salts" (same *Journal* for 1905, Vol. 37, Iss. 7), as well as the publication "Byproducts of the reaction between barium salts and salts of sulfuric acid" in the German journal *Kolloid-Zeitschrift* for 1907.

What is the unusual nature of this information? According to literature data, the novice researcher Peter Weimarn had two scientific supervisors: first, Prof. N. S. Kurnakov, and later (from about 1908) — Prof. I. F. Schroeder (**Figs. 2, 3**) [3, 12, 14]. The analysis of the literature shows that

Fig. 1. Peter Petrovich Weimarn — Prof. at the St. Petersburg (Petrograd) Mining Institute (1908–1919), rector of the Ural Mining Institute (1915–1920) [17]

Fig. 2. Russian academician Nikolai Kurnakov (1860–1941) — Peter Weimarn's first scientific mentor (photo from 1913, Archives of RAS, F. 701, Op. 2, D. 442, L. 1).

Fig. 3. Prof. Ivan Schroeder (1857–1918), director of the Mining Institute (1912–1917) with his student Peter Weimarn (left) [18]

Weimann did not have any joint works with I. F. Schroeder, despite the fact that both were engaged in solubility of solids in various liquids, analyzed the temperature and heat of melting of solids [12, 14, 18]. In any case, it should be stated that outstanding physicochemists N. S. Kurnakov and I. F. Schroeder opened the name of P. P. Weimarn to the scientific world. They directed his research to the border area at the interface between the study of water-salt systems and the physicochemistry of dispersed substances and colloidal solutions. Academician N. S. Kurnakov, in fact, was the first who taught young Peter Weimarn to write substantial articles for serious scientific journals. The methods and results presented even in the earliest articles [15, 19, 20] allowed P. P. Weimarn to become world famous already at the age of 26 [1] and to receive the most prestigious scientific domestic prizes, including the Moscow University and later the prize from the Colloid Society of Germany. Since Weimarn was a student of the academician of the St. Petersburg Academy of Sciences (later — USSR Academy of Sciences) and started his activity as a member of the recognized scientific school of physicochemists of the Mining Institute under the leadership of N.S. Kurnakov, the training of a scientist of the highest qualification, which Peter Weimarn had, is certainly a serious achievement in the history of the RAS. It is only a pity that due to circumstances, including the revolutionary events and civil war in the period 1917–1922, Weimarn had to leave Russia at the age of 42 and could not join the ranks of the Academy members. But the way he presented the successes of Russian science and education to the international community in the most dignified way [1, 3, 5] would have honored any academician.

The dynamics of changes in the number of Weimarn's publications by years (**Fig. 4**) shows that in the "best years" he published 28-39 works per year. The peaks of activity occur in 1910, 1914, 1920 and 1928. In 1910 Weimarn's thesis for the professorship in the Department of Physical Chemistry at the Mining Institute is almost ready and he publishes 28 papers, not counting articles in the *Journal of Mining Institute*.

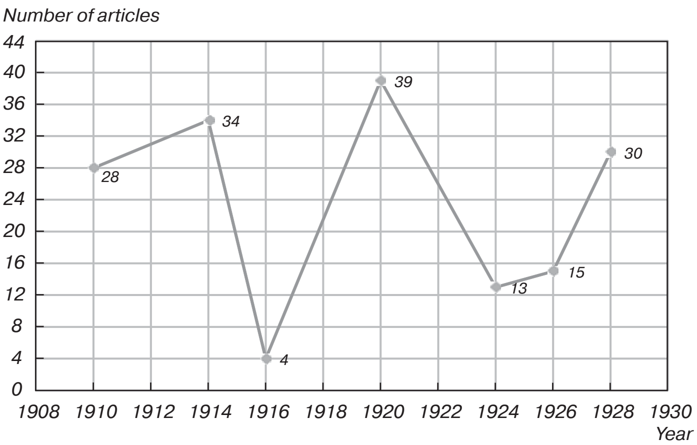

Fig. 4. Number of published articles by P.P. Weimarn per year for different stages of his scientific biography (*by the authors*)

In 1914 the maximum (34 papers) of P. P. Weimarn's publication activity during his work at the St. Petersburg Mining Institute is observed. At this time, he is already well known in the West, at the Institute he is a full Prof., heads the laboratory of physical chemistry and received the most prestigious scientific prizes of Russia, and was awarded the Order of St. Anne (1913) [1–3]. In 1915 he was invited to lead the construction of the Ural Mining Institute and become the first rector of this institute. As a result, in 1916 only 4 articles (**Fig. 4**) of Weimarn are published. He has no time to do science in full force. He has to travel almost every week by train from Ekaterinburg to St. Petersburg and back to get money for the construction at the Ministry, to get and organize the delivery of building materials. Against this background, the absolute maximum of publications in 1920 (39 articles) looks unexpected at first glance, despite the fact that because of the hostilities in Ekaterinburg, Weimarn and his students had already been evacuated to Vladivostok [2, 3]. In our opinion, two circumstances have had an effect:

1. The scientific school already created by P. P. Weimarn in Russia worked. He began to attract new talented students to work together (Janek A. M., Morosow N. I., Anossow W. J. and others).

2. By 1919, the scientific and educational processes were already established; the Ural Mining Institute under the leadership of P. P. Weimarn had already been fully educating students for 2 years [2, 3].

In 1922 P. P. Weimarn emigrated to Japan, and adaptation to new conditions of functioning began, although more comfortable than in revolutionary Russia in 1917–1922. By 1924–1926 Weimarn reaches figures of 13–15 articles/year (**Fig. 4**). Some inhibition is most likely due to the language barrier. According to the results of research in Japan, P. P. Weimarn writes articles mainly in German and English, and less often in French [1]. In 1923, Weimarn became the head of the Dispersoidological Department of the Imperial Industrial Research Institute (Osaka). Peter Weimarn had at his disposal the necessary pure reagents, the necessary equipment, including ultramicroscope, and a full staff and graduate students. By 1928, Weimarn had reached article counts (30 articles/year) that are comparable to his records in the Russian period of activity (**Fig. 4**). In 1930, Weimarn begins to have health problems and is forced to leave his work at Japanese universities (Osaka, Kyoto and others). Nevertheless, the international scientific community praises Weimarn's research achievements over a quarter of a century (1906–1931). In 1932, he receives the prestigious scientific Leanard's Prize from the Colloid Society of Germany [1–3]. The highest award of the Colloid Society was given to P. Weimarn for the discovery, which he first clearly expressed and proved by numerous experiments in Russia and Japan: "the colloidal state is a general possible state of matter (substance)" [20]. In the opinion of Wo. Ostwald, this position has priority according to the date of its publication by the student P. Weimarn in the February issue of *Journal of Russian Physicochemical Society* (1906) [1]. In fact, the whole subsequent scientific activity of Weimarn, including in the status of Prof., in one way or another on the example of several hundred objects added experimental evidence. Prominent among these objects are nanodispersed non-ferrous metals [16, 17], including gold and silver, which Weimarn has been actively pursuing at Osaka and Kyoto Universities [21–23]. It should be noted that the work [23] was done under the direction of Weimarn by a member of his department Eiichi Iwase and is devoted to the formaldehyde method of obtaining solutions of dispersed gold Au with stable red coloring.

The largest number of publications both during his work in Japan and throughout his life was made in the German journal *Kolloid-Zeitschrift* (**Fig. 5**) — more than 200 papers. In second place is the *Journal of Russian Physicochemical Society* (114 works by Weimarn), in which Peter Weimarn stopped publishing in 1916. [1]. In 1908-1914. Peter Weimarn printed some of his priority publications [15–17] in the internal *Journal of St. Petersburg Mining Institute (Journal of Mining Institute)* Wo. Ostwald and other biographers usually do not give references to these works [1–3] due to their hard availability. We had the opportunity to work with the digitized originals of these articles and counted about 26 articles by Weimarn in the journal. 17 of them can be attributed to the problems of dispersoidology, a science created by P. P. Weimarn himself on the basis of a number of sections of traditional colloid chemistry. According to Weimarn, it is a science ‘about surfaces and processes on them occurring’ [24, 25].

Developing the basics of dispersoidology, P. P. Weimarn proposed his classification of disperse systems (**Fig. 6**) [25]. The central concept and term of this classification, which gave the name of the science “dispersoidology”, is “dispersoide”. In Weimarn’s understanding dispersoide is a particle of dispersed solid phase in a colloidal solution with the size not more than 0.1 μm (100 nm), which follows from the inscription at the central arrow going from the top of the scheme to the word “Dispersoides” (“Disperoidy” – in Russ.) in **Fig. 6**.

Therefore, we get one more proof, in addition to those given in [9, 12, 26], that by 1910 Prof. Weimarn was already actively engaged in the synthesis and study of nano-objects. The term “nanotechnology” did not appear until 1974 [7, 13], but in terms of meaning, objects, and methods, P. P. Weimarn’s “dispersoidology” is practically identical to nanotechnology in the modern sense [8] and emerged 50 years earlier than the American physicist R. F. Feynman proposed to engage in the field of nanotechnology. Feynman proposed to deal with tiny objects of atomic-molecular dimensions (1959) [6, 13].

Wo. Ostwald, commenting on student Peter Weimarn’s ability to foresee future trends in science, wrote the following. He compared Weimarn’s activity to ‘the life of an apostle of a young, still undeveloped and therefore

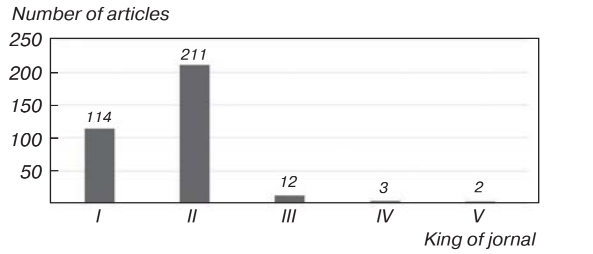

Fig. 5. Number of articles by P. P. Weimarn for the period from 1906 to 1935 in various journals:
I — Journal of Russian Physico-Chemical Society; *II — Kolloid-Zeitschrift*; *III — Kolloid-Beihefte*; *IV — Japanese Journal of Chemistry*; *V — Bulletin of the Chemical Society of Japan (by the authors)*

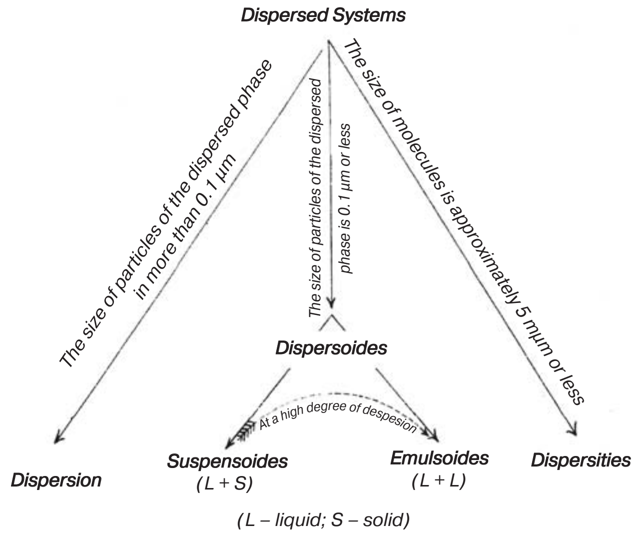

Fig. 6. Fragment of dispersed systems classification according to P. P. Weimarn [25]

sometimes incomprehensible and ignored doctrine’ [1]. It is most likely that Wo. Ostwald meant colloid chemistry, since he was the greatest specialist in this field. But the term ‘colloid’ and the science of colloids have been known since 1861 [15]. Therefore, the expressed figurative comparison is more suitable to the activity of P. P. Weimarn as the founder of a newer field of scientific knowledge — dispersoidology. Prof. Wo. Ostwald, Editor-in-Chief of the *Kolloid-Zeitschrift* and son of the Nobel laureate V. F. Ostwald, also commented very clearly on the “dispersoidological” meaning of the law of P. P. Weimarn (1906) on concentration conditions for the formation of sols of substances in colloidal solutions [12]. Wo. Ostwald correctly noted that it follows from this law that ‘at extremely small and large values of concentration of reaction components the smallest particles are predominantly formed, and at medium ones the largest particles are formed’ [1].

Development of the works on obtaining of nanodispersed metals

P. P. Weimarn was interested in the subject of the preparation and properties of ultradispersed metals in colloidal solutions as early as in the Russian period of his activity [16, 17, 25]. Already in 1911–1912, in addition to Co, Cu, Se, and Te, dispersed Ag and Au entered his field of vision [16, 17]. Working at Kyoto University and at the Industrial Institute (Osaka), P. P. Weimarn devoted most of his research to the preparation of colored solutions of ultradisperse gold [21, 22]. This is due to the importance of such solutions for coloring wood and other fibrous materials [1, 5]. Weimarn still describes the process of obtaining Au-sols in rather general phrases, without emphasizing the exact process temperatures and particle sizes of the obtained solid phase. His research in Japan is more applied, commercially interesting and patentable [1, 3]. Nevertheless, P. P. Weimarn, developing his formaldehyde method of Au-sols synthesis, compared it with citrate, tartrate methods [21]. The main idea of Weimarn's approach was to rapidly cool (using liquefied gases) a dilute liquid solid solution in such a dispersion medium that easily solidifies into a glass, stabilizing the particles of the dispersed solid phase. In this case, the aggregation of tiny particles of ultramicroscopic size is blocked [15, 21]. Metals like gold, which have good thermal conductivity under these conditions easily give "amorphous" solid solutions [15]. As one example of his method, Weimarn cites a process where $AuCl_3$ is used as the starting compound of gold [21]. Hydrolysis in solution produces Au (III) hydroxide. The reducing agent is an alkaline solution (KOH or K_2CO_3) of formaldehyde, which is heated when mixed with the initial Au (III) solution to at least 50 °C [21, 22]. More detailed information on the process parameters we obtain from the works of the Dispersoidological Department of the Imperial Industrial Research Institute of Osaka (Head of Department is Prof. P. P. Weimarn) [23, 27]. The range of used concentrations of substances was 0.005–0.25 (%). The minimum cooling temperature of the solutions was negative (–80 °C) [27, 28]. As a result of application of P. P. Weimarn's methods, the formation of dispersed phase particles, including gold, of micro- and ultramicroscopic sizes was observed. Studies of particle sizes were carried out at room temperature on a Zsigmondy ultramicroscope, which allows to see particles with a minimum size of 3–5 nm [6, 22]. Au-sol color transitions depending on the purity of the reagents used are described in detail in [23]. P. P. Weimarn and E. Iwase state in their works [21–23] that they managed to find modes of obtaining Au-sol with stable red (orange) coloring even when using reagents of ordinary purity, including distilled water. The articles [27, 28] are remarkable in that their author is Nadine von Weimarn — the wife of P. P. Weimarn. Earlier in scientific and biographical literature it was always noted that Nadezhda Nikovaevna (born Lvova N. N.) provided great and, above all, technical assistance in the preparation of P. P. Weimarn's manuscripts. She helped to translate texts from German into Russian, took part in editing the works written by Weimarn [1, 2]. There are practically no comments about her scientific works and publications. Let us pay attention to the years when the works of N. Weimarn in print: article [27] in 1930 and article [28] in 1931. These were the years when Peter Weimarn became seriously ill and had to leave his work in the Dispersoidological Department laboratories [1, 2]. In fact, it turns out that during these difficult years N. Weimarn acted not only as a faithful assistant in all matters, but also as a like-minded colleague of Prof. P. P. Weimarn in scientific research and as a sufficiently prepared specialist with her actual topic in the field of dispersoidology. P. Weimarn and N. Weimarn together have suffered many hardships both in Russia and in Japan. But the fact that Nadine Weimarn has continued her husband's work in science, to which he devoted his whole life, is not just loyalty and dedication. More precisely, the research of N. Weimarn — intention of sacrificing, so typical of Russian women (remember the wives of the Decembrists).

Among other important works performed by P. P. Weimarn in Japan, the work [29] should be noted. Peter Weimarn poses very serious problems that are relevant for dispersoidology (read — nanotechnology) even today. These problems are related to the difficulty of obtaining reproducible data in the synthesis of substances by dispersoidal methods, which is due to the influence of a large number of factors on the course of synthesis [29]. Here it is appropriate to recall the views developed in 1952-2006 by Prof. V. B. Aleskovsky (Associate Member of RAS) and his scientific school [30, 31]. He believed that 1) reproducible synthesis of solids can be carried out in irreversible processes, far from equilibrium; 2) the law of constancy of composition is observed for all solids of any degree of dispersibility [30]. Similar views on the nature of reproducible synthesis, especially on point 2, were developed by P. P. Weimarn as early as 1912 [32] and confirmed in his 1926 paper [29].

P. P. Weimarn's studies are undoubtedly relevant today, in the XXI century. Especially it concerns the works in the field of obtaining nanodispersed metals, including noble Ag, Au [33–35]. Prospects for the use of gold nanoparticles in science and technology are associated with the fact that these particles have valuable catalytic, ferromagnetic, optical and other properties. Gold nanostructures are non-toxic, chemically inert enough, well compatible with various biomaterials. These circumstances determine a wide range of applications of nanogold: from medical devices to electronic circuits and nanodevices [33]. Silver nanoparticles have shown promise for solving medical problems and are actively used as a bactericidal agent [36]. No less demanded in practice is the use of Ag nanowires [37].

Theory, knowledge and experience of P. P. Weimarn's research can be useful for solving problems of the mining and metallurgical industry in the processes of mining and extraction of submicroscopic gold. According to works [35, 38], when washing the product of bio-oxidation, the presence of gold in colloidal form is detected. The formation of colloidal solution of iron arsenate and oxysulfate, as well as foaming in the bio-oxidation units cause irretrievable losses of nanogold, the content of which in the foam product of clay-carbon nature is, on average, 122 g Au/t [38]. A detailed study of the works of P. P. Weimarn and his colleagues on colloidal gold [21–23] may allow us to find additional ways to extract nanodispersed gold within the framework of industrial technologies that are used at modern mining and smelting plants [35, 38, 39].

The formaldehyde method of obtaining nanodispersed gold in colloidal solutions, along with citrate and tartrate methods, is currently used in laboratory and preparative practice [10, 33, 40].

In essence, the ideas and methods of P. P. Weimann substantiated the sol-method in nanotechnology, which is used by researchers in the XXI century [33, 41, 42]. The selection of reagent concentration follows Weimarn's law: sols are formed in solutions of low or strong concentration [2, 12]. When obtaining colloidal gold, often the reducing agent (citrate ion or sodium borohydride) also acts as a stabilizer of the formed metal particles [33, 40]. To stop the growth of nanoparticles, the reaction mixture is usually cooled rapidly, which was done by Weimarn and his followers [22, 23, 27]. The methods and approaches created by P. P. Weimarn and his scientific school in Russia and Japan have become so commonplace among researchers and practitioners of metallurgy [43–45] that they often do not even refer to the pioneers of dispersoidology. This is especially true of their foreign colleagues [43, 46, 47]. The development of methods for the extraction and production of low-dimensional structures of noble and non-ferrous metals from mineral raw materials is an important area of research of the modern RAS [48]. At the St. Petersburg Mining University, relevant works based on the use of the creative heritage of P.P. Weimarn and other Russian scientists are carried out under the scientific supervision of Prof. T. N. Aleksandrova (Corresponding member of RAS) [39, 48]. In addition to these works, which are closely related to the research of the RAS, the world-class scientific directions of the Mining University in St. Petersburg include developments in the field of dispersed substances and materials in chemical technology [49–51], nanotechnology [52–54], which are focused on ensuring sustainable development of the mineral and raw materials complex [55–57].

Prof. Peter Weimarn did much to make the science of dispersoidology, which he created, known and recognised worldwide. He was the first in Russia to give lecture courses on colloidal chemistry and dispersoidology [12], and he succeeded in getting the section "Dispersoidology" included in the curriculum of physical chemistry for students of the Mining Institute in St. Petersburg (1915). He continued his activities in the study and teaching of dispersoidology as rector of the Ural Mining Institute and rector of the Vladivostok Polytechnic Institute. Forced emigration to Japan did not break P. Weimarn. Since 1921, he has been lecturing on dispersoidology in Japanese universities: in Tokyo, Kyoto (**Fig. 7**), Tohoku and others. In 1923, he became head of the Dispersoidological Department at the Imperial Industrial Institute in Osaka [1]. During the period of work in Japan, the theory of dispersoidology underwent a comprehensive experimental verification and was further developed [21, 23, 28]. Orange-colored gold sols were obtained, crystallization and coagulation of metal sols were studied. P. Weimarn and his collaborators developed gold brines for coloring wood. In Japan, Weimarn also researched and applied natural silk, colloidal solutions of cellulose, rubber, latex and other practically important materials [1, 12, 14]. As early as 1907, student Peter Weimarn was invited to co-operate with the *Kolloid-Zeitschrift*. His work attracted the attention of German specialists so much that he was allowed to send new articles in Russian, and they were translated directly in the Editorial Office of the journal. Wolfgang Ostwald, Prof. of the University of Leipzig, Editor-in-Chief of the Journal, gave the highest assessment of Peter Weimarn's scientific achievements and considered his untimely death as 'one of the heaviest and most painful' personal losses for colloid science [1].

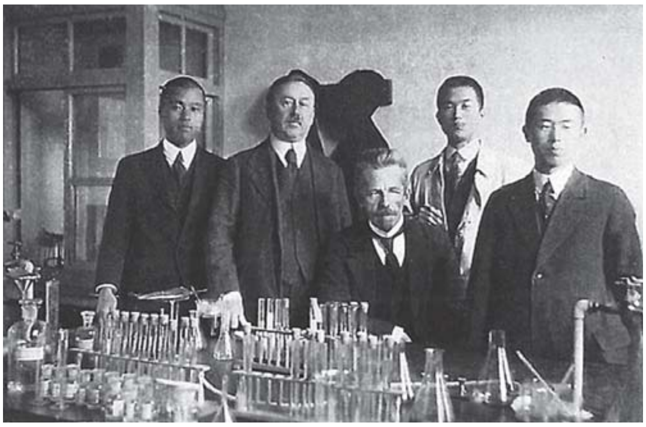

Fig. 7. Prof. P. P. Weimarn (sitting in the centre), S. F. Zlokazov (left), a merchant from Ekaterinburg, with Japanese graduate students in the laboratory of the Imperial Kyoto University [2, 4]

In Russia, even after P. Weimarn's departure to Japan, his significant contribution to the development of Russian physical chemistry was noted by academicians P.A. Rebinder and P. Walden [12]. In the XXI century, academicians of the RAS called Peter Weimarn 'the founding father of nanotechnology' [7, 8]. The idea of P. Weimarn's idea that by changing the dispersion medium during synthesis, one can regulate the surface properties of dispersed metal was successfully reflected in the developed solid-state hydride synthesis of nanostructured metals [9, 58]. Weimarn's position that the melting temperature should decrease in highly dispersed metals [16] was confirmed in the studies of V. Pak, O. Golov et al. [9, 14, 52].

How carefully the scientific heritage of P. Weimarn is treated in Japan is evident from the book by Prof. K. Tamaru [5]. The respect for the personality of Peter Weimarn and his memory is also evidenced by the exemplary condition of the monument and grave of P. P. Weimarn at the European Cemetery in Kobe (Japan) even 80 years after the death of the Prof. (**Fig. 8**).

Fig. 8. The grave of P.P. Weimarn with a monument in the Japanese city of Kobe *(photo by Empress Catherine II Saint Petersburg Mining University's Graduate Student Ngo K. K., 2016)*

The Ural State Mining University (Ekaterinburg) also does not forget about its first rector [2]. Representatives of the Russian diaspora in Kobe, guests from Russia, including those from the Urals, do not forget to honour Peter Weimarn, Honorary Citizen of Ekaterinburg, and lay flowers on his grave. In 1910–1915. P. P. Weimarn, in addition to the Mining Institute, taught at the Imperial St. Petersburg University. Judging by the interesting information about P. Weimarn on the University's website in the section "Biography" [59], Weimarn is well remembered there and his achievements in dispersoidology are appreciated. Australian scientist Felike Korn named one of the first colloidal minerals Weimarnite in honour of Peter Weimarn [7, 10].

Since 2015, the St. Petersburg Mining University of Empress Catherine II has been organizing International Symposia "N&N" with presentations on Weimarn's works. Since 2021, special prizes of Prof. P. P. Weimarn have been awarded annually to the most active participants and scientists in the field of nanotechnology [12]. Textbooks on nanotechnology and nanomaterials by the authors of this article [9, 12] contain sections devoted to the works of P. Weimarn and are used in teaching students in the direction of 'Nanotechnology' at the Saint Petersburg Mining University and Electrotechnical University (Saint Petersburg, Russia).

Conclusions

1. During the entire period of scientific activity (1902–1935), Prof. P. P. Weimarn published about 350 articles in external scientific journals (not including articles in the Journal of Mining Institute, St. Petersburg). After leaving St. Petersburg (1916–1935), Prof. P. Weimarn published 170 articles, which is about 49% of all articles. Thus, after a very fruitful period of work at the St. Petersburg Mining Institute, despite the necessity to supervise the construction of the Ural Mining Institute, the organization of the educational process in Ekaterinburg, evacuation (to Vladivostok, 1919) and emigration (1922), P. Weimarn's publication activity remained practically unchanged. The maximum number of articles per year: in St Petersburg 34 (1914), in Russia 39 (1920), in Japan 30 (1928).

2. In Japan, P. P. Weimarn, relying on the experience gained in Russia, purposefully develops methods for producing orange-colored gold sols with colloidal gold particle size in the micro- and ultramicroscopic range. He develops the theory and studies the regularities of crystallization and coagulation of metals (Au, Ag, etc.). With his collaborators he creates methods of wood coloring with the help of colloidal metals. The formaldehyde method of obtaining gold nanostructures according to P. Weimann is used by researchers of the XXI century and is promising for the extraction of nanogold in metallurgy.

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