

Chain reactions in chemistry and physics: 130th anniversary of Nikolai Nikolaevich Semenov

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Abstract. On the occasion of the 130th anniversary of the outstanding Russian scientist Nikolai Nikolaevich Semenov, the winner of the Nobel Prize in Chemistry in 1956, the main milestones of his biography are described and the main scientific achievements are shown. N.N. Semenov is the discoverer of chain reactions in chemistry, the creator of the theory of chain processes, the theory of branched chain reactions, and the law of the increase in the concentration of active centers over time. From 1931, N.N. Semenov created and continuously led the Institute of Chemical Physics for 55 years; now the institute bears his name. The research and administration work of N.N. Semenov and his personal qualities are described. The paper presents materials about N. N. Semenov preserved at the International Nobel Information Center, which has been honoring the scientist's memory for half a century. It also provides detailed information about Semenov's nomination for the Nobel Prize in Chemistry, as well as the people he himself nominated for the award.

Keywords: Nikolai Nikolaevich Semenov; chain reactions; physics; chemistry; Nobel Prize in Chemistry in 1956.

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Цепные реакции в химии и физике: 130 лет со дня рождения Николая Николаевича Семёнова

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Аннотация. К 130-летию выдающегося отечественного ученого Николая Николаевича Семёнова, лауреата Нобелевской премии по химии 1956 года, описаны основные вехи его биографии и показаны главные научные достижения. Н. Н. Семёнов – первооткрыватель цепных реакций в химии, создатель теории цепных процессов, теории разветвленных цепных реакций, закона роста концентрации активных центров со временем. С 1931 г. Н. Н. Семёнов создал и бессменно руководил Институтом химической физики в течение 55 лет; ныне институт носит его имя. Описана научно-организационная деятельность Н. Н. Семёнова, его личные качества. Показаны материалы о Н. Н. Семёнове в Международном Информационном Нобелевском Центре, который полвека хранит память об ученом. Детально раскрыты сведения о номинировании Н. Н. Семёнова на Нобелевскую премию по химии, а также сведения о том, кого он сам выдвигал на эту премию.

Ключевые слова: Николай Николаевич Семёнов; цепные реакции; физика; химия; Нобелевская премия по химии 1956 года.

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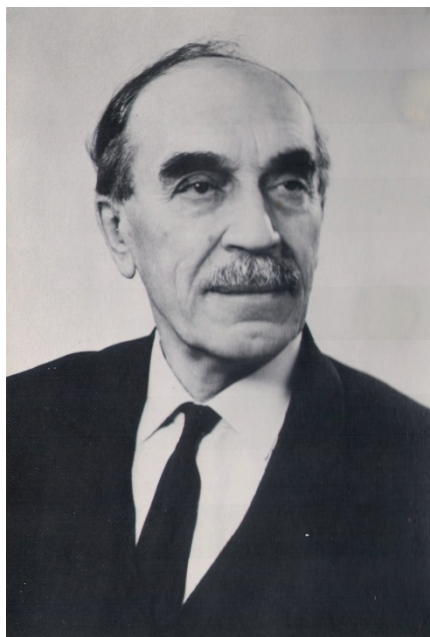


Fig. 1. N.N. Semenov.
A gift from N.N. Semenov to the author
of the article in 1975

Fate gifted the author with the immense joy of communicating with legendary Nikolai Nikolaevich Semenov (Fig. 1), whom he met repeatedly, first in 1975, when Academician I.L. Knunyants introduced us. The great scientist, founder of a new branch of science - chemical physics - twice Hero of Socialist Labor, Nobel Prize laureate, holder of the Lenin and State Prizes, and Academician Nikolai Nikolaevich Semenov turns 130 on April 15.

Nikolai Nikolaevich Semenov was born on April 3(15), 1896, in Saratov. After leaving school in 1913, he enrolled in the physics department of the physics-mathematics faculty at St. Petersburg University, where he studied under the renowned Russian physicist Abram Fedorovich Ioffe (1880–1960). After graduating from Petrograd University in 1917, Semenov worked as an assistant at the physics faculty of Tomsk Technological Institute and the university from 1918 to 1920. In 1920, he returned to Petrograd, where he was appointed head of the laboratory of electronic phenomena, and from 1922 to 1927 served as deputy director of the State Physico-Technical X-ray Institute (SPTXI). In 1926, he was sent to Germany, England, and France to familiarize himself with the leading physics laboratories, and in 1927 he became the head of the physico-chemical sector of SPTXI, on the basis of which the Leningrad Research Institute of Chemical Physics of the USSR Academy of Sciences (LRICP) was established on October 15, 1931. N.N. Semenov was appointed director of the institute, holding the position for 55 years (in 1943,

the Institute of Chemical Physics (ICP) of the USSR Academy of Sciences – ICP - relocated to Moscow, settling on Vorobyovy Gory, where it continues to operate today). In 1972, N.N. Semenov revived the institute laboratory of chain processes and personally headed it.

N.N. Semenov's entire life in science was connected with the Academy of Sciences. When he was elected a full member of the USSR Academy of Sciences, he was only 36 years old! N.N. Semenov was a member of the Bureau (1946–1957) and Academician-Secretary (1957–1963) of the Chemical Sciences Division of the USSR Academy of Sciences, and Vice President of the Academy from 1963–1971. For nearly 30 years (from 1957 until his death), N.N. Semenov served on the Presidium of the USSR Academy of Sciences, working on many of the Academy's councils, sections, and commissions, including those on free radicals, macromolecular compounds, philosophical issues of modern natural science, the physicochemical foundations of producing new heat-resistant inorganic materials, chemical engineering, and biological sciences, among others.

N.N. Semenov completed his first two scientific papers, “On the Collisions of Slow Electrons with Molecules” and “On the Theory of the Passage of Electricity through Gases”, under the supervision of A.F. Ioffe and published them in 1916 in the Journal of the Russian Physical-Chemical Society. After 1922, the young scientist's publications began to appear regularly in Soviet and foreign journals. N.N. Semenov's (1921–1926) physical research focused on three areas: electric fields, molecular physics, and electronic phenomena. To explain phenomena observed in experiments on the oxidation of phosphorus vapor with oxygen, which were incomprehensible from the standpoint of classical concepts of transformation mechanisms, N.N. Semenov in 1926–1927 proposed the theory of branched chain reactions: if the number of chain branches exceeds the number of terminations, the reaction accelerates sharply, leading to ignition of the mixture of reactants, i.e., a “chain explosion”. The scientist developed a rigorous theory of chain termination on the walls and in the volume of a reaction vessel, establishing that the reaction rate is proportional to the square of the vessel diameter or the first power of the pressure within it. He then discovered limiting phenomena in the oxidation of sulfur, hydrogen, carbon monoxide, carbon disulfide, and other vapors, demonstrating the prevalence of chain reactions in inorganic chemistry. Based on experimental results, he developed a general theory

of chain chemical reactions and discovered the law of increasing concentration of active centers over time.

In 1934, N.N. Semenov's fundamental monograph, "Chain Reactions", was published, in which he described his discoveries in detail (Fig. 2). From that time on, chemical physics emerged [1–6]. In 1956, N.N. Semenov, the first Soviet scientist, was awarded the Nobel Prize in Chemistry (which he shared with the English scientist S.N. Hinshelwood) "for his research into the mechanism of chemical reactions." Speaking in Stockholm after receiving the Nobel Prize, N.N. Semenov said: "Natural phenomena know nothing about the fact that we have divided our knowledge into sciences... Only a comprehensive examination of phenomena from the point of view of physics, chemistry, mechanics, and sometimes biology will allow us to recognize their essence and apply them in practice..." [7].

In 1951, N.N. Semenov proposed a chain mechanism for processes occurring on the surface of solid catalysts. Since 1955, problems of controlling homogeneous and heterogeneous catalysis of chain reactions have played a significant role in his work. However, within two decades, this area of research gave way to the kinetics of combustion and explosions. From 1958, N.N. Semenov intensively pursued research in molecular biology and biochemistry, particularly the kinetics of biological processes. In 1967, he was the first in the world to clearly formulate and substantiate the problem of preserving, protecting, and improving the quality of natural waters as one of the most important in modern science. In the 1970s, on N.N. Semenov's initiative, the Institute of Chemical Physics (ICP) began research on chemical bionics (an idea conceived in 1960) – applying the principles of enzymatic catalysis to carry out new catalytic reactions (photosynthesis, nitrogen fixation, etc.) using solar energy.

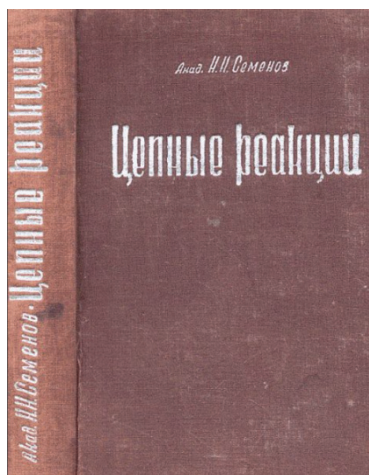


Fig. 2. Cover of N.N.Semenov's monograph, 1934

From 1944 until the last years of his life, N.N. Semenov headed the Department of Chemical Kinetics at the Faculty of Chemistry at Moscow State University. From 1951 to 1957, he simultaneously headed the department at the Moscow Engineering Physics Institute, and from 1957 to 1959, he was a professor in that department. His talent as a teacher, scientific advisor, and director is widely recognized. He created the largest, world-renowned scientific school in chemical physics and trained a whole galaxy of Soviet kineticists, including academicians, corresponding members, doctors, and candidates of science.

In December 1960, at the regular Pugwash Conference in Moscow, N.N. Semenov delivered a brilliant report, clearly and unambiguously entitled: *Eliminating Wars from the Lives of Nations*. Using simple mathematical equations, he clearly demonstrated that the longer the time between the start and end of disarmament, the greater the danger of war. N.N. Semenov's participation in the Pugwash movement of scientists was only one aspect of his work aimed at averting the threat of nuclear war from humanity.

Even in the last years of his life, N.N. Semenov remained a scientific enthusiast, a creative individual distinguished by boundless energy. He was tall and lean, enjoyed hunting and gardening, and was passionate about architecture, theater, music, and painting. He was kind, sympathetic, easy to talk to, and accessible to anyone who needed his advice, as the author of this article repeatedly witnessed during visits to his office at the Institute of Chemical Physics or to his home. A scientist must always remember that neither rank, nor age, nor scientific merit should have any significance in their scientific communication with students, no matter how young they may be. When I think of Nikolai Nikolaevich Semyonov, the same thought always comes to mind: the most important thing in a scientist's personality is not so much what he accomplished himself (after all, others would have made the discoveries), but what he gave to others – students, colleagues, friends, and simply ordinary people (Fig. 3).

In April 1986, during the celebration of the great scientist's 90th birthday, we spent four hours talking at his home on Frunzenskaya Naberezhnaya. Nikolai Nikolaevich talked at length about his life, the difficulties of developing chemical physics, his involvement in the Soviet atomic project, and his meetings with scientists. Ashtrays were scattered throughout his office, as N.N. Semenov smoked almost nonstop, lighting one Novost cigarette after another. When the author of the article dared to

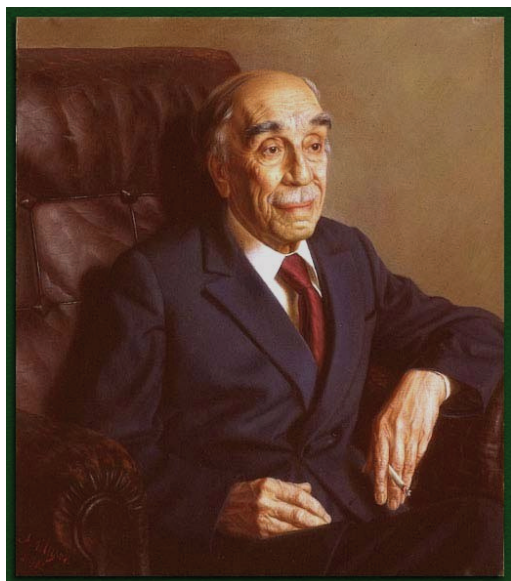


Fig. 3. Portrait of N.N. Semenov by the artist A.M. Shilov

say: “Nikolai Nikolaevich, you smoke a lot. You know that carcinogenic substances form at the phase boundary in a cigarette; it’s a classic chain reaction...” The great scientist listened calmly and then sternly replied: “You, son, first live to be 90, and then you can talk about the dangers of smoking!” This phrase stuck with me for life. Nikolai Nikolaevich Semenov died on September 25, 1986, in Moscow at the age of 90. He is buried at the Novodevichy Cemetery (Fig. 4).



Fig. 4. N.N. Semenov's grave at Novodevichy Cemetery.
Photo by the author in April 2006

The International Nobel Information Center (INIC) has been preserving the memory of our great scientist for half a century. The Nobel Scientific Library, the Nobel Museum, and the INC archives contain a vast amount of material on the life and work of N.N. Semenov (Figs. 5, 6) [8–11]. It is significant that Nikolai Nikolaevich read, corrected, and personally endorsed the author's first anniversary article about him in April 1976 [8]. Numerous books and articles have been written about him [9–16].

From the now-declassified materials of the Nobel Committee in Chemistry for 1901–1974: It became known that N.N. Semenov was nominated for the Nobel Prize seven times: in 1946 by the English physical chemist S.N. Hinshelwood; in 1947 and 1948 by the Swedish physical chemist T. Svedberg, winner of the 1926 Nobel Prize in Chemistry; in 1950 by S.N. Hinshelwood again; in 1955 and 1956 by the Swedish professor L.G. Sillen. The only nomination from the USSR, from Academician A.P. Vinogradov, arrived in Stockholm late and was therefore only taken into account in 1957, when N.N. Semenov had already become a Nobel Prize laureate after six nominations!

It is interesting that N.N. Semenov himself nominated 13 Nobel Prizes by 1974: twice in physics (1957 – P.L. Kapitsa; 1964 – E.K. Zavoisky and K.Ya. Gorter from the Netherlands), 11 times in chemistry (1964 – A.P. Vinogradov and A. Holmes from Great Britain, then A.N. Frumkin, and M. Volmer from Germany; 1965 – A.N. Frumkin and M. Volmer, then A.P. Vinogradov and A. Holmes; 1967 – A.N. Frumkin; 1968 – A.N. Frumkin, American B. Lewis and Ya.B. Zeldovich; 1970 – N.M. Emanuel; 1971 – N.M. Emanuel; 1972 – A.E. Shilov and M.E. Volpin; 1973 – N.M. Emanuel; 1974 – N.M. Emanuel, A.E. Shilov and M.E. Volpin).

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Fig. 5. A stand made by the MINC and donated to the N.N. Semenov Museum in Chernogolovka



Fig. 6. Books about N.N. Semenov, donated by his wife L.G. Shcherbakova-Semyonova

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Conflict of interests

The authors declare no conflict of interest.

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

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