SOVIET PHYSICS USPEKHI VOLUME 9, NUMBER 2 SEPTEMBER-OCTOBER 1966

92:530

PERSONALIA

# *NIKOLAĬ NIKOLAEVICH SEMENOV*

(on his seventieth birthday)

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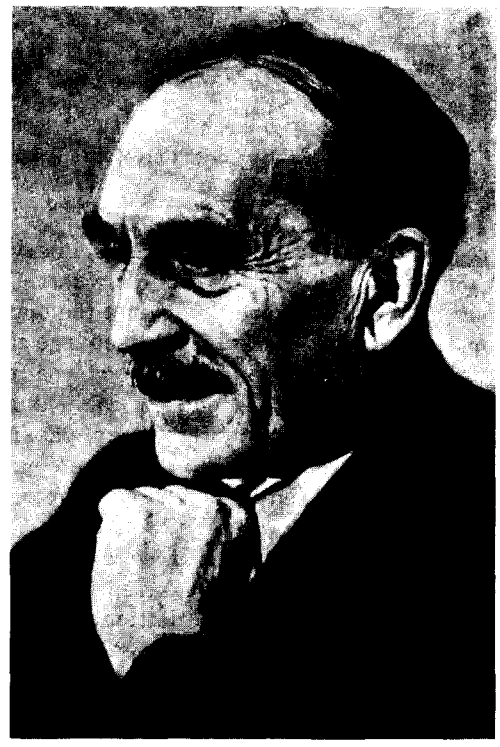
Usp. Fiz. Nauk 88, 765-768 (April, 1966)



ON April 15, 1966 the scientific community noted the seventieth birthday of one of the great contemporary scientists, Academician N. N. Semenov. During the fifty years of his intense, extensive, and very fruitful scientific and organizational activity Semenov contributed greatly to Soviet science. The winner of numerous state prizes of the U.S.S.R. and of the Nobel prize, and a member of many foreign academies and honorary doctor of many universities*, Semenov made Soviet science famous throughout the world. A physicist by education and in his approach, as he remains to this day, a true revolutionary in science, Semenov is one of the originators of a new chapter in physical chemistry—chemical physics—which has emerged as a science on the borderline of classical chemistry and the new trends of physics which were developed in the first third of the twentieth century on the basis of new discoveries in the theory of light, quantum mechanics, and the structure and energetics of atoms and molecules.

Semenov attained world renown by virtue of his and his school's work in the field of chemical kinetics, and above all of the chain theory of chemical reactions. In order to be able to evaluate duly his scientific attainments, one must describe the state of science with regard to the chemical process as it was forty years ago, in the mid-twenties. Owing to a large number of works of numerous chemists of various countries, and above all owing to the work of such eminent representatives of world chemical science as van't Hoff and Arrhenius, Mendeleev and Menshutkin, Bach and Engler, as well as Bodenstein, extensive experimental and theoretical material had accumulated in the mid-twenties. In accordance with the level of theory at that time, kinetics was based on the concept of a simple chemical reaction based on the law of mass action and Arrhenius' law. All the accumulated experimental material was indeed considered from this point of view; this was to a large extent facilitated by the widely current ideas of van't Hoff about the secondary nature (unconnected with the essence of the chemical process) of the rather numerous deviations from the laws of simple kinetics; these van't Hoff ascribed to various external "perturbing influences." An enormous scientific intuition and a broad viewpoint were required in order to see in the experiment of Khariton and Val'ta, which provided evidence of clear violation of the law of mass action in the oxidation reaction of phosphorus vapor and which contradicted all the prevailing conceptions in the field of kinetics, not a special case of an "apparent" violation of the laws of kinetics, but a fundamental phenomenon of very broad and general significance. The revolutionary significance of this discovery and of the quantitative explanation of the phenomenon of inflammation limits of phosphorus vapor provided by Semenov, is most clearly indicated by the negative reaction of Bodenstein, the patriarch and all-acknowledged authority in the field of chemical kinetics, which followed this discovery. However, already two years later, in 1928, it became clear to all through the work of Semenov's

*N. N. Semenov is a foreign member of the U.S. National Academy of Sciences (1963), and of the English Royal Society (1958), an honorary member of the English Chemical Society (1943), the New York Academy of Sciences (1962), the Hungarian (1961), Indian (1954), Rumanian (1965), and Czechoslovak Academy of Sciences, a member of the German Academy of Natural Sciences (1959), honorary doctor of the Oxford (1960), Brussels (1962), and London (1965) universities, of the Budapest Technical University (1965), and of the Milan Polytechnic Institute (1964).

school in the Soviet Union and of the school of Hinshelwood in England that the inflammation limits of phosphorus vapor, far from being a unique and rare phenonemon, are but one of many manifestations of a class of chemical reactions which is widespread in nature. It transpired that a distinguishing feature of reactions of this type is their branched chain mechanism which makes possible a continuous acceleration of the initiated reaction and leads to inflammation. The theory of chain inflammation in its first form was formulated by Semenov in 1928. It is characteristic that the branching process was already then postulated to be a disintegration of molecules into atoms and radicals, a fact which was subsequently experimentally confirmed on a large number of examples. At that time, in 1928, Semenov also derived the law of exponential acceleration of the chain reaction, the celebrated $e^{\varphi t}$ law, which was subsequently named Semenov's Law.

Semenov and his school worked out in detail the fundamentals of the chain theory of chemical reactions. The work of A. V. Zagulin and A. A. Koval'skiĭ and later the work of V. N. Kondrat'ev, M. B. Neĭman, S. Z. Roginskiĭ, Ya. B. Zel'dovich, N. M. Émanuel', A. B. Nalbadyan, V. V. Voevodskiĭ, N. M. Chirkov, and A. E. Shilov and his co-workers at the Institute of Chemical Physics directed by Semenov made an important contribution to the development of chain theory. Having evinced enormous response in world science, chain theory was developed and refined in a small number of papers, penetrating further and further into the technology of the chemical industry and into new technological applications. It is now difficult to imagine these new branches of application without the fundamental principles which chain theory provided. In present-day work in kinetics the initial, formal, kinetic schemes have a chemical basis; they have been replaced by specific chemical schemes which constitute an aggregate of definite elementary processes in which specific chemical entities—molecules, radicals, atoms, and ions—take part. In addition to the usual methods of chemical analysis and kinetics, new methods which were previously unknown or limited in their application at the time chain theory was conceived, have been applied: polarography, chromatography, tracer atoms, optical methods and mass spectrography, electron paramagnetic resonance, the methods of pulse photolysis and shock waves, and a number of other methods. Previously established laws, quantitative relations and calculations have also been refined by means of new and improved methods; precise quantitative agreement of theory and experiment is more and more often the main criterion in deciding the correctness of a theoretical interpretation of experimental data.

Semenov continues to participate in the work of refining and perfecting chain theory with his former interest and energy. We shall not dwell here on the details of contemporary chain theory, referring the reader to the article "Contemporary Theory of Chain Reactions" appearing in this issue. We merely note that the concept of the homogeneous bimolecular initiation of chains and the energy mechanism of branching in chain reactions, characteristic of contemporary chain theory, follow from recent papers by Semenov and his students.

His work on the chain theory by far does not exhaust Semenov's entire broad and varied scientific activity and interest. We cannot enumerate here all the scientific directions and problems which have been or are being worked out by Semenov, with his participation, or according to his proposals. The problem of ionization of gases was, apparently, the first scientific problem to interest him. The work on this problem, begun by him as early as 1916, was continued with his participation in the Twenties by his close students A. F. Val'ter, L. J. Inge, Yu. B. Khariton, and V. N. Kondrat'ev, later by S. Z. Roginskiĭ and A. B. Shekhter, and then by G. Eltenton; it is presently being continued by V. L. Tal'roze and his students using modern mass-spectrometric techniques, and by Yu. S. Sayasov and co-workers on the basis of quantum mechanics.

The beginnings of mass spectrometry in the U.S.S.R. were marked by the work of N. N. Semenov and V. N. Kondrat'ev in 1924. At the Institute of Chemical Physics the works of G. Eltenton started the new, kinetic trend in mass spectrometry which now plays such an important role in studies of the kinetics and mechanism of chemical reactions. At present this direction is being developed in a new, original form at the Institute of Chemical Physics in the works of V. L. Tal'roze and his co-workers.

Another important scientific problem whose elucidation was begun by Semenov and his close students at the beginning of the Twenties is related with the phenomena of adsorption and condensation. The beginnings of this work were marked by the papers of N. N. Semenov and Yu. B. Khariton who discovered the critical temperature and critical density of condensation (1924); N. N. Semenov, Yu. B. Khariton, and Ya. I. Frenkel subsequently provided the theory of this phénonenon (1926). The roots of this trend in the works of Semenov and his school originated in Yu. B. Khariton's undergraduate work on the behavior of molecular beams in inhomogeneous magnetic fields, undertaken as a check of the calculations of P. L. Kapitza and N. N. Semenov (in 1920) from which it followed that a beam of molecules (atoms) of a paramagnetic gas should be noticeably deflected in an inhomogeneous magnetic field. As is well known, analogous experiments were undertaken in 1921, i.e., simultaneously with Khariton (who was at that time only seventeen years old), by Stern and Gerlach. As a result of these experiments they discovered in 1922 the phenomenon of space quantization which came to be called the Stern-Gerlach effect. By the way, this first joint work of Semenov and Khariton is one of

the very few uncompleted works of Semenov—a rare exception, since all the work undertaken by him is, as a rule, carried to completion, i.e., until new, important results are obtained which constitute a further step in the development of science.

Investigations of the phenomena of condensation, in particular condensation from molecular beams, were further developed in the work of Semenov, A. I. Shalnikov, and S. Z. Roginskiĭ, with ever increasing orientation towards the study of chemical reactions in the solid state, and subsequently also in the works of S. A. Vekshinskiĭ.

The third important direction of Semenov's scientific work is connected with investigations of electric fields and the electric breakdown of dielectrics; these were also started at the beginning of the Twenties. Here the foremost and closest students of Semenov were A. F. Val'ter, A. K. Val'ter, L. J. Inge, and N. V. Tomashevskiĭ. As a result of the investigation of the breakdown of dielectrics Semenov constructed the thermal breakdown theory which served as a stimulus for working out of a thermal theory of inflammation which was formulated by him in 1928 simultaneously with the chain theory of inflammation.

The thermal theory of inflammation constituted Semenov's first important contribution to combustion theory. He continued his work on combustion theory in the Thirties. In 1938 Ya. B. Zel'dovich and D. A. Frank-Kamenetskiĭ worked out at the Institute of Chemical Physics the thermal theory of flame propagation which was accorded extensive recognition in world science. One must note the works of Semenov and Zel'dovich in 1938 and 1940, of Semenov in 1940, and particularly the work of V. G. Voronkov and Semenov in 1939 in which they showed experimentally for the first time the possibility of a chain propagation of a flame, in complete quantitative agreement with Semenov's chain theory and with the theory of isothermal flame propagation of Ya. B. Zel'dovich and D. A. Frank-Kamenetskiĭ. It must be added that in conjunction with the theory of normal combustion Zel'dovich worked out at the Institute of Chemical Physics directed by Semenov the theory of detonation which was further developed in the work of S. M. Kogarko, Ya. K. Troshin, and K. I. Shchelkin; Shchelkin worked out the theory of turbulent combustion; A. S. Sokolik formulated the theory of two-stage inflammation which is gaining ever wider recognition in world science. The theoretical conceptions about combustion processes based on these papers have been used as the basis for the standards and rules of safety techniques in the Soviet Union. A. S. Sokolik and A. N. Voinov proposed on the basis of the new conception of the role of gas turbulence in the propagation of flames a new type of motor with precombustion chamber jet ignition. The idea of this type of ignition was realized in practice in a joint work of the group of L. A. Gussak and the staff of the Gor'kiĭ Automobile Plant.

Without dwelling on the other scientific trends and problems, worked on by Semenov himself and with his direct participation, we note merely that a large number of scientific ideas due to him were developed in many works of his students and also of scientists who do not belong to his school. It must be said that Semenov acquired entirely the ability of his illustrious teacher A. F. Ioffe to give away his scientific ideas without any claim whatsoever to co-authorship of the papers developing these ideas. As an example one might cite his idea of carrying out reactions in thin films of a substance adsorbed on solid surfaces, which led in the works of N. M. Chirkov and his co-workers to the establishment of a new field of kinetics of liquid acid-catalyst reactions which are of considerable theoretical and practical significance; further we cite his idea (originating from the theory of heterogeneous breaking of chains) of the possibility of acting on a chain reaction with the aid of rods or dust introduced into the reaction zone and slowing down the reaction by absorbing active centers. This idea of his was developed in the works of A. B. Nalbandyan and S. M. Shubina, A. I. Serbinov, and in a number of other works at the institute. As is well known, an analogous idea is also used in atomic reactors where the absorbers of active centers of the nuclear chain reaction—the neutrons—are cadmium rods introduced into the reactor. We also mention Semenov's idea of acting on liquid-phase reactions with ions obtained in the gaseous phase which was developed by B. I. Pavlov and his co-workers and yielded a series of interesting results.

A most fruitful idea of Semenov's was to attract Yu. B. Khariton (at the end of the Twenties) to work out the theory of the combustion and detonation of condensed substances. As is well known, the work of Khariton and his co-workers A. F. Belyaev, V. K. Bobolev, and A. Ya. Apin, and also of P. F. Pokhilo in this field yielded brilliant results which advanced this branch of science with its immense practical importance considerably.

The organization of a laboratory, and subsequently of a section, to study combustion of condensed systems at the Institute of Chemical Physics and at its Branch headed by F. I. Dubovitskiĭ is only an isolated episode in Semenov's immense organizational work in forming and strengthening the Institute of Chemical Physics which he established and whose director he has been from the moment of its inception in 1931 to this very day. In 1959 a polymer section was established at the Institute on Semenov's initiative. Polymer reactions, and particularly the study of their kinetics, were thus included into the circle of investigated reactions (we note that this section is headed by the physical chemist and kineticist A. M. Markevich). In 1960 Semenov established in his institute a section for the study of chemical and biological processes, headed by the physical chemist and kineticist N. M. Émanuel'. Under his direction kinetic methods of investigation are ap-

plied to solve problems of molecular biology and the study of pathological processes.

The enterprise and scope of the scientific and organizational work of Semenov, who is now also the vice-president and chairman of the Section of Chemico-technological and Biological Sciences of the Presidium of the U.S.S.R. Academy of Sciences, is well known far beyond the limits of the Institute of Chemical Physics. We recall here that Semenov took an important part in organizing such institutes as the Ukrainian Physico-technical Institute in Khar'kov, and the Dnepropetrovsk and Tomsk Physico-technical Institutes. Semenov participated closely in the organization and formation of the Leningrad Physico-technical Laboratory from which the Electrophysics, Thermotechnical, and Acoustical Institutes subsequently came into being. He devoted also much effort to the formation and strengthening of the Leningrad Physico-technical Institute from which the Institute of Chemical Physics separated in 1931. Since 1922, when Semenov was only 26 years old, up to the time when the Institute of Chemical Physics was organized he was the deputy of the director of the Leningrad Physico-technical Institute, A. F. Ioffe.

Semenov was, (together with A. F. Ioffe, A. N. Bakh, Ya. I. Frenkel, V. A. Kistyakovskiĭ, N. I. Shilov, A. N. Frumkin, and others) one of the organizers of the All-union Physico-chemical Conferences which played an exclusively important part in uniting physicists and chemists in solving problems common to theoretical chemistry and related scientific fields.

In his extensive scientific and organizational activity Semenov devoted much effort to the education of scientists. In this respect he put from the very beginning his faith in youth, in whose creative ability he already then deeply believed. The extensive recruiting of second-year students of the Physico-mathematical Faculty of the Leningrad Polytechnic Institute for the Laboratories of the Leningrad Physico-technical Institute which he carried out in 1921—1922 was considered by many to be a bold and risky experiment. However this was, as it turned out, the only correct way to educate scientists rapidly. Subsequently this method came to have extensive and valid claims; to be sure, nowadays fourth-, fifth-, and more rarely third-year students come into our laboratories. In directing the work of a young scientific co-worker, research or graduate student, Semenov, believing in the creativity of youth, always allows him maximum independence. He follows the same method also when directing a group working on a given topic or a laboratory group.

Semenov's distinguishing traits, which characterize his work as a scientist, are his scientific enthusiasm, his creative approach to any problem, and the intense energy with which he undertakes the solution of all scientific and organizational problems. The living example of Semenov, a great scientist, full of enthusiasm and creative energy, inspires his students, co-workers, and all those whose fortune it is to work hand in hand with him for the good of Soviet science and for the good of the Soviet people.

Translated by Z. Barnea