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SERGEI ALEKSEYEVICH KHRISTIANOVICH (the 100th Anniversary of his Birth)☆

The 9th of November 2008 is the 100th anniversary of the birth of an outstanding Russian scientist in the field of mechanics, Academician Sergei Alekseyevich Khristianovich, who made significant contributions to the development of science and technology both within his own country and abroad.

He was born in St Petersburg into a family of landowners from Orel Province. He spent his childhood in the country, on an estate not far from Orel, and was educated in the manner customary to the gentry: he studied with teachers, and had a French governess (he spoke French almost as his native tongue). The Revolution came, and then the Civil War. When, in 1920, Denikin's army withdrew from Orel, Khristianovich's parents, to avoid repression, were forced to leave with them. In Rostov-on-Don, the entire family went down with typhus. His parents and elder sister died, but the young Sergei survived, left orphaned and homeless, without means of support. He lived in poverty, neglected, until, in 1922, he happened to meet his aunt, M. N. Bek, in Rostov. Through her, Sergei became acquainted with Professor D. I. Ilovaiskii, who had known his parents, and who became his guardian and played a major part in the fate of the future scientist. In 1923, he moved to Petrograd, and there, in 1925, he finished middle school and entered Leningrad State University.

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In 1930, he graduated successfully from the university's Mathematics Department, specializing in Mathematics and Mechanics. He was an unusually gifted man and, through his energy and spirit, managed, in a short period of time, to obtain a good, thorough education. At university he studied under excellent professors and teachers: V. I. Smirnov, N. M. Gyunter, N. Ye. Kochin, et al., and his fellow students included young, talented and future outstanding scientists: S. L. Sobolev, V. A. Ambartsumyan, S. G. Mikhlin, L. V. Kantorovich, B. B. Devison and others. As he himself once said, "I was with very good people. It was my good fortune that there were many of them". It should be pointed out that, at the same time as his university studies, he had to earn his keep by teaching in a cookery school, in a club for invalids and on book-keeping courses.

After graduating from Leningrad State University in 1930, he started work at the State Hydrology Institute in Leningrad. A very important problem was tackled at the institute in this period: the compilation of an inventory of water resources for the Soviet Union to provide for the largest hydraulic engineering construction of that time and the supply of water to new, growing industrial centres. He was charged with calculating unsteady flows in channels and rivers, in connection with the development of the Volga Hydro-electric Power Station Cascade project. The solution of this problem involved the integration of non-linear hyperbolic-type differential equations. Riemann started research in this field, and this was later taken up by Hadamard; they considered wave propagation in a gas and the flow of air at supersonic speeds. These problems proved to be mathematically very similar. To solve such problems, he developed the method of characteristics and obtained his first important scientific results. In subsequent years, this approach was widely used by him and by his students and followers in supersonic aerodyamics and plasticity theory.

In 1935–1937, in Moscow, while studying for his doctorate at the V. A. Steklov Mathematical Institute of the USSR Academy of Sciences, he continued to work on solving non-linear hyperbolic equations with many variables (the Cauchy problem), but now in the field of plasticity theory. In 1936 he submitted a solution of the problem of the stress distribution in the plastic zone around a hole of arbitrary shape, which was highly rated by Hadamard. At the same time, he began to work on the non-linear seepage of groundwaters, and also to study problems of the mechanics of high-speed flight. As he himself recalled, "The years of work at the Mathematical Institute were very fruitful. I managed to get a great deal done, more than at any time thereafter in such a short period". His colleagues at the Mathematical Institute were I. M. Vinogradov (director), M. A. Lavrent'ev, S. L. Sobolev, N. Ye. Kochin, P. Ya. Kochina, A. N. Kolmogorov, I. M. Gel'fand, L. A. Lyusternik and P. S. Aleksandrov – in this illustrious company the great scientist continued to grow.

Having defended two doctoral theses at the same time (in Physical and Mathematical Sciences and in Engineering Sciences), in 1939, he was elected a Corresponding Member of the Academy of Sciences for his studies in the field of hydrology.

At this time, under the supervision of Academician B. N. Galerkin, a new institute was founded – the Institute of Mechanics of the Academy of Sciences, and Khristianovich was made its deputy director. He worked there for only a very short time however: in spite of all his efforts, it proved impossible to obtain the right building and the necessary experimental equipment for the institute.

In 1940, at the invitation of the new head of the N. Ye. Zhukovskii Central Aerohydrodynamic Institute (TsAGI), an outstanding organizer General I. F. Petrov, he moved to the TsAGI, where he worked for 14 years, initially as Head of the Laboratory of High-Speed Aerodynamics (1940–1942), and then as Deputy Head of aerodynamics (1942–1953). Without doubt, these were the years of his highest creative development. In this period, under his supervision, the scientific principles of transonic and supersonic aviation and of jet aviation were developed. While at the TsAGI, he published about 20 papers, containing both basic and engineering research results on a number of aspects of high-speed gas dynamics: the flow around bodies of arbitrary shape and flows in channels and nozzles.

In what was to become a classical work, *Gas Flow Around Bodies at High Subsonic Speeds* (1940), he used the ideas of S. A. Chaplygin to develop the theory of compressible gas flow around plane and axisymmetric bodies at transonic speeds, applying an original and effective body of mathematics for this. In his next work of the same year, *The Effect of Compressibility on Wing Characteristics*, he proposed a method of calculating the pressure distribution over an airfoil and the lift. Based on the results obtained in these publications, high-speed airfoils were developed.

Aviation was confronted with the problem of breaking the sound barrier, and in 1941 he published his work *On Supersonic Gas Flows*, in which he studied the laws governing the gas flow overcoming the speed of sound, and found the local criterion of continuous overcoming. This study made it possible to explain the formation of shock waves and the sharp increase in drag during transonic flight. His study *On the Design of Laval Nozzles* was of great importance for the design of wind tunnels. He showed that, to ensure uniform supersonic flow, a plane surface of transition through the critical speed must be created. In his study *On Ejector Design* he gave the fundamentals of the theory of a classical ejector ensuring operation of a supersonic wind tunnel. At the TsAGI, directly under his supervision, a powerful experimental foundation was established for studying high-speed aerodynamics, the most powerful in the world at that time. Unique wind tunnels were constructed for testing aircraft. These tunnels made it possible to improve the cooling system, the stability and the controllability of aircraft, to increase their speed and to raise the flight ceiling, and from 1943 onwards Soviet aircraft began to surpass the corresponding German aircraft in quality. In 1943, in recognition of his work, he was elected a Member of the Academy of Sciences in the Department of Physics and Mathematics.

Mention must be made of another important result he obtained, together with F. R. Gantmakher, L. M. Levin and I. I. Slezinger, at the very height of the war. On the instructions of the government, in the shortest time, they solved the problem of significantly increasing the hit accuracy for "Katyusha" rocket launchers. The solution was very simple from the technological point of view – by creating tangential channels in the missiles, the latter were rotated at the very start of flight by a small part of the gas propellant exhausting through these channels.

In 1948, TsAGI published the remarkable work by Khristianovich, V. G. Gal'perin, I. P. Gorskii and A. I. Kovalev entitled *The Physical Principles of Transonic Aerodynamics*. This work presented the results of research on transonic flow around airfoils, including the experimentally discovered "stabilization law" or "freezing principle". According to this law, local Mach numbers on the airfoil before the shock wave do not depend on the flight Mach number, and the Mach number distribution over the airfoil does not change when the gas velocity increases at infinity. In the same year, under his editorship, the monograph *Applied Gas Dynamics* was published, written together with his colleagues V. G. Gal'perin, M. D. Millionshchikov and L. A. Simonov, where results obtained at the TsAGI scientific school in this area were presented.

In the post-war years, continuing his work at the TsAGI, Khristianovich was actively engaged in the development of science: radio-electronics, rocket and aviation technology and the nuclear industry – the country required specialists combining an extensive scientific education and good engineering training. On the suggestion of a number of greatest Soviet scientists, primarily Academicians Kapitsa and Khristianovich, higher educational establishments of a new type were set up: the Moscow Institute of Physics and Technology (MFTI) and the Moscow Engineering Physics Institute. The main principles upon which these institutes were based were the careful selection of the most gifted young people for training, the employment as teachers of leading scientists and engineers in key areas of science and technology and the participation of students in direct work at enterprises and at scientific research institutes by creating chairs based there. In 1947, he was head of the Department of Physics and Technology of the M.V. Lomonosov Moscow State University, which then split off to form the MFTI, and he became the first head of the newly created institute.

In 1946, he was elected onto the Presidium of the USSR Academy of Sciences, and in 1953 he moved to work mainly within the Academy of Sciences, where, until 1965, he was Academic-Secretary of the Department of Engineering Sciences. Under his supervision, intensive expansion, construction and reorganization of the Department of Engineering Sciences took place during these years. His scientific work was focused on solving gas dynamics problems related to nuclear explosions. At the Institute of Chemical Physics, he and his students, young MFTI graduates, constructed the non-linear theory of weak waves with high pressure gradients – short wave theory. A number of important problems were solved using this theory: shock wave propagation in the atmosphere, the interaction of shock waves with different obstacles and the reflection of shock waves from free surfaces and rigid walls. He took a direct part in tests of an atomic and then a hydrogen bomb. For these developments, he was awarded a State Prize (his third).

At the same time, at the I.M. Gubkin Moscow Institute of Petroleum, he worked on the crack theory and problems of petroleum mechanics. Together with Yu. P. Zheltov and G. I. Barenblatt, he developed the theory of hydraulic fracturing of oil strata. This method of increasing oil-well yields remains the main method employed in the oil and gas industry. This period saw his first papers on sudden surges of coal and gas. This laid the foundation for the very clear and adequate theory of this catastrophic phenomenon that he developed in the 1970s and 1980s.

In the mid-1950s, all the scientific research establishments were concentrated in the central regions of the country, primarily in Moscow, Leningrad and Kiev, while in its eastern regions – in the Urals and Siberia, there were practically none. On the initiative of Khristianovich, M. A. Lavrent'ev and S. L. Sobolev, in 1957, in Novosibirsk, a large scientific centre – the Siberian Branch of the USSR Academy of Sciences – began to be constructed. In the post of first deputy chairman of the Siberian Branch of the USSR Academy of Sciences, in 1957–1962, he was put in charge of the construction and design of the scientific centre. At the same time, under his supervision, the Institute of Applied and Theoretical Mechanics was built there, and he was the institute's director from 1957 to 1965. This institute now bears his name. One of the main lines of research with which he was engaged in the Siberian Branch was the design of steam-gas heat and power installations, with simultaneous cleaning of fuel at power stations, in a cycle, for electric power generation. Such stations had already been built in Russia and abroad, and had proved to be highly efficient.

In 1965, for a number of reasons, including his health, he returned to Moscow, where he began work as scientific manager of the All-Union Scientific Research Institute of Engineering Physics and Electronic Measurements of the State Standards Committee of the USSR (Gosstandart) (1965–1972). From 1972, he was chairman of the Intercollegiate Council for Quality at Gosstandart. As an associate member of the State Committee of the Council of Ministers of the USSR for Science and Technology, he helped in setting up a number of lines of scientific research in the country.

In 1972, he moved to the Institute for Problems in Mechanics of the USSR Academy of Sciences (now the A. Yu. Ishlinskii Institute for Problems in Mechanics of the Russian Academy of Sciences) and worked there until the end of his life (28 April 2000). This period of his scientific activity is characterized by his retirement from practically all administrative duties and the decision to concentrate on science alone. The fields in which he chose to work are interesting: the theory of plasticity, sudden surges of coal, rock and gas and problems of the development and exploitation of oil and gas fields. To each of these problems he had, in his time, devoted a fair amount of time and effort, and his return to them indicates that he considered these to be important and inadequately investigated. It must be said that each of the studies he conducted in this period was pioneering.

In his work in the field of plasticity theory, he continued research he had begun back in Novosibirsk together with Academician Ye. I. Shemyakin. In his book *Deformation of Strain-Hardening Plastic Material* he proposed a new model, on the basis of which a general theory of plasticity for complex stress state was constructed. This theory, which was called the semi-microscopic theory of plasticity (SMTP), and, at first glance, is very complex and difficult to understand, made it possible, with astonishing accuracy, to explain experiments conducted for the most complex load trajectories. It was developed further in the study *The Plastic Deformation of Strain-Hardening Metals and Alloys. Constitutive Equations and Calculations Using Them*, conducted by Khristianovich together with his students. This showed that, for a broad class of structural materials (polycrystalline metals and alloys) with a monotonic strain-hardening curve, their ductile properties are determined entirely by just two constants – the strain-hardening coefficient and the yield point, found from a simple macroscopic experiment, for example, from a tensile test. From this theory stems the universality of the common strain-hardening curve in 'stress intensity–strain intensity' coordinates. His study *The Plastic Deformation of Strain-Hardening Metals and Alloys, Analysis of Experimental Data and the Solution of Elastoplastic Problems* gives the results of a comparison of calculations by the SMTP equations with data of numerous experiments with different types of load trajectory for various materials (steels, aluminium alloys, etc.). Good agreement between the theoretical predictions and experimental data for a broad class of load trajectories was demonstrated.

His next line of research at the Institute for Problems in Mechanics was the problem of combating sudden surges of coal, rock and gas. In earlier studies devoted to this subject (1953), as he himself stressed, it was not the main concern to understand the mechanism of the development of sudden surges. The work *Sudden Coal (Rock) and Gas Surges. Stresses and Strains* presented this mechanism, which consisted in the formation in the seam of an oriented system of gas-filled cracks perpendicular to the discharge direction. The coal seam in the undisturbed state does not filter, and isolated pores contain free gas under near- mining pressure. Seepage capacity occurs in the seam as a result of discharge of the seam in the course of conducting mining operations (the creation of workings) by the growth from these pores of a system of cracks, mainly in planes oriented perpendicular to the direction of least compression. This conclusion is extremely important for developing effective methods of preventing sudden surges of coal and gas.

In the last years of his life, he was occupied mainly with problems associated with oil and gas production. He addressed similar questions in the mid-1950s, when he developed the theory of hydraulic oil-strata fracturing. Advances in these areas made it possible to take a fresh look at such traditional fields as oil-strata mechanics and the theory of oil seepage within the strata. He came up with the new concept of the structure of the ground skeleton of oil-field traps, proposing to consider them as a microcracked porous medium in which oil is contained in pores connected by crack-like formations by which oil seepage occurs. In the work *On the Principles of Seepage Theory* he introduced a new constant that, in explicit form, reflects the structure of the pore space. This approach made it possible to compile new equations of seepage theory that, under certain conditions, are identical with the traditional equations.

On the basis of the ideas he and his students proposed, a new method was developed for increasing the productivity of oil and gas wells – the geo loosening method. An integral part of this method was the testing of core samples taken from wells of the field being investigated on a unique system set up at the Institute for Problems in Mechanics of the Russian Academy of Sciences on his initiative for the testing of three-axial independent loading. This method successfully passed pilot-plant tests at a number of West Siberian and Kama Region fields.

For his entire life, from his youth until his death, Khristianovich combined his scientific studies with active teaching work. From 1946 to 1950 he was a Prorector of the M. V. Lomonosov Moscow State University, from 1950 to 1957 and from 1965 until his death he was a professor at the MFTI and from 1959 to 1965 he was a department head at Novosibirsk State University. Among his students there are many great scientists, in all fields in which he worked.

His many talents – scientist, manager, teacher – are astonishing. Once, at an international scientific forum where he was delivering a paper, a foreign professor came up to him and asked whether "Khristianovich" was a very common name in the USSR, as he had come across it in the most diverse fields of science. The range of scientific problems that he studied and for which he obtained oustanding results is very wide: hydroaerodynamics, strength, plasticity, seepage and power installations; a common aspect of these problems was that they always arose out of practice, and involved the solution of the most acute problems facing the country. He worked to specific ends that were of great practical importance, and therefore his contribution to the development not only of basic science but also of technical engineering ideas in his home country and throughout the world was enormous. His services were highly valued by his country – he was given the title Hero of Socialist Labour, received three State Prizes and was awarded six Orders of Lenin and other orders and medals.

His brilliance as a scientist is demonstrated by the fact that he always viewed a phenomenon in a novel way, with new ideas. The profundity and fruitfulness his ideas have been confirmed by time – they have been used, and will continue to be used, by many subsequent generations of researchers.

Translated by P.S.C.