

PERSONALIA

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In memory of Aleksei Alekseevich Abrikosov

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The outstanding theoretical physicist, laureate of Nobel, Lenin, State, and many other prizes, Member of the Russian Academy of Sciences (RAS), the National Academy of Sciences of USA, and foreign Member of the Royal Society of London, Aleksei Alekseevich Abrikosov, passed away surrounded by family on 29 March 2017 after a long illness. In the physics of the 20th century, his name is associated with many discoveries in condensed matter theory and in quantum electrodynamics. However, A A Abrikosov entered the history of science first and foremost as the creator of the theory of second-order superconductivity.

A A Abrikosov was born on 25 June 1928 in Moscow in the family of well-known physicians. The Abrikosov family was known in the Russian Empire from the early 19th century as the founders and owners of a confectionery shop which gradually became a large concern and was awarded the title of 'Supplier to the Court of His Imperial Majesty'.

In 1943, A A Abrikosov finished high school and entered Moscow Power Engineering Institute. In 1945, he transferred to the Faculty of Physics of Lomonosov Moscow State University (MSU). A A Abrikosov's scientific growth was directly influenced by L D Landau. At the age of 19, he passed the theoretical minimum, in a year he graduated *cum laude* from the Faculty of Physics of MSU, and next year he defended his Candidate of Sciences thesis devoted to the study of thermal diffusion in fully or partially ionized plasma.

Almost two of the subsequent decades of A A Abrikosov's scientific work were spent at the Institute for Physical Problems (IPP) of RAS. In 1951–1952, he and N V Zavaritsky, an experimentalist from the same Institute, were engaged in verifying the predictions of the recently developed Ginzburg–Landau theory of superconductivity concerning critical magnetic fields for thin films. The result of this work was the theory of 'second-group superconductors' (now referred to as type II superconductors). After that, A A Abrikosov passed to studying the magnetic properties of massive second-order superconductors and came to the conclusion that the transition from the superconducting to normal state with increasing field proceeds gradually, the field having two critical values. Between these critical values, the external magnetic field in the form of thin filaments of the magnetic flux, surrounded by vortex currents, gradually penetrates the superconductor. These quantum vortices form a regular structure (now known as the Abrikosov vortex lattice). Having compared his results with the experimental curves of superconducting alloy magnetization obtained in the 1930s, A A Abrikosov found a remarkable coincidence. The authors, however, explained their data by the inhomogeneity of the specimens. His paper, without which it is now impossible to imagine the physics and technology of superconductivity, appeared in 1957, but the experimentalists only bought in to the vortex lattice ten years later after direct observations using the magnetic decoration method.

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Aleksei Alekseevich Abrikosov
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In the mid-1950s, A A Abrikosov studied the hydrogen phase transition from the dielectric molecular to the metallic atomic phases and was also occupied with the structure of hydrogen planets. Moreover, he managed to resolve some contradictions existing at that time in quantum electrodynamics. The corresponding work underlay the content of his Doctor of Sciences thesis, which he defended in 1955. That same year, P L Kapitza appointed him an Academic Secretary of the IPP Scientific Council.

The 1950s was a time of rapid development of quantum electrodynamics and solid state physics. In 1955, together with L D Landau and I M Khalatnikov, A A Abrikosov published a fundamental study which later received the name 'Moscow Zero', where the Green's functions and the effective cross sections of the Compton effect and mutual electron and positron scattering at high energies are calculated. The new computing methods constructed there were based on the summation of main diagram sequences and were later used to solve a number of problems in statistical physics. These methods (together with some other beautiful ideas, for example, the method of analytical continuation of Feynman diagrams from imaginary to real frequencies for obtaining kinetic characteristics at finite temperatures) were developed by A A Abrikosov along with L P Gor'kov and I E Dzyaloshinskii and laid the basis of their book *Methods of Quantum Field Theory in Statistical Physics*. It became a handbook for theoretical physicists in many countries where it was translated and published.

Following the discovery of type II superconductivity, A A Abrikosov in co-authorship with L P Gor'kov and other colleagues obtained some most important results in the newly formulated microscopic theory of superconductivity. Among them was the analysis of the high-frequency properties of superconductors, the elaboration of microscopic methods for studies of electron scattering by impurities, the investigation of the properties of superconductors with magnetic impurities, the discovery of gapless superconductivity, the explanation of the Knight shift, and the calculation of Raman scattering intensity in normal metals and superconductors.

In the 1960s, A A Abrikosov's scientific interests moved towards the theory of normal metals, semimetals, and semiconductors. He was engaged in the Kondo problem, i.e., he studied the conductivity of metals with magnetic impurities and found that, depending on the sign of exchange interaction, the effective scattering either vanishes or increases greatly (this phenomenon is referred to as Abrikosov–Suhl resonance). A A Abrikosov argued the possibility of hydrogen transition to the metal metastable state under high pressure and, together with his colleagues, formulated the theory of bismuth type semimetals and gapless semiconductors. As a result, the crystal structure of semimetals was explained, the types of symmetry allowing a gapless spectrum were found, the spectrum of carriers and its behavior under pressure were analyzed, and the exciton phases in a magnetic field were examined. This work is especially topical today in connection with the discovery of graphene and the related prospects of the development of nanoelectronics. In 1964, at the age of 36, A A Abrikosov was elected a Corresponding Member of the USSR Academy of Sciences. It was, however, 23 years later that he became a Full Member of the Academy.

In the 1970s–1980s, A A Abrikosov participated in the formulation of the theory of quasi-one-dimensional systems and studied the properties of spin glasses. He constructed an original method for calculating the conductivity of a quasi-one-dimensional metal, which permits allowance for electron jumps between filaments and electron scattering by phonons and impurities. A A Abrikosov carried on active scientific, organizational and pedagogical work at the L D Landau Institute of Theoretical Physics (he was one of the founders of this Institute) and also at the Department of Theoretical Physics headed by him at the Moscow Institute of Steel and Alloys (MISA). In 1987, he published a book *Fundamentals of the Theory of Metals* which was based on his brilliant lecture courses delivered at the Moscow Institute of Physics and Technology and MISA. This book is an encyclopedia of the theory of normal metals and superconductors. In the period from 1988 to 1991, he headed the Institute for High-Pressure Physics of RAS.

At the beginning of the 1990s, A A Abrikosov accepted an offer to head the Theoretical Group in the Argonne National Laboratory and left for the USA. The most intriguing problem in condensed matter physics in those days was the explanation of the phenomenon of high-temperature superconductivity, and A A Abrikosov, in close contact with the experimentalists of the Laboratory, devoted himself to studies in this field. They revealed the existence of a specific singularity in the spectrum of cuprate superconductors, after which A A Abrikosov proposed his version of the theory of high-temperature superconductivity that explained and unified the variety of existing experimental findings.

Anybody who had occasion to meet A A Abrikosov, to work with him, to participate in the regular symposia on theoretical physics, organized by him, remembers his erudition and adherence to principles, his excellent talent as a narrator, and splendid writer's gift.

A A Abrikosov will be remembered as a great scientist whose work influenced many fields of physics and paved the way to a new comprehension of superconductivity. He was a very bright man with a brilliant sense of humor, which helped him to overcome the difficult periods of a life so full of events.

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