# Alexei Alexeevich Abrikosov

(1928–2017)

## To the 90th birthday of A.A. Abrikosov

June 25, 2018 marks the 90th anniversary of the birth of Aleksei Alekseevich Abrikosov, the outstanding theoretical physicist of XX century, a 2003 Nobel laureate in physics and winner of numerous other prestigious international prizes, Member of the National Academy of Sciences of the USA, Russian Academy of Sciences (RAS), and foreign Member of the Royal Society of London. For a long time his name is associated with a number of brilliant works and discoveries in condensed matter theory and in quantum electrodynamics (QED). However, Aleksei Abrikosov (in the West — Alex Abrikosov) entered the history of science first and foremost as the creator of the theory of type-II superconductivity.

Aleksei Abrikosov was born in Moscow into a family famous in Russia for establishing a confectionary that served the czar's family. His father, Alexei, Vice-President of the Academy of Medical Sciences, was a famous pathologist entrusted with Vladimir Lenin's autopsy, and his mother, Fanny, was also a well-known pathologist. His uncle Dmitri Abrikosov was the Russian Empire's last envoy to Japan, while his aunt Anna Abrikosova was a Russian Catholic Religious Sister, the foundress of a Byzantine Catholic community, and victim of Stalin's concentration camps.

In 1943, when he was 15, Alexei Abrikosov graduated from high school and entered the Moscow Power Engineering Institute. In 1945, he moved to the Physics Department of the Lomonosov Moscow State University (MSU). Alexei Abrikosov's scientific growth was directly influenced by ingenious theorist Lev Landau. At the age of 19, he passed the Landau's theoretical minimum, and in a year he graduated cum laude from the Physics Department of MSU. In 1950, at the age 22, Alexey Abrikosov defended his PhD thesis devoted to the study of thermal diffusion in fully or partially ionized plasma. Almost two of the subsequent decades of Alexei Abrikosov's scientific work were spent at the Institute for Physical Problems (IPP) of RAS.

In 1951–1952, Aleksei Abrikosov and Nikolay Zavaritsky, an experimentalist from IPP, were engaged in verifying the predictions of the recently developed Ginzburg–Landau (GL) theory of superconductivity concerning critical magnetic fields for thin films.

From Abrikosov's Nobel lecture*: "Nikolay Zavaritskii started to measure the critical field of thin films. Theory and experiment fitted perfectly, including the change of the nature of the transition: first order at larger thicknesses and second order at smaller ones. Everything seemed OK, but Alexander Shalnikov, the boss of Zavaritskii, was not satisfied. He said that the films used by Zavaritskii were bad, since they were prepared at room temperature. The atoms of the metal, evaporated on a glass substrate, could agglomerate, and therefore the film, actually consisted of small droplets. In order to avoid that, Shalnikov recommended to maintain the glass substrate at helium temperature during evaporation and until the measurements were finished. Zavaritskii followed this advice, and the result was a surprise: the dependence of the critical field on the thickness, or temperature (the theory contains the ratio of the thickness to the penetration depth, which depends on temperature), did not fit the predictions of the GL theory. Discussing these results with Zavaritskii, we couldn't believe that the theory was wrong: it was so beautiful, and fitted the previous data so well. Therefore, we tried to find some solution in the framework of the theory itself, and we found it.*

*The equations of the theory, where all entering quantities were expressed in the corresponding units, depended only on the dimensionless "material" constant, which was later called the Ginzburg–Landau parameter κ. Its value could be defined from the surface energy between the normal and superconducting phases. The latter, in its turn, could be calculated from the period of the structure of the intermediate state. These data for conventional superconductors led to very small values of κ and, therefore, the calculations in the paper by Ginzburg and Landau were done for this limiting case. It was also established that with κ increasing the surface energy between the superconducting and normal layers would become negative, and since this contradicted the existence of the intermediate state, such a case was not considered".*

After that, Abrikosov went on to study the magnetic properties of massive second-order superconductors. He managed to find the formal solution of the GL equations for $\kappa > 1/\sqrt{2}$. As a result, Abrikosov 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 Ukraine by Lev Shubnikov & Yuri Ryabinin, and in the Holland by Wander De Haas & Josina Casimir-Jonker in the 1930s, Abrikosov found a remarkable coincidence. These authors, however, explained their data by the inhomogeneity of the specimens without any hypothesis about the nature of such a behavior. Abrikosov's paper appeared in 1957, but the community believed into the vortices and vortex lattice only ten years later, after their direct observations, using the magnetic decoration method.

In the middle of the 50th, Abrikosov along with his great teacher Landau and Isaac Khalatnikov, tried to understand the grounds of QED, based on the assumption of point interaction as the limit of "smeared" one. The calculations involved the exact summation of perturbation series and the derivation of asymptotic expressions for the Green's function. As a result, a formula was found that links the true physical and bare charges. However, an analysis of this formula showed that the physical charge disappears in the limit of point interaction (the so-called "Moscow zero") and the theory loses its meaning. Only 20 years later, papers appeared which suggested schemes (non-Abelian gauge theories) where such a zero is absent.

Late fifties were the exciting period of discoveries in superconductivity, and Abrikosov actively takes part in these studies. In 1959 he, together with Lev Gor’kov, elaborates the microscopic methods for studies of electron scattering by impurities in normal metals and superconductors. One year later they investigate the properties of superconductors with magnetic impurities and discover the unexpected effect of gapless superconductivity: contrary to the widely adopted statement of Bardin–Cooper–Schrieffer theory and Landau criterion of superconductivity, the gap in quasi-particle electron spectrum proves to be not necessary condition for the superconductivity existence as a phenomenon.

In 1959, following the works of Japanese physicist Takeo Matsubara, Arkady Migdal and Victor Galitski, the new temperature diagrammatic technique was developed by Abrikosov, along with Gor’kov and Igor Dzyaloshinskii. It was based on their achievements in QED and some other beautiful ideas: the method of analytical continuation of Feynman diagrams from imaginary to real frequencies, etc. Abrikosov with colleagues continues studies of superconductivity in the newly formulated microscopic approach: Abrikosov, Gor'kov and Khalatnikov derive an equation describing the behavior of superconductors in high-frequency electromagnetic field, the basis for future high-frequency applications of superconductors. Abrikosov and Gor'kov formulate the theory of Knight shift in superconductors, Abrikosov, in coauthorship with Leonid Falkovsky, calculated the Raman scattering intensity upon reflection of light from the surface of a superconductor.

In 1960’s Abrikosov's scientific interests shifted towards the theory of normal metals, semimetals, and semiconductors. He was engaged in the Kondo problem and found that, the effective scattering either vanishes or increases greatly, depending on the sign of exchange interaction. In particular, Abrikosov and Falkovsky formulated the theory of bismuth type semimetals. As a result, the crystal structure of semimetals was explained. It may be also said that Abrikosov’s and Sergey Beneslavskii’s studies of semimetals and gapless semiconductors became a prototype for the future Dirac materials. He was the first who mapped the gapless semiconductor problem on the theory of second order phase transitions.

In 1961, Abrikosov, Gor’kov, and Dzyaloshinskiy published the book “Methods of Quantum Field Theory in Statistical Physics”. This became, in fact, a handbook for theoretical physicists in many countries where it was translated and published.

In the 1970s–1980s, Abrikosov’s scientific interests shifted towards the properties of one-dimensional systems. He predicts the transition of a bismuth-type semimetal to an excitonic insulator in a strong magnetic field, in collaboration with Ivan Ryzhkin develops an original method for calculating the conductivity of a quasi-one-dimensional metal, which permits accounting for electron jumps between filaments and electron scattering by phonons and impurities.

Abrikosov carried on active scientific, organizational and pedagogical work at the Landau Institute of Theoretical Physics (he was one of the founders of this Institute in 1965). In 1987 he published a book “Fundamentals of the Theory of Metals” which was based on his well-known lecture courses delivered at the Moscow Institute of Physics and Technology and Moscow Institute of Steel and Alloys (MISA). This book became an encyclopedia of the theory of normal metals and superconductors. Since 1976 Abrikosov headed the Department of Theoretical Physics at the MISA.

Abrikosov and Khalatnikov together with the scientists of Ilia Mechnikov Odessa University were the organizers of the Odessa symposiums in theoretical physics, which were held since 1961 until the end of 80s. Later, Abrikosov and Moisei Khaikin from IPP organized the biannual schools in “Physics of Metals” conducted in different cities of USSR since 1976 and until 1991. All those, who had the possibility to see and listen to Abrikosov there, to work with him, to take part in the regular symposia on theoretical physics, organized by him, remember his remarkably high erudition, rigorous adherence to principles, and his narrator’s gift.

At the beginning of the 1990s, Abrikosov accepted an offer to head the Theoretical Group at the Argonne National Laboratory and left for the USA. There, in close collaboration with the experimentalists, Abrikosov proposed his version of the theory of high-temperature superconductivity that explained the variety of existing experimental findings.

The last foresight of the great scientist was expressed in his paper devoted to the theoretical analysis of large magnetoresistance in non-magnetic silver chalcogenides, which allowed him to create the theory of quantum magnetoresistance, anticipating the needs of graphene physics several years in advance.

The last Prize in Abrikosov’s life was Vladimir Vernadsky Gold Medal — the highest international award of the National Academy of Sciences of Ukraine. In 2015 Aleksei Abrikosov, a distinguished scientist at the U.S. Department of Energy’s Argonne National Laboratory, was recognized again for his groundbreaking discoveries in the physics of superconductivity. As part of the medal presentation, Director Peter Littlewood read a letter to Abrikosov from Boris Paton, President of the Ukrainian National Academy: “*The National Academy of*

*Sciences values your outstanding contributions to development of the theory of normal and superconducting metals and your very long, active cooperation with Ukrainian scientists*".

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

This issue of the Low Temperature Physics is only a small part of appreciation from his pupils and colleagues, who knew him personally, and will always remember him with gratitude.

*Andrey Varlamov,*
*Vadim Loktev*