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# In memory of Daniil Il'ich Khomskii

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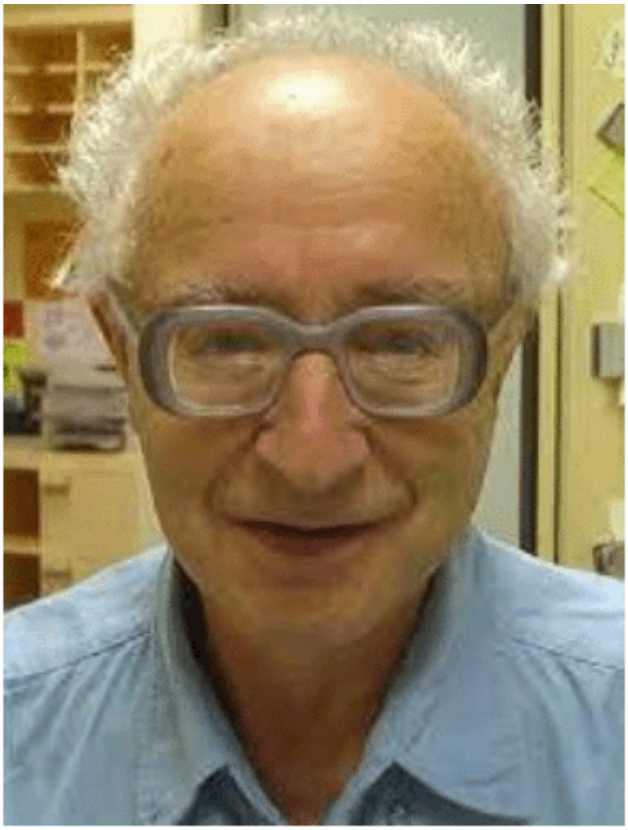
Daniil Il'ich Khomskii — an outstanding scientist and remarkable man — passed away on August 12, 2024. The death of Daniil Il'ich was the result of a tragic incident that had occurred two years before, when a motorcyclist who lost control hit him on the sidewalk. Daniil Il'ich never recovered from the severe injuries he sustained.

D I Khomskii was born on September 18, 1938 in Leningrad. After graduating from the Physics Department of M V Lomonosov Moscow State University in 1962, he was assigned to the Karpov Institute of Physical Chemistry. In 1965, he became a postgraduate student in the Theoretical Department at the P N Lebedev Physical Institute (research supervisor L V Keldysh). In 1969, he defended his thesis for the degree of candidate of physical and mathematical sciences; in 1982, he defended his doctoral thesis. The most important part of D I Khomskii's scientific biography is associated with the Theoretical Department (currently the I E Tamm Theory Department) at the P N Lebedev Physical Institute, where he made his way from a postgraduate student to a leading research fellow. In 1990, he was invited to conduct scientific research at the University of Cologne (Germany); from 1992 to 2003, he worked as a professor at the University of Groningen (Netherlands), and then he returned to the University of Cologne, where he served as professor until his death. While working abroad, D I Khomskii continued to maintain close scientific ties with Russian physicists (theoreticians and experimentalists) and trained a number of world-renowned theoretical physicists. An indispensable participant of many international conferences, scientific schools, and seminars held in Russia, D I Khomskii was for many years the scientific editor of *Uspekhi Fizicheskikh Nauk* and a member of the Bureau of the Scientific Council of the Russian Academy of Sciences on Magnetism. He was also elected a member of the American Physical Society and was an honorary professor of the Universities of Loughborough (Great Britain) and New South Wales (Australia).

In the titles of both his candidate and doctoral theses, Daniil Il'yich made the main emphasis on the properties of systems with strong interelectron correlations, and the identification of the uniqueness and importance of such systems runs through his entire scientific activity. D I Khomskii's works in this area made a fundamental contribution to the theoretical study of the presence of interrelations between spin, orbital, charge, and lattice degrees of freedom in solids and qualitatively changed many ideas in modern condensed matter physics.

D I Khomskii developed a theoretical model that made it possible to consider spin and orbital variables at the same level. Currently, this is one of the standard models of modern condensed matter physics, known to the vast majority of theoretical physicists working in this field as the Kugel–Khomskii coupling; moreover, this rich and diverse field of science is often called orbital physics. In addition, he proposed a concept of effective reduction in the dimensionality of a system due to orbital degrees of freedom (due to this phenomenon, compounds with a three-dimensional crystalline structure behave like low-dimensional magnets) and a theory of the occurrence of spontaneous electric polarization due to charge ordering, and developed a microscopic description of the physical properties of substances that are key to solid state physics, such as $VO_2$, $LaCo_3$, $Cr_2$, and many others.

The scientific legacy of D I Khomskii is not limited to orbital physics alone. In the late 1960s, he was the first to introduce the concept of confinement into solid-state physics (by analogy with the theory of elementary particles), when, during the motion of a current carrier, for example, against the background of an antiferromagnetic order, a 'string' of inverted spins remains behind this carrier. This concept turned out to be very popular in describing metal–insulator transitions and electron phase separation in magnetic materials.



Daniil Il'ich Khomskii
(18.09.1938–12.08.2024)

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Translated by I A Ulitkin

D I Khomskii delivers a report at the International Winter School of Theoretical Physicists Kourovka-XXXVII (Granatovaya Bukhta resort house, Verkhnyaya Sysert settlement, 25 February–3 March 2018).

Daniil Il'ich Khomskii and his portrait (friendly caricature by Leonid Aleksandrovich Maksimov, "the best painter among physicists and the best physicist among painters").

D I Khomskii made a significant contribution to the physics of variable-valence compounds with heavy fermions. In particular, he provided a successful phenomenological description of the thermodynamic and transport properties of heavy-fermion systems in a two-component model, and, within the framework of this model, the features of superconductivity of such systems were clarified. He also studied in detail atomic mechanisms for the formation of mixed valence and heavy-fermion states.

Daniil Il'ich had many important achievements in the theory of superconductivity. Beginning in 1970, he was part of the group led by V L Ginzburg at the Theoretical Department of the P N Lebedev Physical Institute which was engaged in the theoretical analysis of possible mechanisms of high-temperature superconductivity. The result of this work was the collective monograph *Problems of High-Temperature Superconductivity* (Moscow: Nauka, 1977 settlement), the first book in the world on this topic, published long before the discovery of high-temperature superconductivity in cuprates. This book included a chapter written by D I Khomskii jointly with D A Kirzhnits and E G Maksimov, based on their work, in which a very powerful method (called the KMK method in the literature) was proposed for describing the superconducting state in terms of the effective permittivity. This method made it possible to test the limits of applicability of the standard Bardeen–Cooper–Schrieffer approach, to obtain important corrections to it, and to describe more complex situations associated with nonphonon mechanisms of superconductivity. After the discovery of superconductivity in cuprates, he developed a model of the electronic structure of these compounds, according to which the holes that appear as a result of doping are mainly concentrated on oxygen. This model was independently, albeit somewhat later, proposed and developed by Emery and bears his name (unfortunately, not Zvezdin's of Khomskii's).* Daniil Il'ich paid much attention to heavily doped high-temperature superconductors, analyzing the concept of the Mott transition (metal–insulator) as applied to these supeconductors. He showed that the charge redistribution between the $CuO_2$ planes in cuprates and the charge reservoir (chains in 123 cuprates, and Bi and Tl planes in the corresponding compounds) should occur at $T_c$ and below, which can explain many structural and other anomalies observed in these materials.

D I Khomskii also wrote a large series of studies in the field of electron phase separation, the emergence of inhomogeneous states and percolation properties of some systems with strongly correlated electrons. In particular, he showed that the homogeneous skewed state in the double exchange model is unstable with respect to phase separation. Similarly, phase separation can occur in charge-ordered states with a deviation from half-filling (from one electron to two sites) and in compounds with competing spin states. The obtained results were used to interpret many properties of manganites with colossal magnetoresistance and cobaltites with transitions between spin states.

Daniil Il'ich is the author of pioneering studies in the field of multiferroics, materials that combine magnetic and ferroelectric characteristics. Suffice it to say that his 2006 paper on the mechanisms of multiferroic formation and the corresponding 2009 mini-review in the *Physics* bulletin of the American Physical Society have together received more than 3000 citations.

This does not exhaust the breadth and diversity of D I Khomskii's scientific achievements. One can also mention his work on low-dimensional magnets, spin-Peierls systems, and spin-ice-type structures. D I Khomskii published more than 350 scientific papers, including reviews, which, according to Google Scholar, have been cited more than 28,000 times, his Hirsch index being 82.

Last but not least, Daniil Il'ich's cheerfulness, modesty, kindness, and enthusiasm were legendary in our condensed matter physics community. The door in his office was always open to both experimentalists with new results and theoreticians with new ideas. His contributions to collaborative work were always valuable and often decisive for further progress. Daniil Il'ich's knowledge of the world of strongly correlated materials was astounding — behind his back people called him a walking encyclopedia, even when he was well into his 80s. His comprehensive 500-page book, *Transition Metal*

* See the following papers: Zvezdin A K, Khomskii D I "'Chemical' mechanism of electron pairing in metalloxide superconductors" *JETP Letters* **46** supplement, pp. 102–105 (published in June 1987) and Khomskii D I, Zvezdin A K "'Neutral oxygen' and superconductivity of metalloxide systems" *Solid State Communications* **66** (6) 651–655 (1988).

*Compounds* (Cambridge University Press, 2014) was only a small part of the wealth of knowledge stored in his head. His ability to explain even very complex concepts of modern theory quite simply was astonishing, which was clearly demonstrated in many of his reviews and lectures, starting with the first Russian-language review (published in *Physics of Metals and Metal Science*, Vol. 29, p. 31) on the Hubbard model in 1970 (based on his lectures at Kourovka in 1969, when he was still a postgraduate student), which remains one of the best introductions to the problematics of strongly correlated systems to this day, and ending with his remarkable book, *Basic Aspects of the Quantum Theory of Solids* (Cambridge University Press, 2010).

For us, disciples, colleagues, and friends of Daniil Il'ich Khomskii, his demise is a great and irreparable loss, and the memory of him will always live in our hearts.

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