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In memory of Éduard Leonovich Nagaev

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Éduard Leonovich Nagaev, DSc in physics and mathematics, an outstanding expert in quantum solid state theory, died suddenly on 14 December, 2001.

Éduard Leonovich Nagaev was born on 5 April 1934 in the town of Penza, in a family of chemistry engineers. He grew up in Moscow where he got his education. From 1951 to 1956 he was a student of the M V Lomonosov Moscow State University (Physics Department) and majored as an experimentalist at the Low-Temperature Physics Laboratory. His diploma project, with N E Alekseevskiĭ as his advisor, was devoted to measuring the magnetic susceptibility using a Hartshorn bridge. However, Nagaev then found his right place in physics as a theoretician during his postgraduate years (1956 – 1959) when he was investigating the transport properties of ionic crystals and the chemisorption on their surfaces. Even this first work which made up his PhD thesis (1962) manifested the main features of his research method: independent thinking (his first articles, and indeed most of his later publications, were written without co-authors), the ability to formulate original theoretical ideas that would bring together seemingly disparate sets of experimental facts, plus a brilliant command of the mathematical tools of theoretical physics. Nagaev as a theorist was advancing owing to, among other factors, close cooperation with a group of talented young physicists who were taking part in V L Bonch-Bruevich's colloquium on semiconductor physics. Interaction with this physics school greatly expanded the scope of his interests in physics and later led him to the yet unsolved aspects of the physics of magnetic semiconductors. As a matter of fact, É L Nagaev created this exceptionally beautiful field of solid state physics from scratch and was developing it stage-by-stage until the very last days of his life.

Having completed his postgraduate courses and worked for three years at the Research Institute for Electrotechnical Glass, É L Nagaev found the position of senior research scientist at the Research Institute of Current Sources (VNIIT, later reorganized into the NPO 'Kvant' Scientific Production Association). Éduard Leonovich worked at this research institute for almost 30 years; he was immediately recognized there as a talented physics theorist and soon rose to the position of head of the newly created Theory Sector of VNIIT (later transformed to a laboratory). For twelve years from 1966, É L Nagaev read a special course to the students of the Moscow Institute of Physics and Technology, which was very popular with the students, and in fact the students of this institute later formed the core of his laboratory research staff. In 1992 É L Nagaev transferred to the Russian Academy of Sciences, first to the L F Vereshchagin Institute for High Pressure Physics and then, in May 2001, to the Institute of Radioengineering and Electronics.

Éduard Leonovich Nagaev
(05.04.1934 – 14.12.2001)

From 1960 to1970 Éduard Leonovich carried out fundamental work which formed the foundation of the theory of magnetic semiconductors. In 1967 he was able to show that under certain conditions a microscopic ferromagnetic region is formed around a conduction electron in an antiferromagnetic semiconductor, and that this region may move through the crystal. The new quasi-particle was given the name 'magnetic polaron', or ferron. The ferron concept proved to be extremely fruitful. For the first time it was demonstrated that the interaction of conduction electrons with localized spins can result in the formation of a nonuniform ground state. The formation of such thermodynamically stable phase-separated states significantly alters the behavior of electric, magnetic, and optical properties of magnets with itinerant electrons. The interaction of nonuniform states with impurities also becomes essentially nontrivial.

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The recognition of this new physics required the solution of a number of diverse problems for degenerate and non-degenerate magnetic semiconductors, which later formed É L Nagaev's DSc thesis (1971). This research was later described in detail in the monograph *Physics of Magnetic Semiconductors* (Moscow: Nauka, 1979); an extended version appeared in English in 1983 (Moscow: Mir).

The fundamental concept of the nonuniform state in magnetic semiconductors gained wide recognition, which earned É L Nagaev (together with A I Larkin and D E Khmel'nitskiĭ) a certificate for the discovery of "The phenomenon of heterophase localization of conduction electrons in semiconductors".

This concept grew in importance with the passage of time and manifested ever newer facets, for instance in the problem of high-temperature superconductivity. É L Nagaev summarized work in this field in his review written for *Physics Uspekhi* in 1995. The idea of phase separation proved especially fruitful recently, in connection with the discovery of the effect of colossal magnetoresistance in manganites. Éduard Leonovich actively joined the research in this very new field and published a considerable number of original papers and the first-in-the-world literature review on the colossal magnetoresistance effect (*Physics Uspekhi,* 1996). Just before his death he completed and submitted to the publishers the monograph *Colossal Magnetoresistance and Phase Separation in Magnetic Semiconductors* (London: Imperial College Press, 2002).

Another field of É L Nagaev's interest, somewhat connected to magnetic semiconductors, was the theory of magnetic compounds with complex magnetic interactions. What is meant here is a magnetic material in which biquadratic, three- and four-spin exchanges are important, in addition to the Heisenberg bilinear exchange. É L Nagaev also considered conductors with itinerant electrons, where the exchange is essentially of non-Heisenberg form and the effective Hamiltonian with the multi-spin magnetic interaction cannot be constructed in an explicit manner. He was able to show that nontrivial properties of such materials allow description on the basis of the electron Hamiltonian. Éduard Leonovich analyzed this group of phenomena in his book *Magnets with Complex Exchange Interactions* (Moscow: Nauka, 1988) but he often returned to this topic later in connection with, for example, metamagnetism which also proved to be important for systems with colossal magnetoresistance.

Another sizable segment of É L Nagaev's publications dealt with photoinduced magnetism and the magnetoelectric effect, that is, with changes in the properties of magnetic materials in response to light and an applied electric field. He studied various options of restructuring the magnetic structure by light, came up with a kinetic theory of photoinduced phase transitions in magnetic semiconductors and predicted the generation of magnetoelectric waves in ferromagnets. He gave an excellent exposition of these phenomena in a review (together with V F Kovalenko) for *Physics Uspekhi* in 1986.

Éduard Leonovich also made important contributions to the theory of small metal particles. In a way, this was a precursor of the now explosively growing physics of nanostructures and nanocomposites. He showed that as a result of the dependence of the Fermi energy on particle size, the interaction between particles is essentially non-Coulombic. É L Nagaev predicted the existence of a specific interaction forces between small particles, which he called the 'mutual charging forces'. He also explained why mutual charging forces between metal particles are many orders of magnitude stronger than forces between non-metallic particles. He also investigated other specific features of tiny particles, such as adsorption and chemical reactions on their surfaces. The reader will find the details in his reviews for *Physics Uspekhi* (1992) and *Physics Reports* (1992).

The list above does not exhaust the diversity of É L Nagaev's scientific creativity. He importantly contributed to the theory of electron processes in gases and electrolytes, to polarons and excitons, to metal-dielectric transitions, superconductivity, the isotope effect and so forth.

Éduard Leonovich Nagaev was a man of stunning ability at hard work. His normal day comprised 14 to 16 hours of work (and often more, especially when writing reviews and books). He published four monographs and more than 300 journal publications (predominantly without co-authors), of which 14 were reviews.

É L Nagaev's results were widely recognized. In 1984 he won the USSR State Prize. In 1992 he received the P L Kapitza Fellowship of the Royal Society, and from 1997 to 2001 the State Award for Outstanding Russian Scientists. In the last ten years, able at last to travel abroad unobstructed, É L Nagaev regularly delivered invited talks to numerous international conferences and gained prestigious international grants.

The world of Éduard Leonovich Nagaev went far beyond physics. His knowledge of art, poetry and history was overwhelming in its profoundness and professionalism. A dedicated tourist, he canoed down an enormous number of rivers and with knapsack traversed all the mountainous ranges of this country.

The typical style of É L Nagaev was directness and complete rejection of even traces of hypocrisy or insincerity and unfair play. He would never hide his opinion on any subject and would openly express it or publish it in press regardless of the rank of the other party, which caused numerous conflicts, misunderstanding and offense. All this made his life much too complicated and may have led to his untimely death.

In the memory of all us who knew him, Éduard Leonovich Nagaev will live on as a pioneer in science, a brilliant and, as is often said these days, charismatic personality, an immensely honest and painfully vulnerable human being.

A F Andreev, V G Bar'yakhtar, A V Vedyaev, V L Ginzburg,
Yu V Gulyaev, V E Zil'bervarg, Yu A Izyumov,
I K Kamilov, K I Kugel', S G Ovchinnikov,
D I Khomskiĭ, V G Shavrov