

PERSONALIA

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In memory of Yurii Vasil'evich Kopaev

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Full Member of the Russian Academy of Sciences (RAS) and Director of the Division of Solid State Physics of the RAS Lebedev Physical Institute (FIAN in *Russ. abbr*.), Professor Yurii Vasil'evich Kopaev, died tragically on 24 December 2012 in a traffic accident.

We lost a wonderful person loved by everyone, a physically and spiritually beautiful human being who lived and worked flamely and with enthusiasm, applying his extraordinary gift and invariably a grain of his soul to his every undertaking.

The path that led this brilliant scientist to condensed matter physics is anything but typical. After graduating from a rural high school and a technical college of light industry (in 1956), Yu V Kopaev entered the Moscow Institute of Light Industry. It was there that he developed a keen interest in physics, mostly due to the influence of S S Vasil'ev, an excellent teacher, who took part in the early work on studying chain reactions. Yearning to do independent research work led Yu V to transfer in 1959 to the Moscow Power Engineering Institute (MEI in *Russ. abbr*.). While still an MEI student, Kopaev indeed started independent research projects in the Department of Semiconductor Devices. On the recommendation of Professor K V Shalimova (Head of the Department), L V Keldysh, then a young researcher at FIAN, agreed to supervise Kopaev's graduation thesis; this factor played a decisive role in Yu V Kopaev's scientific fate. Having graduated from MEI postgraduate studies in 1964 and after defending his PhD thesis (with L V Keldysh as his supervisor), he went to work in Zelenograd at the Research Institute of Molecular Electronics. The young scientist immediately gained much authority already there: his special talent of actively generating fruitful ideas was obvious, and he generously shared them with colleagues. In 1970, Yu V Kopaev moved on to FIAN's Theoretical Physics Department, where he submitted and defended his Habilitation thesis for a DSc degree in 1972. In 1992, Yu V Kopaev rose to heading the Laboratory of Semiconductor Physics at the FIAN Division of Solid State Physics (OFTT), and in 1995 to directorship of the FIAN OFTT.

In 1964, Keldysh and Kopaev publish their famous paper on the theory of dielectric phase transitions (the Keldysh–Kopaev model), in which they showed that the modified Bardeen–Cooper–Schrieffer (BCS) formalism in the theory of superconductivity can be efficiently applied to describe metal–insulator phase transitions in solids. By analogy with the superconducting transition, the phase transition in the model can be interpreted as a Bose condensation of electron–hole pairs (excitons). Later on, the dielectric phase in the Keldysh–Kopaev model was given the name 'exciton insulator', the term that is now commonly used. The Keldysh–Kopaev exciton insulator model gained the status of the standard method for description of interelectron correlations in the limit of weak interactions. Yu V Kopaev and his co-workers were able to show that the exciton insulator model describes a wide variety of experimentally observable states: charge and spin density waves (band antiferromagnetism), weak ferromagnetism of collectivized electrons, and the ferroelectric state in covalent crystals. They also studied various exotic states that arise in this model: states with spin and charge current waves (orbital antiferromagnetism). This last state is interesting in that under certain conditions it represents a qualitatively new type of ordered state in which the ordering parameter is the density of the toroidal dipole moment (toroidal moments form the third independent family of electromagnetic multipoles, along with the electric and magnetic moments). The hypothesis of spontaneous currents flowing in crystals is currently experiencing a genuine renaissance in connection with the discovery of a new class of solids known as topological insulators. In a topological insulator, spontaneous current (of electrons or spins) flows over the surface of the material.

Yurii Vasil'evich Kopaev
(21.10.1937 – 24.12.2012)

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In 1982, a research team involving Yu V Kopaev submitted the completed project "Prediction, detection, and study of gapless semiconductors and exciton phases," which was awarded the USSR State Prize.

In 2011, Yu V Kopaev was honored with The P N Lebedev Gold Medal of the Russian Academy of Sciences for a series of papers, "Toroidal ordering in crystals."

A notable series of papers written by Yu V Kopaev and co-workers were devoted to studying nonequilibrium phase transitions in semiconductors. Among other things, they suggested and studied in detail the electron mechanism of laser annealing. The destruction of crystal structure is connected with the emergence of structural instability in response to excitation of nonequilibrium charge carriers (nonequilibrium phase transition); it has indeed been observed in a number of semiconductors. This body of work, "The discovery of the phenomenon of pulse-oriented crystallization in solids (laser annealing)," received the USSR State Prize in 1988 (awarded to the team of authors).

In the field of developing the physical foundations of nanoelectronics, Yu V Kopaev and his colleagues formulated new principles of processing and converting information based on the controlled transformation of coherent states in quantum heterostructures that contain tunneling-linked quantum wells, and proposed new types of functionally integrated quantum logic elements. Yu V Kopaev, in collaboration with V F Elesin, developed a microscopic kinetic theory of the quantum cascade laser and suggested design options that result in lower critical currents and increased operating temperature.

A considerable part of Yu V Kopaev's research activities was devoted to investigating the physics of the superconducting state. Much of this research was carried out while he worked at the FIAN Theoretical Physics Department, where he was invited by V L Ginzburg to join the high-temperature superconductivity group. Yu V Kopaev investigated the possibility of constructive interference of dielectric and superconducting correlations long before the discovery of high-temperature superconductivity in cuprates which are, in fact, doped dielectrics. It was shown for the first time that the partial dielectrization of the electron spectrum can result in a considerable rise in the superconducting transition temperature and in changes in the properties of the superconducting state as compared with the standard BCS model. A large body of this research program was published in the collective monograph, *Problems of High-Temperature Superconductivity*, issued in 1977 (editors V L Ginzburg and D A Kirzhnits), which was almost immediately translated into English and published in the USA.

In more recent years, Yu V Kopaev and colleagues suggested and elaborated a new mechanism of superconductivity that takes into account the peculiarities of the electronic structure of HTSC cuprates, which permit superconducting coupling with large total momentum of each pair under shielded Coulomb repulsion. The study of competition and coexistence of the superconducting and dielectric states in HTSC cuprates led to understanding the nontrivial pulse dependence of the superconducting order parameter and to a qualitative interpretation of the phase diagram and key physical properties of cuprates.

Professor Yu V Kopaev devoted much time to training young scientists and engineers. Thirty-eight years of his life were devoted to teaching at the National Research University 'Moscow Institute of Electronic Technology' (MIET) in Zelenograd. He gave the courses 'Solid State Physics', 'Physics of Semiconductors', 'Physical Nature of Biological Fields', 'Disordered Semiconductors', 'Kinetic Processes in Semiconductors', 'Physics Basis for Nanoelectronics', and 'Topological Insulators'. Yu V Kopaev's lively lectures, rich in content and nontrivial, were main events for the many students for whom he opened the door to a life in science. He supervised to 15 successful defences of PhD theses, five of which later extended and transformed to the Habilitation theses. On Yu V Kopaev's initiative, which pre-emptied many ideas of the Federal 'Integration' Program, the joint FIAN and MIET Research & Education Center 'Quantum Devices and Nanotechnologies' was established, which merged the research potential of the FIAN Division of Solid State Physics in solid state physics and the physics of semiconductors and the experience of MIET research workers in developing and designing semiconductor instruments and integrated circuits. In 2003, Yu V Kopaev was awarded the Prize in Education of the President of the Russian Federation. He also received the Order of Honor for his achievements in science.

Yu V Kopaev devoted much of his time and effort to working as deputy editor-in-chief of the *Journal of Experimental and Theoretical Physics*, seated on the editorial boards of the journals *Crystallography Reports* and *Proceedings of Universities. Electronics*, was a member of the Learned Council of the RAS Lebedev Physical Institute and of the Specialized Learned Councils of FIAN, IOFAN, and MIET, chaired the section Theory of the Condensed State under the Presidium of the RAS Science Council on the Physics of Condensed Media, chaired the Expert Council on Physics and Astronomy of the RFBR, and was member of the Commission on Nanotechnologies of the Presidium of the RAS. For many years, Yu V Kopaev organized and chaired monthly meetings of scientific sessions of the Physical Sciences Division of RAS on fundamental problems of physics and acted as Chairman of the International Conference 'Fundamental Problems of Superconductivity'.

Yu V Kopaev's numerous talents, profound erudition, and wonderful human qualities attracted many people to his circle. By the end of his life, the list of his coauthors alone grew to 96. Yu V Kopaev worked, created, and excited others until his very last day. He was always aware of the latest science news, was always ready with a fresh idea ('just thought it up yesterday'), was a role model for the young, and provided support to the older generation. Now that he is gone, what we have left from him is a refreshed FIAN Division of Solid State Physics equipped with modern experimental facilities and technological equipment, an actively expanding program for studying topological insulators, an idea of searching for charged topological insulators in quasi-2D layered compounds with a charge density wave that is waiting for its experimental confirmation. He also left behind numerous disciples and his grateful colleagues, of course a large loving family which meant so much to him, and the memory of him, which we will always cherish.

Zh I Alferov, A F Andreev, A L Aseev,
S N Bagaev, V I Belyavskii, A A Gorbatsevich,
V F Elesin, L V Keldysh, O N Krokhin,
G A Mesyats, N N Sibel'din, Yu A Chaplygin