

## In memory of Boris Yakovlevich Zeldovich

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The corresponding member of the Russian Academy of Sciences (RAS), outstanding Russian physicist, specialist in the field of physical and nonlinear optics, laureate of the USSR State Prize and Max Born Prize, and Fellow of the American Optical Society Boris Yakovlevich Zeldovich passed away at the age of 74 after a prolonged and serious illness on December 16, 2018. B Ya Zeldovich is the author of a large number of pioneering studies, discoveries, and books that brought him wide recognition in the scientific community.

Boris Yakovlevich was born on April 23, 1944 in Moscow into a family of physicists. His father — the famous academician Yakov Borisovich Zeldovich — and his mother — Varvara Pavlovna Konstantinova, a representative of a famous family of physicists — instilled in their children a taste for physics from childhood. Boris Yakovlevich's first teacher was undoubtedly Yakov Borisovich. From his father, Boris Yakovlevich inherited for the rest of his life an uncompromising attitude to science and aversion to careless work.

In 1961 B Ya started his studies at the Moscow State University from which he graduated *summa cum laude* with B S in Physics in 1966. He continued his education at the graduate school of the Institute of Theoretical and Experimental Physics of the USSR Academy of Sciences and received his Ph.D. in Physics in 1969.

While working at the Lebedev Physical Institute of the USSR Academy of Sciences (FIAN), Boris Yakovlevich created several new areas of research that gained worldwide recognition. These included pioneering studies of giant optical nonlinearity in nematic liquid crystals, relationship of the Coriolis force with magneto-optical Faraday effect in the rotating coordinate system, dislocations of the wavefront of light beams, and some others. The most well known in the scientific community was his series of papers devoted to wavefront reversal (WFR). In the English-language literature, this phenomenon is also referred to as phase conjugation or even time reversal. This surprising phenomenon fascinated many researchers in our country and abroad. About 15 to 20 teams from different countries worked over 20 years after the discovery of WFR on its physics and different applications. Along with the conceptual importance of demonstrating the very reality of the reversibility of linear light propagation, many WFR applications were found. They include the correction of amplifying media inhomogeneities in high-power laser systems, analog monitoring of a radiating object, dispersion compensation in telecommunication optical fibers, and many others. For these and other reasons,



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(23.04.1944 – 16.12.2018)

B Ya Zeldovich's first publication (together with V I Popovich, V V Ragul'skii, and F S Faizulov) on WFR [*Pis'ma Zh. Eksp. Teor. Fiz.* **15** 160 (1972)] was given the status of a discovery. Later, the authors of the discovery (already in an expanded team) were awarded the USSR State Prize.

The earlier paper by B Ya Zeldovich and D N Klyshko (*Pis'ma Zh. Eksp. Teor. Fiz.* **9** 69 (1969)), in which they predicted simultaneous radiation by a parametric oscillator of a spontaneous photon pair in a common quantum state, was included in the classical fund of science. The sources of entangled photons are now being used in many advanced quantum technologies, namely, in quantum cryptography, quantum computers, and quantum sensors. Such sources operate exactly the way predicted in that paper.

The work of Boris Yakovlevich on the nonlinear optics of liquid crystals is also now classical. The giant optical nonlinearity in these systems predicted by him together with N V Tabiryan in the 1980s became an independent area of nonlinear optics, where both fundamental and applied uses are being intensely developed.

In 1987, Boris Yakovlevich was elected a corresponding member of the USSR Academy of Sciences. The same year he moved to Chelyabinsk, where he founded a university-academic laboratory of nonlinear optics and which is now a structural subdivision of the Institute of Electrophysics of RAS (Yekaterinburg) and the South Ural State University (SUSU) (Chelyabinsk Polytechnical Institute at that time). Boris Yakovlevich made a decisive contribution to the development at SUSU of professional physical education and, by and large, it was he who founded this line of development. This work of Boris Yakovlevich is now being continued at the Laboratory of Nonlinear Optics and at the Department of Optoinformatics of the Physical Faculty of SUSU. In 1994, Boris Yakovlevich was invited to work at the University of Central Florida (UCF/CREOL) in Orlando, FL, and he moved with his family to the USA. However, his contacts with the Laboratory of Nonlinear Optics in the Urals lasted to a considerable degree.

A great contribution of Boris Yakovlevich was connected to the introduction of a new concept, namely, the spin-orbital interaction of a photon. This is, in fact, the quantum-mechanical interpretation of the term of mutual influence of the polarization of light and its propagation. Before 1991, the influence of the polarization of light upon its trajectory and the influence of the trajectory upon polarization had been examined independently. Boris Yakovlevich's contribution consisted of considering these effects as mutually inverse, and in the framework of such an approach he theoretically substantiated the experimentally observed optical analog of the Magnus effect. The introduction of the new concept of spin-orbital interaction of photons led to the prediction and experimental investigation of new phenomena. The influence of polarization on the trajectory was predicted and experimentally observed in the waist of a focused asymmetric circularly polarized light beam. Almost thirty years have passed since the first publication, but interest in this field has not subsided, and spin-orbital interaction is investigated not only in light but also in electron and neutron beams.

A large series of Zeldovich's studies was devoted to the examination and theoretical substantiation of second harmonic generation in isotropic media. Although from symmetry considerations it follows that the second harmonic generation in such media is impossible, the radiation frequency transformation was revealed quite by chance in an optical fiber. Several teams of scientists, Boris Yakovlevich and his colleagues from the Laboratory of Nonlinear Optics among them, were engaged in this study. Experiments were performed not only on fibers, but also on bulk glasses, and the effect itself was interpreted as a spontaneous violation of local symmetry caused by the nonzero value of cube of electromagnetic field, in turn allowing generation of the second harmonic. Furthermore, the use of the concept of fields with a nonzero cube allowed the prediction, calculation, and observation of polar asymmetry of the angular distribution of electrons.

While most researchers know Boris Yakovlevich for his great discoveries, such as wave-front reversal or seminal optical nonlinearity in liquid crystals, he possessed exceptional ability to bring a theory to modeling in applied research and engineering. At UCF, he continued his fundamental theoretical studies of radiation propagation. At the same time, he collaborated actively with an experimental group studying of holographic optical elements for the spectral, angular, and time control of laser beams and with a start up

company developing and manufacturing these holographic elements. Software developed in Zeldovich's group is currently used in development of holographic hardware. The participation of Boris Yakovlevich—a high-class theoretician—in applied work led to the creation of new optical elements with unique properties, in particular, a laser pulse expander and compressor based on the volume Bragg grating with a variable period (Chirped Bragg Grating). This element does something for which a recent Nobel Prize was awarded—it stretches and compresses laser pulses, providing high-power ultra-fast pulse generation. The new compressor is peculiar for the fact that its volume is a thousand times smaller than that of known compressors, and it is insensitive to shocks and vibrations. This enabled lasers with such compressors to be brought from research laboratories to clinics and industry. As a result, practically all new lasers for cataract surgery are based on Bragg compressors.

Although a well-known scientist, a corresponding member of the Academy of Sciences, the author of studies on wave front reversal, and—later in America—a full university professor, Boris Yakovlevich was very modest, pleasant, and friendly with everybody. He was ready to help and support not only intimate friends but also absolute strangers. He laughed merrily at jokes, inspiring everybody around him. His manner of lecturing was remarkable—without a microphone his voice easily filled any hall, and after the lecture the listeners seemed to have been pumped with knowledge and energy. He liked to discuss scientific problems while writing on paper in large font. He wrote down one equation after another, and with each new formula the problem lessened, and these pages full of equations easily made up an almost ready scientific paper. He did all this so easily and contagiously that, falling under his scientific and personal charm, one would immediately wish to gain deep insight into science and to be able to explain it as brilliantly as Zeldovich did. His gift as a teacher might be compared with his talent as a scientist. He taught everybody physics, always and everywhere. First his friends, then schoolchildren in his physical classes, students at Moscow State University (MSU) and the Moscow Institute of Physics and Technology (MIPT—Phystech), innumerable colleagues and their students, his undergraduate and graduate students, their colleagues and friends, his own children, and the children of his friends! Owing to his teaching talent, many people will bring love and respect to science through their lives.

The wonderful memory of the remarkable scientist and teacher will remain in the lives of those who happened to meet Boris Yakovlevich Zeldovich and to work with him.

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