

E.I. Rashba and the semiconductor theory sector at the L.D. Landau Institute for Theoretical Physics

D. E. Khmelnitskii*

Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom



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A first-hand account of the intense research collaborations and scientific output of E.I. Rashba at the Landau Institute for Theoretical Physics over the period, spanning a quarter of a century (1966–1991), is provided.

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In 1966, E. I. Rashba moved from Kiev to Chernogolovka, near Moscow, to establish the Semiconductor Physics sector at the newly founded Institute for Theoretical Physics. His 25 years of work there became a significant part of his legacy.

At the time, Rashba was 39 years old and had already accumulated extensive research experience in semiconductor physics, semiconductor-based devices, and the physics of molecular crystals. That same year, he was awarded the Lenin Prize, the highest scientific honor in the USSR.

Chernogolovka, located 50 kilometers from Moscow, was home to a newly established research center under the USSR Academy of Sciences. Two institutes had just been founded there: the Institute of Solid State Physics and the Institute for Theoretical Physics, which, 2 years later, was renamed the L. D. Landau Institute.

The leaders of research units at the Landau Institute had several key responsibilities. First, they played a crucial role in establishing the institute as a center for research across all branches of theoretical physics. Secondly, as part of a broader scientific hub, they were expected to collaborate with experimentalists working in various institutions in Chernogolovka. Additionally, they had the opportunity to supervise students at the Moscow Institute of Physics and Technology (Phystech), guiding them toward their Master's and Ph.D. degrees.

Rashba was the only theoretical physicist at the institute with substantial research experience in semiconductor physics. Over the course of 25 years, he led a large and highly active research group—though in 1966, when the institute was just beginning, this was only the start of his journey, along with the rest of the new research center.

While most research units at the Landau Institute were formed around distinguished group leaders, typically surrounded by their former students and long-time collaborators, Rashba took a different approach. Instead of assembling a team from familiar colleagues, he proposed that the institute invite two accomplished researchers who had no prior

research connection with him—Y. B. Levinson and V. I. Melnikov.

Before coming to Chernogolovka, Levinson worked as a senior researcher at the Institute of Semiconductors in Vilnius, while Melnikov, after earning his Ph.D. under the supervision of Z. S. Gribnikov, worked as a junior researcher at the Institute of Semiconductors in Kiev. Upon joining the Landau Institute, both continued to pursue their independent research while also collaborating with Rashba.

Levinson arrived in Chernogolovka with an already well-established reputation for his work on hot-electron kinetics, which had earned him a State Prize. His most significant contribution during 1969–1991 was the development of a theory of nonlocal heat transport in dielectrics, which provided a solution to the so-called Peierls paradox and demonstrated that, as a result of a cascade of phonon-phonon scattering processes, heat conduction displays an essential nonlocality and nonclassical scaling [1].

Melnikov joined as a junior researcher but, during his time in Chernogolovka, he grew into a theoretical physicist of remarkable depth, versatility, and originality. His work—particularly in collaboration with Meshkov on the Kramers escape problem [2] and with Brener and Iordanskii [3] on dendritic growth—is now widely recognized as classic research in the field.

Melnikov's path to these achievements included significant collaboration with Rashba. In 1969, Melnikov and Rashba [4] discovered a new optical phonon mode coupled to the strong-coupling polaron. Two years later, in 1971, they laid out a theory of the effects of elastic electron scattering in semiconductors on electric-dipole spin resonance [5].

Between 1975 and 1977, Melnikov, Rashba, and Gogolin published a series of papers on Anderson localization in one-dimensional (1D) conductors. Interest in this topic at the L.D. Landau Institute arose following the pioneering work of Berezinskii [6]. Gogolin *et al.* [7] demonstrated that a weak interaction between electrons and phonons in a disordered 1D conductor leads to the destruction of localization. They also derived the corresponding conductivity value.

Gogolin and Melnikov [8] further investigated a special case of a disordered 1D metal with a half-filled conduction band. They identified a singularity in the density of states as a function of the Fermi momentum—known as the “Dyson singularity”—and determined how the localization length

*Contact author: dek12@cam.ac.uk

depends on the Fermi momentum near the quarter of the inverse lattice vector. Several collaborative publications with experimentalists [9] explored the application of these theories to the properties of conducting polymers.

Rashba and Levinson [10] also contributed significantly to the training of young physicists, supervising numerous students through their Master's and Ph.D. research. Rashba's students—Edelstein, Gogolin, Meshkov, and Kusmartsev—as well as Levinson's students—Bulgadaev, Kazakovtsev, and Esipov—remained in Chernogolovka, strengthening the theoretical research community in the new center.

A significant portion of Rashba's work was coauthored with experimentalists from the Institute of Solid State Physics (ISSP). His collaborations included studies with V. L. Broude and E. F. Sheka on exciton properties in molecular crystals and with V. F. Gantmakher on magneto-impurity oscillations in semiconductors.

During his 25 years in Chernogolovka, Rashba pursued a diverse range of theoretical studies. Many of these built upon research he had initiated in Kiev. In particular, in collaboration with Gribnikov and Kravchenko, Rashba continued exploring electron kinetics in semiconductors and semimetals with multivalley energy bands [11]. The key observation was that transport in multivalley systems results in a counterflow of currents in different valleys, a phenomenon now known as charge-neutral “valley currents,” observable through the so-called size effect predicted by Rashba and his collaborators and observed experimentally by a group at ISSP.

Working with Edelstein, Rashba revitalized J. Phillips' concept of Mott excitons associated with hyperbolic points in the energy spectrum. Edelstein and Rashba [12] proposed studying hyperbolic excitons in the presence of a strong magnetic field, highlighting the experimental advantages of this setup for exciton observation. Additionally, in collaboration with Meshkov, Rashba [13] investigated the rate of nonradiative transitions on acceptors.

One of Rashba's most influential contributions came through his work with Bychkov [14], where they applied

Rashba's earlier results on spin-orbit interaction (SOI) effects in Bloch electron bands in three-dimensional semiconductors to two-dimensional electron systems. As in previously studied systems, SOI produces band splitting linear in momentum near the Γ point, which makes it a dominant effect at low energies. In addition, in two dimensions the strength of the SOI interaction, as well as its sign, could be controlled by externally applied electric fields, opening multiple avenues for inducing and controlling spin transport. This research had a profound impact on both theoretical and experimental physics, leading to the widely recognized concept of the “*Rashba spectrum*” and earning Rashba the title of “*Father of Spintronics*.”

In the 1980s, Rashba revisited problems related to exciton autolocalization due to coupling with phonons. Collaborating first with S. I. Pekar and E. F. Sheka, then with F. V. Kusmartsev and, finally, with A. S. Ioselevich, he examined the symmetry breaking of the autolocalization barrier due to the Jahn-Teller effect, as well as exciton luminescence and the temperature dependence of the rate of autolocalization [15].

During these 25 years, Rashba published numerous review articles and contributed to several influential books. Together with V. L. Broude and E. F. Sheka, Rashba coauthored *Spectroscopy of Molecular Excitons*. With S. M. Kozel and S. A. Slavatskii, he co-authored *Collection of Problems on Physics*, a book that has been popular and widely used by generations of physics undergrads. Rashba also played a key editorial role in major scientific volumes. Together with M. D. Sturge, he co-edited *Excitons*, a volume in the Modern Problems in Condensed Matter Science series. Later, in collaboration with G. Landwehr, he co-edited *Landau Level Spectroscopy* in the same series.

By 1991, as Rashba embarked on the American chapter of his career, he could look back on the past 25 years as a period of substantial success.

Data availability. No data were created or analyzed in this study.

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