Akakii Melikidze

Description of Scientific Research

The work that I do is mainly concentrated in two partially overlapping fields: The dynamics of topological defects such as superfluid and superconducting vortices and the physics of open quantum systems, i. e. systems which strongly interact with their environment.

Density wave systems in strong electric fields

My early work was concerned with the possibility that density wave materials undergo a transition to a new phase in strong electric fields. This new phase is analogous to the mixed state of type-II superconductors in magnetic field and is characterized by the presence of induced dislocations of the density wave. It was found that the response of density wave materials to strong electric field can be of two types, similar to the two types of superconductors. The type of the response is strongly temperature dependent. In particular, all density wave materials have been predicted to be of type-II in the low temperature limit thus allowing the existence of a mixed state. In the same limit, it was shown that the critical electric field strength is sufficiently small to be accessible experimentally. Such experiments are now being prepared in Princeton in P. M. Chaikin’s lab.

Reference: Akakii Melikidze, *Vortices in density wave systems subject to transverse electric fields*, Physical Review B **58**, 13534 (1998).

Localization in dissipative quantum mechanics

As part of my doctoral research, I have worked on two major projects. The first project dealt with the quantum dynamics of particles in a dissipative medium, such as muons in metals. I considered the localization of such particles on attractive short range potentials. In the absence of dissipation, the well-known solution of this problem helps one to understand the effect that disorder has on transport in various dimensionalities. It turns out that the presence of a dissipative medium leads to much stronger localization. In particular, the bound state of the particle on the attractive impurity exists in all dimensions. This implies that heavy particles moving in a Fermi liquid in the presence of disorder always form an insulator. The results also offer a new perspective on the possibility of strong Cooper pairing in non-Fermi liquid states. Currently, in my collaboration with A. Mishchenko, we study the exact Monte Carlo solution of this model.

References: Akakii Melikidze, *Localization on short-range potentials in dissipative quantum mechanics*, Physical Review Letters **87**, 100401 (2001); *Quantum friction*, published in *Topology of strongly correlated systems*, P. Bicudo et al., Eds. (World Scientific, Singapore 2001).

Magnetic vortices in superconductors

The other project was concerned with the quantum creep of magnetic vortices in type-II superconductors at low temperatures in a regime where vortices are believed to move by quantum tunneling through potential barriers caused by disorder. I studied the tunneling of a single vortex by using a phenomenological description of the vortex dynamics in terms of two forces: the transverse Magnus force and the longitudinal friction force. The dissipation of energy by the friction force strongly complicates the analysis since it requires that the environment, which absorbs the energy, be explicitly treated. An exact solution of a model of dissipative vortex tunneling showed an unexpected result: the minimum of the tunneling probability when the friction force is comparable to the Magnus force. This result has been independently obtained by G.-H. Kim and M. Shin who analyzed a similar model numerically. At present, the experiments by A. J. J. van Dalen et al., which explore the relevant regime, are not conclusive enough to confirm or disprove this prediction.

More recently, I have been trying to understand the peculiarities of the vortex dynamics in d-wave superconductors. It is expected that quasiparticles near the nodes of the gap play a major role. Indeed, it was found that the scattering of the nodal quasiparticles by half-quantum vortices, which is somewhat similar to the Aharonov-Bohm scattering, strongly suppresses the motion of the vortices. By arguing that this so-called orthogonality catastrophe makes a dominant contribution to the vortex action at low temperatures, a simple yet consistent description of the quantum vortex creep in d-wave superconductors has been proposed. In addition, it was found that the effect disappears for doubly-quantized vortices, which suggests an intriguing possible tendency to form exotic states by pairing vortices.

References: Akakii Melikidze, *Exactly solvable model of dissipative vortex tunneling*, Physical Review B **64**, 024515 (2001); *Orthogonality Catastrophe for Vortices in d-Wave Superconductors*, `cond-mat/0212640`.

Decoherence in spin systems

In collaboration with V. V. Dobrovitski, B. N. Harmon, H. A. De Raedt, and M. I. Katsnelson, we analyzed decoherence in a simple spin system. It consists of a compound central system made up of two spins 1/2 and is coupled to a set of spins 1/2 in the environment. This system was found previously to exhibit an unusually slow decoherence at long times. Based on an exact solution of a simplified model, we have been able to identify the parity of the central system, i.e. the fact that the system comprises even number of spin-1/2 entities, as the crucial feature of the model which is responsible for the much slower decoherence. Numerical tests of these ideas showed excellent agreement. The results suggest that compound spin systems should be considered strong candidates for the realization of long-lived quantum states.

Reference: A. Melikidze, V. V. Dobrovitski, H. A. De Raedt, M. I. Katsnelson, and B. N. Harmon, *Parity Effects in Spin Decoherence*, `quant-ph/0212097`.

My current interests also include the theory of shot noise in single-electron transistors in the regime of quantum measurement, the anomalous conductance quantization in weak links, statistical theory of random knots and others.