Popular science summary of the project *Current and spin fluctuations in quantum dot systems*

Progress of miniaturization and research methods has opened a possibility to investigate the physical phenomena taking place in systems of the size of few nanometers (the nanoscopic systems). Phenomena occurring at this scale are different from the ones which we encounter in our daily experience. On the one hand, in nanoscopic systems the quantum mechanical effects, like the quantum interference (e.g. the Aharonov-Bohm effect) may play an important role. On the other hand, dynamics of such systems has a stochastic, i.e. random, character. Due to this fact one can observe strong fluctuations of the measured quantities like current or the magnetic moment. Such fluctuations may provide important information about the nature of the physical phenomena taking place in the system. Moreover, the stochastic processes may lead to completely new physical effects, like the operation of the Maxwell's demons based on nanoelectronic devices, which locally reduce the entropy of the system.

Our attention will be payed to the theoretical analysis of the systems of quantum dots, also referred to as artificial atoms. In such systems single electrons are confined in nanostructures of the size of few nanometers, which leads to the occurrence of the quantized energy levels. Quantum dot systems provide a convenient way to study the physical processes taking place on the nanoscale level due to tunability of their parameters, like the position of energy levels or strength of the coupling to the electrodes, as well as possibility of the relatively easy theoretical description.

One of the aspects of our project will be the investigation of the fluctuations of current flowing through quantum dots. We will characterize such fluctuations using the methods of statistical physics. Special attention will be focused on the application of a novel approach which analyzes the statistical distributions of the waiting times between the subsequent tunneling events. While most of the studies of electronic transport have focused on the properties of the stationary state (for long measurement times), our studies are devoted to a new aspects: processes at short time scales (so called transient currents). This topic has received much attention in the least years, both due to interest in fundamental physical phenomena, and potential applications, for example in analysis of the dynamics of qubits (quantum bits). We will investigate how the current fluctuations are influenced by the effects associated with the quantum nature of the coupling of the quantum dot to the electrodes. One of such effects in the quantum interference, associated with summing of the wave-functions of the electrons travelling on different paths. The other ones are the memory effects, due to which evolution of the system depends not only on its present state, but also its history. Investigation of the fluctuations will enable a deeper understanding of the dynamics of stochastic processes taking place in the studied systems. This is important from the fundamental reasons, especially as similar effects occur not only in quantum dots, but also atoms in resonant cavities, superconducting nanostructures, and maybe even biological systems. Our research is also important from a point of view of potential applications of quantum dot systems in nanoelectronics. For example, we will study whether the quantum effects can reduce the fluctuations in nanoelectronic systems, and therefore increase the predictability of their operation.

Alongside with the charge, an important feature of the electrons is its spin, i.e. the intrinsic angular momentum, associated with its magnetic moment. In the last years it has become possible to observe the fluctuations of the magnetic moment of single electrons in quantum dots. Analysis of such fluctuations provide information about the spin dynamics of the system without necessity of perturbing it, as in magnetic resonance method. Our research will be focused, among others, on the phenomenon of switching between two different phases of the systems – the strongly and the weakly fluctuating. Such processes may play an important role in complex magnetic systems, for example spin chains. It is why it is worthwhile to deepen our understanding of such processes using simple models based on few quantum dots. We want to investigate, for example, whether the analysis of spin noise enable to determine the time scale of switching. Studies of the spin dynamics in quantum dot systems may be also important from a point of view of applications in spintronics, e.g. as qubits in quantum computers.