Project: ***Spin-dependent thermoelectric effects in hybrid nanoscopic systems***

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Objectives of the project

The key objective of the proposed project is theoretical description of the spin-related thermoelectric transport properties in quantum dot-based hybrid systems. Of particular interest will be the search for new thermoelectric phenomena arising from the competition and/or synergy of magnetism, superconductivity and topology at the nanoscale. Fundamental issues regarding the interplay of charge, spin and heat transport through nanoscopic objects will be described and analyzed. The model systems considered for testing the raised fundamental problems related to spin-dependent thermoelectrics will be a quantum dot or a system of coupled quantum dots attached to multiple (two or more) external electrodes possessing different physical properties. The choice of quantum dot systems is dictated by their unique properties and features. Firstly, quantum dot's properties can be easily tuned and controlled in an experiment. Secondly, nanostructures, such as quantum dots, are characterized by completely different and unique thermoelectric response in comparison with bulk materials. Particularly, in nanostructures all the interesting dynamics occur on a scale much smaller than the typical scale over which electrons relax to a local thermal equilibrium. As a consequence, such systems can exhibit much richer physics associated with highly nonequilibrium distributions not accessible in bulk materials. Additionally, due to relatively long decoherence length, the effects related to quantum interference can be also observed. Thermoelectrics aims to find the best way of generating large power with the highest efficiency. Moreover, in addition to this promising application perspective, thermoelectrics also focus on more fundamental issues. In particular, thermoelectric response gives access to a deeper information about electron transport properties of considered nanostructures. Furthermore, hybrid nanostructures, such as quantum dots coupled to external leads of different properties (magnetic, superconducting, topological, etc.) provide the opportunity for a search of novel, earlier unknown, physical properties, especially thermoelectric ones. Thus, our studies will be concentrated on spin-related thermoelectric properties of the considered hybrid nanostructures involving quantum dots coupled to external leads possessing different properties, which interplay or compete with each other. Particularly, we will examine the impact of superconductivity of various symmetry (e.g., s-wave, p-wave), magnetism of metallic ferromagnets and magnetic insulators as well as topological properties of materials on the spin-dependent thermoelectric properties of quantum dot-based hybrid nanostructures.

Methodology

The electron transport and thermoelectric properties of the considered systems will be described theoretically by means of various well-established calculation techniques depending on considered transport regime and/or the physical effects that should be captured. In a general case, for multi-terminal quantum dot-based hybrid systems, each electrode can be hold at different temperature. To describe correctly the thermoelectric response of the system in equilibrium (the differences in temperatures are vanishingly small) and out-of-equilibrium (the differences in temperatures are arbitrary large), non-equilibrium Green's function method will be utilized. It will be modified accordingly to describe thermoelectric properties of the considered hybrid systems proposed in the project. In particular, the analysis of physical quantities such as density of states, transmission probability and conductance, depending on the parameters characterizing the studied systems, will be performed. Accordingly, the thermoelectric quantities both in equilibrium and nonequilibrium will be calculated. The conductance, thermal conductance, Seebeck coefficient, thermoelectric figure of merit and their spin counterparts will be determined. Moreover, another important quantities, such as electric power and thermal efficiency, accessible only in systems being driven out-ofequilibrium, will be also determined. Depending on the considered problem, other computational techniques, including the slave-boson method adequate for describing systems in a strong coupling regime, the real-time diagrammatic technique as well as *master rate* equation method dedicated for a weak coupling regime, etc., which allow for description of thermoelectric properties of systems driven out-of-equilibrium, will be used.

Impact of the project

Comprehensive analysis of thermoelectric transport characteristics will certainly contribute to further development of spintronics, in particular to a better understanding of the fundamental effects and processes responsible for transport properties of hybrid quantum dot systems combining magnetic properties of ferromagnetic metals and/or magnetic insulators from the one side with those arising from proximity to superconductors and/or topological insulators. It is expected that the results will contribute to the intensification of research on hybrid quantum dot systems, partly due to the fact that some aspects of the project will be performed in collaboration with foreign theoretical group.