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"Emergent Relativistic Effects in Condensed Matter - From Fundamental Aspects to Electronic Functionality”

Summary of the research programme

Electronics, and more recently optoelectronics and spintronics, are mostly based on transport and optical properties of conventional semiconductors and metallic systems. The electronic structure of these materials is well studied. While their energy dispersions can be complex, their electronic transport characteristics can often be understood from textbook electronic band models. In the past few years, novel classes of materials have been identified which might enable a paradigm shift for future electronics. Many of these materials have in common that their itinerant electrons exhibit (pseudo-)relativistic behaviour: in graphene, electrons behave as massless Dirac particles, enabling studies of relativistic phenomena “in a pencil trace”. In topological insulators, the electron spin is locked to the momentum, since the relativistic spin-orbit coupling defines the character of the relevant band structure. In novel two-dimensional semiconductors, such as transition metal dichalcogenides, strong spin-orbit coupling locks spin and valley degrees of freedom. Finally, relativistic spin-orbit coupling at interfaces, surfaces and in nanostructures gives rise to spin-orbit fields that influence electrical transport and optics and enable novel topological phenomena.

Here, we intend to investigate the fundamental properties of these special electronic band structures and the emergent relativistic effects they entail or induce. Moreover, our common aim is to explore if and how the Dirac-like band structures and strong spin-orbit coupling in novel material classes and nanostructures can be exploited for future electronic concepts and lead to new, as yet unforeseen functionalities. Following the above objectives, we will develop a strong synergy, fostered by shared expertise among state-of-the art experimental investigations and modern theoretical approaches, to uncover electronic, transport, magnetic and optical properties of a variety of such materials and systems. These include molecules, carbon nanotubes and nanowires, two-dimensional crystals, topological insulators and superconductors. Furthermore, hybrids of these material systems will be in the focus as well as functionalized surfaces and interfaces. We put emphasis not only on steady state phenomena but in particular also on novel (pseudo-)relativistic effects in the time and frequency domain.