Universität Basel

Research Project

Hydronics

Third-party funded project

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Organisation / Research unit
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Department
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Hydrodynamic transport of heat or charge in solids is an exotic phenomenon, discovered more than 50 years ago for the case of coherent thermal transport ("second sound"), that has gained much prominence recently, due to its prediction and experimental observation in low-dimensional materials and nanostructures. While in most materials internal scattering processes lead to diffusive transport, pronounced anisotropy, low-dimensionality, or reduced temperatures can lead to hydrodynamic transport. These include coherent propagation of transport excitations, vortices in the viscous hydrodynamic transport, peculiar dependence on temperature or magnetic field, friction, slip and super-linear dependence of conductance as a function of width. Recent observations of hydrodynamic effects in 2D materials (graphene or 2DEGs) and in anisotropic 3D materials (PdCoO, $SrTiO_3$, WP_2) for both charge and heat are striking, deserve extensive microscopic understanding, and can lead to engineering novel devices.

There are major open key questions addressed in this proposal: i. **Theory and simulation**: Several hydrodynamic transport regimes have been posited - from second sound and coherent transport waves to friction effects in nanostructures. Viscosities can now be predicted and provide a bridge between Boltzmann transport and Navier-Stokes hydrodynamics. ii. **Materials science**: To reach the hydrodynamic regime materials will have to be cleanly fabricated. There is no sufficient understanding of the role of defects or of the influence of substrates and boundaries on the emergence of the hydrodynamic regime. iii. **Experimental physics**: Certain hydrodynamic signatures are yet to be confirmed experimentally, others have been shown only once and need to be reproduced. Oftentimes, evidence of hydrodynamic transport has to be based on several different effects to be conclusive. Further, clean demonstrations need to be developed for the measurement of heat, which pose well-known methodological challenges. iv. **Device engineering**: Materials, for which a hydrodynamic transport regime is expected, often fall into the realm of future device applications for other reasons (*e.g.*, topological protection, high electronic mobility, optoelectronic properties). It is unclear how future, scaled devices will either suffer from hydrodynamics, or can even exploit hydrodynamic transport for device functionality.

These research questions motivate a synergetic approach combining these four areas of science by partnering of four research groups with leading expertise in all these areas. Furthermore, it is proposed to combine the study of ***hydrodynamic*** effects in both ***heat and charge transport*** to exploit obvious synergies, such as the important role of electron-phonon scattering. The project will create a theoretical framework to extract hydrodynamic parameters (*e.g.* the viscosity of a phonon system) from first principles. Materials will be grown and patterned to explore the limitations of designable hydrodynamic systems. Then, materials will be designed by layering and patterning of geometries to control hydrodynamic effects. Experiments will measure second-sound (pump-probe laser spectroscopy), non-local dissipation (scanning thermal microscopy), and quantify thermal, electrical and thermoelectric conductance and magnetoconductance of samples as a function of their dimensions. Finally, basic functional demonstration using 2-terminal and 3-terminal devices will be made showing rectification and drag-effects for heat and charge pumps.

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