Spontaneous thermal Hall conductance in superconductors with broken time-reversal symmetry

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The off-diagonal components of thermal conductance tensor, thermal Hall conductivities (THCs), have extensively been studied in recent condensed matter experiments to investigate fractionalized quantum spin liquids [1], and quantum Hall systems [2]. Under zero magnetic field, THCs spontaneously become non-zero for time-reversal symmetry (TRS) broken systems, and can have contributions from phonons, topologically protected edge states etc. Neglecting the phonon contribution, we focus on the additional bulk effect, impurity pair breaking in TRS broken superconductors. Inspired by Sr_2RuO_4 [3], the low temperature THC was calculated [4] for the chiral p-wave superconductors induced by isotropic impurities. Compared to topological part of THC, this contribution is found to be orders of magnitude larger as it scales with the density of states at the Fermi level. Motivated by other TRS broken superconductors, UPt_3 [5], URu_2Si_2 [6] and $SrPtAs$ [7], we extend the THC calculations to i. finite temperatures ii. other TRS broken order parameters, iii. anisotropic impurities.

For this study, the non-equilibrium quasiclassical (QC) Green's function formalism is utilized. Non-zero THC components, K_{ij}, come from the vertex correction (anomalous Eliashberg propagator) term. This term is obtained by a systematic expansion of the QC transport equation in slowly varying bulk center of mass coordinate to first order. K_{ij} is obtained analytically around the gapless regime ($\epsilon \to 0$) for low temperatures and is numerically calculated for finite temperatures. Concerning the low temperature limit, the QC method can address the formation of impurity bands at low temperatures and allows for non-zero THCs meanwhile the Boltzmann kinetic equation approach fails to describe.

We find that the zero field K_{xy} is non-zero for both p- and d-wave pairing superconductors. Anisotropic impurities scatter the quasiparticles around the gapless regions of Fermi surface forming a momentum dependent impurity band. K_{xy} can be of the same order as the diagonal component (K_{xx}) for varieties of impurity potential strength $\delta_s, \delta_p \neq \{0, \pi/2\}$. We present our results and discuss the experimental implications.

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