Superconducting devices – evaluating the impact of dissipative heating

It is believed that superconducting electronics is the key to the second quantum revolution and therefore understanding the dynamics of superconducting condensate is of high relevance. Apart from conducting electricity with no resistance, another hallmark of superconductivity is the behavior in an external magnetic field. While so-called type-I superconductors screen magnetic fields out of their interior, type-II samples can be penetrated [1] by Abrikosov vortices that carry one magnetic flux quantum each. Upon applying external current, Lorentz force is exerted on the vortices. The movement of vortices leads to dissipation (heating), weakening the condensate. A vortex crossing through a superconducting stripe is trailed by its heat trace. Qualitatively speaking, depending on the thermal coefficients of the material, this may lower the barrier for the entry of a subsequent vortex. This thermal impact, however, is still awaiting a systematic theoretical study.

The master student will be introduced to simulation codes developed in the Condensed Matter Theory Group. The time-dependent Ginzburg-Landau (tdGL) theory [2-3] is to date the best suited tool for studying the dynamics of superconducting condensate at the mesoscale. Although derived as a phenomenological expansion of the free energy in superconducting order parameter and its derivatives, the theory was proven to be strictly linked to microscopic properties [4]. The code has the thermal balance equation coupled to that formalism. The student's task will be to study the vortex crossing through a superconducting stripe or more complex nanoengineered device taking into account the thermal effects. The impact of heating will be determined, depending on thermal coefficients (heat capacity, heat transfer, heat conductivity), superconducting material properties (coherence length), sample size, and external excitations (magnetic field, electric current).

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[3] Kramer, L., & Watts-Tobin, R. J. Theory of Dissipative Current-Carrying States in Superconducting Filaments. Physical Review Letters 40, 1041 (1978).

[4] Gor'kov, L. P. Microscopic derivation of the Ginzburg-Landau equations in the theory of superconductivity. Journal of Experimental and Theoretical Physics 36, 1364 (1959).