Nonequilibrium quantum phase transitions in a two-dimensional itinerant electron system

Aditi Mitra,[1] So Takei,[1] Yong Baek Kim,[1] and A.J. Millis[2]

[1] *Department of Physics, University of Toronto, 60 St. George Street, Toronto, Ontario, Canada*
[2] *Department of Physics, Columbia University, 538 W. 120th Street, New York, NY, 10027*

Abstract

We discuss extentions for a Hertz-Millis-type theory of quantum phase transition to a nonequilibrium case by considering a two-dimensional itinerant electron system sandwiched between two metallic leads held at different chemical potentials. We first show how the problem can be expressed using the Keldysh functional integral, in which the effective action can be written as a theory for the fluctuations of the ordering field. The main result we find is that the renormalization group equations for the system at zero temperature and nonzero voltage are identical to the equilibrium finite temperature case with the "effective" temperature $T_{eff} = \frac{\Gamma_L \Gamma_R}{(\Gamma_L + \Gamma_R)^2} V$. As a consequence, a phase diagram in the plane of T_{eff} and control parameter can be constructed that is very similar to the one obtained in the equilibrium case. For the case of Ising spins, we also derive the equation of motion for the magnetization dynamics in the semi-classical limit and find that the order parameter obeys the Langevin equation in the low-frequency, long-wavelength limit.