Hydrodynamic Modelling of High Mobility 2D Electron Systems

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With electronic transport in metals, Fermi Liquid Theory and Boltzmann Transport stand as cornerstones to understanding the complex interplay between charge carries and the myriad of scattering mechanisms they encounter. In the regime of clean conductors, such as high mobility 2D Electron Gas (2DEG) systems, momentum-conserving electron-electron (e-e) interactions may dominate over all possible scattering mechanisms, where the mean-free path due to these interactions is less than both the width of the conducting channel and the mean-free path due to momentum-relaxing scattering. In such circumstances, commonly referred to as hydrodynamic transport, the collective behavior of electrons emerges, resembling a fluid-like flow rather than discrete single particle effusive motion. Hydrodynamic transport was first theoretically proposed in 1963 by R. N Gurzhi [1,2] and first reported experimentally in a GaAs 2D wire by L. W. Molenkamp and M. J. M. de Jong in 1994 [2,3], and has gained renewed interest in recent years due to the possibility of measuring a quantized dissipation-less viscosity. As shown by Ahn and Das Sarma, the high mobility achieved in GaAs/AlGaAs 2DEGs make it ideally suited to host and study hydrodynamic electron transport [5,6].

In this study, we present a semiclassical hydrodynamic approach to model 2D electron systems, focusing on their collective behavior from the basis of single particle transport. Starting with Boltzmann's equation for a 2DEG with both momentum conserving and relaxing scattering, macroscopic quantities are obtained by taking the continuum limit, resulting in a Navier-Stokes-like equation describing the electron's collective behavior and their viscosity due to e-e interactions. The resulting equations of continuity and conservation are leveraged to determine the electron motion and electric potential profile anywhere in the system when a current is applied. The viscous effects that directly result from our hydrodynamic model predict nonzero nonlocal signals outside of the current path [7].

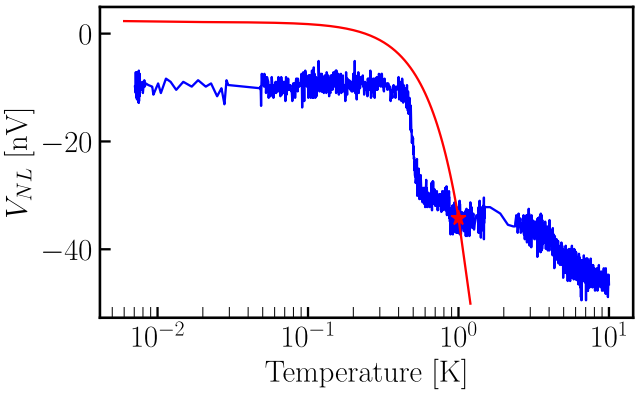

Fig.1. Temperature dependence of nonlocal signals obtained *via* experiment (blue) and simulation (red). The onset of electron-phonon interaction occurs at ~1K, shown starred in red.

We further validated our hydrodynamic model by simulating temperature-dependent nonlocal measurements using the material properties and geometry of a 2DEG Corbino device suspected to exhibit hydrodynamic behavior [6,7]. At the onset of hydrodynamic transport, the nonmonotonic behavior of our 2DEG system closely matched experimental observations [Fig. 1], providing strong agreement between the predicted and observed nonlocal transport characteristics. This agreement underscores the robustness and predictive power of our hydrodynamic modelling in accurately capturing the complex electron transport phenomena in high mobility 2DEG systems.

References

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