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Theory of Coulomb Drag in Spatially Inhomogeneous Materials

Coulomb drag between parallel two-dimensional electronic layers is an excellent tool for the study of electron-electron interactions. In actual experiments, the layers display spatial charge density fluctuations due to imperfections such as charged impurities in the surrounding environment. However, at present a systematic way of taking these inhomogeneities into account in drag calculations has been lacking, making the interpretation of experimental data problematic. On the other hand, there exists a highly successful and widely accepted formalism describing transport within single inhomogeneous layers known as effective medium theory. In this work, we generalize the standard effective medium theory to the case of Coulomb drag between two inhomogeneous sheets and demonstrate that inhomogeneities in the layers have a strong impact on drag transport. In the event of exciton condensation occurring between the layers, we show that drag resistivity takes on a value determined by the amplitude of density fluctuation.
Specializing to drag between graphene sheets in which the existence of spatial charge density fluctuations is well-known, we show that these inhomogeneities play a crucial role in explaining existing experimental data. In particular, the temperature dependence of the experimentally observed peaks in drag resistivity can only be explained by taking the layer density fluctuations into account. We also propose a method of extracting information on the correlations between the inhomogeneities of the layers. The effective medium theory of Coulomb drag derived here is general and applies to all two-dimensional materials.

Figures

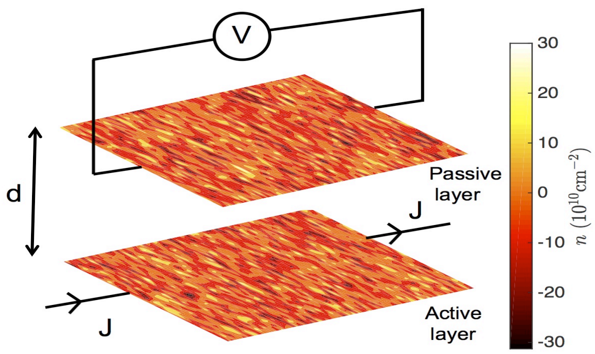

Figure 1: Schematic of Coulomb drag between two inhomogeneous sheets of two-dimensional material.

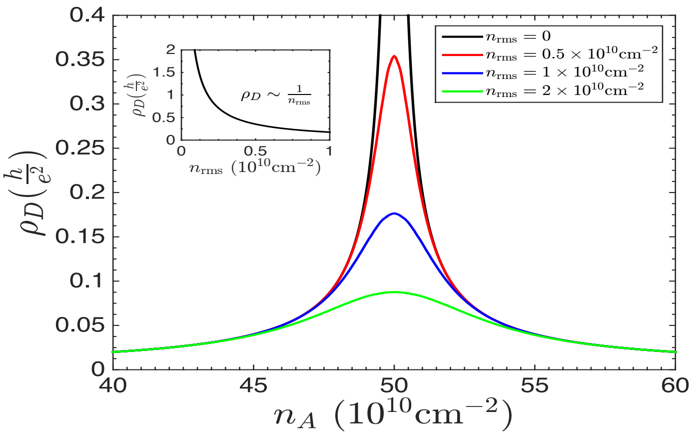

Figure 2: Drag resistivity in the assumed presence of exciton condensation as a function of n_A for charge density fluctuations with different root mean square values $n_{rms}^A = n_{rms}^P = n_{rms}$. n_P is held constant at -50 x 10^{10} cm^{-2}. Inset: Drag resistivity at $n_A = -n_P = 50$ x 10^{10} cm^{-2} as n_{rms} is varied.

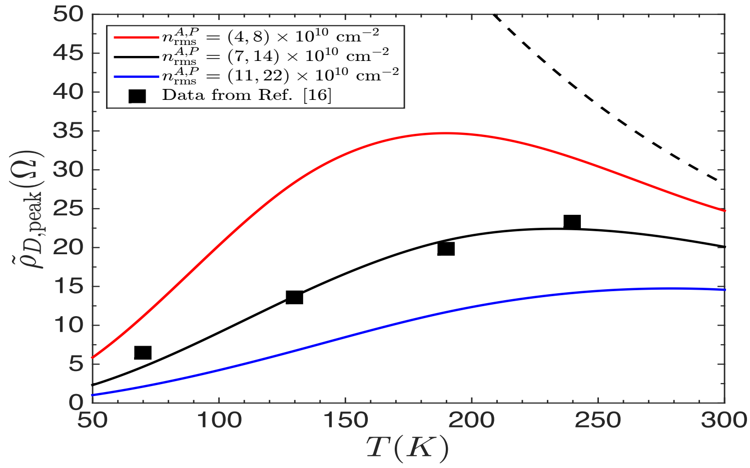

Figure 3: The behavior of the renormalized peaks in drag resistivity for different density fluctuation strengths for uncorrelated inhomogeneities as a function of temperature. The dashed line shows the homogeneous case.

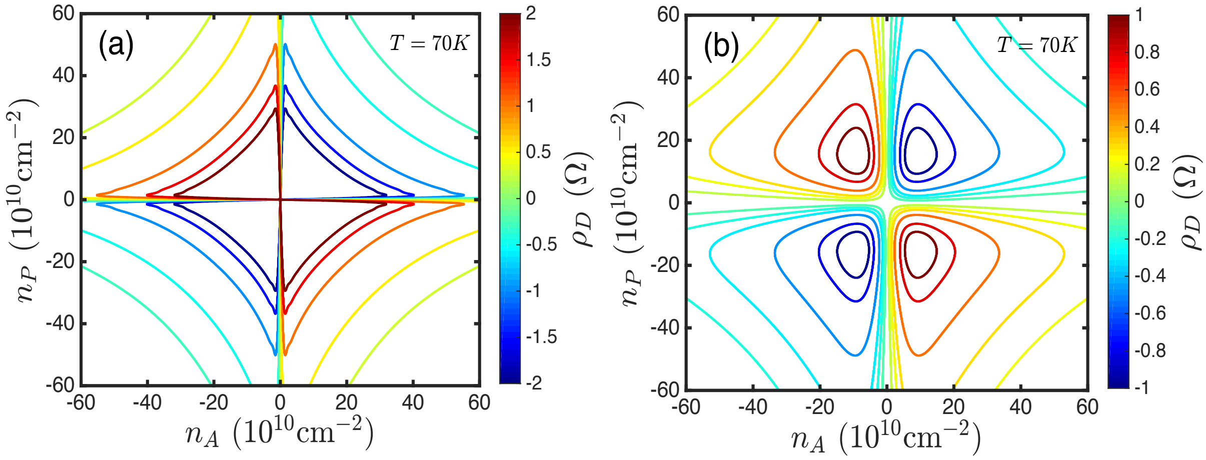

Figure 4: Influence of inhomogeneity on drag resistivity contour lines. (a) The drag resistivity contour lines are strongly concave in the homogeneous case. (b) In the presence of uncorrelated charge inhomogeneity, with $n_{rms}^{A,P}$ = (7,14) x 10^{10} cm^{-2}, the contour lines are straight.