Scattering-Dominated Transport Among Massive and Massless Dirac Fermions.

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The impact of electron-electron scattering on the transport characteristics of various two dimensional (2D) conductors, which do not adhere to Galilean invariance, has garnered significant attention over the years. These studies typically focus on systems that involve two distinct types of charge carriers, characterized by differing charges or effective masses. The presence of two different charge carrier plasma or system, each with distinct masses, poses a challenge to the traditional concept of Galilean invariance. Consequently, the direct proportionality between the net current and the total particle momentum is no longer upheld . Exploring the unique scenarios of strong friction between electrons and holes, particularly in degenerate 2D semimetals, has led to the observation of resistivity proportional to T^2 in HgTe-based quantum well.

In a system comprising two subbands with significantly differing masses, it can be anticipated that the resistivity will exhibit a pronounced increase with rising temperature. This increase occurs due to the relationship between the resistivity limits at high and low temperatures, which is proportional to the effective mass ratio, as described in [1]. In such systems, the dominance of interactions in the transport process surpasses the Drude resistivity resulting from impurity or phonon scattering. The behavior of transport governed by interactions at elevated temperatures is characterized by the principles of hydrodynamics and is often referred to as electronic fluid behavior [1].

In the context of our study, we focus on 2D electrons confined within a triple quantum well (TQW) based on HgTe (fig.1a). This system displays a coexistence of energy bands featuring both linear and parabolic-like spectra at low energy and therefore lacks the Galilean invariance. This research employs a combined theoretical and experimental approach to investigate the transport properties of this two-component system across various regimes. By manipulating carrier density and temperature, we tune our system from a fully degenerate regime, where resistance follows a temperature-dependent behavior proportional to T^2 (fig.1b,c), to a regime where both types of electrons adhere to Boltzmann statistics. In non-degenerate regime electron interactions lead to resistance that is weakly dependent on temperature. Notably, our experimental observations closely align with the theoretical predictions derived in this study. This work establishes the HgTe-based TQW as a promising platform for exploring different interaction dominant scenarios for the massless-massive Dirac system.

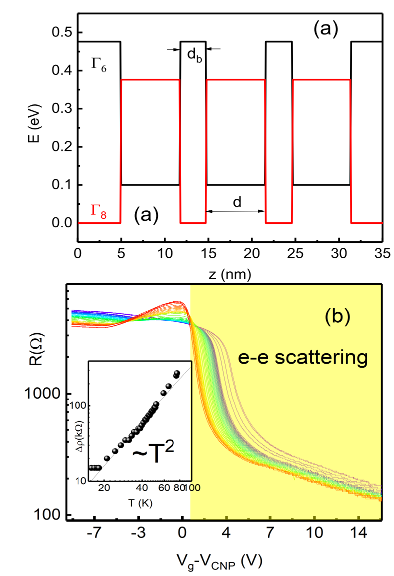

Fig. 1. (a) The conduction and valence band edges of the triple quantum well are schematically shown. The widths d_b of the HgTe wells and the thickness db of the $Hg1_xCd_{x-1}T$ e barriers (x=0.3) are indicated. (b) Resistance as a function of the gate voltage at different temperatures. The insert-the excess resistivity $\Delta\rho(T) = \rho(T) - \rho(T = 4.2K)$ as a function of the temperature for the total density $N_h = 5 \times 10^{11} cm^{-2}$.

References

[1] G. M. Gusev, A. D. Levin, E. B. Olshanetsky, Z. D.Kvon, V. M. Kovalev, M. V. Entin, and N. N. Mikhailov, Phys. Rev. B 109, 035302 (2024).