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Dissipationless electron transport, multicomponent superfluidity and other strongly-correlated quantum many-body states in electron-hole double bilayer graphene

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The recent reported observation[1] in zero magnetic field of electron-hole superfluidity at temperatures of a few Kelvin in two atomically close (~ 1 nanometre separation), but electrically isolated, n- and p-doped bilayer graphene sheets, a system that was first proposed in Ref. [2], raises exciting prospects in the quest for heat-free electron transport in nano devices[3], and for the investigation of the superfluid BCS-BEC crossover in a solid state device.[2,4] By sweeping the carrier densities using metallic gates, the long-range Coulomb pairing interaction strength can be continuously tuned through the crossover regime. The electric fields from the metallic gates also open small, tunable band gaps between the conduction and valence bands of each sheet.

Interesting physics effects arise (a) from the long-range nature of the superfluid pairing interaction, (b) from the associated competition between screening and superfluidity (the condensate pairs are neutral)[4,5], (c) from multicondensate effects arising from the small band gaps[6], and (d) from the potential for high transition temperatures, exploiting the extremely strong electron-hole pair interactions.

In addition to superfluidity, this system is predicted to generate other strongly-correlated quantum many-body states, including a coupled Wigner crystal and a density-modulated one-dimensional charge density wave. [7, 8] However, the recently observed puzzling sign reversals in the Coulomb drag in this system at fixed temperatures around 100 K as a function of density[9,10], are not associated with exotic many-body states, but instead are primarily a result of multiband effects in two-component Fermi liquids. Multiband effects are particularly strong because of the small magnitude of the bandgaps separating the conduction and valence bands.[11]

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