Phase evolution in the spin-incoherent Luttinger liquid

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Electronic transport in non-interacting one-dimensional conductors reveals the quantized conductance in multiples of the universal quantum $2e^2/h$ in the ballistic regime. In experiments, so-called 0.7 structure appears as a quasi-plateau in the conductance at very low electron density in the wire. One of the possible mechanisms is a formation of the Wigner crystal at intermediate temperature $J \ll T \ll E_F$ where J is the exchange constant [1]. This state is called the spin-incoherent Luttinger liquid (SILL) where the electron spins have no correlation but the charge modes are in the ground states.

To examine how the transmission phase evolves in the SILL, we consider a model Hamiltonian $H = H_{2D} + H_{1D} + H_T$ where H_{2D} is the Hamiltonian for the two-dimensional (2D) electron gas, H_{1D} is the Hamiltonian for the one-dimensional (1D) wire, and H_T is the Hamiltonian for the tunnel region between 2D and 1D regions [2]. The tunnel region consists of two different paths forming a closed loop where the phase evolution due to the wavenumber k and Aharanov-Bohm flux ϕ in the magnetic field produces a small oscillating component in the transmission probability which can be simulated by the expression $T(k) = 1 - T_0 \cos(|k|L - \phi)$ where $0 < T_0 < 1$ and L is the length of tunnel path. While the spectral function of the noninteracting Fermi liquid in 1D is simply given by $A_{1D}(k, \epsilon) = 2\pi\delta(\epsilon - \epsilon_k)$, the low-energy spectral density for a finite spin-incoherent wire in zero magnetic field has been obtained by the expression $A_{1D}(k, u) \propto e^{-k^2u^2/2}/\,(5 + 4\cos ka)$ [3] where u represents the fluctuation of electron position and a is the mean spacing of electrons.

The conductance is calculated using the standard tunneling current formula as functions of k_F and ϕ for the normal Fermi liquid and the SILL in 1D. For the normal Fermi liquid, the oscillation shows an ordinary k_F dependence of $\cos(k_F L - \phi)$. For the SILL, the oscillation behaves quite differently due to the peculiar spectral function. For the SILL with large u, the Wigner crystal is formed but electrons are still fluctuating largely around their original position. The spectral function has a single peak at $k \sim 0$ and then the oscillation becomes only weakly dependent on k_F. For the SILL with small u, electrons can fluctuate only a small amount around their original position due to the strong repulsive interaction and a “stiff Wigner crystal” is formed. In this case, the spectral function has large peaks near $k \sim \pm 2k_F$ and then the oscillation shows $2k_F$ dependence as $\cos(2k_F L - \phi)$. In the recent experiment, $k_F \to 2k_F$ shift of the transmission phase in the 0.7 structure has been observed in parallel QPCs [4] and we consider it as an evidence of the Wigner crystallization in the SILL.

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