MAR08-2007-001471

Abstract for an Invited Paper
for the MAR08 Meeting of
the American Physical Society

Observation of spin-charge separation and localization in one-dimensional quantum wires[1]

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We have been able to measure hallmark properties of electrons confined to one-dimensional (1D) wires. Profoundly affected by interactions, the 1D electron liquid is a Luttinger-liquid. Single particle elementary excitations, which survive in spite of interactions in higher dimensions, completely lose their integrity in a Luttinger-liquid. Instead, the elementary excitations of the 1D electron liquid are all collective, with long range correlations and are spin-charge separated. In spite of the drastic influence of electron-electron interactions on the many-body states, the observation of these effects in experiment has been elusive. Our wires were fabricated from a GaAs/AlGaAs heterostructure using cleaved edge overgrowth. The sample I shall discuss contained two parallel wires, 20nm and 30nm thick, which were separated by a 6nm insulating AlGaAs barrier. A series of top gates allowed us to contact each wire separately, and thus allowed us to control both the energy and the momentum of the electrons tunneling between the wires. The resulting tunneling conductance was a direct measure of the spectral function in each of the wires, and thus enabled us to map the dispersions of the 1D many-body elementary excitations. Pushing the wires to low density allowed us to probe the regime where interactions dominate over kinetic energy. In this regime we clearly observed two spin modes and one charge mode of the coupled wires. Mapping the dispersion velocities as a function of decreasing density, we found good agreement between the data and theoretical calculations of the velocity of the antisymmetric charge mode of the coupled wires. The theory also predicted an additional symmetric charge mode, that was not observed. The spin velocities were found, within experimental precision, to be smaller than theoretically predicted. Reducing the density of electrons even further, we found an abrupt transition in the extent of the 1D states along the wires: At high densities they were extended and had well defined momenta, while at low densities they localized as a result of interactions and exhibited Coulomb blockade physics. A simultaneous measurement of the two-terminal conductance, which displayed the typical stepwise drop with decreasing density, showed that a localization transition was concurrent with each conductance drop.

[1]Experiments performed at the Weizmann Institute of Science.

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