# The One-Dimensional Wigner Crystal in Carbon Nanotubes

Vikram Deshpande [1], Marc Bockrath [1]

[1] Mail Stop 128-95 California Institute of Technology, Pasadena CA 91125

In the absence of disorder, a dilute system of carriers interacting through long-range Coulomb forces has been predicted to form a periodic solid called the Wigner crystal. We demonstrate using low-temperature single-electron transport spectroscopy that a low-density hole system in low-disorder carbon nanotubes with a band gap is a realization of the one-dimensional (1D) Wigner crystal. The two inequivalent Dirac points defining the nanotubes' band structure yield an isospin degree of freedom so that the holes act as a spin and isospin chain. We find three distinct regimes as the applied axial magnetic field and carrier density are varied : a fully spin and isospin polarized regime, an isospin-polarized, spin antiferromagnetically-ordered regime, and an unpolarized regime. These regimes arise from a competition between exchange and magnetic energy in the spin and isospin chain. We account for our observations quantitatively using the gapped Luttinger-liquid model of Levitov and Tsvelik, where carriers are represented by solitons. We also observe unexpected behavior of the Kondo effect, which we attribute to the interplay between the spin and isospin degrees of freedom that yields larger spin states than would be predicted using a shell-filling picture. Our observation provides a clean platform for testing theories of interacting electrons in 1D and also indicates the possibility of using this many-body state for solid-state quantum information processing.