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The One-Dimensional Wigner Crystal in Carbon Nanotubes[1]

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Electron-electron interactions strongly affect the behavior of low-dimensional systems. In one dimension (1D), arbitrarily weak interactions qualitatively alter the ground state producing a Luttinger liquid (LL) which has now been observed in a number of experimental systems. Interactions are even more important at low carrier density, and in the limit when the long-ranged Coulomb potential is the dominant energy scale, the electron liquid is expected to become a periodically ordered solid known as the Wigner crystal. In 1D, the Wigner crystal has been predicted to exhibit novel spin and magnetic properties not present in an ordinary LL. However, despite recent progress in coupled quantum wires, unambiguous experimental demonstration of this state has not been possible due to the role of disorder. We demonstrate using low-temperature single-electron transport spectroscopy that a hole gas in low-disorder carbon nanotubes with a band gap is a realization of the 1D Wigner crystal [1]. We observe for the first time three distinct regimes as a function of carrier density and axial magnetic field: (I) a completely spin and isospin polarized state, (II) an isospin polarized, spin antiferromagnetic state, and (III) an unpolarized state with a four-fold addition energy period. The transitions among these regimes can be quantitatively and intuitively explained using a Wigner crystal picture based on a gapped LL model [2] with the carriers represented by spatially localized solitons. 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. [1] V. V. Deshpande and M. Bockrath, arXiv:0710.0683v1 [cond-mat.str-el] [2] L. S. Levitov and A. M Tsvelik, Phys. Rev. Lett. 90, 016401 (2003)

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