Imaging the Quantum Wigner Crystal of Electrons in One-Dimension

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Abstract

The quantum crystal of electrons, predicted more than eighty years ago by Eugene Wigner, is still one of the most elusive states of matter. Experiments have searched for its existence primarily via measurements of macroscopic properties, but since these resemble those of non-interacting electrons, a clear-cut observation of this crystal is still lacking. In this talk, I will present our recent experiments that observe the one-dimensional Wigner crystal directly, by imaging its charge density in real space. To measure this fragile state without perturbing it, we developed a new scanning probe platform that utilizes a pristine carbon nanotube as a scanning charge detector to image, with minimal invasiveness, the many-body electronic density within another nanotube. The imaged density looks utterly different than that predicted by single-particle physics, but matches nicely that of a strongly interacting crystal, in which the electrons are ordered like pearls on a neckless. The quantum nature of the crystal emerges when we explore its tunneling through a potential barrier. Whereas for non-interacting electrons only a single electron should tunnel across the barrier, images of the density change upon tunneling show that in our system a small crystal tunnels collectively, involving the motion of multiple electrons. These experiments provide the long-sought proof for the existence of the electronic Wigner crystal, and open the way for studying even more fragile interacting states of matter by imaging their many-body density in real space.

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