WIGNER MOLECULES IN SEMICONDUCTOR QUANTUM DOTS AND TRAPPED ULTRACOLD BOSONIC CLOUDS

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Strongly correlated phenomena associated with symmetry breaking in small finite-size systems will be reviewed [1], with a focus on the strongly correlated regime of electrons in two-dimensional semiconductor quantum dots (QDs; often referred to as artificial atoms and molecules) and trapped ultracold bosonic atoms in harmonic traps. The talk will emphasize universal aspects and similarities of symmetry breaking found in these systems, as well as in more traditional fields like nuclear physics and quantum chemistry.

A complete description of the strongly correlated regime requires approximations beyond the mean-field level. A unified description of strongly correlated phenomena in finite systems of repelling particles (whether fermions or bosons) has been achieved through a two-step method of symmetry breaking at the unrestricted Hartree-Fock (UHF) level and of subsequent symmetry restoration via post Hartree-Fock projection techniques [1]. The general principles of the two-step method can be traced to nuclear theory (Peierls and Yoccoz) and quantum chemistry (Löwdin). Quantitative and qualitative aspects of the two-step method are tested and validated by large-scale exact diagonalization calculations.

I will discuss how this method can describe a wide variety of novel strongly correlated phenomena. These include:

(I) Chemical bonding, dissociation, and entanglement in quantum dot molecules and in electron molecular dimers and trimers formed within a single elliptic QD, with potential technological applications to solid-state quantum computing.

(II) Electron crystallization along the vertices of concentric polygonal rings and formation of rotating Wigner molecules (RWMs) in circular QDs. At zero magnetic field (B), the RWMs rotate rigidly; at high B, the RWMs exhibit a non-rigid rotational inertia, with the rings rotating independently of each other.

(III) At high B, the two-step method yields analytic many-body wave functions, which are an alternative to the composite-fermion and Jastrow-Laughlin approaches, offering a new point of view of the fractional quantum Hall regime in QDs.

(IV) Description of crystalline phases of strongly repelling ultracold bosons (impenetrable bosons/ Tonks-Girardeau regime) in 2D rotating harmonic and toroidal traps.

Recent applications concern: (1) symmetry-conserving rotating vortex clusters that incorporate quantum fluctuations beyond the broken-symmetry Gross-Pitaevskii vortex solutions [2]; (2) interpretation of non-universal phase lapses in electron transmission through a quantum dot [3]; (3) fractional-quantum-Hall-effect analogies and differences in graphene quantum dots at zero magnetic field [4].

References

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