Addition spectrum of few-electron dots — electron molecule, MDD and FQH states

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The correlated electronic state in a few-electron quantum dot, which has been envisaged as an artificial atom[1], is theoretically investigated here for various numbers of electrons and over a wide range of magnetic fields, and compared with experimental results for the dot with a pillar structure. The states considered include the electron-molecule (spontaneous electron configuration rotating in the dot), maximum-density droplet (MDD) and fractional quantum Hall (FQH) liquid.

To explain the data accurately for various numbers of electrons a realistic form of the electron-electron interaction in the dot has turned out to be necessary, where the effects of finite thickness, screening, image charges, gate-voltage dependence of the confining potential are incorporated. The modified interaction, which differs considerably from the bare or screened Coulomb interactions conventionally used to study quantum dots, is finite at short range and decreases like r^{-3} at long range.

Energy spectra, chemical potentials and addition energies are then calculated by exact diagonalization of the Hamiltonian. The theoretical result for the chemical potential $\mu_N = E_N - E_{N-1}$, shown in figure 1 (bottom frame), is then compared with the experimental result obtained from the gate-voltage dependence of the current through the dot (top frame). For the first time, very good agreement is obtained for both the magnitude of μ_N and the position of features, such as the boundaries of the MDD (for $\nu = 1$; dashed lines) and other transitions (arrows) for higher magnetic fields ($\nu < 1$). A theory based on pure Coulomb interactions would be incapable of explaining the position of the features *and* the magnitude of μ_N, and we specifically identify the effects of finite thickness and screening that are important factors in reproducing experimental results.

A very high field regime, $B > 14$ T, has also been investigated, where we have in particular compared the addition energies calculated in the electron-molecule theory[2] with the exact-diagonalization result for up to 8 interacting electrons. The electron-molecule result is remarkably accurate in the high-field regime for small numbers of electrons. For larger numbers of electrons some molecular peaks disappear at the fields for which the 1/3 FQH state would occur in the bulk 2DEG, which we identify here as an analogue of FQH states in a dot.

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[2] P.A. Maksym, H. Imamura, G. Mallon, and H. Aoki, J. Phys. Condens. Matter **12**, R299 (2000).

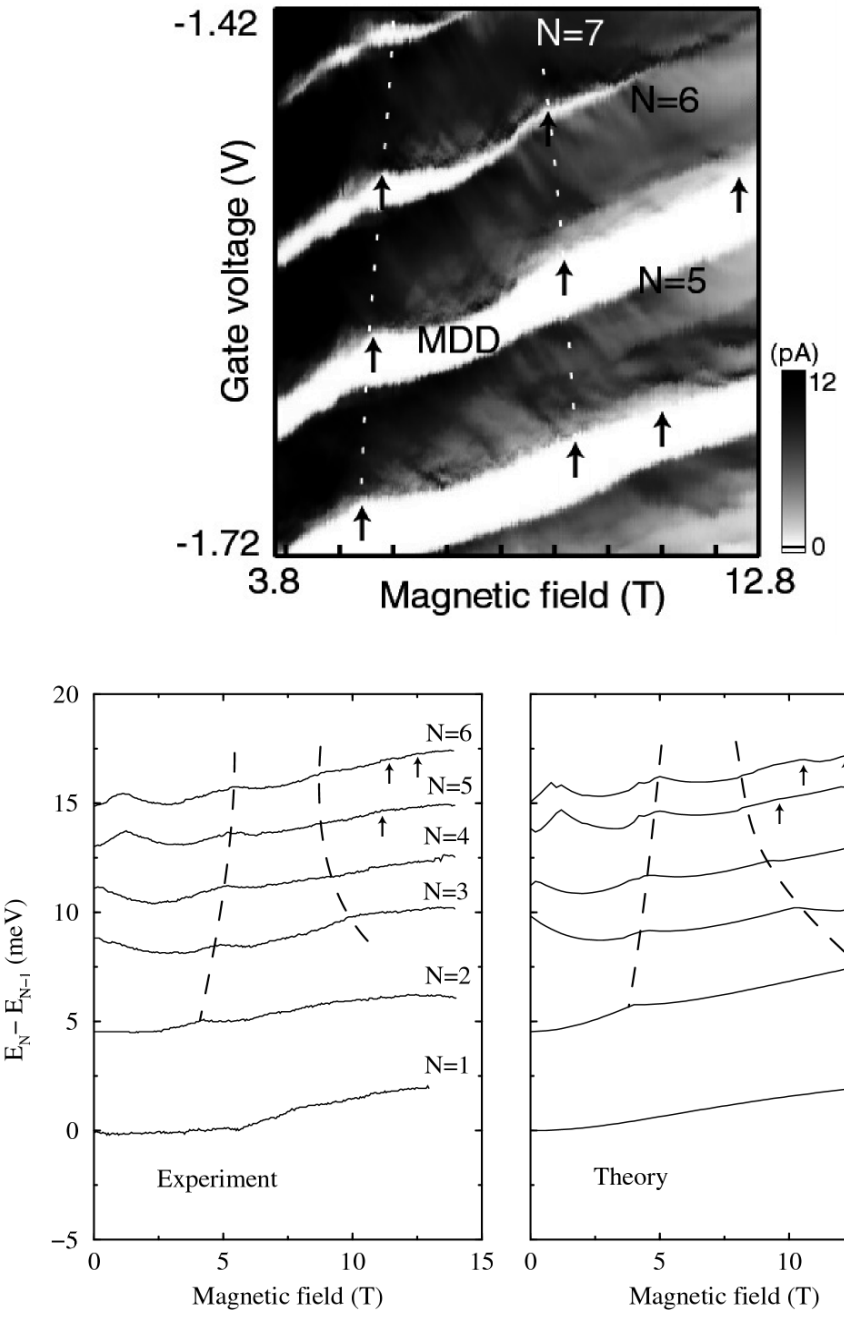

Figure 1: Typical experimental current as a function of gate voltage and magnetic field (upper panel), and a comparison of experimental and theoretical chemical potential (lower). Dashed lines indicalte MDD regions, arrows other transitions.