Spin structures in inhomogeneous fractional quantum Hall systems

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Formation of domains in highly correlated fractional quantum Hall states is the anticipated explanation of the huge longitudinal magnetoresistance (HLM) phenomenon. We use a finite size model employing exact diagonalization to see how domains build up and to study their properties. Although there has been tremendous experimental effort to investigate HLM and its applications [1] there is, to our knowledge, no established theoretical model which allows for understanding the fundamentals of the HLM.

The HLM phenomenon [2] can be used to measure indirectly polarization of nuclear spins in GaAs/GaAlAs heterostructures by means of conductivity measurements rather than by e.g. NMR [3]; applications in quantum computing are not far to seek. The HLM has been experimentally studied on high–mobility two–dimensional electron gases in the fractional quantum Hall regime (filling factor $\frac{2}{3}$) where the ground state is known to be unpolarized in the total spin for lower magnetic fields and spin polarized for higher magnetic fields [4]. If inhomogeneity is introduced domains are thus likely to form at fields near to the ground state transition (Fig. 1). Note that the domains should be distinguished in terms of the total spin (a two–particle observable) rather than e.g. z–component of the total spin or polarization [$p(x) = (n_\uparrow - n_\downarrow)/(n_\uparrow + n_\downarrow)$; i.e. one–particle observables].

We extend the standard model developed by Yoshioka *et al.* [5] (finite size system in toroidal geometry) by adding magnetic modulation (mimicing an underlying field of nuclear spins). The inhomogeneous magnetic field (acting only on spins; i.e. spatially varying Zeeman splitting) is taken to have both perpendicular and in–plane components, this is necessary to make the crossing states mix. Electrons thus effectively experience different magnetic fields in different parts of the system and the local expectation value of the total spin $\langle S\rangle(x)$ is not spatially constant (see Fig. 2). We find that $\langle S\rangle(x)$ resembles the modulation profile near the ground state crossing (also in Fig. 2), even in a system with long–range correlations; this shows a tendency to build domains. The local expectation value of S_z follows approximatelly $\langle S\rangle(x)$ while the polarization $p(x)$ shows no remarkable features. Particle densities also become inhomogeneous far beyond the level of finite size effects. The shape of the modulation (hard–wall or cosine–like, various alignment of the perpendicular and in–plane part) has no dramatic effect on the observed structures. The amplitude of $\langle S\rangle(x)$ is proportional to the amplitude of the magnetic modulation provided the inhomogeneity is weak. We also investigated systems with short–range interaction instead of Coulomb interaction where finite size effects are suppressed.

References

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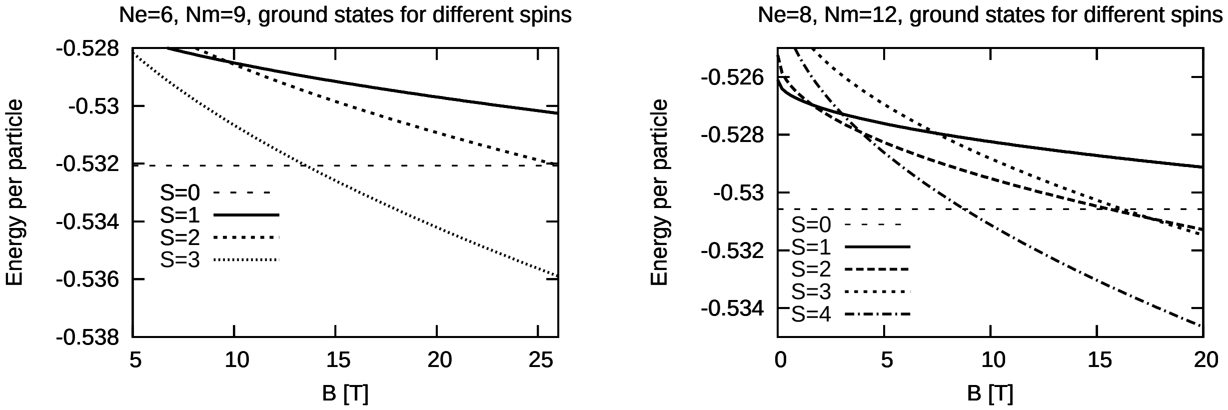

Figure 1: Homogeneous six– and eight–electron system at filling factor $\frac{2}{3}$. Transition from the spin unpolarized ($S = 0$) to spin fully polarized ground state ($S = N_e/2$, N_e is the number of electrons in the finite system) when the Zeeman splitting increases. Energy units are $e^2/(4\pi\varepsilon\ell)$, $\ell^2 = \hbar/(eB)$.

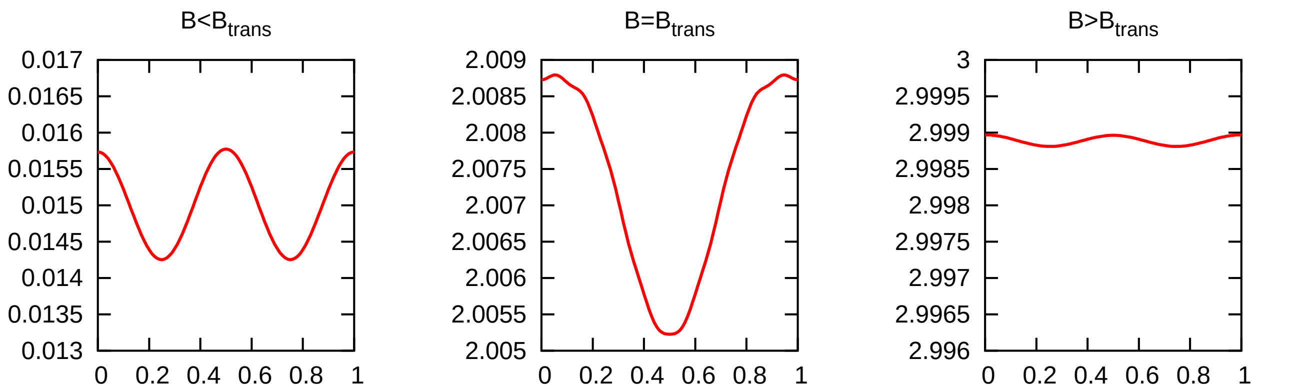

Figure 2: Local expectation value of the total spin (averaged over 3-fold nearly degenerated ground state), $\langle S\rangle(x)$ for a six electron system where Zeeman splitting varies along x–direction (Zeeman splitting is larger at $x \approx 0 \equiv 1$ and smaller at $x \approx 0.5$). $\langle S\rangle(x)$ approaches the values of homogeneous system when B is far from B_{trans} (ground state crossing at Fig. 1). Fluctuations are enhanced at $B \approx B_{trans}$ and they mimic the spatial variations of the Zeeman splitting.