Exact diagonalization studies of composite fermions with spin

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Almost all fractional quantum Hall (FQH) states observed in the lowest Landau level (LL) occur at filling factors of the form $\nu = n/(2pn+1)$, where $n \neq 0$ and $p>0$ are integers. They are understood as integral quantum Hall states of "composite fermions" (CFs), particles consisting of electrons binding an even number ($2p$) of vortices of the many-electron wave function and filling n Landau-like "Λ levels" (ΛLs) in an effective magnetic field B^*.

In strong magnetic fields and in typical host materials, the single-electron Zeeman spin splitting E_Z is often sufficiently large to ensure complete spin polarization of the system, and then the CFs may be considered as fermions with (effectively) no spin freedom. However, if either magnetic field is weak or the effective gyromagnetic factor g^* of the host material is small, the regime of low E_Z may be realized, in which the degree of spin polarization depends on electron correlations and varies in a nontrivial manner as a function of filling factor ν.

In fact, the structures purposefully designed to provide full control over g^* in the FQH regime have been recently realized and investigated [1]. The theory of FQH effect in this case involves the CFs carrying (like the electrons) spin σ=1/2.

In this paper we present the results of extensive exact diagonalization studies of FQH systems with arbitrary spin polarization. The calculations have been carried out in standard spherical geometry, but using a recently improved algorithm, which allowed the treatment of sufficiently large systems to test the CF theory with spin. In particular, we have confirmed: (i) formation of condensed FQH states with different polarization and their competition as well as the connecting spin transitions (induced by variation of relative strengths of Zeeman and Coulomb energies); (ii) emergence of spin waves identified as CF-excitons; (iii) emergence of CF quasiparticles carrying spin and their interaction with spin waves, giving rise to large spin textures, related to skyrmions in the underlying uniform ground states. We have also extracted from the computed spectra the pseudopotentials of effective CF-CF interactions (with spin) in or between different ΛLs, important for the emergence of the "second generation" of FQH effect at such fractions as ν=4/11 or 3/8.

[1] Ch. Betthausen et al., private communication.