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Spin transitions in the fractional quantum Hall systems

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Abstract

We study the electron spin polarizations of fractional quantum Hall states by numerically diagonalizing the Hamiltonian for finite systems in the spherical geometry. At Landau level filling fractions $\nu = \frac{2}{3}$ and $\frac{2}{5}$ we find spin unpolarized ground states at low magnetic fields and fully polarized states at high fields. Close to the transition points, we find indications of stable states with *intermediate* spin polarization. Our results are in a qualitative agreement with the recent experiment of Kukushkin et al. [Phys. Rev. Lett. 82 (1999) 3665]. © 2000 Published by Elsevier Science B.V. All rights reserved.

Keywords: Fractional quantum Hall effect; Spin transitions

1. Introduction

In the fractional quantum Hall effect [1] (FQHE) the combination of small Zeeman energies and strong electron–electron interactions provides us interesting possibilities to explore the electron spin degrees of freedom in two-dimensional electron systems [2]. It has been known for quite some time [3,4], that spins may deviate from being fully polarized at certain filling fractions. Observations of spin transitions from unpolarized or partially polarized states to fully polarized states have, indeed, been reported at several filling fractions [5,6] by measuring the magnetic field dependence of the excitation gap.

A detailed experimental picture on magnetic field driven spin transitions has emerged just recently [7]. Interestingly, the experimental data at Landau level filling fractions $\nu = \frac{2}{3}$ and $\frac{2}{5}$ reveal features of stable *half-polarized* states in between the unpolarized and fully polarized phases. These observations are quite remarkable, because such half-polarized states have, as yet, not been found to appear either in experiments [5,6] or numerical studies [2–4,8,9] of the two-dimensional electron gas. Furthermore, the conventional noninteracting composite fermion picture fails to explain these features.

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2. Model and results

Our numerical diagonalizations at $\nu = \frac{2}{3}$ and $\frac{2}{5}$ are done in the spherical geometry [8,9] with Coulomb interaction and spin degrees of freedom properly included. As found in Ref. [10], a class of singlet, angular momentum $L = 0$ ground states appears when the number of flux through the surface of the sphere is $N_\phi = m(N-1) + \alpha N/2$, with m an odd integer and $\alpha = \pm 1$. The half-polarized states at this N_ϕ appear as excited states and might explain, as shown below, the novel features observed recently [7].

In Fig. 1(a) and (b), we present our results for the energy per electron E/N for unpolarized, half-polarized, and fully polarized states at $\nu = \frac{2}{3}$ and $\frac{2}{5}$, respectively. The Zeeman energy is ignored here. In the thermodynamic limit, the half-polarized states have indeed lower energies than the fully polarized states. Our bulk estimates[1] for the energy per electron E/N are:

ν	Unpolarized	$\frac{1}{2}$-Polarized	Polarized
$\frac{2}{3}$	− 0.5267	− 0.5224	− 0.5179
$\frac{2}{5}$	− 0.4391	− 0.4360	− 0.4326

in units of $E_c = e^2/\varepsilon\ell_0$.

[1] Bulk limit was obtained by fitting a quadratic polynomial of variable $1/N$ to the exact energies. For half-polarized states only linear extrapolations could be performed.

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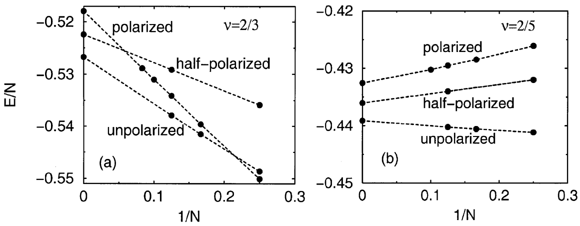

Fig. 1. Extrapolations of E/N for unpolarized, half-polarized, and fully polarized (a) $\nu = \frac{2}{3}$ and (b) $\nu = \frac{2}{5}$ states in the spherical geometry. The unit of energy is $e^2/\varepsilon\ell'_0$, where $\ell'_0 = (\nu N_\phi/N)^{1/2}$.

When the Zeeman energy $Z = |g|\mu_B B$ is taken into account and increased from zero, the singlet states become eventually unstable against higher polarized states. Among the different polarizations considered here, we find that the half-polarized state at $\nu = \frac{2}{3}$ is locally stable for $0.0172 < Z/E_c < 0.0180$. Similar stability at $\nu = \frac{2}{5}$ appears for Zeeman energies $0.0124 < Z/E_c < 0.0136$. These findings agree qualitatively with the recent experiment [7].

We may classify our states somewhat further. Interesting quantity is the total angular momentum L of the system. While the unpolarized and fully polarized states have $L = 0$, our half-polarized states satisfy $L - S = 0$, where S is the total spin of the system. This suggests, that the symmetry of the half-polarized states is quite different from the unpolarized and fully polarized FQHE states which are, of course, isotropic.

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