Spontaneous magnetization of composite fermions in second Landau level of graphene

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Composite fermions (CFs) are topological quasiparticles emergent in two-dimensional (2D) electron systems in high magnetic fields when electrons are confined in a degenerate Landau level (LL). Roughly speaking, a CF is an electron binding a portion of the external magnetic field in form of an infinitely thin solenoid carrying flux $2p{\cdot}hc/e$; more precisely, it is a bound state of an electron and an even number ($2p$) of quantized vortices of the polynomial many-body wave function. The emergence of CFs underlies fractional quantum Hall effect (FQHE); indeed, almost all observed FQH states occur at filling factors $\nu = n/(2pn\pm1)$, which correspond to n completely filled CF LLs (called ΛLs).

Like electrons, CFs also have spin. Different configurations of filled ΛLs are possible, labeled by $n_\uparrow$ and $n_\downarrow$. For a given $n = n_\uparrow + n_\downarrow$ (i.e., given ν), the ground state polarization $(n_\uparrow - n_\downarrow)/n$ is determined by the relative magnitudes of CF cyclotron energy, spin splitting, and interaction.

FQHE occurs in different materials, including graphene characterized by a different set of excited electron LLs from 'conventional' semiconductors like GaAs. In this work we study spin transitions in graphene, at ν = 2/3, 2/5, 3/7, 3/5, 4/9, and 4/7, corresponding to $n = \pm2, \pm3$, and ±4 (and $2p=2$). We show that CFs in the second LL of graphene (G-LL$_1$) are as robust as those in the lowest LL (G-LL$_0$). Nonetheless, they show dramatically different spin dynamics. In particular, in G-LL$_1$ the 2/3 and 2/5 FQH states corresponding to two filled ΛLs, the ferromagnetic state has slightly lower interaction energy than the singlet, producing maximal spin polarization even without the Zeeman gap. The other states of the form $n/(2n \pm 1)$ also remain fully polarized down to the lowest Zeeman energies. This physics also reflects through a lack of softening of the spin wave dispersion for the fully polarized states. The CF in G-LL$_1$ thus provide an example where exchange interaction between the fermions dominates their kinetic energy (effective cyclotron energy), leading to an instability into a spontaneously spin-polarized ground state. The specific predictions regarding polarization and spin modes can be verified by tilted field transport, NMR and resonant inelastic light scattering experiments.

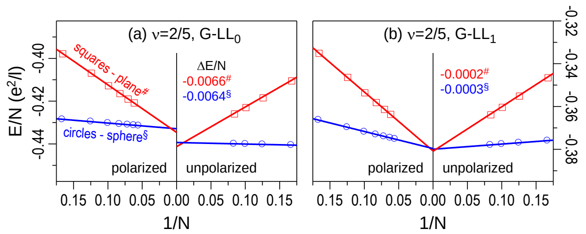

Fig.1 Correlation energies per electron (E/N, in units of e^2/ℓ, where ℓ is the magnetic length) for competing polarized and unpolarized states, $(n_\uparrow, n_\downarrow) = (2,0)$ vs. $(1,1)$, at $\nu = 2/5$ in first and second LLs in graphene, calculated on a Haldane sphere for different electron numbers N and extrapolated to $1/N = 0$. Blue and red data points were obtained using pseudopotentials from different geometries: sphere and disk, respectively. Extrapolated energy differences $\Delta E = E$(unpolarized) - E(polarized) are also quoted in units of e^2/ℓ. Clearly, $\Delta E \approx 0$ in G-LL$_1$, in contrast to $\Delta E < 0$ in G-LL$_0$.