Soft Magnetorotons and Broken-Symmetry States in Bilayer Quantum Hall Ferromagnets

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Two-dimensional electron systems in quantizing magnetic fields exhibit a variety of collective phases. The additional degree of freedom associated to layer occupation makes bilayer systems at total Landau level filling factor $\nu_T = 1$ particularly interesting. At this filling factor a phase transition exists between incompressible and compressible phases. The incompressible phases are stable at large tunneling gap Δ_{SAS} and/or low interlayer distances d. The compressible phases are stable at large d and low Δ_{SAS}. The transition is finely tuned by the interplay between Δ_{SAS} and the intra- and inter-layer Coulomb interactions. In the incompressible phases the different wave-vector dependences of depolarization and excitonic terms produce, at finite wave-vector, a magnetoroton (MR) minimum in the dispersion of the charge-density tunneling excitation (CDE). In current theories the incompressible–compressible phase transition is linked to an instability due to softening of the magnetoroton CDE mode [1, 2]. Recent experimental results on ground state properties close to the phase boundary were focused on Coulomb drag and interlayer tunneling at very low values of Δ_{SAS} [3, 4]. These works offered evidence of a Goldstone mode in the incompressible phase.

In our experiments the transition between incompressible and compressible phases is addressed by probing with inelastic light scattering the low-energy excitations of bilayer quantum Hall (QH) ferromagnets close to the phase boundary [5]. These experiments seek direct evidence of soft MR modes, and attempt to uncover the impact of excitonic terms of interactions in the quantum phase transitions of the $\nu_T = 1$ bilayer systems. Resonant inelastic light scattering methods take advantage of breakdown of wave-vector conservation in a QH ground state due to residual disorder to give experimental access to critical points in the mode dispersion such as the one at the MR minimum.

Our experiments succeeded in detecting the low-lying magnetoroton minimum in the electron bilayers [5]. Results were obtained from high-mobility $GaAs/Al_{0.1}Ga_{0.9}As$ double quantum wells with relatively high $\Delta_{\mathrm{SAS}} \approx 0.3-0.6\,\mathrm{meV}$. These results show that the MR peak softens and sharpens markedly when the phase boundary for transitions to highly correlated compressible states is approached. We interpreted the observed energies and intensities of zero wave-vector CDE and MR peaks with Hartree-Fock evaluations that link soft magnetorotons to enhanced excitonic Coulomb interactions [1, 2, 5, 6]. The results support the picture that the ground state of the bilayers at ν_T=1 evolves towards a broken-symmetry state caused by the excitonic collapse of the energy of tunneling excitations [1, 2]. The marked narrowing of the MR band and its interpretation within a time-dependent Hartree-Fock approximation suggest that the new ground state might be characterized by a roton wave-vector $q_R \sim {l_B}^{-1}$.

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