

# First-order metal-excitonic insulator transition in quantum Hall electron bilayers

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The ground states of quantum Hall bilayers at total filling factor  $\nu_T=1$  are determined by the interplay between the ratio of the interlayer separation and magnetic length ( $d/l_B$ ) and the tunneling gap  $\Delta_{SAS}/E_C$ , the energy splitting between the symmetric and asymmetric combinations of quantum well levels in unit of the Coulomb energy ( $E_C = e^2/\epsilon l_B$ )<sup>1</sup>. At large enough  $\Delta_{SAS}/E_C$  or low  $d/l_B$  the ground state is incompressible and can be described as an excitonic state<sup>2</sup> due to population of electrons in the antisymmetric excited level induced by interlayer correlation. The order parameter of this excitonic quantum Hall state measures the excitonic density in the ground state and can be determined in inelastic light scattering experiments from measurements of the energy splitting between the spin wave at the Zeeman energy  $E_Z$  and spin flip excitation (SF<sub>SAS</sub>) across the tunneling gap<sup>2</sup>. At low values of  $\Delta_{SAS}/E_C$  or large values of  $d/l_B$ , the ground state is compressible<sup>1</sup>.

Here we show the evolution of the order parameter of the excitonic insulating phase as the inter-layer correlations are continuously decreased by reducing  $\Delta_{SAS}/E_C$  with the application of an in-plane component of the magnetic field<sup>3</sup> in a tilted-field geometry. The fine adjustment of the tilt angle with a precision of better than 0.1° allows us to monitor the SF<sub>SAS</sub> excitation energy and the mode intensity as the  $\nu_T = 1$  phase boundary is approached. Both the observed discontinuity of the order parameter at the phase transition and the sharp drop of SF<sub>SAS</sub> integrated intensity suggest that a first-order quantum phase transition separates the excitonic incompressible state from the compressible phase<sup>4</sup>. We also demonstrate that the compressible state that emerges abruptly at the phase transition is a composite fermion (CF) metal<sup>5</sup> stabilized by the intra-layer electron correlation. Evidence for the occurrence of the CF phase in the bilayer at  $\nu_T = 1$  is linked to the observation of a low-lying continuum of spin excitations below the Zeeman gap in the inelastic light scattering spectra. These spin excitations are attributed to quasiparticle excitations across the Fermi energy of the CF metal. Their behavior as a function of the tilt angle suggests that the CF metallic phase becomes fully spin-polarized for  $E_Z/E_C > 0.013$ . The observed discontinuous phase transition highlights the competition between inter- and intra-layer electron correlations. The competition of the order parameters of the excitonic and composite fermion metal phases under the condition of weak residual disorder results in the observed first order character of the quantum phase transition<sup>6</sup>.

## References

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